OPERATIONAL INTERACTIONS OF SPERM WHALES AND KILLER WHALES WITH THE PATAGONIAN TOOTHFISH INDUSTRIAL FISHERY OFF SOUTHERN CHILE

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Abstract

Interactions of sperm whales (*Physeter macrocephalus*) and killer whales (*Orcinus orca*) with Patagonian toothfish (*Dissostichus eleginoides*) fishery operations were assessed in southern Chile during surveys with observers on board industrial fishing vessels between April 2002 and March 2003. For the 180 hauls monitored, the evidence of damaged catch when cetaceans were present included toothfish lips (n = 121), heads (n = 16) and trunks (n = 3). The mean rate of depredation was 3% (±2% CI 95%; n = 180 sets) and ranged between 0 and 100%. Considering that no interactions were recorded in 153 (84%) of the effectively monitored sets, and that the mode and median of the depredation rate was 0, the global impact of cetaceans on the fishing yield is considered to be low. When mixed sightings of killer and sperm whales were encountered (n = 12), the rate of depredation decreased to 0%; this could be the result of killer whales preferring to predate on sperm whales rather than on the fish caught on the line, as suggested by the response of sperm whales to the presence of killer whales (grouping into tight parallel formations). High sperm whale densities were found to be associated with various 'hotspots' which had high fishing yields. This relationship tends to support the hypothesis that the richest fishing grounds are also traditional feeding grounds for sperm whales. Financial loss associated with operational interactions involving depredation was US$92 684 (CI 95% US$47 302–153 745) for the whole fleet, with a mean loss per set of US$138 (CI 95% US$74.76–249.3).

Résumé

Les interactions de cachalots (*Physeter macrocephalus*) et d'orques (*Orcinus orca*) avec les opérations de pêche à la légine australe (*Dissostichus eleginoides*) ont fait l'objet d'une évaluation dans le sud du Chili au cours de campagnes d'évaluation menées en présence d'observateurs d'avril 2002 à mars 2003 sur des navires de pêche industrielle. Pour les 180 poses surveillées, l'évidence d'une capture de légine endommagée lorsque des cétacés étaient présents comprenait : lèvres (n = 121), têtes (n = 16) et troncs (n = 3). Le taux moyen de déprédation était de 3% (±2% intervalle de confiance à 95%; n = 180 poses), variant de 0 à 100%. Étant donné qu'aucune interaction n'a été relevée sur 153 (84%) des poses effectivement surveillées, et que le mode et la médiane du taux de déprédation étaient de 0, il est considéré que l'impact des cétacés sur le rendement de la pêche est faible. Lors des observations à la fois d'orques et de cétacés (n = 12), le taux de déprédation tombait à 0%; ce résultat pourrait s'expliquer par le fait que les orques préfèrent attaquer les cachalots plutôt que les poissons capturés sur les palangres, ce que suggère la réponse des cachalots à la présence l'orques (regroupement en formations parallèles serrées). Les fortes densités de cachalots semblaient être associées à divers "points chauds" qui affichaient des rendements de pêche élevés. Ce rapport tend à conforter l'hypothèse selon laquelle les lieux de pêche les plus productifs sont également des secteurs d'alimentation traditionnels des cachalots. La perte financière associée aux interactions opérationnelles provoquant une déprédation représentait 92 684 dollars américains (intervalle de confiance à 95% 47 302–153 745 dollars américains) pour la totalité de la flottille, avec une perte moyenne par pose de 138 dollars américains (intervalle de confiance à 95% 74,76–249,3 dollars américains).

Резюме

Оценка взаимодействия кашалотов (*Physeter macrocephalus*) и косаток (*Orcinus orca*) с промысловыми операциями патагонского клыкача (*Dissostichus eleginoides*) была проведена на юге Чили во время съемок при наличии наблюдателей на промышленных промысловых судах в период между апрелем 2002 г. и мартом 2003 г. В ходе 180 наблюдавшихся выборок свидетельства поврежденной рыбы в улове, когда киты были поблизости, включали губы (*n* = 121), головы (*n* = 16) и туловища (*n* = 3). Средний показатель опустошения составил 3% (±2% CI 95%; *n* = 180 постановок) и колебался в пределах от 0 до 100%. Принимая во внимание тот факт, что в случае 153 (84%) внимательно наблюдавшихся постановок не было зарегистрировано никакого взаимодействия, а мода и медиана показателя опустошения равнялись 0, воздействие китов на промысловый улов в глобальном масштабе считается низким. Уровень опустошения снижался до 0%, когда косатки и кашалоты наблюдались вперемешку (*n* = 12); возможно, это объясняется тем, что косатки в качестве добычи предпочитают кашалотов, а не пойманную на ярус рыбу, о чем свидетельствует реакция кашалотов на присутствие косаток (группируются в тесные параллельные ряды). Было обнаружено, что высокая плотность кашалотов связана с различными «горячими точками», где высоки промысловые уловы. Эта связь говорит в пользу гипотезы о том, что богатые промысловые площадки являются также традиционными кормовыми площадками для кашалотов. Финансовый ущерб, связанный с операционным взаимодействием, включающим опустошение, составил US$92 684 (CI 95% US$47 302–153 745) для всей флотилии, при среднем ущербе US$138 (CI 95% US$74.76–249.3) для одной постановки.

Resumen

Las interacciones operacionales entre cachalotes (*Physeter macrocephalus*) y orcas (*Orcinus orca*) con la pesquería industrial de austromerluza negra (*Dissostichus eleginoides*), fueron evaluadas a través de viajes de pesca en buques industriales con observadores científicos a bordo, entre abril del 2002 y marzo del 2003. En 180 lances observados la evidencia de daños cuando los cetáceos estuvieron presentes incluyeron: labios (*n* = 121), cabezas (*n* = 16) y troncos (*n* = 3). La tasa promedio de depredación fue 3% (±2% IC 95%; *n* = 180 lances) y varió entre 0% y 100%. Considerando que no se observó interacción en 153 (84%) de los lances efectivamente observados, y que la moda y la mediana de la tasa de depredación fue cero, el impacto global de los cetáceos sobre el rendimiento de pesca se considera bajo. Cuando se avistaron grupos mixtos de cachalotes y orcas (*n* = 12) la tasa de depredación disminuyó a cero; lo anterior podría deberse a que las orcas prefieren depredar sobre los cachalotes que remover peces de los espineles, como lo sugiere la respuesta defensiva de los cachalotes frente a las orcas (agrupamientos en formaciones paralelas). Altas densidades de cachalotes fueron encontradas asociadas con varios caladeros que tuvieron altos rendimientos de pesca. Esta relación tiende a apoyar la hipótesis que los caladeros de mayor producción pesquera son también zonas de alimentación tradicional de los cachalotes. La pérdida monetaria asociada con interacciones operacionales vinculadas a la depredación fue de USD 92 684 (IC 95% USD 47 302–153 745) para la flota completa durante la temporada, con un promedio de pérdida por lance de USD 138 (IC 95% 74,76–249,3).

Keywords: *Physeter macrocephalus*, *Orcinus orca*, *Dissostichus eleginoides*, fisheries interactions, South America, depredation, CCAMLR

Introduction

Interactions between marine mammals and Patagonian toothfish (*Dissostichus eleginoides*) fishery operations have been reported to occur in the Atlantic sector of the Southern Ocean, mainly off South Georgia, primarily with killer whales (*Orcinus orca*) and secondarily with sperm whales (*Physeter macrocephalus*) (e.g. Ashford et al., 1996). Other areas in which interactions have been reported include the Falkland/Malvinas Islands and the southern coast of South America (Ashford et al., 1996). In particular, off southern Chile, little information is available on the magnitude of these interactions, in spite of anecdotal and unpublished information from fishers and scientific observers suggesting that interactions are frequent, with negative consequences for both cetaceans and the fishery (Salas et al., 1987; Ashford et al., 1996; Donoghue et al., 2003).

The Patagonian toothfish fishery began as exploratory during 1955 in Chile (González, 1962) and now extends throughout the country, with southern Chile being the area of best yields (Lemaitre et al., 1991). The fishery is segregated between artisanal and industrial operations. While the former operates north of 47ºS, does not have fishing quotas and is limited only by vessel size (maximum 18 m) and longline length (maximum 12 000 hooks per line), the latter, operating south of 47ºS, is subject to an individual quota that corresponds to a percentage of the total allocated catch as determined by public auction.

Measures used by fishers to counteract the interactions are only suspected and the impact of marine mammals on the fishing yield has not yet been assessed. Current knowledge indicates that killer whales may consume an important proportion of the fish caught, while sperm whales may occasionally become entangled with the longlines, leading to damage to or loss of gear (Ashford et al., 1996).

For the reasons outlined above, the Chilean Government, through the Fisheries Research Fund (Fondo de Investigación Pesquera), issued a call to develop a project to assess the problem of interactions between marine mammals and the industrial and artisanal Patagonian toothfish fishery in southern Chile (39ºS–57ºS). The specific objectives of this investigation were: (i) to determine the marine mammal species interacting with the fishery, and (ii) to characterise and quantify the interaction of marine mammals and the fishery on a spatial and temporal basis. This paper deals only with observations derived from industrial fishing vessels operating in the vicinity of the CCAMLR Convention Area.

Materials and methods

Study area

The region surveyed comprises the slope waters lying between 47ºS and 58ºS at the southwestern tip of South America (Figure 1). Southern Chile is in immediate proximity to Subareas 48.1 and 88.3, in both of which fishing for finfish is prohibited. This region is in close proximity to fishing grounds to the east within the CCAMLR Convention Area (Subarea 48.3) and probably shares the same populations of marine mammals and Patagonian toothfish stocks.

Observer coverage

Seven surveys were completed on board fishing vessels between April 2002 and March 2003. A total of 222 hauls were observed and 1 310 585 hooks were monitored. Of these, 180 hauls were selected for inclusion in this analysis because of the particular attention paid by the observers to marine mammal interactions, as the study also included the assessment of seabird interactions with the fishery. Temporal distribution of effort was markedly influenced by the seasonal pattern of the fishery, i.e. low during late autumn and winter, reaching a peak during September and October and gradually decreasing throughout the austral summer.

Observer protocol

Trained scientific observers used specially designed forms to record a number of parameters (e.g. geographic position, meteorological conditions, catch, number of damaged fish, marine mammal species present in the vicinity of the line, description of the fishing method through direct observation of the operation, with particular emphasis on line hauling).

Fish remains, as well as damaged fish attributed to marine mammal depredation, were measured to compare this information with allometric relationships and to evaluate whether marine mammals preferred particular species or sizes of captured fish.

Analysis

Depredation rates (TDLC(%)) were calculated as the proportion of damaged fish landed per line and per fishing trip according to the following relationship (modified from Yano and Dahlheim, 1995):

$$TDLC(\%) = \left(\frac{ND}{NT + ND} \right) * 100$$

where *ND* is the number of damaged fish, ascertained by the number of remaining heads, lips or trunks, and *NT* is the total number of fish showing no evidence of damage.

To assess if the same whales were interacting with the vessels, photo-identification techniques were used because of the proximity of whales to the vessels (particularly sperm whales) using a digital8 video camera. This tool was included as a pilot effort to understand cetacean population structure and distribution by comparing the results of this study with existing photographic databases from the eastern South Pacific (Hal Whitehead, Dalhousie University, Canada).

Observation data were initially analysed with descriptive statistics in order to determine the

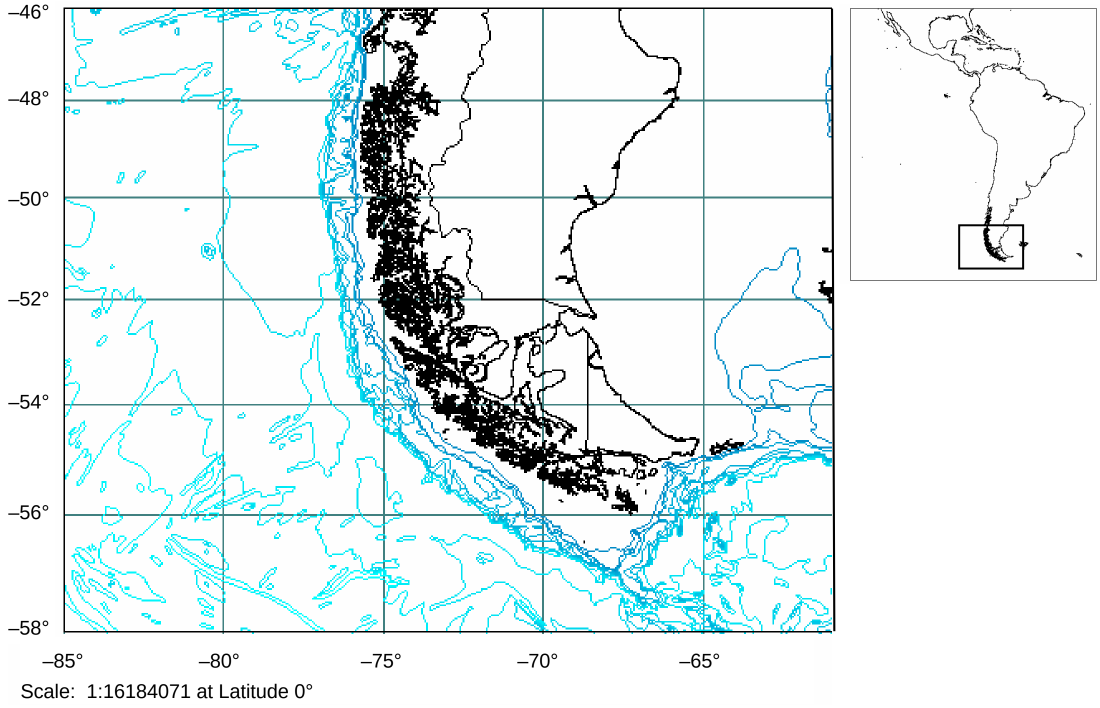


Figure 1: Study area in which operational interactions of marine mammals with the Patagonian toothfish fishery were examined.

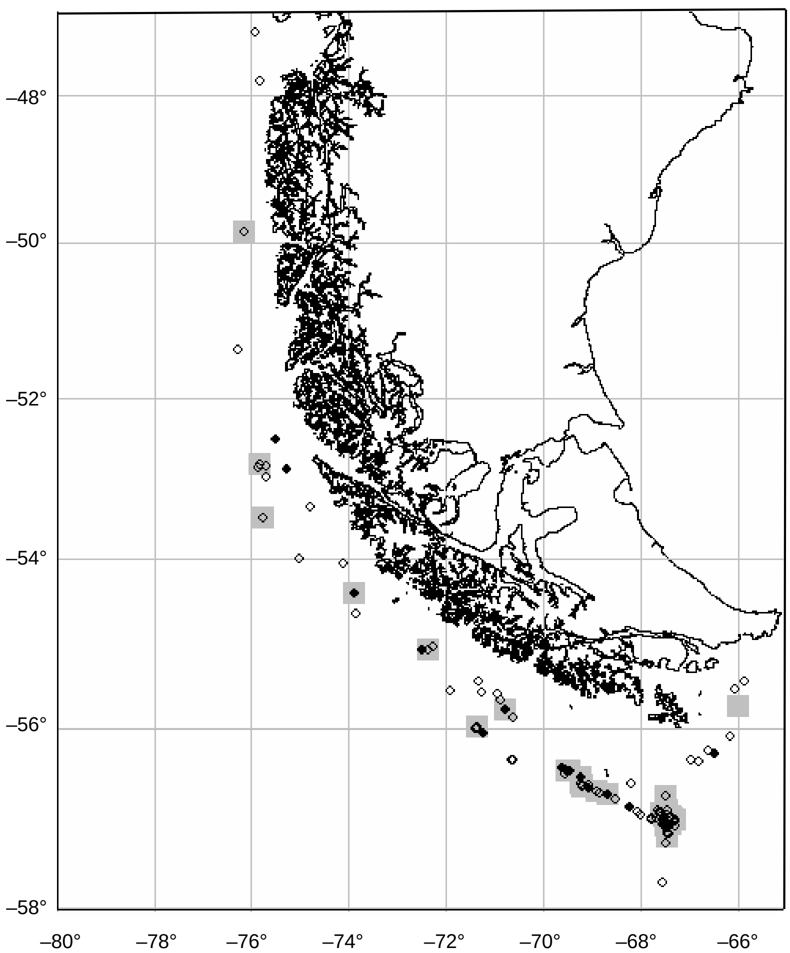


Figure 2: Sperm whale (open circles) and killer whale (closed circles) sightings in relation to areas in which interactions between cetaceans and the Patagonian toothfish fishery occurred (grey squares).

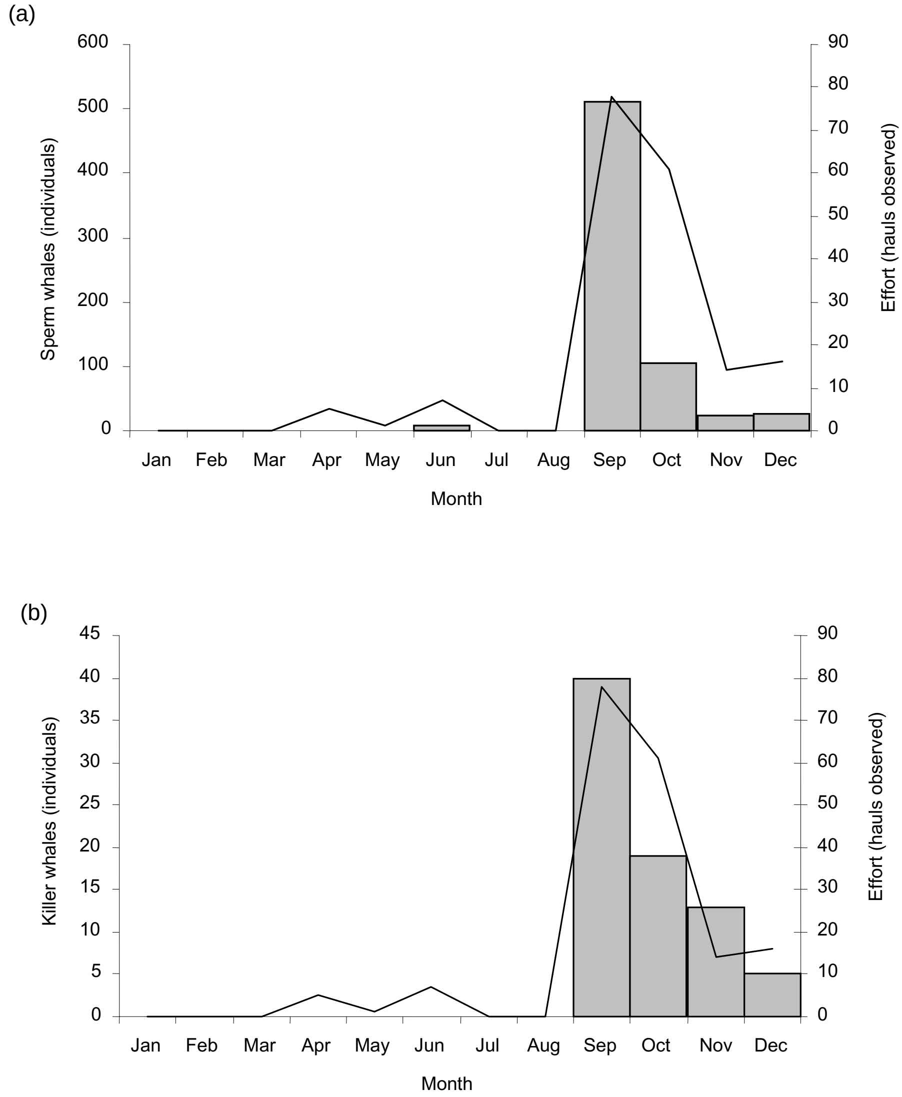


Figure 3: Number of individuals of most recurrent cetacean species – (a) sperm whales; (b) killer whales – associated with fishing operations for Patagonian toothfish, per month and number of hauls observed.

frequency of occurrence of different phenomena, as well as associated probability parameters on a spatio–temporal scale. To make robust estimates of confidence intervals (CIs) for depredation rates and financial loss, a bootstrap using 1 000 iterations was performed (Manly, 1997). A Geographic Information System (GIS) was used to assess the spatial and temporal extent of interactions, as well as to identify interaction 'hotspots' by overlapping georeferenced hauls with marine mammal sightings and interaction locations.

Results and discussion

Marine mammal species observed during fishing operations

Five species were recorded in the vicinity of fishing operations: sperm whales, killer whales, long-finned pilot whales (*Globicephala melas*), South American sea lions (*Otaria flavescens*) and South American fur seals (*Arctocephalus australis*). During navigation to and from fishing grounds, six sightings of 10 sperm whales were made, five of sea lions and two of fur seals.

During setting operations, 24 groups of sperm whales were sighted (n = 41 individuals) and during hauling operations, 108 groups of sperm whales (n = 674, mean group size = 6), 18 groups of killer whales (n = 77, mean = 4) (Figure 2) and one group of pilot whales (n = 15) were recorded. Interactions with fishing operations, however, were only evident when sperm whales and/or killer whales were present.

Sperm whales were present with higher frequency than any other species on the fishing grounds (Figure 3). In 60% of all monitored sets sperm whales were present, while killer whales were observed in only 10% of these.

Figure 4: Examples of records from the sperm whale (left) and killer whale (right) photo-identification database.

The encounter dynamics of both species during the hauls suggests that sperm whales tend to be present with higher frequency when killer whales are not, while killer whales tend to occur with higher frequency when sperm whales are present. This suggests that the presence of one species is not independent of the presence of the other (Chi-square$_{(0.05,\ 1\ gl)}$ = 2.7238, p = 0.0989). The sighting frequency of the most regularly sighted species (sperm and killer whales) was closely related to observer effort (Figure 3) and September was the month when most sightings of both species were made.

Photo-identification

A total of 35 sperm whales was individually photo-identified as well as two killer whales. The quality of photographs and video sequences varied considerably between days and individuals, however, the observations conducted allowed the feasibility of the method to be confirmed (Figure 4). Only one re-sighting was confirmed and corresponded to a sperm whale coded as PM10-Fip-020914 which was first sighted on 14 September 2002 at 57.037ºS 67.517ºW. This individual was re-sighted on 21 September 2002 at 57.126ºS 67.320ºW by a different ship. All records obtained were included in a photo-identification database for further analysis and subsequent comparison with other areas.

Operational interactions

No direct observations were made of cetaceans attacking the line. However, when killer whales were present and damaged fish were being hauled, frenzied activity was observed on several occasions near the line and close to the surface some 50–100 m from the vessel where large numbers of seabirds congregated, possibly to feed on the remains of fish depredated by killer whales.

Only one fatal entanglement of a sperm whale with the line was recorded during an exploratory trip undertaken during late 2001, suggesting that this issue does not pose a major threat to cetacean populations. However, this is a problem that needs to be studied in more detail, particularly north of 47°S in Chile where some artisanal fishers use illegal counter measures such as ramming, shooting or even explosives to deter sperm whales or any other marine mammal that may affect the fishery.

Damaged catch

Three types of evidence were found on the hooks after depredation on the line had occurred: lips, heads and trunks. Considering the difficulty of differentiating between probable 'culprits' such as cetaceans, sharks, squid or the effect of mechanical drag caused by hauling the line, most of this damaged catch (unless obviously attributable to other sources) was attributed to the category 'depredated by marine mammals'. Although this possibly maximises the depredation rate attributable to killer and sperm whales, it could also account for those fish which were taken but of which no evidence was left. Whichever is the case, and in spite of observers making every effort to identify other possible causes of damage, this highlights the need to develop more effective methods of assessing this interaction.

It is assumed that by-catch was not consumed by cetaceans as no evidence for damaged individuals from species other than Patagonian toothfish was found. A total of 121 lips, 16 heads and 3 trunks were recovered which suggests the loss of at least 140 toothfish in the portions of hauls observed. Extrapolating this value to complete hauls (100% coverage) increases this figure to 199 individuals. Considering that monitored vessels caught 15 135 toothfish during the study period, cetaceans would have consumed only 1.73% of the total catch (IC 95% 0.887–2.883) as estimated through a bootstrap, which means that on average only one toothfish would be depredated per set.

An analysis regarding the size of depredated fish in relation to the catch indicates that sperm and killer whales would have consumed toothfish of all size classes from the fishing gear (Figures 5a and 5b), and this is substantiated by Yukhov's (1972) observations (as identified by Ashford et al., 1996) of stomach contents of sperm whales in the southern Indian Ocean. This is important as it means that whales would not be selecting larger fish from the line as expected.

Frequency of occurrence of heads and trunks was noted to be higher when killer whales were present, suggesting that this species bites and tears the fish from the line. The characteristics of the damage left by killer whales on depredated fish are similar to those described by Yano and Dahlheim (1995) and Secchi and Vaske (1998). In contrast, when only sperm whales were present, mostly lips were found on the line. Due to the position of the sperm whale's mouth in relation to the rest of its head, these animals presumably take the fish with the body in a sideways, or possibly upside-down, position by pulling or sucking the whole fish from the hook while leaving the weakest link attached to it, the lip.

Depredation rates

Given that observers have multiple tasks on board, the whole of the line cannot be monitored. For this reason, the observed depredation rate was extrapolated to the whole line in order to complement the unobserved portion. This approach possibly maximises (or may even minimise) the actual depredation rate given that depredation does not necessarily occur uniformly along the line.

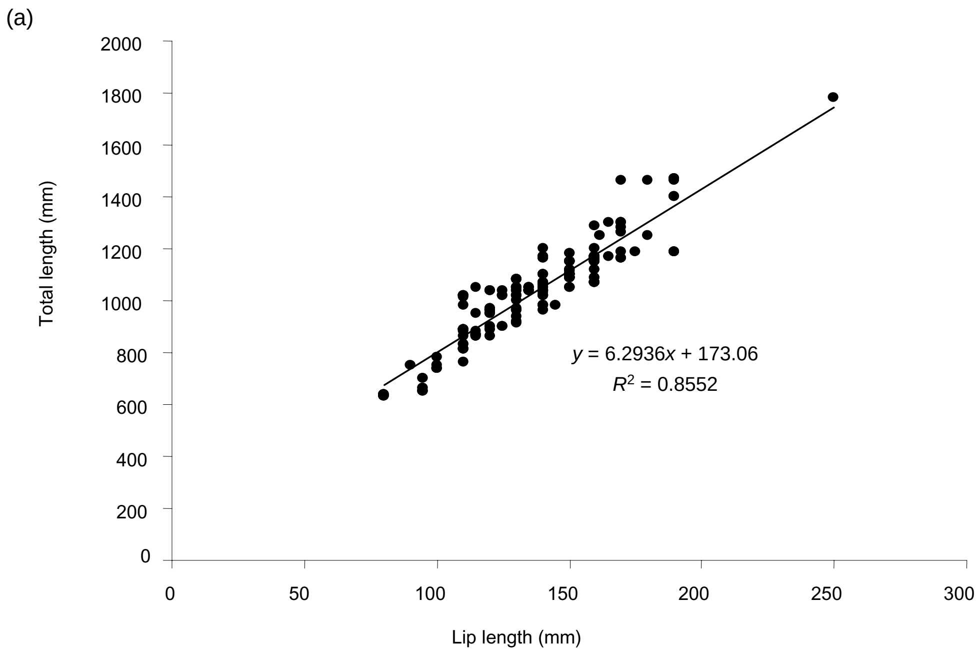
The mean depredation rate was 3% (±2% IC 95%; n = 180 sets) and ranged between 0 and 100%. Considering that in 153 (84%) of the actually monitored sets there was no interaction whatsoever and that the mode and median was 0, the global impact of cetaceans on the fishing yield is considered to be low (Figure 6).

Mixed sightings of killer and sperm whales were observed on 12 occasions and no depredation was observed during most of these events (Figure 7). A possible explanation for this is that some groups of killer whales prefer to attack aggregated sperm whales rather than to take fish from the line. This is further supported by the observations made when killer whales arrived in the area and sperm whale surface behaviour was modified by their grouping into tight parallel arrangements (possibly a defensive formation). This is consistent with the feeding habits and ranging patterns of type A killer whales as described by Pitman and Ensor (2003). This inter-specific interaction would be positive to the fishery due to the reduction in depredation from the longline.

Spatio–temporal distribution and intensity of interactions

Most interactions with whales occurred along the middle of the Pacific-South American continental shelf slope as well as near relevant bathymetric features such as islands (Figure 8).

Given that observation effort was inconsistent and subject to the decisions of the fishing master(s), it is difficult to identify temporal patterns of relative abundance. However, some patterns can be tentatively identified. High sperm whale densities were found to be associated with different hotspots such as: (1) 57ºS 68ºW (slope lying west and south of Diego Ramírez Archipelago), (2) 55.5ºS 71.5ºW (south of Ballenero Channel) and (3) 53ºS 75ºW (western mouth of the Magellan Strait) (Figure 8). Most interactions occurred in hotspots 1 and 2, both of which had high fishing yields. As a comparison, the high number of sperm whales observed during September 2002 (54 groups of 512 individuals) is slightly lower than historical records of the total number of sperm whales observed (not captured) between 1958 and 1981 along the entire central coast of Chile (n = 571) (Aguayo-Lobo et al., 1998).



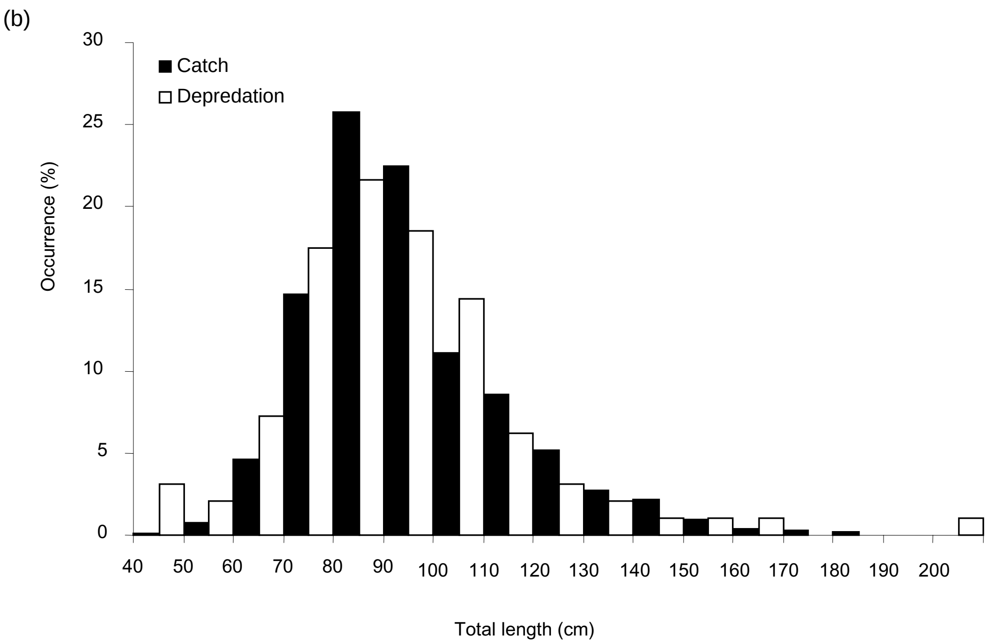


Figure 5: (a) Allometric relationship between lip length and standard length for the Patagonian toothfish in southern Chile (n = 202); (b) length frequency of Patagonian toothfish caught by longline (black bars) and those depredated by sperm and killer whales (white bars) in southern Chile as derived from lip length and the linear function described in (a).

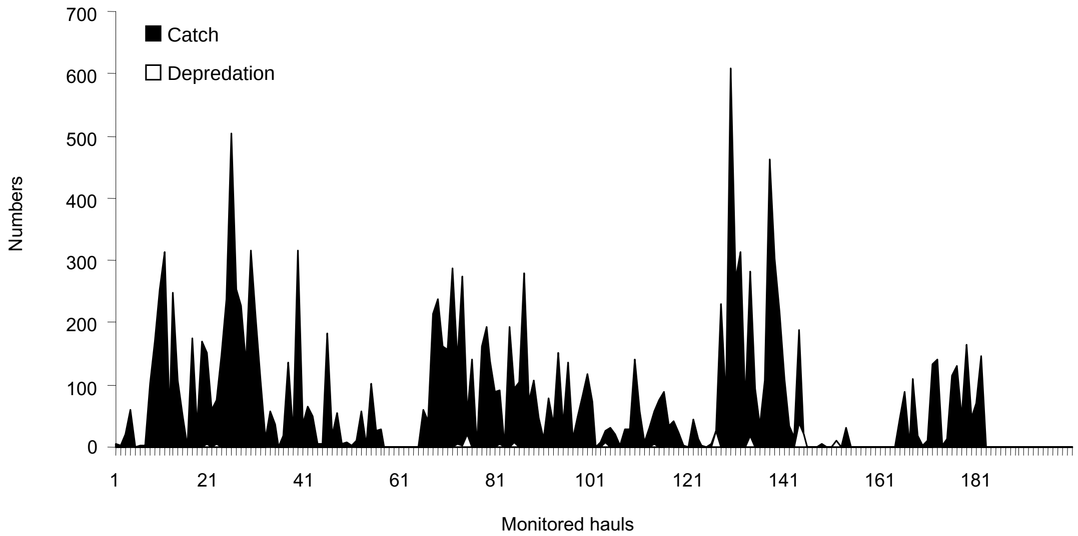


Figure 6: Total catch of Patagonian toothfish by the commercial longline fleet off southern Chile (black) versus depredation attributed to cetaceans (white) in 180 monitored sets during 2002.

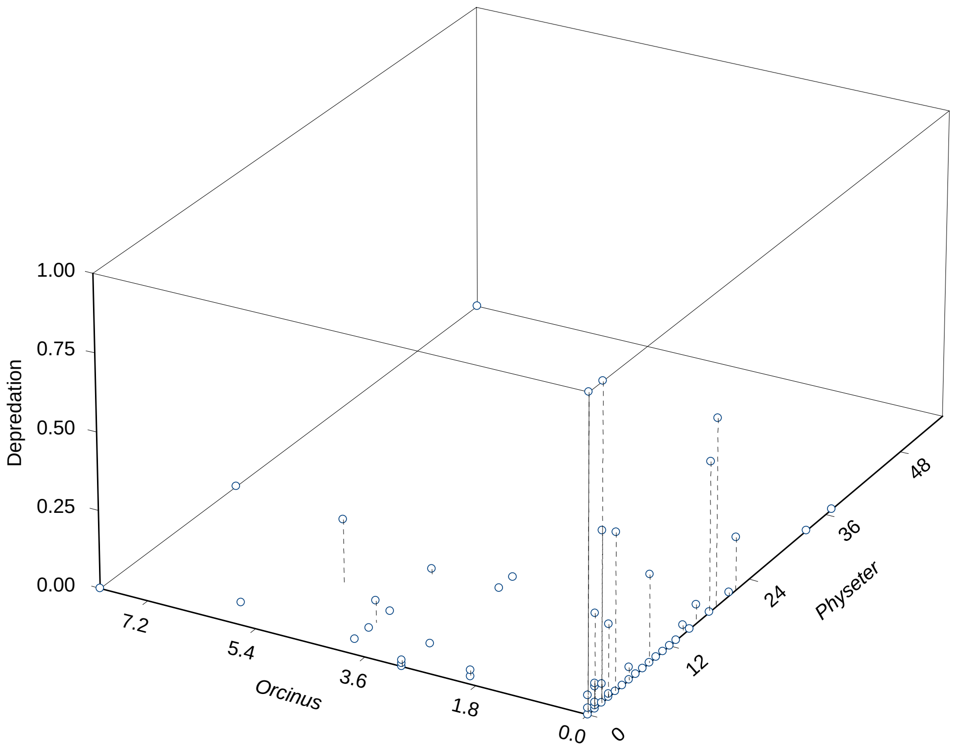


Figure 7: Three-dimensional representation of individual and mixed effect of the number of killer whales (*Orcinus* axis) and sperm whales (*Physeter* axis) on the depredation rate (Depredation axis). The central plane presents low values (mixed effect) while those closer to the axes are considerably higher (solitary effect), particularly (and almost exclusively) when sperm whales are present.

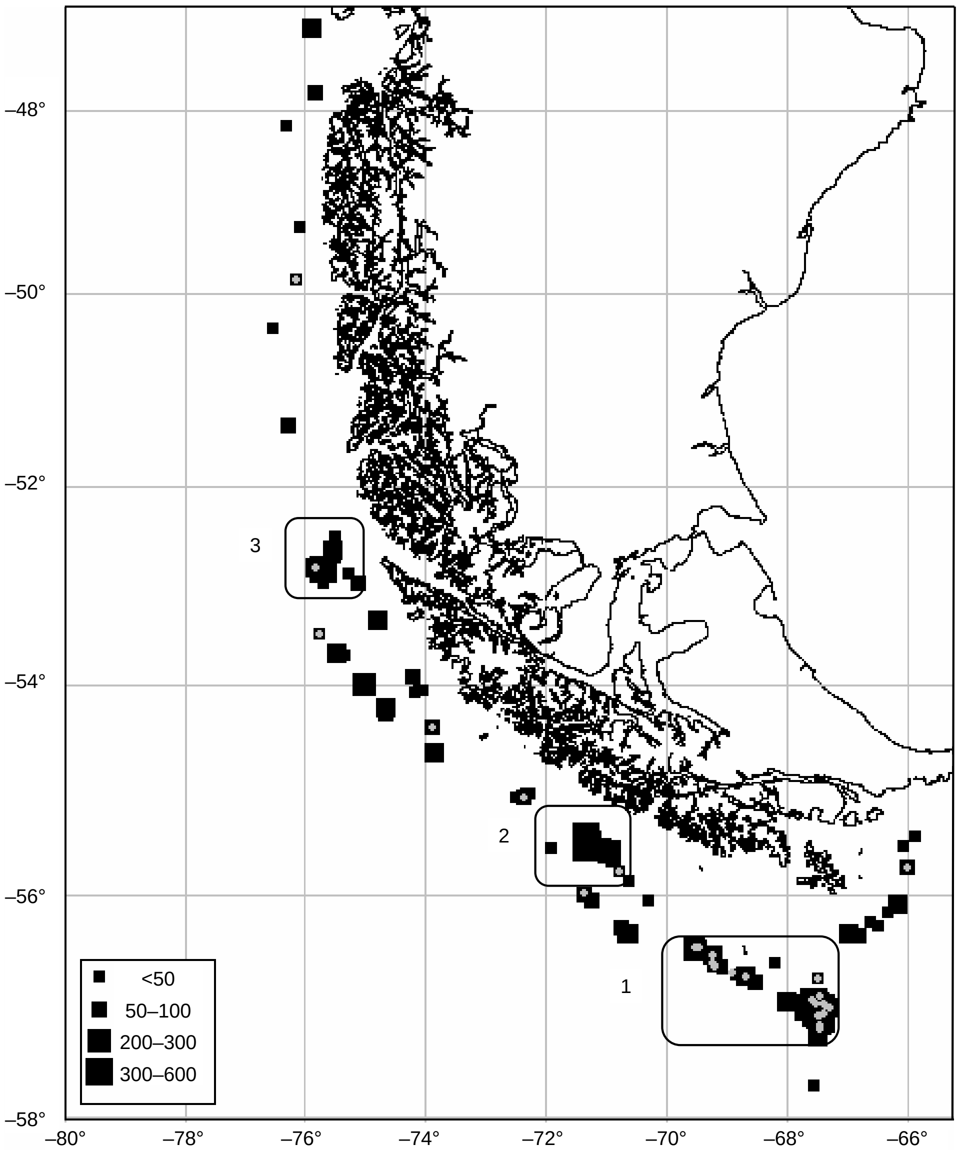


Figure 8: Yields from the Patagonian toothfish fishery in southern Chile (legend indicates number of fish per set) and locations of operational interactions as evidenced by remains of depredated Patagonian toothfish (grey circles). Boxed hotspots of interaction correspond to: (1) Diego Ramírez Archipelago and surrounding waters, (2) south of Ballenero Channel, and (3) western mouth of the Magellan Strait, which are also sectors in which large aggregations of sperm whales were observed (see also Figure 2).

If the catch-per-unit-effort (CPUE) is considered to be an index of Patagonian toothfish abundance and observations are classified with respect to sperm whale sightings, a positive but non-significant relationship (Mann–Whitney *U*-test, $p = 0.408$) is found between the fishing yield and sperm whale presence (Figure 9). This relationship (notwithstanding its non-statistical significance) tends to support the hypothesis that the richest fishing grounds are also traditional feeding grounds for sperm whales (Figures 8 and 9) and therefore a spatio–temporal overlap between the fishery and feeding sperm whales occurs. More dedicated data accumulated over the years could shed further light on this issue.

Financial loss

Taking into account the observations on the total amount of damaged fish, the financial loss associated with longline depredation amounts to US$15 522 (conversion factor = 7.8 kg/individual at US$10 per kg). Extrapolating to the whole fleet and applying a bootstrap, this figure increases to US$92 684 (CI 95% US$47 302–153 745) with a mean loss of US$138 per set (CI 95% US$74.76–249.3).

Interestingly, despite the low depredation levels found, the financial loss may be significant (at least from a scientist's point of view). However, these values have to be taken with caution given

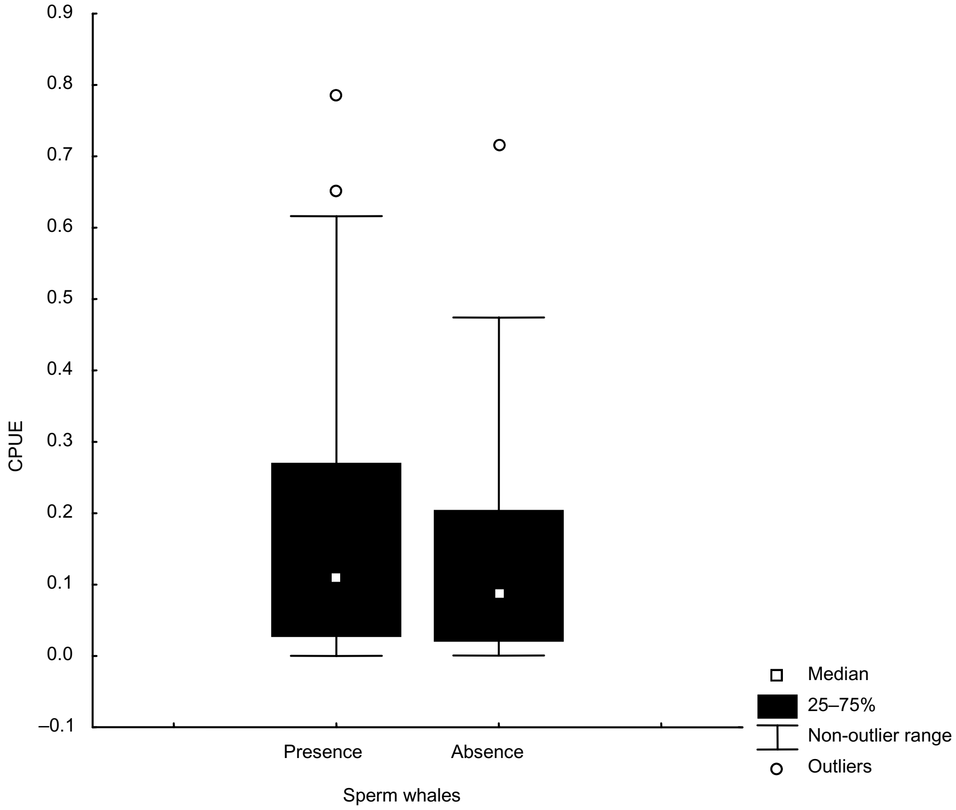


Figure 9: CPUE of Patagonian toothfish by the Chilean commercial longline fleet under two scenarios: presence and absence of sperm whales in the vicinity of the fishing operation (Mann–Whitney *U*-test, $p = 0.408$).

that they are probably maximised by the current low yield of the fishery and the actual high value of Patagonian toothfish on the market. In this analysis the cumulative effect of other operational interactions, such as entanglement of the line (due to its infrequent occurrence) or the loss (of time and money) incurred when the ship reacts to the presence of cetaceans by moving to another setting spot was not taken into account.

Conclusions

Operational interactions between cetaceans and the Patagonian toothfish fishery in southern Chile were evident when sperm whales and/or killer whales were present. However, complementary evidence suggests that these species are not the only 'culprits' and highlights the need to better understand the species and processes involved in the interactions by using additional research techniques such as video cameras attached to the longline (longline-cam). Acoustic monitoring could also prove useful for detecting whales at night and for examining the relationships between the type and rate of vocalisation and the rate of depredation. Photo-identification techniques were also successfully implemented during this study in order to identify recurrent individual whales to the fishery, but in view of the varying quality of the photographs, future studies could benefit from using faster high-resolution digital cameras.

Although the global impact of killer and sperm whales on the fishing yield is considered to be low, financial loss can be significant. An apparent (but not significant) relationship tends to support the hypothesis that the richest fishing grounds are also traditional feeding grounds for sperm whales. This needs to be further investigated since the industry might be able to mitigate the problem by compromising between avoiding hotspots or expecting that there will be a high probability of interaction with killer and/or sperm whales.

In this regard, independent investigations of the ecology of species involved in interactions with longline operations should be encouraged, since there is a considerable lack of knowledge on the distribution, abundance and ranging patterns of most marine mammal species in Chile. Examples of this were the unexpected large aggregations of sperm whales found in some areas off the southern tip of South America. Such studies should complement the implementation of scientific observer programs that use standard protocols which include detailed, controlled and careful experimentation aimed at mitigating these occurrences (see Donoghue et al., 2003 for a detailed list). Partnerships between the industry and the scientific community are essential to ensure that such investigations take place.

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