SC-05-21

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No boundaries for whales interacting with fishing activities targeting Patagonian toothfish (*Dissostichus eleginoides*)

Relates to agenda item: 7.4 Working paper ☒ Info paper ☐

Delegation of French territory and European Union

Abstract

With the development of longlines targeting Patagonian toothfish (Dissostichus eleginoides) in the Southern Ocean, killer whales and sperm whales have concurrently developed a new behaviour feeding on fish caught on these longlines, termed 'depredation'. This specialised behaviour increases the frequency of interactions of the two odontocete species with fishing vessels and results in decreased fishing yields for fishers. In addition, uncertainty around the depredated part of the catch can affect the accuracy of modelling the dynamic of Patagonian toothfish populations and, consequently, the management of stocks.

Depredation in itself very rarely results in mortality of killer whales and sperm whales, but there has been evidence of lethal interactions with vessels, such as injuries consistent with being shot or near explosives, in the past.

In this paper, based on the fishery data collected by France and Spain, we documented whale interactions in fisheries operating on the Del Cano rise, a region overlapping with several national and international jurisdictions (French EEZ, SIOFA and CCAMLR). We explored potential links through comparisons of photo-identification data collected from vessels on the Del Cano Rise and in adjacent waters, such as the Crozet EEZ, where an established toothfish fishery operates and whale interactions are frequent and well-documented since the late 1990s, and from Prince Edward and Marion islands EEZ. We further examined the movements of depredating whale individuals, including across management boundaries. Results from photo-identification revealed that 26 killer whales and 2 sperm whales travelled across boundaries with movements between the Crozet EEZ and Del Cano rise in SIOFA. Based on the available data, we estimated that 8% of catches were removed by killer

whales and sperm whales in the Del Cano-SIOFA area. In adjacent areas, the estimated local catch removal is included in the stock assessment approaches. Crucially, however, several killer whale individuals were newly identified in and unique to the Del Cano-SIOFA area, indicating that in this region the behaviour of depredation is in its early stages of development and learning. Depredation behaviour can rapidly spread across individuals as seen in adjacent areas, and thus we strongly recommend the implementation of mitigation measures by vessels to prevent this serious issue from intensifying in the Del Cano-SIOFA area.

Recommendations (working papers only)

Based on the results presented in this paper as well as the long-term experience both within CCAMLR and the Crozet and Kerguelen EEZ, we recommend that SIOFA-SC

1) Acknowledges the existence of depredation in the SIOFA area and the impact that depredation can have on toothfish catches in the SIOFA Area

2) Adopts a mandatory protocol for documenting marine mammal interactions with all fishing vessels operating in its Area that is compatible with that of CCAMLR (see Gasco et al 2013)

3) Adopts the following actions to longline fishing vessels subject to killer whale interactions in order to reduce the risk of spreading depredation behaviour:

A) stop hauling and buoy off the line when killer whales are sighted,

B) steam away at least 30 nautical miles,

C) not haul any line within a radius of 30 nautical miles around the initial observation point, and

D) restart hauling of the buoyed-off line once killer whales are absent.

No boundaries for whales interacting with fishing activities targeting Patagonian toothfish (*Dissostichus eleginoides*).

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Abstract

With the development of longlines targeting Patagonian toothfish (*Dissostichus eleginoides*) in the Southern Ocean, killer whales and sperm whales have concurrently developed a new behaviour feeding on fish caught on these longlines, termed 'depredation'. This specialised behaviour increases the frequency of interactions of the two odontocete species with fishing vessels and results in decreased fishing yields for fishers. In addition, uncertainty around the depredated part of the catch can affect the accuracy of modelling the dynamic of Patagonian toothfish populations and, consequently, the management of stocks.

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Recommendations

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Introduction

Killer whale and sperm whale depredation interactions with toothfish longlines have been documented as a severe issue in the Crozet EEZ since the late 1990's (Tixier et al. 2010). These interactions have been extensively monitored and studied through long-term observation and photo-identification, consistently collected by fishery observers during fishing operations involving depredation events since then. Estimating the removal of catch from longlines by odontocetes during the fishing or hauling process is a key component to understanding total removal of biomass from an exploited fish stock. Knowing interaction and depredation rates allows to correct reported catches to account for the additional mortality due to depredation and therefore key to modelling the full impact (catches and depredation) of fishing activities on Patagonian toothfish stocks. Several methods are commonly applied to estimate the rate of catch removal, and in the adjacent areas to Del Cano the depredation rate has been estimated using the CPUE method (Gasco et al. 2015) or a GLM approach (Tixier et al 2016) for the stock assessment of Patagonian toothfish in Kerguelen EEZ and Crozet EEZ stock assessment (Sinègre et al., 2017a, Sinègre et al., 2017b).

The Del Cano Rise is a submarine feature covering approximately 600 km in longitude and 200 km in latitude. This region, adjacent to waters under the jurisdiction of the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), is located between two Economic Exclusive Zones (EEZ): the Crozet EEZ (France) to the East and the Prince Edward and Marion islands EEZ (South Africa) to the West (Figure 1). It has the particularity to be managed by two international organizations: the Southern Indian Ocean Fisheries Agreement (SIOFA) north of 45°S and CCAMLR south of 45°S. Fishing for Patagonian toothfish is authorized by SIOFA in Del Cano rise area and fishing has occurred with variable catch levels in the last 17 years. There is no toothfish fishing permitted on the Del Cano Rise south of 45°S in CCAMLR waters.

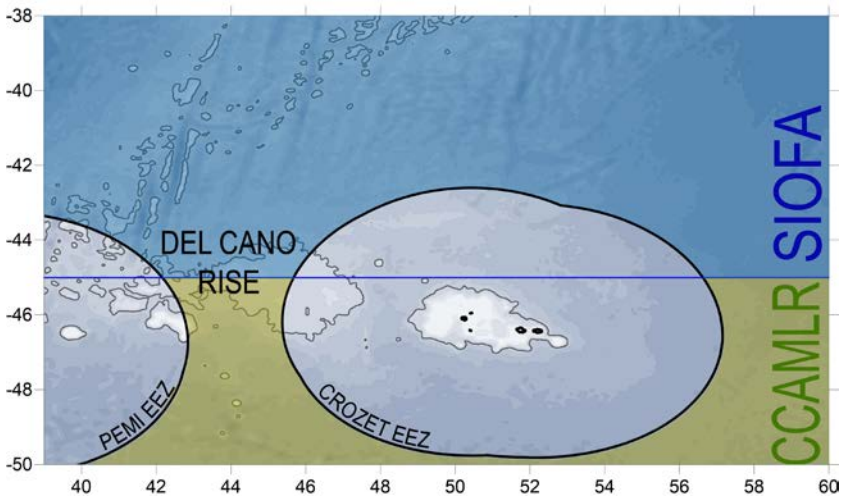

Figure 1 Map of the study area showing the EEZ boundaries of Prince Edward and Marion Islands (PEMI) and Crozet, the Del Cano Rise area the two jurisdictions (SIOFA and CCAMLR separated by the 45°South latitude). The grey line represents 2000 meters depth.

At its 38th meeting in 2019, the Scientific Committee of CCAMLR and its Working Group on Fish Stock Assessment (WG-FSA) received and reviewed information on depredation in the Del Cano region, welcoming that this information was shared with its scientists and enabling consideration of depredation in this region in existing CCAMLR stock assessments. The SC noted on the fact that due to the photo identification effort, it was possible to identify multiple instances of killer and sperm whale individuals depredating both in the Del Cano Rise area and within Crozet and Kerguelen, and highlighted the importance of understanding depredation rates in estimates of removals and management of toothfish fisheries. A request was made to bring this issue to the attention of SC-SIOFA.

Unlike CCAMLR where data on whale interactions with longline fishing vessels are collected through the Scheme of International Scientific Observation (SISO), reporting interactions with marine mammals is not mandatory within SIOFA waters. However, data on depredation has been collected in the SIOFA area by French scientific observers who apply the same observation protocol as in the French EEZ which is compatible with the data collection protocol of CCAMLR (Gasco et al. 2013), as well as by scientific observers onboard Spanish vessels who have documented depredation opportunistically with different levels of effort. During the three most recent fishing seasons (2017-2019); depredation and interaction data was recorded using the protocol in the CCAMLR scheme (SISO) for two trips, and presence-only information was collected during one trip.

This paper integrates all available information on whale interactions with fisheries in the Del Cano rise area and examines their potential links to adjacent regions. More specifically, this study:

- examined whether the killer whales involved in depredation interactions in the Crozet EEZ were also depredating in the Del Cano – SIOFA region;
- assessed the frequency at which depredation interactions occurred (interaction rate) and the proportion of the catches removed by whales during these interactions (depredation rate).

Killer whale movements between Del Cano - SIOFA and Crozet EEZ

Killer whale population movements

As part of the French data collection protocol, the scientific observers on board French fishing vessels consistently take photographs of whales during depredation interactions following a standardized photo-identification protocol implemented since 2003 using DSLR cameras and telephoto lenses (described in Gasco et al. 2013), both within the French EEZs and during activities in the adjacent Del Cano–SIOFA area. Scientific observers on Spanish vessels operating in the Del Cano-SIOFA area in the last 3 years did not take photographs following a standard protocol, as documenting depredation is not mandatory within SIOFA. However, observers took photographs opportunistically using their own cameras or cell phones.

We used these photographs taken by fishery observers onboard French and Spanish vessels targeting Patagonian toothfish to identify the depredating killer whale individuals and to examine their movements between Del Cano-SIOFA and Crozet EEZ.

A total of 432 pictures were used in the Del Cano–SIOFA region over the 2003-2018 period, including 423 pictures taken from French vessels and 9 pictures taken from Spanish vessels. These pictures were analysed and compared to existing killer whale photo-identification catalogues developed by the Centre d'Etudes Biologiques de Chizé (CNRS) in France (Tixier 2014a, 2014b) and the Marine Research Institute in South Africa (Reisinger 2014).

Of the 9 pictures taken from Spanish vessels between 2018 and 2019, 6 pictures had been taken with a compact camera and showed 3 distinct individuals, but the quality was too low to allow any matching with certainty or naming of new individuals. One individual photographed in 2019 is likely to be "C023" from the Crozet killer whale population, but could not be matched with absolute certainty. The remaining 3 pictures were taken with an SLR camera and showed 1 individual with a quality high enough to confirm that this was a new individual since no match was found with previously known individuals in either the Crozet or Prince Edward and Marion islands killer whale catalogues. As further pictures are required to assign an identification code to these 4 individuals and add them to catalogues, in this paper they were referred to as "NO ID".

From the photographs taken by French observers, 33 distinct killer whale individuals were identified in the Del Cano-SIOFA region. Of these 33 individuals, 26 killer whales had previously been identified within the Crozet EEZ (Tixier et al. 2014a, 2014b). Among these 26 individuals (Figure 2), 3 have also been sighted within the Kerguelen EEZ.

Despite the low photo-identification effort in SIOFA (432 images were available), up to 15% of the overall Crozet resident population has been observed in 2011 in SIOFA (average per year: 7.4%), indicating a clear link to Crozet and spatial use of this entire region by the local killer whale population.

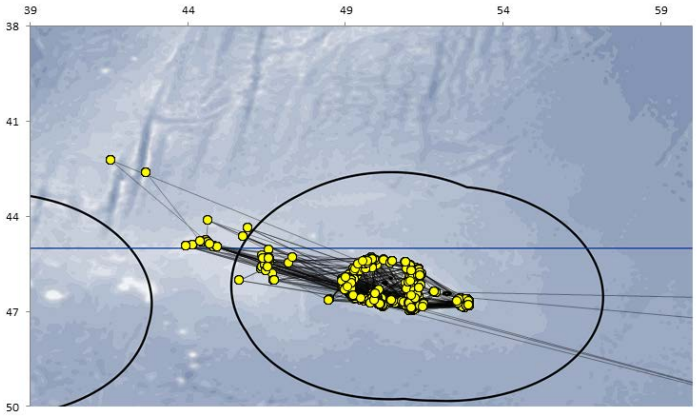

Figure 2 Locations of 26 killer whale individuals observed in the Del Cano rise outside and also within Crozet EEZ, dark lines represents movements between observations, lines heading East correspond to individuals observed in Kerguelen.

In 2010 and 2013, 7 individuals were photographed at Del Cano-SIOFA but were not, to date, observed in Crozet or Kerguelen EEZs (Figure 3).

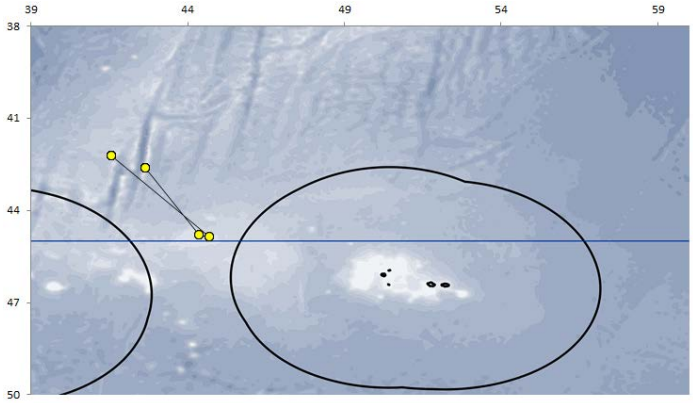

Figure 3 Locations of 7 killer whale individuals observed only in the Del Cano - SIOFA area. Thin lines represent the movements of individuals between sightings.

Table 1: Cross matrix census of Del Cano SIOFA killer whale individual's presence in adjacent EEZ. * 4 individuals could not be identified due to lower photo quality.

	Del Cano SIOFA
Crozet EEZ	26
PEMI EEZ	0
Del Cano SIOFA	7 (+4*)
Total	33 (+4*)

Development of killer whale interactions in the Del Cano region

The first killer whale interactions in the SIOFA area were documented in 2005 by observers on French fishing vessels (Figure 4). From then on, interactions within SIOFA were further recorded in 2010, 2013, 2014, 2015 on French fishing vessels, and 2017 and 2018 on Spanish fishing vessels. All individuals that were observed both within the Crozet EEZ and at Del Cano were first seen at Crozet, and then in the Del Cano-SIOFA area outside the Crozet EEZ; none of the new individuals from del Cano have been sighted within the Crozet EEZ to date. Of the 26 killer whales seen both within Crozet and at Del Cano, 20 were seen once at Del Cano-SIOFA, while six were seen twice at Del Cano. Three of the individuals seen in the Del Cano area and regularly observed in the Crozet EEZ have also been sighted in the Kerguelen EEZ, one in 2006 and two in 2015. Figure 4 shows the chronology of killer whale interactions in the southern Indian Ocean (Crozet, Kerguelen and SIOFA regions).

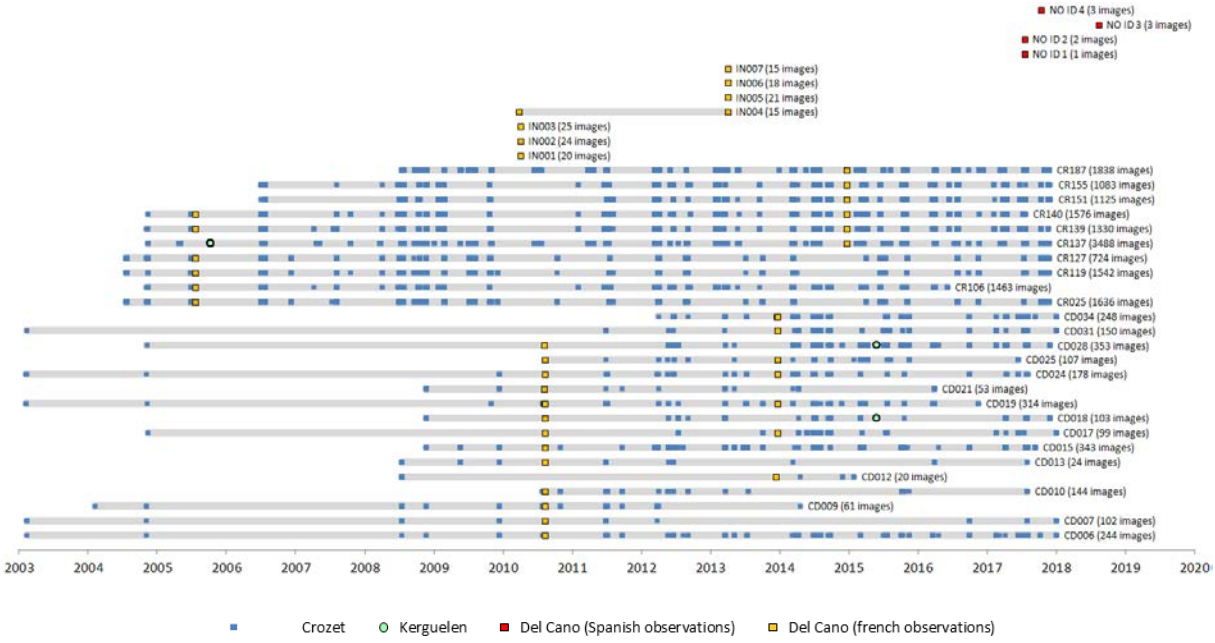

Figure 4 Identification of killer whales through photo-identification over time. Horizontal lines correspond to each individual, names are given on the left of their last observation along with the number of images matched to each identity. Individuals at the top left corner starting with "NO ID" correspond to photos provided from Spanish vessel where individuals could not be matched to known individuals due to the insufficient quality of the pictures.

Sperm whale movements between Del Cano-SIOFA and Crozet EEZ

As part of the French data collection protocol, the scientific observers on board French fishing vessels consistently take photographs of whales during depredation interactions following a standardized photo-identification protocol implemented since 2003 using DSLR cameras and telephoto lenses (described in Gasco et al. 2013), both within the French EEZs and during activities in the adjacent Del Cano–SIOFA area. These images were matched with the photo-ID catalogue of sperm whales developed by Centre d'Etudes Biologiques de Chizé (CNRS) in France (Tixier 2015) and movements were reconstructed from the fishing locations where pictures were taken. Additional images of sperm whales were collected opportunistically from Spanish vessels and were also analysed. Unfortunately, the low quality of those pictures did not allow either to match them with known individuals or to find new individuals.

Given the difficulty of photographing sperm whale tail flukes, which is their identifying characteristic, only three individuals were identified from the pictures collected in the Del Cano-SIOFA area (Figure 5):

- "CRO_045" was also observed within French EEZ of Crozet,
- "CRO_141" was only observed in the Del Cano - SIOFA area and

- “KER_040” was also observed regularly in Kerguelen EEZ from 2008 to 2012 then in Del Cano - SIOFA area in 2013 and back again in Kerguelen in 2016.

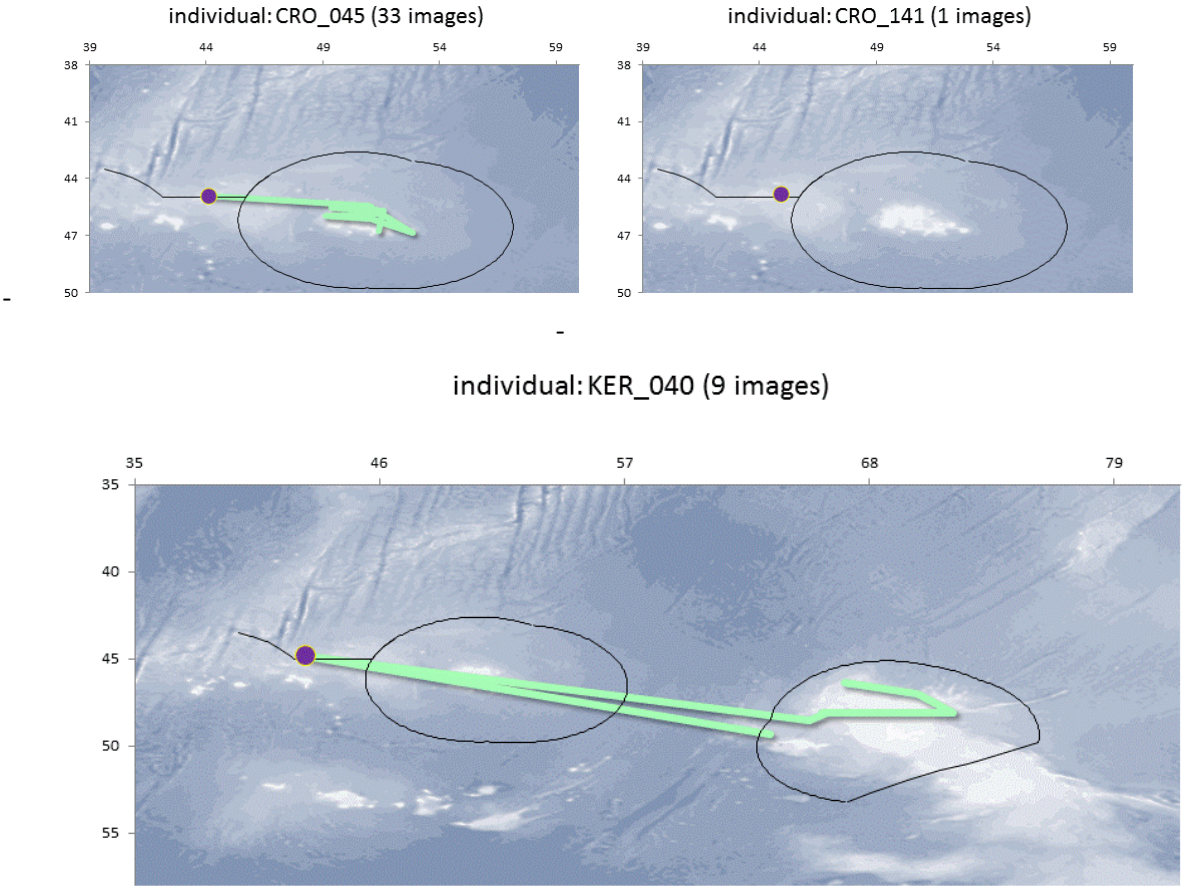

Figure 5. Sperm whale individuals observed in the Del Cano - SIOFA area. Green lines represent movements between observations and purple dots represent observations in the Del Cano - SIOFA area. Number of images used to produce each map is shown in brackets.

Estimation of whale interaction rates at Del Cano - SIOFA

We estimated interaction rates for killer whales and sperm whales separately (see Annex 1 for a description of the depredation rates calculation) based on Spanish and French data collected on a haul-by-haul basis where available. We used these data from 2009/2010 to 2018/2019 (n=754 hauls) to estimate interaction rate per year.

Interaction rates greatly varied between years for both killer whales and sperm whales (Table 2), with no clear temporal trend. The interaction rate of sperm whales was generally higher than that of killer

whales. In recent years, killer whale interaction rate ranged from 0% to 4% and sperm whale interaction rate ranged from 14% to 44%.

Table 2. Number of longlines set and interaction rates for killer whales and sperm whales by season in the Del Cano - SIOFA area.

		Longlines set:		interaction rates:	
		FRENCH	SPANISH	Killer whale	Sperm whale
SEASONS	2009_2010	14		0,0%	0,0%
	2010_2011	107		28,0%	23,4%
	2011_2012	88		9,1%	7,5%
	2012_2013	105		0,0%	42,5%
	2013_2014	244		13,6%	19,0%
	2014_2015	137		10,2%	16,5%
	2015_2016				
	2016_2017	32		0,0%	43,8%
	2017_2018		260	2,7%	14,7%
	2018_2019	27	47	4,3%	14,9%
	total	754	307		

Estimation of depredation rates at Del Cano - SIOFA

Depredation rates were estimated using the CPUE method (Gasco 2015, see Annex 2 for a brief method description) for the three cases of marine mammals retrieving fish hooked on longlines:

- Killer whales observed alone
- Sperm whales observed alone
- Both species observed together

This method was applied on the entire dataset, aggregating all years and regions, because annual data was insufficient to estimate depredation rates for each year separately as a timeseries.

Overall, the total amount of toothfish retrieved from the lines by those two marine mammals reaches almost 8% of the fish caught on the line on average across the fishery (1.7% due to killer whales without sperm whales associated on the lines, 3.2% due to sperm whales without killer whales associated and 2.6% when both species were associated on the lines, see method in annexe).

Discussion

Following queries at MoP-6 regarding whether depredation occurred in the Del Cano-SIOFA area and if so to what extent, this paper set out to examine whether depredation has been observed in this region, to quantify the extent of depredation at Del Cano – SIOFA, and to assess whether there were links between killer whales observed at Del Cano – SIOFA with adjacent areas. Here, we showed clearly that depredation has occurred in the Del Cano -SIOFA area and that the individuals involved in this region have previously been sighted engaging in the same behaviour in adjacent areas.

There was clear evidence of depredation activity by killer whales with at least 33 individuals interacting with fishing vessels in the Del Cano – SIOFA area, of which 26 were previously known individuals from the adjacent Crozet EEZ. At least 7 individuals were completely new in the Del Cano region, not matched to previously documented individuals in PEMI or Crozet. The Crozet killer whale observation programme has operated and systematically collected data both from land since 1964 and at sea since the 1990's with over 100,000 photographs evaluated, and 297 individuals identified, of which 80-90 are currently thought to interact with the longline fishery. It is therefore very likely that these seven individuals did not originate in the Crozet region, where depredation behaviour has developed over the past 30 years and where learning transfer has been observed over this time. It should be considered a possibility that these 7 individuals may have been 'naïve' to depredation prior to the arrival of the longline toothfish fishing fleet, and acquired the behaviour from killer whales who have engaged in this activity around Crozet when encountering those individuals. This means that potentially 11 individuals (if the 4 not identified are included) have been less exposed to toothfish fisheries and may be less prone to depredation.

Given that approximately 80-90 individuals are known and systematically observed to be interacting with fishing activities at Crozet Island (Tixier et al 2017), the information from Del Cano shows that a large proportion of the Crozet killer whales are also present there suggesting that these individuals can broaden their home-range up to at least Del Cano-SIOFA. When considered per year, the annual proportion of exchange was variable with up to 15% of Crozet killer whales seen in the Del Cano region. Given the much lower fishing effort on Del Cano compared to Crozet, and given the even lower observation effort for whale interactions, it is likely that this is an underestimation. Nevertheless, these results show substantial overlap in the habitat use by the killer whales seen in Del Cano and Crozet. Whether the resident populations of Crozet explored this area in response to new fishing vessel presence at Del Cano, or are seen there because it is part of their home range is not possible to distinguish within the currently available data. However, given the very recent development of a longline fishery in Del Cano in comparison to the more established fisheries at Crozet, Kerguelen, and Prince Edward and Marion Islands, a systematic recording at the very least of whale presence or absence during fishing activities (see method in Gasco et al 2013) could have not only provided valuable data on the development of depredation in a previously unfished region, but also crucial information on how such behaviour spreads over time and space. None of the individuals

observed in the Del Cano–SIOFA area were matched with the individuals from PEMI. It is unclear at present whether this is due to more limited connectivity between Del Cano and PEMI, or whether the photo identification effort deployed from fishing vessels in PEMI is much lower than that at Del Cano or Crozet.

As well as identifying depredation behaviour in the Del Cano – SIOFA region and highlighting population links of killer whales to adjacent areas, we were also able to estimate interaction rates of killer whales with fishing vessels in Del Cano. The interaction rates were variable between years, and could reach up to 28% of all observed lines also documenting killer whale interactions in the Del Cano – SIOFA region. The observed rates were overall substantially lower than those documented at Crozet Island, where on average 40% of observed longlines also report interactions with killer whales (Tixier et al 2019).

In addition to the links and impact determined for killer whales, we further demonstrated for the first time that depredation also took place by sperm whales in the Del Cano region. While there appears to be a strong link between Crozet and Del Cano for killer whales but not to PEMI or Kerguelen, the observed sperm whales were linked to both Crozet and Kerguelen, which was not an expected result considering the high site-fidelity behaviour of sperm whales (Labadie et al. 2018).

The interaction rate of sperm whales with fishing vessels in the Del Cano region was highly variable between years, reaching up to 40% of observed longlines also reporting interaction with sperm whales. These rates were overall lower than those in adjacent Crozet Island where the interaction rates average around 60% of observed longlines also reporting interactions with sperm whales (Tixier et al 2019). Although only three individuals were identified in the current dataset, it is highly likely that the number of interacting individuals is substantially higher than that given the determined interaction rate. Sperm whale photo identification is far more difficult to conduct than for killer whales because identification is only possible by using the fluke shape which is visible only for a few seconds between long dives, which is why there were far fewer images available. It is therefore more challenging to determine sperm whale depredation and identify individuals, links, and movements, and the fact that with the low fishing and observation effort it was still possible to identify at least 3 individuals suggests that sperm whale depredation as estimated here is likely an underestimation.

Synthesizing and analysing all available data on interactions, depredation, and fishing effort in the Del Cano – SIOFA area allowed us to estimate the rates of removed catch for killer whales, sperm whales, and both species seen together. Overall, the estimate is at 8% meaning that of the reported total catches to date, an additional approximate 8% were removed from the fished toothfish biomass that were not recorded as landed because they were removed by sperm whales and killer whales during the hauling process. Even if this rate is lower than the one estimated in Crozet EEZ, this supplementary mortality due to depredation removal should be considered when setting catch limits for the Del Cano region in future.

A key issue that became apparent during this study is the inconsistent data collection on interactions, including varying degrees of quality of photographs. The reconstruction of the timeseries of catches in the Del Cano area (Sarralde et al 2020) shows that four Parties have fished in this region over time, of which two have collected data on depredation and whale interactions but only one in a continuous and consistent manner. At present, SIOFA has no overarching guidelines or processes in place that allow for consistent and comparable collection of data regarding whale interactions and depredation. Interaction and depredation rates are to some extent variable and uncertain also due to no systematic documentation of depredation in the SIOFA area.

Depredation is not an issue unique to SIOFA (Tixier et al. 2019), and in adjacent CCAMLR this interaction has been recorded and studied systematically over the past decades. Since the inception of its working group on incidental mortality associated with fishing (WG-IMAF) in 1994 the scientific community in CCAMLR began to gain, gradually, an understanding not only of fishing-related mortalities of marine mammals, but crucially also of non-lethal interactions with fishing vessels by marine mammals and the resulting catch removals and impact on stock assessment assumptions. Interactions by marine mammals with longline fishing vessels began to be recorded in 1996 and today there are standardised data collection protocols for all longline fisheries within CCAMLR under SISO, developed at dedicated workshops, including detailed guides on taking photographs for identification purposes. These data are now key in the estimation of catch removals by marine mammals in several of the toothfish stock assessments in the Southern Ocean. CCAMLR has also acknowledged the link between depredating individuals pursuing fishing vessels both within CCAMLR and within SIOFA, and noted on the importance of understanding depredation rates in toothfish catch removals and management.

Within SIOFA the collection of interaction data is, to date, voluntary and it is only due to the additional collection of information by scientific observers on French and Spanish vessels that we were able to show, for the first time, that depredation occurs in the SIOFA area and has an estimable component of additional catch removal from the affected region. A region-wide, consistent data collection programme would have allowed to explore the full potential impact of depredation in the region, as well as illuminate the connectivity and importance of the Del Cano region to sperm whales and killer whales known from Crozet and Kerguelen EEZ. Crucially, the lack of any systematic data collection consisting of most basic parameters such as presence-absence now and during the first years of the Del Cano fishery means that we are not able to track and understand the development and spread of depredation on a relatively recent longline fishery, nor historically estimate the catch component removed by depredation. This is particularly pertinent given the CPUE and biomass dynamics recently estimated for toothfish in the Del Cano region (Sarralde et al 2020).

Conclusions and recommendations

Depredation has clearly been identified as an issue not only in adjacent areas, but all across the Southern Ocean and also globally (Tixier et al. 2019). Over the decades this problem and its

dynamics have been studied around Crozet Island and Kerguelen Island, where the longest time series are available on killer whale and sperm whale depredation, a series of measures have been developed and tested to minimise the spread of depredation. Between the two islands, Crozet Island suffers from substantial killer whale depredation which is a rarer occurrence in the Kerguelen EEZ (Tixier et al 2019), where additionally the majority (22 of 23) of killer whales are known depredating individuals from Crozet. To minimise the spread of depredation behaviour into adjacent areas, strict mitigations measures are being enforced consisting of a) buoying of the line, b) steam away on a 30 nautical miles distance and stay away from the buoyed off line, c) prohibit fishing to any vessel within a 1.5 ° longitude X 3° latitude rectangle around the observation of killer whale during 10 days. These mitigation measures are currently applied in the Kerguelen EEZ and proved to be effective to prevent the spreading of the depredation behaviour (Arrêté 2019-77).

The results of this paper have collectively highlighted The importance of a consistent and compatible data collection scheme not only across vessels operating in the SIOFA area, but also across management boundaries such as CCAMLR and SIOFA, as marine mammal populations clearly move across these boundaries. Depredation in SIOFA waters can therefore also have an impact on the toothfish fisheries in adjacent areas, for example through propagation of depredation behaviour to naïve pods or through additional fishing mortality for different toothfish sub-populations located across management areas.

Based on the results presented in this paper as well as the long-term experience both within CCAMLR and the Crozet and Kerguelen EEZ, we recommend that SIOFA-SC

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    B) steam away at least 30 nautical miles,
    C) not haul any line within a radius of 30 nautical miles around the initial observation point, and

    D) restart hauling of the buoyed-off line once killer whales are absent.

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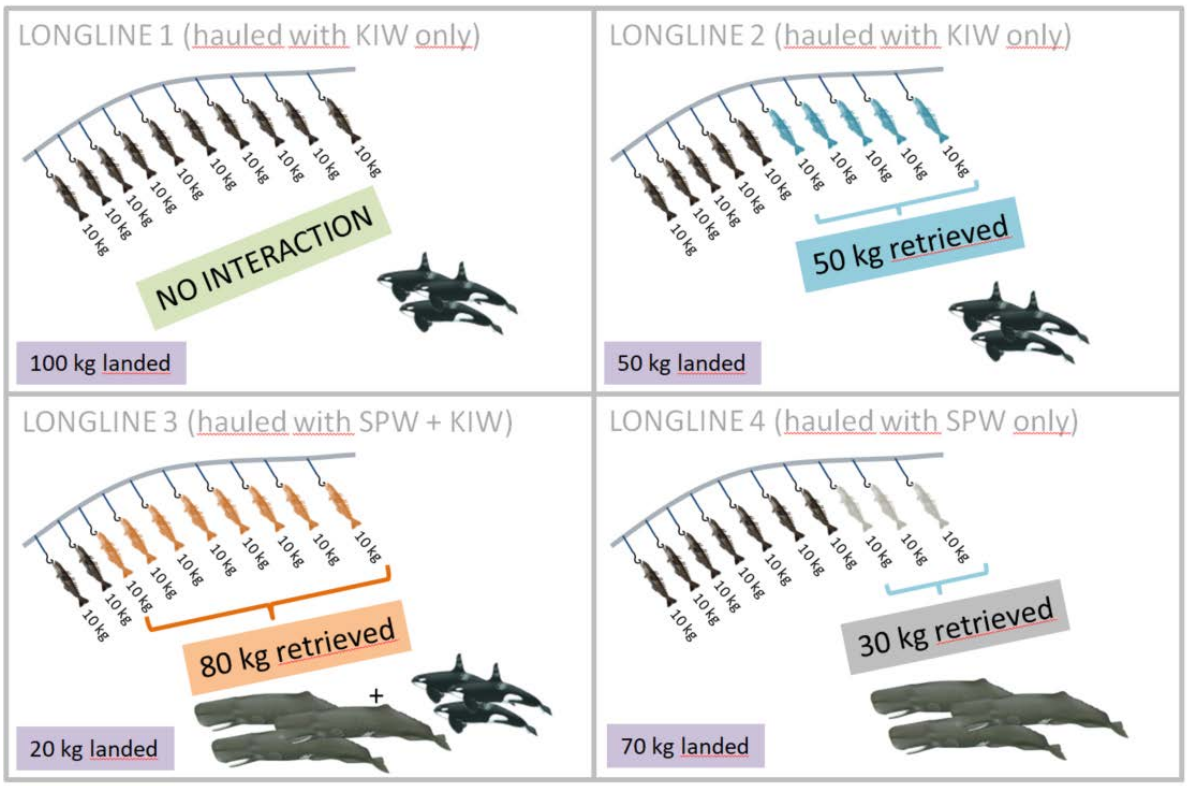
Annexes

Annex 1: Estimating interaction and depredation rates.

The interaction rate (for one species of marine mammal) corresponds, for an area, to the number of longlines hauled in presence of this species reported as interacting with fishing operations by retrieving part of the catch, divided by the total number of longlines hauled and observed for marine mammals in this area.

The depredation rate corresponds to the estimated weight of fish lost due to marine mammals divided by the total weight caught on the fishing gear (estimated loss + weight landed on board). Only lines observed for marine mammals interactions are considered in the calculation of depredation rate.



Interaction rate is defined as:

$$\text{IR (Interaction Rate)} = \frac{\text{Longlines with interaction}}{\text{Longlines observed}}$$

$$\text{IR}_{(\text{KIW})} = \frac{2}{4} = 50\%$$

$$\text{IR}_{(\text{SPW})} = \frac{2}{4} = 50\%$$

Depredation rate is defined as:

$$\text{DR (Depredation Rate)} = \frac{\text{weight retreived}}{\text{weight retreived} + \text{weight landed}}$$

For the three cases, depredation rates are:

$$\text{DR}_{(\text{KIW only})} = \frac{50\text{ kg}}{30\text{ kg} + 80\text{ kg} + 50\text{ kg} + 240\text{ kg landed}} = 12{,}5\%$$

$$\text{DR}_{(\text{KIW + SPW})} = \frac{80\text{ kg}}{30\text{ kg} + 80\text{ kg} + 50\text{ kg} + 240\text{ kg landed}} = 20{,}0\%$$

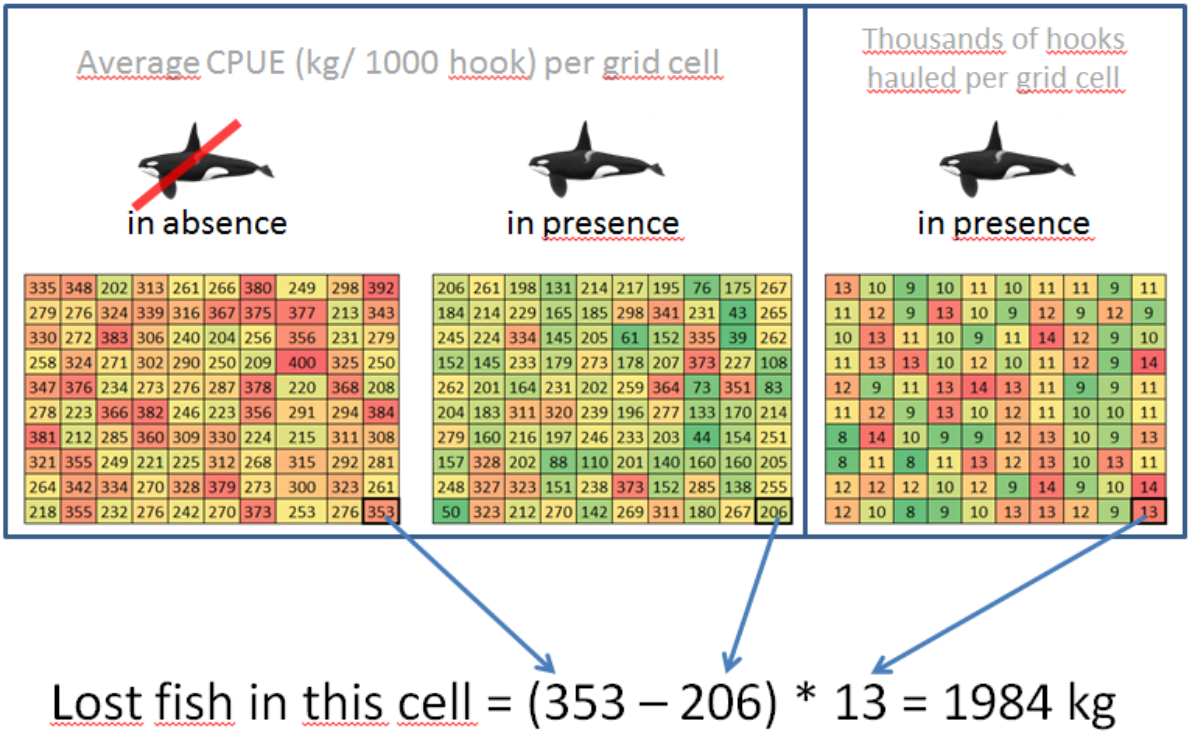
$$\text{DR}_{(\text{SPW only})} = \frac{30\text{ kg}}{30\text{ kg} + 80\text{ kg} + 50\text{ kg} + 240\text{ kg landed}} = 7{,}5\%$$

Overall, depredation corresponds to the sum of the three cases:

$$\text{DR}_{(\text{overall})} = \frac{30\text{ kg} + 80\text{ kg} + 50\text{ kg}}{30\text{ kg} + 80\text{ kg} + 50\text{ kg} + 240\text{ kg landed}} = 40{,}0\%$$

Annex 2: The CPUE method

This method uses the difference between the average CPUE in absence and the average CPUE in presence within each spatial cell of a grid over the area multiplied by the number of hooks hauled in presence in each cell, example for one cell is shown below.



Simplified example of the principal of the "CPUE" method.