CCAMLR Science, Vol. 17 (2010): 163–178

ESTIMATING THE IMPACT OF DEPREDATION BY KILLER WHALES AND SPERM WHALES ON LONGLINE FISHING FOR TOOTHFISH (*DISSOSTICHUS ELEGINOIDES*) AROUND SOUTH GEORGIA

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Abstract

Observer data collected on longliners between 2003 and 2009 were analysed to look at the levels of depredation caused by killer whales (*Orcinus orca*) and sperm whales (*Physeter macrocephalus*) around South Georgia. Since 2003, cetaceans have been observed on 22% of 14 300 observed lines, with killer whales present on 3.8% and sperm whales on 17.7% of lines. Killer whales appear in pod sizes normally of 4 to 10 animals, and often appear to actively seek out fishing vessels and 'strip' the line of a large number of toothfish, usually depressing CPUE by about 50%. Sperm whales occur in smaller pod sizes, normally between 1 and 4 animals, and have a relatively lower impact on catches, depressing CPUE by up to 20%. Sperm whales have been more frequently encountered in recent years, occurring in larger pod sizes, whereas killer whale encounters and pod sizes have remained relatively constant. Most interactions from sperm whales occur during May at the start of the season with the sightings becoming fewer towards the end of the season in August. Killer whale interactions appear to be more consistent with no obvious pattern between months. Both species demonstrate an east to west migration throughout the season that is not related to the pattern of fishing effort. By comparing catch rates with and without the presence of cetaceans, accounting for other determinants of toothfish CPUE through a generalised linear model, it is estimated that the amounts of toothfish removed from longlines by cetaceans have varied between 1% and 8% of the declared catches over the period 2003–2009, with an average of 3.6%.

Résumé

Les données collectées par les observateurs sur les palangriers de 2003 à 2009 ont été analysées afin d'examiner les niveaux de déprédation exercée par les orques (*Orcinus orca*) et les cachalots (*Physeter macrocephalus*) autour de la Géorgie du Sud. Depuis 2003, on note la présence de cétacés sur 22% des 14 300 palangres observées, dont 3,8% concernent des orques et 17,7%, des cachalots. Les orques, qui apparaissent généralement en troupeaux de 4 à 10 individus, semblent souvent rechercher activement les navires de pêche et « arrachent » un grand nombre de légines des lignes de pêche, entraînant généralement une baisse d'environ 50% de la CPUE. Souvent en plus petits troupeaux de 1 à 4 individus, les cachalots ont un impact relativement moins important sur les captures, pouvant faire baisser la CPUE de 20% au maximum. Ces dernières années, la présence de cachalots est plus fréquente et la taille des groupes, plus importante. Par contre, les rencontres d'orques et la taille de leurs troupeaux sont restées relativement constantes. La plupart des interactions avec des cachalots ont lieu en mai, au début de la saison, et les rencontres s'atténuent vers la fin de la saison en août. Elles semblent plus homogènes avec les orques et aucune tendance n'est mise en évidence entre les mois. Les deux espèces migrent d'est en ouest pendant la saison sans que cela soit lié à la tendance de l'effort de pêche. Une comparaison des taux de capture avec ou sans la présence de cétacés, compte tenu d'autres déterminants de la CPUE de légine par le biais d'un modèle linéaire généralisé, il est estimé que les quantités de légine prélevées des palangres par les cétacés ont varié entre 1% et 8% des captures déclarées pendant la période de 2003 à 2009, soit une moyenne de 3,6%.

Резюме

Были проанализированы данные наблюдателей, собранные на ярусоловах в период 2003–2009 гг., с целью выяснения уровней хищничества со стороны косаток (*Orcinus orca*) и кашалотов (*Physeter macrocephalus*) вокруг Южной Георгии. Начиная с 2003 г. киты были замечены на 22% из 14 300 наблюдавшихся ярусов, из них косатки – на 3.8%, а кашалоты – на 17.7% ярусов. Косатки появляются группами, обычно включающими от 4 до 10 китов, и, как представляется, зачастую активно разыскивают промысловые суда и "снимают" с ярусов большое количество клыкача, как правило сокращая CPUE почти на 50%. Кашалоты встречаются меньшими группами, обычно насчитывающими от 1 до 4 китов, и оказывают относительно меньшее воздействие на уловы, снижая CPUE не более чем на 20%. В последние годы кашалоты стали встречаться чаще и более многочисленными группами, тогда как встречаемость и размеры групп косаток остаются относительно постоянными. Больше всего взаимодействий с кашалотами происходит в мае, в начале сезона, а по мере приближения окончания сезона в августе их наблюдается все меньше. Взаимодействие с косатками, по видимому, более постоянно и не имеет явного распределения по месяцам. В течение всего сезона оба вида осуществляют миграцию в направлении с востока на запад, что не связано с распределением промыслового усилия. Путем сравнения коэффициентов вылова при наличии и в отсутствие китов и принятия во внимание других определяющих факторов для CPUE клыкача в обобщенной линейной модели было определено, что количество клыкача, снятого с ярусов китами, в период 2003–2009 гг. изменялось в пределах от 1% до 8% заявленного вылова при среднем значении 3.6%.

Resumen

Se analizaron los datos de observación recolectados a bordo de palangreros entre 2003 y 2009 para evaluar el nivel de la depredación llevada a cabo por orcas (*Orcinus orca*) y cachalotes (*Physeter macrocephalus*) alrededor de Georgia de Sur. Desde 2003, se ha registrado la presencia de cetáceos en 22% de las 14 300 líneas observadas, observándose orcas en 3.8% de estas líneas y cachalotes en 17.7% de las mismas. Las orcas son observadas normalmente en grupos de 4 a 10 animales, y a menudo parecen estar persiguiendo activamente a los barcos de pesca y arrebatando un gran número de austromerluzas del palangre, reduciendo por lo general la CPUE en un 50% aproximadamente. Los cachalotes andan en grupos menos numerosos, generalmente de 1 a 4 animales, y tienen un impacto relativamente menor en la captura, disminuyendo la CPUE hasta un 20%. En los últimos años los encuentros con cachalotes ocurren con mayor frecuencia, siendo sus grupos más numerosos, mientras que la frecuencia de los encuentros con orcas y el tamaño de los grupos de este cetáceo han permanecido relativamente constantes. La mayoría de las interacciones con cachalotes ocurre en mayo, al comienzo de la temporada, disminuyendo los avistamientos paulatinamente a medida que se aproxima el fin de la temporada. Las interacciones con las orcas son más constantes, y no se observa ninguna tendencia mensual obvia. Ambas especies se desplazan de este a oeste durante la temporada, y esta migración no está relacionada con la distribución del esfuerzo pesquero. A través de la comparación de las tasas de captura en presencia y ausencia de cetáceos y tomando en cuenta otros determinantes de la CPUE de austromerluza con un modelo lineal generalizado, se estimó que la cantidad de austromerluzas sacada de los palangres por los cetáceos varió entre 1% y 8% de las capturas declaradas durante el período 2003–2009, siendo el promedio de 3.6%.

Introduction

Interactions involving sperm whales (*Physeter macrocephalus*) and killer whales (*Orcinus orca*) in the Southern Ocean have been well documented in recent years, most recently by Kock et al. (2008). Around South Georgia they were first recorded by Ashford et al. (1996) and more recently by Purves et al. (2004). Purves used CCAMLR observer data collected from around South Georgia to look at interactions between 2000 and 2002 and concluded that there was a high inter-vessel variation of sightings and that interactions were concentrated around geographical ‘hotspots’. The catch-per-unit-effort (CPUE) was found to be slightly higher when sperm whales were seen but significantly lower in the presence of killer whales, suggesting that sperm whales are attracted to areas of high catch rates.

Since 2002, anecdotal information from both fishers and scientific observers suggest an increase in the numbers of cetaceans and in the overall levels of depredation which will affect both the fishing industry and fishery management. Industry perceives marine mammals as direct competitors for a resource, with economic losses coming directly from loss of catches and indirectly from the increased effort associated with avoiding the cetaceans (by relocating the vessel) and replacing the lost catch. In addition, fishery managers must decide how to account for what can be considered an unattributed source of fishery-related mortality. For instance, in the sablefish fishery that operates off the coast of Alaska, the Bearing Sea and Aleutian Islands, a scientific longline survey is used as an indicator of stock biomass in the assessment. Survey and commercial line sets affected by killer whales are excluded from the assessment, although during 2007 it was found this had no significant effect on CPUE (Hanselman et al., 2008). Sets affected by sperm whales, however, are not excluded as their effects are considered minimal.

Within the Southern Ocean, cetacean–fisheries interactions have been recorded around South Georgia (Subarea 48.3), Crozet and Kerguelen Islands (Subareas 58.6 and 58.5) and Prince Edward Island (Subarea 58.7). In the Crozet and Kerguelen fishery, depredation has been estimated since 2001. Standardised CPUE indices are adjusted according to estimated levels of depredation, which have varied from year to year since 2001 (SC-CAMLR, 2007a). Currently only limited data on depredation levels from the Prince Edward Islands exist with one observer estimating that during the 2004/05 season two fish were being taken for every one hauled. This is not taken into account when estimating total mortality and the impact of depredated lines is not built into any assessment (SC-CAMLR, 2007b).

This paper examines data collected by observers in Subarea 48.3 between 2003 and 2009 and determines the distribution and extent of the depredation by cetaceans around South Georgia.

Methods

From 2003 to 2009, scientific observers on all longline fishing vessels operating in South Georgia were required to collect information on the abundance of cetaceans around their vessels during each observed longline haul during the fishing season (May to August). In addition to the presence or absence and abundance of cetaceans, their distance from the vessel and whether they were observed feeding on the line were also recorded (CCAMLR, 2009). The proportion of observed hauls was above 85% for most years.

Both sperm whales and killer whales take fish off the lines, and in some cases it was possible to observe the direct impacts of depredation on hooked toothfish, for instance when fish had clearly been bitten or only fish lips remained attached to hooks. However, in many cases it was not possible to directly observe predation activities, for instance when fish were completely removed from the line. Therefore, an alternative method for estimating the weight of toothfish taken from the line was used. Since they take fish off the lines, cetacean depredation should lead to a reduction in CPUE, expressed as kg of toothfish per thousand hooks, and depredation can therefore be inferred from the relative reduction in CPUE on lines with cetaceans present compared to lines without any cetaceans present. However, many other factors influence the CPUE of longlines, including year, vessel nationality, depth, month and area of capture (Hillary et al., 2006). Therefore, generalised linear models (GLMs) and generalised additive models (GAMs) were constructed with these various factors to investigate the impacts of depredation on longline CPUE. For the purpose of this analysis it was assumed that whenever cetaceans were present they were feeding off the line.

Results

Patterns of interaction

There are some seasonal and spatial patterns to the behaviour of cetaceans at South Georgia. The highest rate of sperm whale interactions occurs during May, when they are observed on approximately 26% of the lines. This drops off in June and July to around 16% and finally in August to under 12%. This trend is significant (R^2 = 0.318, n = 27, P < 0.01). There was no such trend in killer whale interactions (R^2 = 0.0003), although the pod size appears to be lower in the middle of the fishing season (Figure 1). These observations are not a reflection of the level of fishing activity, which declines only slightly towards the end of the season; over the seven years, 27% of observed sets have been set in May, 26% in June and July, and 21% in August.

Figure 2 shows the distribution of interactions for both species by month during the season based on the aggregated data from 2003 to 2009. During May, sperm whale interactions are spread around the island, with a large proportion taking place in the south. In June and July these interactions move away from the south to the north and west, with all the sightings in August to the northwest of the island and north of Shag Rocks. Killer whales show a more obvious east–west movement with interactions concentrated to the northeast during May and spreading across the island during June and July. Nearly all the interactions occur to the west in Shag Rocks during August. This east–west movement can also be seen in Figure 3 which shows the proportion of sightings of each species in each area, assuming the split between east and west at 39°W. Killer whales are clearly shifting areas, sperm whales appear to move back to the east during August, although sightings drop everywhere during this month but proportionately more in Shag Rocks. Examination of the fishing effort data over the same time does not indicate that this movement is simply following the fishing fleet; for example, August has the least amount of fishing effort in Shag Rocks but this is where the majority of sightings are for both species.

Estimation of cetacean impact

The number of observed sets affected by cetaceans is shown in Table 1. Over the whole period there has been some variability in the proportion of sets affected, with high points being 2005 and 2006 for both species, and 2009 for sperm whales. In 2006 and 2009, in particular, there was a high abundance of sperm whales around longline sets. Overall, 4% of sets were affected by killer whales and 18% by sperm whales.

A GAM, constructed with year, vessel nationality, depth, month, area and number of cetaceans present, is shown in Figure 4. In general, as has been demonstrated by toothfish assessments in Subarea 48.3 (Hillary et al., 2006) toothfish CPUE is significantly affected by the vessel's flag state (which is usually a function of the fishing strategy adopted by that nationality, and the gear used), the depth at which fishing occurs, the month of fishing and the area in which fishing occurs. Overlaid on top of this pattern one can see the influence of cetaceans: killer whales tend to remove large amounts of the catch from longlines, and arrive in pods of 4 to 10 animals, although larger numbers of animals do not have a greater impact on CPUE. Sperm whales, on the other hand, tend to arrive in pods of 1 to 4 animals, and the amount of fish removed appears to be linearly related to the pod size.

Another feature that deserves mention is the tendency for sperm whales to be more frequently encountered in areas of high CPUE. Killer whales do not show this behaviour to the same extent (Figure 5).

In order to estimate the impact of cetacean depredation on total extractions, the declared catches were corrected to take account of the CPUE reduction when cetaceans are present. A generalised linear model was constructed along the lines of Figure 4, using all sets monitored by observers (representing between 75% and 95% of all sets made during a season) but with the impact of cetaceans expressed as presence/absence rather than by number of animals. This was undertaken for each of the years 2003 to 2009; the proportionate decline in CPUE predicted by the model attributable to having sperm whales, killer whales or both present during a set was calculated and these data were used to correct declared catches on sets having those interaction types:

$$T_y = C_{y,n} + \sum_{l=1}^{3} \frac{C_{y,l}}{e_{y,l}}$$

where T is the corrected total catch in year y for observed sets, $C_{y,n}$ is the declared catch in year y on observed sets which had no cetacean interactions, $C_{y,l}$ is the declared catch in year y on observed sets which had interactions of type l, and e is the ratio of CPUE (kg/hook) between observed sets having interactions of type l and sets having no cetacean interactions. The three interaction types were killer whales, sperm whales and both species. An overall correction factor for the year can then be calculated as T divided by the sum of the individual Cs.

Noting that some high CPUE areas were disproportionately affected by sperm whales, the analysis was repeated for two sets of fine-scale rectangles: high CPUE areas and all other fine-scale areas. The choice of the high CPUE areas was made according to two schemes:

(a) three fine-scale rectangle squares qualitatively chosen as displaying the highest CPUE and sperm whale occurrence: the gully area, which is the fine-scale rectangle centred on 53.75°S 40.5°W in Figure 2, western Shag Rocks (53.25°S 42.5°W) and SE South Georgia (55.25°S 36.5°W);

(b) the five fine-scale rectangles with the highest CPUE in any one year.

The results confirm the much higher impact of killer whales, with CPUE usually being reduced by 50%, but no consistent pattern between high and low CPUE areas. The results for sperm whales confirm that the impacts are lower than for killer whales (up to 20% reduction), but the results in terms of proportional reduction between high and low areas under schemes (a) and (b) are different (Figure 6).

The total number of fish deaths caused by fishing can be assumed to be the sum of the recorded catch and the losses to cetacean depredation, and can be calculated by correcting for the reductions in CPUE calculated by the linear models. The correction factors changed only fractionally when the two-stage models were considered, compared to the simple model, since most of the catches were taken from the non-high CPUE areas (Table 2).

The maximum effect of cetaceans appears to have been to increase the apparent catch by 3.6%, but with no general trend during the time period from 2003 to 2009 (Table 2). The large difference in CPUE caused by killer whales does not translate to a very large difference in unrecorded catch, because the proportion of sets where they are present is between 3 and 5%. Over the seven years of study, mean pod size for killer whales actually dropped (significantly: individual t-tests on years 2003 and 2004 compared to 2008 and 2009, $P < 0.01$) (Figure 7). On the other hand, the pod size of sperm whales has increased slightly (again, significantly, t-test on 2009 against 2003, $P < 0.05$), particularly in some years, which combined with the high levels of encounter in these years significantly increased the nuisance value of sperm whales in 2006 and 2009 (Table 1).

Discussion

A symposium held in Samoa in 2002 concluded that using fish-remains on the line could provide a standardised method of estimating number of fish lost by calculating number of remains or damaged fish as a percentage of the total fish caught in a given fishery (Donoghue et al., 2003). This method was first suggested by Yano and Dahlheim (1995) when calculating loss due to killer whales in the southeastern Bearing Sea. However, it may be problematic to try to assess the impacts of depredation directly from evidence of damage to fish, as anecdotal information from observers at South Georgia suggest that remains very rarely come up when cetaceans are present, as the whole fish are often taken, and this would ultimately lead to an underestimate of the amount of fish lost. Thus, the comparison of standardised CPUE is potentially a more reliable method of estimating total losses.

Although sperm and killer whale interactions are perceived to interfere with the operation of the fishery in Subarea 48.3, results of this study suggest that the mitigation measures employed by fishing vessels – tying-off lines when whales are present, and taking avoidance measures – are being effective in minimising the impact of depredation. Although catch rates of affected lines are significantly depressed, the overall additional tonnage taken by whales is estimated to be relatively steady at about 3.6% per year.

The method adopted in this paper appears to be applicable to estimating the impacts of cetaceans on longline catches of toothfish in the Southern Ocean, but it does rely on there being sufficient data from every fine-scale area to be able to estimate well the depressive impact of cetaceans on CPUE. This is likely to be the case only when there are sufficient numbers of 'no cetacean' longline sets, because cetacean presence is only one of the potential factors that may influence CPUE – the others, clearly being time of year and vessel and/or nationality. The results presented in Table 2 suggest that, although it was technically important to undertake the analysis separately for fine-scale rectangles with high and low CPUE, for South Georgia this had very little practical impact on the results, adjusting the correction factors. This may not be the same in other areas of the Southern Ocean, where cetacean impacts are higher, such as at Crozet (Roche et al., 2007).

There was no evidence of increasing trends in the number of killer whales present around vessels, nor the number of lines that are affected. However, this study confirms that there was a trend of increasing interactions between sperm whales and the fishery over the years 2003 to 2006, followed by two years of low interaction, and finally another year of very high interaction in 2009 (Table 1). This has been caused by an increasing incidence of sperm whales, and some small increases in their pod size. Although this has not led to more losses, fishing vessels are increasingly required to take avoidance actions – tying-off the lines to return at a later date, or steaming to another part of the fishing grounds – which increases their fishing effort and costs.

Because killer whales cannot dive to the depths inhabited by adult toothfish (tagging studies have recorded a maximum diving depth of 265 m (Baird et al., 2005)) and sperm whales are thought to be able to reach up to 3 000 m (Whitehead, 2002), bringing toothfish into range, it might be suggested that depredation by killer whales represents additional mortality that would not naturally occur; and that by sperm whales probably represents an alternative natural predation. The correlation between high toothfish CPUE and the presence of sperm whales, which is not evident in the case of killer whales, supports the hypothesis that sperm whales may be

Table 1: Number of observed sets affected by cetaceans 2003–2009. KIW = killer whales, SPW = sperm whales. Note that the entire observer dataset was trimmed to remove records outside the main fishing season (May to August) and extremely shallow or extremely deep sets as these were generally research sets.

Year	KIW + SPW	KIW	None	SPW	Number of KIW observed	Number of SPW observed	Affected by KIW (%)	Affected by SPW (%)	KIW/ set	SPW/ set
2003	29	71	2 563	403	1090	946	3.3	14.1	0.36	0.31
2004	11	40	1 533	326	551	730	2.7	17.6	0.29	0.38
2005	23	59	1 292	322	522	811	4.8	20.3	0.31	0.48
2006	30	56	1 239	363	670	1 096	5.1	23.3	0.40	0.65
2007	14	68	1 626	261	755	582	4.2	14.0	0.38	0.30
2008	18	51	1 511	223	496	463	3.8	13.4	0.28	0.26
2009	22	58	1 606	495	573	1 384	3.7	23.7	0.26	0.63
Total	147	403	11 370	2 393	4 657	6 013	3.8	17.7	0.33	0.42

Table 2: Calculation of total catch corrected for cetacean depredation. Note that under method (a) there were very few sets each year from some of the high CPUE areas with both cetaceans present, and therefore the proportional reductions in CPUE for these areas were set equal to the reductions in the low CPUE areas. The total catch from high CPUE areas with both cetaceans present was less than 0.2% of the total catch over 2003–2009, and in consequence this adjustment had no material effect on the result.

	Correction factor (single-stage model)	Correction factor (2-stage CPUE model, method (a))	Correction factor (2-stage CPUE model, method (b))	Reported catch (tonnes)	Corrected catch (tonnes), single-stage model	Corrected catch (tonnes), 2-stage model (a)	Corrected catch (tonnes), 2-stage model (b)
2003	4.1%	3.1%	2.9%	7 528	7 840	7 760	7 750
2004	3.8%	3.9%	3.9%	4 497	4 669	4 671	4 671
2005	3.4%	5.1%	8.1%	3 057	3 160	3 213	3 303
2006	4.2%	4.9%	4.4%	3 535	3 683	3 707	3 690
2007	3.8%	3.3%	2.7%	3 539	3 672	3 656	3 634
2008	1.1%	2.1%	1.2%	3 864	3 906	3 946	3 908
2009	3.3%	3.9%	3.6%	3 383	3 496	3 514	3 505
Total				29 403	30 425	30 467	30 461
% increase over reported catch					3.5%	3.6%	3.6%

gathering in areas of high toothfish concentration as part of their normal foraging strategy. A similar conclusion was reached by Roche et al. (2007) from Crozet and Kerguelen Islands.

Using the estimates of total toothfish losses to the cetaceans (Table 2), and the number of cetaceans observed (Table 1) it is possible to estimate the average consumption per animal. For killer whales, this has fluctuated at around 90 kg/day which is consistent with estimates of daily energy requirements (Perez and McAlister, 1993; Sigurjónsson and Víkingsson, 1997). For sperm whales, this has declined annually at South Georgia from approximately 150 kg/day in 2003 to 25 kg/day in 2009. This is much lower than their estimated daily energy requirements (equivalent to 400–500 kg, using the estimates for daily energy requirements of between 600 and 830 000 kcal/day, and assuming a fish/squid diet energy equivalent of 1.3 kcal/g). Thus, sperm whales feeding in the area of vessels must still be obtaining most of their diet from their own foraging activities.

Moreover, it is not clear that sperm whales naturally feed on large quantities of toothfish. Studies of sperm whale diets point to them being predominantly made up of squid (Santos et al., 2001; Clarke and Pascoe, 1997; Clarke, 1996), and that in the Antarctic the cranchid *Mesonychoteuthis* and onychoteuthid Kondakovia make up the majority of the total tonnage consumed by sperm whales (Santos et al., 2001), although there have been suggestions that these studies are biased because of different retention properties of toothfish and squid hard parts in sperm whale stomachs. The predominant occurrence of sperm whales over the northwestern South Georgia shelf could be linked to the potentially higher abundance of squid in this area (González and Rodhouse, 1998; Xavier et al., 2002), as well as the opportunity to forage on toothfish. Thus, it is considered precautionary to include in assessments the removals from longlines by sperm whales, as additional mortality that would not necessarily occur in the absence of fishing.

There are a number of possibilities for the apparent seasonal movement demonstrated in Figure 2. The more obvious trend is in the killer whale movement which shows the majority of sightings at the start of the season in the east and at the end to the west, which could imply that the animals are coming in from another area to coincide with the toothfish fishing season and leaving at the end as part of a migratory cycle. Pitman and Ensor (2003) identified three different forms of killer whale that operate around Antarctica; based on body size, markings, habitat type and diet they were classified as Types A, B and C. Through observer photographs the killer whales at South Georgia have been identified as Type B, which have been most commonly sighted off the Antarctic Peninsula, although other sightings do indicate a circumpolar distribution.

It is thought that killer whales in general leave Antarctica and travel north during the austral winter, and although little is currently known about the particular migration of Type B whales, they have been identified off the Falkland Islands (Pitman and Ensor, 2003) indicating that they do follow a northward migration pattern. It is possible, therefore, that they migrate northwards from the peninsula during the austral winter, following the Antarctic ridge and arriving at South Georgia from the east at the beginning of May, continuing westwards towards the end of the season and moving on towards the Falkland Islands or South America, although positive identification through photographs has yet to confirm this. Other areas where they could migrate from are the islands to the east, Kerguelen, Crozet, Prince Edward and Marion Islands, which are also known to suffer depredation. However, the fishery at Kerguelen and Crozet is year-round with no detectable seasonal variation, the whales have been identified tentatively as Type A, and with possibly one Type C sighted, different types, and most pods have been recognised as being present all year round (P. Tixier, pers. comm.). The fishery at Prince Edward and Marion Islands is also open all year but currently only one licensed vessel operates there, this would not be sufficient to support the normal population apparent at South Georgia.

The other possibility is that there is no migratory pattern and that the there is a resident killer whale population present year-round at South Georgia. During the season it has been possible, through studying of markings from observer photographs, to identify 34 individuals (M. Unwin and P. McCarthy, unpublished). They have also been sighted outside the season; most significantly a large group of killer whales, estimated at 30–40 individuals, was sighted in coastal waters, and has been associated with longliners, having been spotted interacting during line-weighting trials in February (A. Black, pers. comm.). Acoustic surveys conducted during the austral summers of 1998, 1999 and 2000 also detected the presence of killer whales, although numbers could not be estimated (Leaper et al., 2000). This would also suggest that some form of prey-switching is occurring, since Type B killer whales are not thought to be fish feeders, being normally observed feeding on seals, penguins and possibly other species of whale. During the fishing season, however, they are seen feeding on toothfish, presumably as it requires less effort to hunt when they are around than mammals. Type B have also been observed as being innovative hunters, for example by knocking iceflows to dislodge seals (Pitman and Ensor, 2003); taking fish from lines can be seen as another form of innovation.

The data suggest that sperm whales are at a maximum abundance in May and June, reducing somewhat in July and August. The cause of this northwestwards movement may be to take advantage of the large spawning of *Illex* squid north of the Falkland Islands in July and August. Sperm whales around South Georgia are all thought to be male, so breeding migrations to the tropics are also potentially important. However, there may be some resident populations at South Georgia. An acoustic survey for sperm whales, conducted during 1998/99 and 2000, indicated the presence of 42 individuals (giving a population density of between 0.13 and 0.19 animals per 1 000 km^2) (Leaper et al., 2000). Historical records also show that they were caught in low numbers when whaling was permitted, although this shore-based whaling was restricted to the summer months (Moore et al., 1999).

Further work needs to be done to find out more about the movements of these animals, both during the season and outside it. Attempts to tag the animals in the past have been unsuccessful, due to the difficulties of doing this from the vessel, however, sightings of animals in other areas can be verified through building up a photo library of both species and coordination between researchers in different areas.

Conclusion

The amount of toothfish removed from longlines by cetaceans varied between 1% and 8% of the declared catches over the period 2003–2009, with an average of 3.6%. There was no evidence of increasing trends in the numbers of killer whales present around vessels, nor the number of lines that are affected. However, we confirm that there was a trend of increasing interactions between sperm whales and the fishery over the years 2003 to 2006, followed by two years of low interaction, and finally another year of very high interaction in 20009. The actions taken by fishing vessels to avoid actions such as tying off the lines to return at a later date, or steaming to another part of the fishing grounds appear successful in reducing interactions but result in an increase in fishing effort and costs to the vessel.

Acknowledgements

We would like to thank Michael Unwin and Paul McCarthy for their work in putting together the Identification Guide, all the observers who worked in Subarea 48.3 and who collected the data for use in this analysis, and Dr K. Reid who provided useful comments on an earlier draft.

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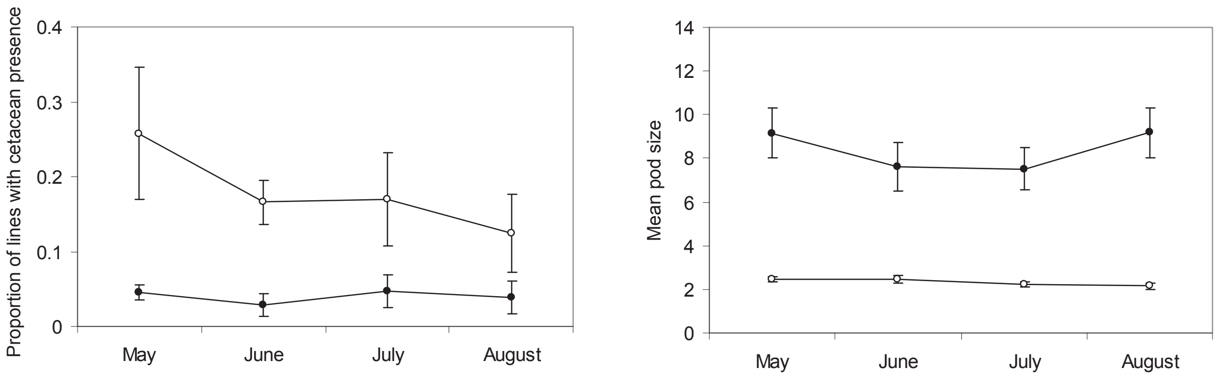

Figure 1: Proportion of lines reporting encounters with cetaceans (left) and average pod size during encounters (right) for killer whales (closed circles) and sperm whales (open circles). Estimated 95% confidence intervals are plotted. The left-hand figure presents average of the proportion of observed lines within one year that encountered cetaceans, and therefore $n = 7$ for each point. The right-hand plot presents, for sperm whales, the average pod size for all sets in which sperm whales were encountered over the whole time period, and likewise for killer whales. For killer whales, the number of observed lines was 181, 102, 172 and 108 for May–August respectively. For sperm whales, the number of observed lines which encountered whales was 969, 639, 609 and 363 respectively.

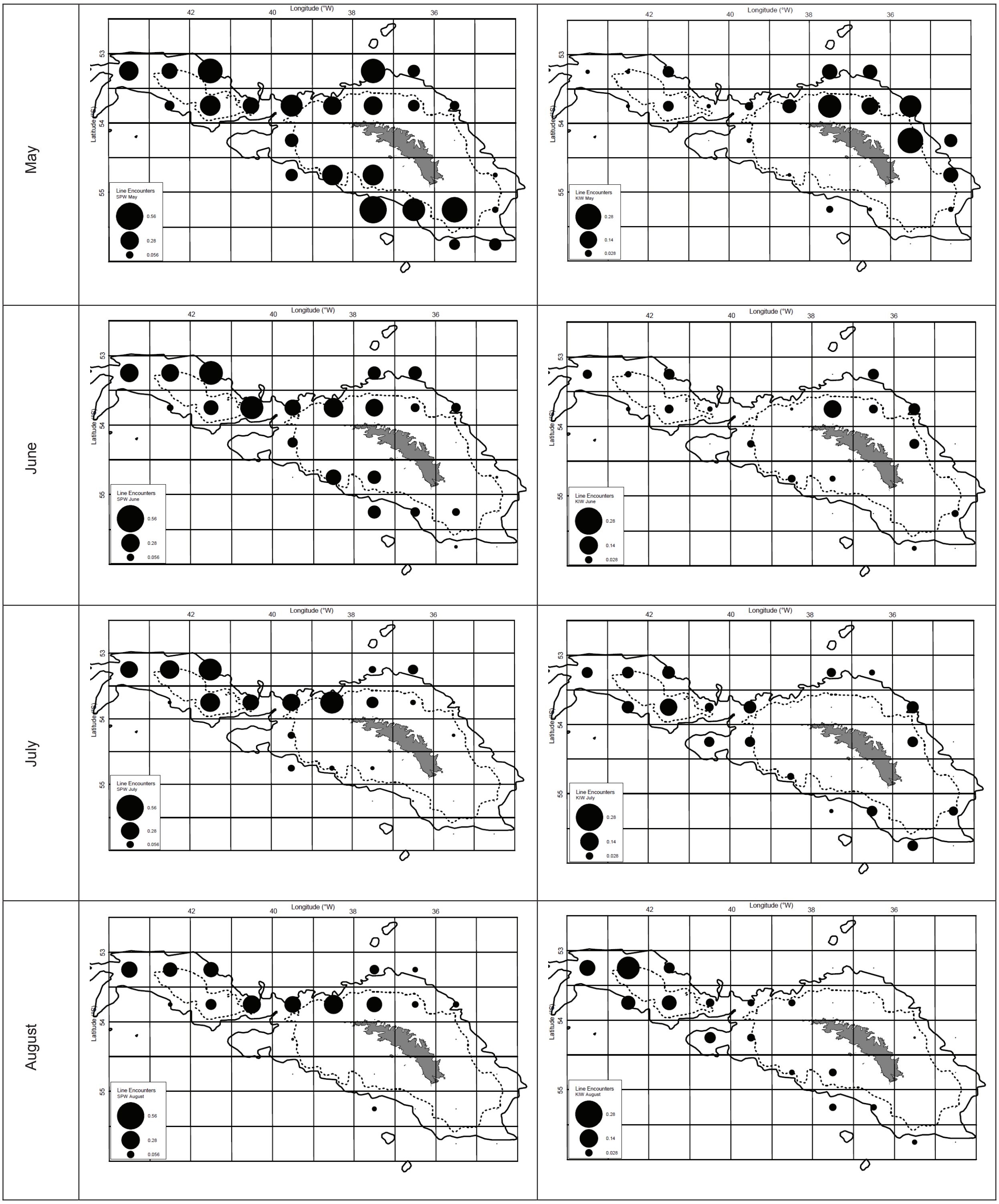

Figure 2: Monthly distribution of cetacean sightings. The data plotted are the number of sperm (left) or killer (right) whales encountered over the whole period from 2003 to 2009 divided by the total number of lines that were observed in that period. The grids are CCAMLR fine-scale rectangles.

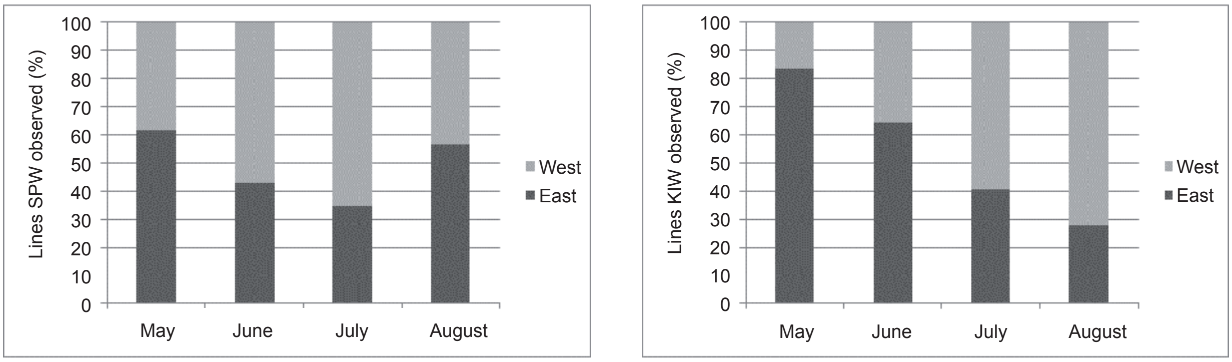

Figure 3: Proportion of cetacean sightings throughout season to the east and west of 39°W.

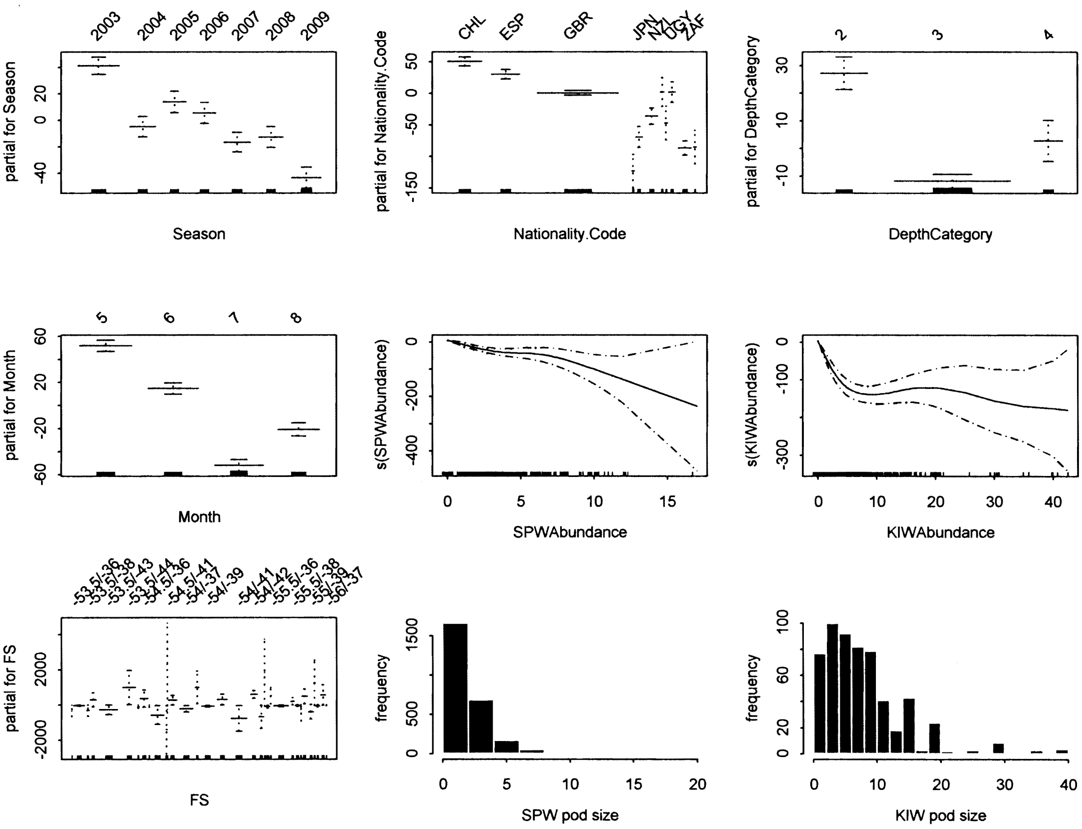

Figure 4: Analysis of cetacean interaction data from South Georgia, 2003–2009. The first seven plots (top to bottom, left to right) show the partial effect on CPUE of each of the parameters of a generalised additive model (GAM) on CPUE (kg/hook) – fishing season, vessel nationality, fishing depth (2 = 500–1 000 m), month (May to August), fine-scale rectangle, sperm whale (SPW) and killer whale (KIW) abundance – where data are individual hauls monitored by observers. Histograms of abundance of killer and sperm whales are also shown (y-axis is the number of records over the period 2003–2009).

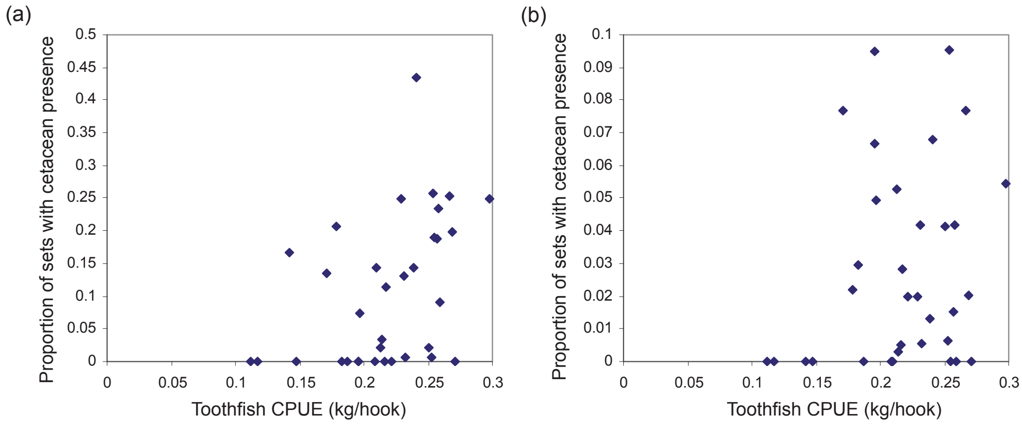

Figure 5: Relationship between cetacean occurrence and toothfish CPUE (2003–2009) for (a) sperm whale (SPW) (correlation: R^2 = 0.180, p < 0.05) and (b) killer whale (KIW) (correlation: R^2 = 0.044, p > 0.05). Each fine-scale rectangle is represented by an individual point.

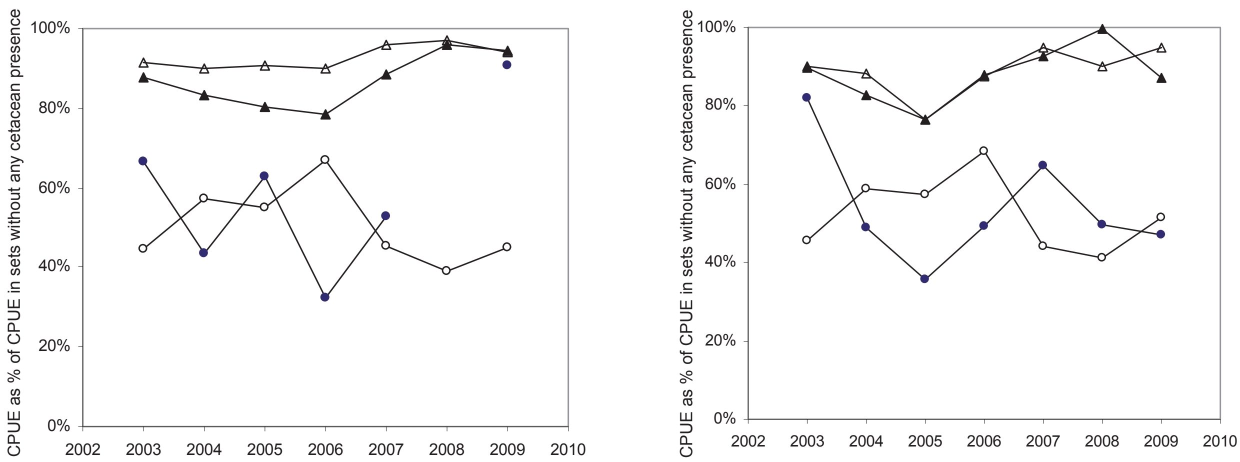

Figure 6: Estimated impacts of killer whales (KIW) and sperm whales (SPW) on CPUE in high CPUE and low CPUE areas, calculated using two methods ((a), left and (b), right; see text for further explanation) of identifying high CPUE areas. Symbols: triangles = sperm whales, circles = killer whales; filled symbols = high CPUE, open symbols = low CPUE.

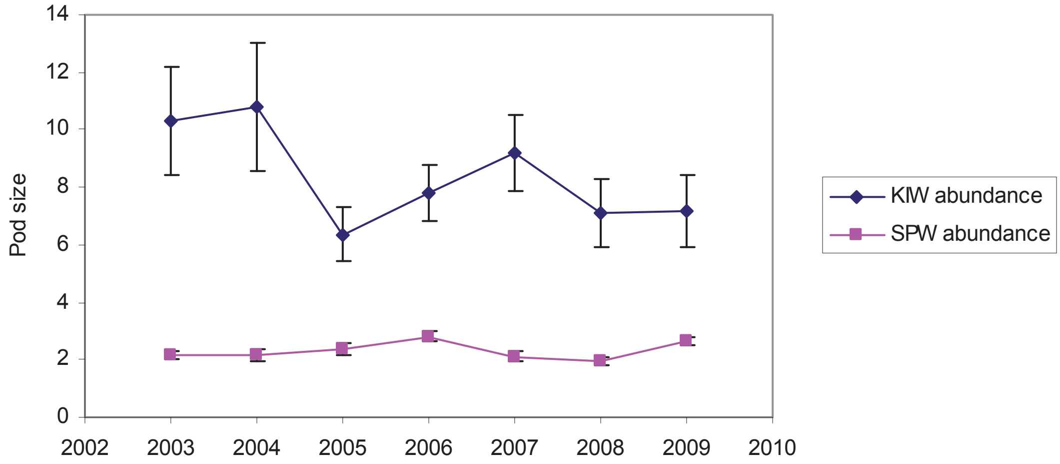

Figure 7: Mean (+95% CI) of killer whale and sperm whale pod size observed around fishing vessels in Subarea 48.3.

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du navire, profondeur de pêche (2 = 500–1 000 m), mois (de mai à août), rectangle à échelle précise, abondance des cachalots (SPW) et abondance des orques (KIW) – les données correspondant à des traits de chalut individuels suivis par les observateurs. Les histogrammes de l'abondance des cachalots et des orques sont également indiqués (en ordonnée figure le nombre d'enregistrements pour la période 2003–2009).

Figure 5: Relation entre la fréquence des cétacés et la CPUE de légine (2003–2009) pour (a) le cachalot (SPW) (corrélation : R^2 = 0,180, p < 0,05) et (b) l'orque (KIW) (corrélation : R^2 = 0,044, p > 0,05). Chaque rectangle à échelle précise est représenté par un point.

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Табл. 1: Количество наблюдавшихся постановок, подвергшихся нападению китов в 2003–2009 гг. KIW = косатки, SPW = кашалоты. Учтите, что весь набор данных наблюдателей был откорректирован с целью удаления данных, выходящих за рамки основного промыслового сезона (май–август), а также очень мелкие или очень глубокие постановки, поскольку это в большинстве своем исследовательские постановки.

Табл. 2: Расчет общего вылова с поправкой на хищничество китов. Учтите, что в рамках метода (a) каждый год было очень немного постановок в ряде районов с высоким CPUE, когда присутствовали оба вида китов, поэтому для этих районов было установлено такое же пропорциональное сокращение CPUE, как и для районов с низким CPUE. Общий вылов в районах с высоким CPUE при наличии обоих видов китов составлял менее 0.2% общего вылова в период 2003–2009 гг., вследствие чего эта поправка не оказала существенного воздействия на результат.

Табл. 3: Общие оценочные потери клыкача в результате хищничества (т), рассчитанные по двухэтапной модели (b).

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Рис. 1: Доля ярусов, по сообщениям, подвергшихся нападению китов (слева) и средний размер стада при встрече (справа) для косаток (закрашенные кружки) и кашалотов (незакрашенные кружки). Показаны оценочные 95% доверительные интервалы. На графике слева показано среднее годовое значение доли наблюдавшихся ярусов, подвергшихся нападению китов, поэтому для каждой точки n = 7. На графике справа показан средний размер стада кашалотов для всех постановок, при которых отмечалось присутствие кашалотов в течение всего периода времени, и то же самое для косаток. В случае косаток количество наблюдавшихся ярусов в период с мая по август составляло соответственно 181, 102, 172 и 108. В случае кашалотов количество наблюдавшихся ярусов, подвергшихся нападению китов, составляло соответственно 969, 639, 609 и 363.

Рис. 2: Ежемесячное распределение наблюдений китов. Данные на графике показывают количество кашалотов (слева) или косаток (справа), встреченных в течение всего периода 2003–2009 гг., поделенное на общее количество ярусов, наблюдавшихся в этот период. Сетка представляет собой мелкомасштабные клетки АНТКОМ.

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Рис. 4: Анализ данных о взаимодействии с китами у Южной Георгии, 2003–2009 гг. Первые семь графиков (сверху вниз, слева направо) показывают частичное воздействие на CPUE (кг/крючок) каждого из параметров обобщенной аддитивной модели (GAM) – промыслового сезона, государства судна, глубины лова (2 = 500–1 000 м), месяца (май–август), мелкомасштабной клетки, численности кашалотов (SPW) и косаток (KIW), где данные представляют собой отдельные выборки, мониторинг которых велся наблюдателями. Показаны также гистограммы численности косаток и кашалотов (ось y – количество зарегистрированных данных за период 2003–2009 гг.).

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Рис. 7: Среднее значение (+95% ДИ) размера стад косаток и кашалотов, наблюдавшихся вокруг промысловых судов в Подрайоне 48.3.

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Figura 2: Distribución mensual de avistamientos de cetáceos. Se graficó el número de cachalotes (izquierda) o de orcas (derecha) encontrados en el período 2003 a 2009 dividido por el número total de líneas observadas en ese período. El cuadriculado corresponde a los rectángulos en escala fina de la CCRVMA.

Figura 3: Proporción de avistamientos de cetáceos durante la temporada al este y oeste de 39°W.

Figura 4: Análisis de los datos sobre interacciones con cetáceos en Georgia del Sur, de 2003 a 2009. Los primeros siete gráficos (de arriba a abajo, de izquierda a derecha) muestran el efecto parcial de cada uno de los parámetros del modelo aditivo generalizado (GAM) en la CPUE (kg/anzuelos) – temporada de pesca, nacionalidad del barco, profundidad de la pesca (2 = 500–1 000 m), mes (mayo a agosto), cuadrículas en escala fina, abundancia de cachalotes (SPW) y abundancia de orcas (KIW) – representando los datos lances individuales vigilados por los observadores. También se muestran histogramas de la abundancia de orcas y de cachalotes (el eje de las ordenadas (eje y) representa el número de registros para el período 2003 a 2009).

Figura 5: Relación entre la presencia de cetáceos y el índice CPUE de austromerluza (2003–2009) para (a) cachalotes (SPW) (correlación: $R^2 = 0.180$, $p < 0.05$) y (b) orcas (KIW) (correlación: $R^2 = 0.044$, $p > 0.05$). Cada rectángulo en escala fina ha sido representado por un sólo punto.

Figura 6: Impacto estimado de las orcas (KIW) y cachalotes (SPW) en la captura por unidad de esfuerzo (CPUE) en áreas donde este índice es alto y bajo, calculado utilizando dos métodos ((a), izquierda y (b), derecha; ver el texto para obtener mayores detalles) para identificar las áreas de alto CPUE. Símbolos: triángulos = cachalotes, círculos = orcas; símbolos rellenos = alta CPUE, símbolos sin rellenar = baja CPUE.

Figura 7: Promedio (+95% CI) del tamaño de los grupos de orcas y de cachalotes observados cerca de los barcos de pesca en la Subárea 48.3.