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KILLER WHALE (*ORCINUS ORCA*) AND SPERM WHALE (*PHYSETER MACROCEPHALUS*) INTERACTIONS WITH LONGLINE VESSELS IN THE PATAGONIAN TOOTHFISH FISHERY AT SOUTH GEORGIA, SOUTH ATLANTIC

M.G. Purves✉
Marine Resources Assessment Group Ltd
47 Prince's Gate, London SW7 2QA
United Kingdom
Email – martinpurves@telkomsa.net

D.J. Agnew
Renewable Resources Assessment Group
Imperial College, Royal School of Mines
Prince Consort Road, London SW7 2BP
United Kingdom

E. Balguerías
Instituto Español de Oceanografía
Centro Oceanográfico de Canarias
Apartado de Correos 1373
Santa Cruz de Tenerife, España

C.A. Moreno
Instituto de Ecologia y Evolucion
Universidad Austral de Chile
Casilla 567, Valdivia, Chile

B. Watkins
Marine and Coastal Management
PO Box X2, Roggebaai 8012
Cape Town, South Africa

Abstract

Killer whale (*Orcinus orca*) and sperm whale (*Physeter macrocephalus*) interactions with longline fishing operations were recorded by CCAMLR observers between 2000 and 2002 at South Georgia (Subarea 48.3). Demersal longlines, targeting Patagonian toothfish (*Dissostichus eleginoides*), were deployed in depths of 169 to 2 150 m. Most effort was concentrated along the 1 000 m depth contour. Sperm whales were the most abundant marine mammal observed in the vicinity of vessels when lines were being hauled, being present during 24% of hauling observations. Killer whales, the second most frequently sighted cetacean, were present during 5% of haul observations. A high inter-vessel variation was noted for interactions with both species. A comparison of geographic plots of cetacean sightings during hauls to fishing positions showed that interactions occurred over a wide geographic range. These were mostly correlated to the fishing effort on the different grounds, although some 'hotspots' for interactions were noted. Killer whale pods were generally small (2–8 animals), while solitary animals and larger pods (>15 animals) occurred less frequently. Sperm whales were most often solitary when interacting with fishing vessels, although smaller groups (2–3 animals) were also relatively common. Interactions with killer whales were most often observed in the day, generally in the afternoon, while night-time interactions were relatively few and usually occurred before midnight. Interactions with sperm whales followed a similar pattern, occurring most often in the afternoon, while very few interactions were observed at night. Catch rates were significantly lower when killer whales were present when compared to hauls during which no cetaceans were present. Catch rates were slightly higher in the presence of sperm whales and it is possible that sperm whales were attracted to some areas because of abundant prey (toothfish). However, in areas with lower catch rates, indications are that depredation by sperm whales can lead to a decrease in catches. Some mitigation measures have been tried by vessels to reduce interactions with cetaceans, although no quantitative studies have been carried out to measure their effectiveness. Apart from the obvious economic implications of fish loss due to depredation, ecological implications such as the effect of unrecorded fish removals on stock assessment models, modifications in the behaviour of marine mammals and entanglements with fishing gear are also important considerations. Further investigations are needed to determine the extent and effects of longline–cetacean interactions, to enable observer protocols to be standardised so as to ensure the collection of valuable data, and to assess and implement mitigation strategies under controlled experimental conditions.

Résumé

Les interactions des orques (*Orcinus orca*) et des cachalots (*Physeter macrocephalus*) avec les opérations de pêche à la palangre ont été enregistrées par les observateurs de la CCAMLR entre 2000 et 2002 en Géorgie du Sud (sous-zone 48.3). Des palangres démersales visant la légine australe (*Dissostichus eleginoides*) ont été posées à des profondeurs de 169 à 2 150 m. L'effort de pêche était principalement concentré sur l'isobathe de 1 000 m. Le cachalot était le plus abondant des mammifères marins observés à proximité des navires lors du virage des palangres, étant présent lors de 24% des virages observés. Venait ensuite l'orque, dont la présence a été observée lors de 5% des remontées de palangres. Une forte variation entre navires a été remarquée pour les interactions avec les deux espèces. Une comparaison des courbes géographiques des observations de cétacés durant la remontée des palangres par rapport aux positions de pêche indique que les interactions se sont produites sur un vaste secteur géographique. Ces interactions étaient principalement corrélées à l'effort de pêche sur les différents lieux, bien que quelques «points chauds» aient été relevés. Les troupeaux d'orques généralement rencontrés étaient de petite taille (2 à 8 animaux); les individus solitaires et les troupeaux plus importants (>15 animaux) étaient moins fréquents. Alors que les cachalots étaient le plus souvent solitaires lors de leur rencontre avec les navires de pêche, il était néanmoins relativement commun d'observer de petits groupes (2–3 animaux). Les interactions avec les orques étaient principalement observées pendant la journée, et plus particulièrement l'après-midi. Pendant la nuit, elles étaient relativement moins nombreuses et se produisaient avant minuit. Il en était de même pour les cachalots qui se manifestaient souvent dans l'après-midi; pendant la nuit, très peu d'interactions étaient observées. Lors des poses effectuées en présence d'orques, les taux de capture étaient nettement moins élevés qu'en l'absence de tout cétacé. Les taux de capture étaient légèrement plus élevés en présence de cachalots; il est possible que ceux-ci soient attirés vers certains secteurs par l'abondance des proies (la légine). Cependant, dans les secteurs aux faibles taux de capture, il semble que la déprédation par les cachalots puisse mener à une diminution des captures. Les navires ont tenté de mettre en place des mesures d'atténuation des interactions avec les cétacés, mais aucune étude quantitative n'a été réalisée pour mesurer leur efficacité. Outre les conséquences économiques évidentes de la perte de poisson due à la déprédation, des implications écologiques telles que l'effet sur les modèles d'évaluation des stocks de prélèvements de poisson non enregistrés, les modifications comportementales des mammifères marins et l'enchevêtrement avec les engins de pêche sont également des considérations importantes. Il est nécessaire de poursuivre la recherche pour déterminer l'ampleur et les effets des interactions palangre–cétacés, pour permettre la normalisation de protocoles d'observation qui assureront la collecte de données précieuses, et pour évaluer et mettre en œuvre des stratégies d'atténuation de ces interactions dans le cadre de conditions expérimentales suivies.

Резюме

Взаимодействие косаток (*Orcinus orca*) и кашалотов (*Physeter macrocephalus*) с промысловыми операциями ярусоловов отмечалось наблюдателями АНТКОМа в районе Южной Георгии (Подрайон 48.3) в период 2000–2002 гг. Демерсальные ярусы для лова патагонского клыкача (*Dissostichus eleginoides*) использовались на глубинах от 169 до 2150 м. Большая часть усилия была сосредоточена вдоль 1000-метрового контура глубины. Из морских млекопитающих вблизи судов во время поднятия ярусов больше всего наблюдалось кашалотов – они присутствовали во время 24% наблюдавшихся выборок. Косатки – второй наиболее часто наблюдавшийся вид китообразных – присутствовали во время 5% выборок. Отмечалось большое расхождение между судами по количеству случаев взаимодействия с обоими видами. Сравнение географического положения участков, где киты наблюдались во время выборки яруса, с местами ведения промысла свидетельствует о широком географическом диапазоне происходивших случаев взаимодействия. В большинстве своем они связаны с промысловым усилием на разных участках, хотя было отмечено несколько «горячих» точек взаимодействия. Группы косаток как правило были небольшими (2–8 животных), а одиночки и более крупные группы (>15 животных) встречались реже. При взаимодействии с промысловыми судами кашалоты чаще всего действовали в одиночку, хотя небольшие группы

(2–3 животных) также встречались довольно часто. Взаимодействия с косатками в основном наблюдались в дневное время, обычно во второй половине дня, случаев же ночного взаимодействия было сравнительно мало, и они происходили обычно до полуночи. Аналогичным образом происходило и взаимодействие с кашалотами – чаще всего во второй половине дня и очень редко ночью. По сравнению с уловами в отсутствие китов коэффициент вылова при наличии косаток был значительно ниже. Коэффициент вылова был немного выше, если поблизости находились кашалоты; возможно, что кашалотов привлекает к некоторым районам большое количество добычи (клыкача). Однако имеются свидетельства того, что в районах с более низким коэффициентом вылова опустошение, причиняемое кашалотами, может привести к снижению вылова. Для сокращения взаимодействия с китами суда попытались предпринять ряд смягчающих мер, но никакого количественного анализа для выяснения их эффективности проведено не было. Помимо явных экономических последствий от потери рыбы в результате опустошения, важно учитывать также экологические последствия, в т.ч. влияние незарегистрированного изъятия рыбы на модели оценки запаса, изменения в поведении морских млекопитающих и запутывание в рыболовных снастях. Необходимо продолжать исследования с тем, чтобы определить размеры и результаты взаимодействия ярусного рыболовства и китов, провести стандартизацию протоколов наблюдателей с целью обеспечить сбор ценных данных, а также оценить и обеспечить выполнение смягчающих мер в контролируемых экспериментальных условиях.

Resumen

Los observadores de la CCRVMA registraron las interacciones de orcas (*Orcinus orca*) y cachalotes (*Physeter macrocephalus*) con las operaciones de pesca de palangre en Georgia del Sur (Subárea 48.3) durante los años 2000 al 2002. Se utilizaron palangres demersales para la pesca de austromerluza negra (*Dissostichus eleginoides*) en el intervalo de 169 a 2 150 m de profundidad, concentrándose la mayor parte del esfuerzo en la isóbata de los 1 000 m. Los cachalotes fueron los mamíferos marinos más avistados alrededor de los barcos durante el virado de las líneas, estando presente en un 24% de las operaciones de virado observadas. El segundo grupo de cetáceos observados en orden de abundancia fueron las orcas, registrándose su presencia en un 5% de los lances observados. Hubo una gran variación entre los barcos con respecto a las interacciones con ambas especies. La comparación de la posición geográfica de los cetáceos avistados con respecto al total de lances de pesca mostró que las interacciones ocurren en una extensa área. Estas observaciones se correlacionaron en su mayor parte con el esfuerzo de pesca en los distintos caladeros, a pesar de que se destacaron algunos "focos de mayor actividad". En general las orcas se observaron en grupos pequeños (2–8 animales); menos frecuente fue la presencia de animales solitarios o grupos más numerosos (>15 animales). En el caso de los cachalotes, las interacciones más frecuentes con los barcos de pesca ocurrieron con ejemplares solitarios, a pesar de que también fue común observarlos en grupos pequeños (2–3 animales). Las interacciones con orcas por lo general ocurrieron durante el día, especialmente en la tarde; las interacciones por la noche fueron escasas y generalmente sucedieron antes de la medianoche. Las interacciones con los cachalotes tuvieron un patrón similar, con una mayor actividad durante la tarde y muy poca durante la noche. Las tasas de captura fueron notablemente más bajas en presencia de orcas, comparado con aquellas de lances sin cetáceos presentes. Las tasas de captura fueron ligeramente superiores en presencia de cachalotes, y es posible que éstos hayan sido atraídos a algunos lugares por la abundancia de la presa (austromerluza). Sin embargo, en áreas donde las tasas de captura fueron menores, se sabe que la depredación por parte de los cachalotes podría ocasionar una disminución de la captura. Se han probado algunas medidas de mitigación para reducir las interacciones con los cetáceos, pero no se han realizado estudios cuantitativos para medir su eficacia. Aparte de las consecuencias obvias de orden financiero por la pérdida de pescado debido a la depredación, también es importante considerar las consecuencias ecológicas tales como: el efecto producido por la remoción de peces no detectada en los modelos de evaluación de poblaciones, las modificaciones del comportamiento de los mamíferos marinos, y los enredos en los artes de pesca. Se necesita realizar más estudios para determinar el alcance y efecto de las interacciones entre cetáceos y las operaciones con palangres, con miras a normalizar los protocolos de observación de manera que aseguren la recopilación de datos de utilidad, y para evaluar e implementar medidas de mitigación en condiciones experimentales controladas.

Keywords: longline, interactions, depredation, *Orcinus orca*, *Physeter macrocephalus*, *Dissostichus eleginoides*, South Georgia, toothfish, CCAMLR

Introduction

The longline fishery for Patagonian toothfish (*Dissostichus eleginoides*) is concentrated around sub-Antarctic islands and seamounts, mostly within waters regulated by CCAMLR. This fishery is currently the most important in the CCAMLR Convention Area, and fishing grounds near South Georgia and Shag Rocks in CCAMLR Subarea 48.3 (South Atlantic sector) are among the most significant. Vessels from eight different Member States have been involved in the fishery at South Georgia over the past three seasons. Fishing in this zone is restricted to the winter months to reduce the incidental mortality of seabirds hooked on longlines. Other mitigation measures include the weighting of gear for a faster sink rate and the restriction of line-setting during night-time only.

All vessels granted a licence to fish for Patagonian toothfish in the Convention Area are required to have an independent scientific observer on board. These observers, appointed and working under the auspices of the CCAMLR Scheme of International Scientific Observation, record details of the vessels' operations and fishing strategy, take samples of catches and by-catches to determine their biological characteristics, and record interactions, entanglement and incidental mortality of birds and mammals due to fishing operations. Historically, observers neglected marine mammals, as the focus was on seabird interactions and the incidental mortality recorded on longlines in this fishery. Marine mammal observations were often made at random and without a set standardised sampling protocol in mind. Data on mammal abundance and interactions are thus difficult to quantify between voyages and between different seasons and fishing areas. Interactions with killer whales (*Orcinus orca*) and sperm whales (*Physeter macrocephalus*) have been reported from this fishery as early as 1994 (SC-CAMLR, 1994), but in recent years anecdotal reports by observers and fishers seem to indicate an increase in the levels of depredation.

No reliable estimates exist of the current population size of toothed whales in the area around South Georgia. In the Southern Ocean, adult male sperm whales are present south to Antarctica, and females may be seen off South Africa, Western Australia, New Zealand and Chile (Gaskin, 1982). Sperm whales feed primarily on large mesopelagic squid, but some teleost fish and sharks have also been reported as prey items (Gaskin, 1982). Patagonian toothfish has been recorded in the stomachs of sperm whales near Tierra del Fuego (Solyanik, 1963), in the vicinity of Islas de los Estados (Staten Island) (Korabelnikov, 1959) and in the Indian Ocean adjacent to the Prince Edward and Crozet Islands and Kerguelen (Yukov, 1972). Yukov (1972) reported that between 1 and 12 toothfish, ranging in size from 70 to 130 cm (4 to 20 kg) were found in sperm whale stomachs. Antarctic toothfish (*D. mawsoni*) has also been reported from the stomachs of harpooned sperm whales in the Southern Ocean (Abe and Iwami, 1989). The range of killer whales in the Southern Ocean extends to the shores of Australia, South Africa, South America and Antarctica, including the Ross Sea at 78°S (Rice, 1998). Killer whales generally feed on a wide range of prey, and in the South Atlantic this includes rays, sharks, teleost fish, small cetaceans and pinnipeds (Gaskin, 1982). There are no reports of killer whales preying on toothfish apart from depredated fish taken off longlines.

Interactions between killer whales and longline vessels have been well documented in a number of different fisheries around the world (Yano and Dalheim, 1995a, 1995b; Secchi and Vaske, 1998; Visser, 2000; Watkins, 2000), and depredation levels of almost 100% have been recorded on some lines (Secchi and Vaske, 1998). Sperm whale interactions have been reported from the black cod longline fishery in the Gulf of Alaska (Hill et al., 1999; Sigler et al., 2002), where interactions range from depredation of catch to the presence of whales around the vessel with no apparent connection to fishing operations. In the Patagonian toothfish fishery, Nolan et al. (2000) and Ashford et al. (1996) reported observations of killer whales and sperm whales interacting with longline vessels at the Falkland/Malvinas Islands and South Georgia respectively. Ashford et al. (1996) reported high levels of depredation with 'almost the entire catch' lost off some lines. Off Chile, sperm whales have been reported as being entangled in longline fishing gear, feeding on fish off the lines, and following vessels for days (SC-CAMLR, 1994). Crespo et al. (1997) also reported killer whales and sperm whales taking bait and catches from longlines close to Tierra del Fuego off South America. On some lines hauled at the Prince Edward Islands, south of South Africa, observers have estimated toothfish losses due to depredation by killer whales to be as high as 50% (Tilney and Purves, 1999).

The depredation of toothfish off longlines has obvious economic impacts. There are, however, other factors that should also be of concern. Although CCAMLR is not currently in a position to quantify the level of cetacean-induced toothfish mortality, such mortality is a management concern and stock assessment models should ideally take this into account. The standardisation of observer protocols for recording mammal interactions might make future assessments of the level of depredation more reliable. Other important ecological factors are the change of behaviour of cetaceans when they become more reliant on longline-caught fish, incorporating a shift away from their natural diet, and the possibility that they may become entangled in fishing gear. Cetacean–longline interactions at South Georgia over the past three seasons were investigated, and mitigation measures employed by some vessels are reported here.

Materials and methods

Fishing vessels operating in the longline fishery at South Georgia ranged in length from 44 to 59 m (mean = 53 m), with a GRT of between 532 and 951 tonnes (mean = 695 tonnes). The length of longline sets ranged from 826 to 22 800 hooks with an average line length of 7 655 hooks in the 2000, 2001 and 2002 seasons. Fishing depth in these seasons ranged from 169 to 2 150 m with an average of 1056 m, while most of the fishing effort was concentrated along the 1 000 m depth contour. All longlines were set on the bottom and soak times ranged from 6 to 28 hours.

Marine mammal data collected by scientific observers on 8 vessels in 2000, 6 vessels in 2001 and 11 of 15 vessels in 2002 were analysed (Table 1). For the purpose of this study an 'interaction' was defined as the presence of whales in the vicinity of a longline vessel. The reason for this was that observers did not always make it clear whether cetaceans were actively interacting with fishing gear or not. In some cases, particularly when sperm whales were involved, depredation was also difficult to observe as it did not occur at the surface.

Plots correlating whale presence with fishery locations

For the 2000, 2001 and 2002 seasons the mid-positions of all sets, defined as the mid-point between the start and end positions, were plotted for the selected voyages using GIS (MapInfo) software. This was compared to geographic plots of the mid-positions of hauls, where sperm whales and killer whales were observed, in order to see whether interactions occurred more frequently in specific areas or whether these were more dependent on fishing location. The study area at South Georgia is depicted in Figure 1.

Marine mammal presence and evidence of depredation

During the 2000 season observers noted the times and frequencies of marine mammals observed in the vicinity of the vessels during hauls. Observation protocols had, however, not yet been standardised and although this data was used for the plots to correlate the presence of cetaceans with fishing positions, it was not used in analysis to determine the frequency of interactions of the different species with the vessels, temporal patterns and the effect on catch rates. After the 2000 season, in order to standardise marine mammal data collection by observers, the observation protocol was modified. At the start of each of six half-hourly hauling observations conducted per day, the abundance of the different mammal species in the vicinity of the vessels would be noted. These hauling observations were selected at random intervals in order to cover as much as possible of the period when lines were being hauled in a day. Observations were done from a fixed position on deck, in the vicinity of where the lines were being hauled. The observation position varied between different vessels and was selected on the basis of safety considerations, visibility of the line during hauling and the need not to obstruct the view of the hauling process from the bridge. In most cases observers were stationed directly above the line hauler on the starboard side of the vessel. The standard survey area was defined as being within a radius of 500 m around the vessel, but weather conditions, such as fog and limited visibility during the night, influenced observations.

Interactions with fishing operations and the number of mutilated fish observed were also recorded. From the 2001/02 observer data the number of hauling observations during which sperm whales, killer whales or Antarctic fur seals (*Arctocephalus gazella*) were present were calculated for each of the selected voyages, and this was expressed as a percentage of hauls when each of the species was present. These included observations during which mammals were not necessarily interacting with fishing operations, but were observed in the vicinity of the vessel. The reason for this is that interactions with fishing gear, especially those involving sperm whales, were often difficult to identify.

Group sizes and temporal differences

The frequency of interactions with specific group sizes of killer whales and sperm whales was also analysed for the 2001/02 observer data. During further data analyses, observations were grouped into four six-hourly periods (viz. 0000–0600 h, 0600–1200 h, 1200–1800 h and 1800–0000 h) to give an indication of the temporal differences of interactions between species. These periods also gave a rough indication of the frequency of interactions occurring at night (1800–0600 h). The

Table 1: The number of vessels per Flag State used for data analyses of marine mammal data collected by scientific observers. The total number of vessels that were licensed to fish at South Georgia is also shown for the different seasons.

Season	Number of Vessels per Flag State				Total Number of Vessels used for Data Analyses	Total Number of Vessels with Fishing Licences
	UK	Chile	Spain	South Africa		
2000	3	3	1	1	8	11
2001	2	2	1	1	6	10
2002	4	4	2	1	11	15

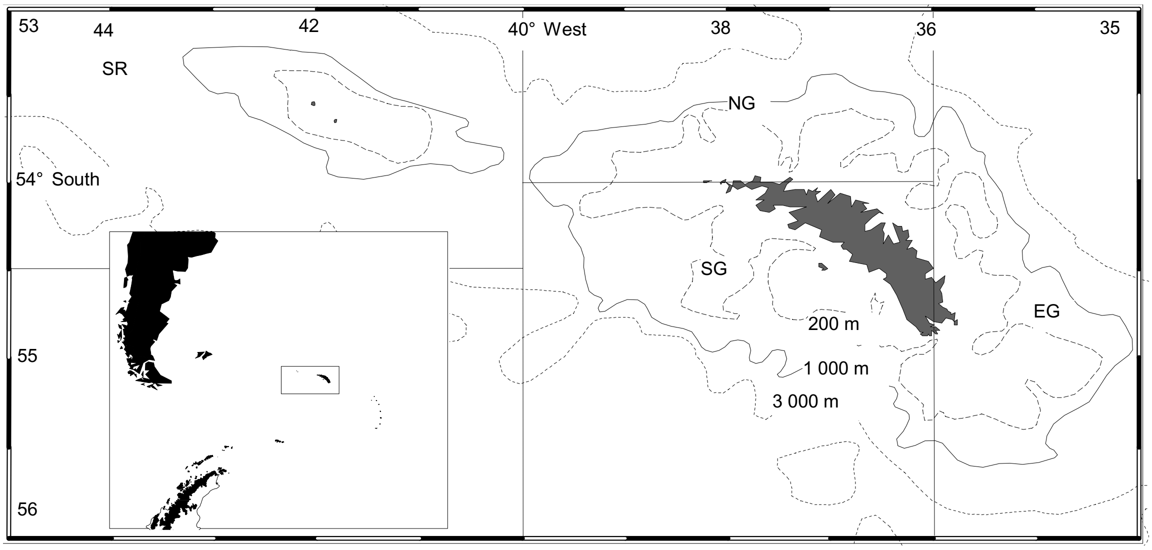

Figure 1: Map of the fishing grounds at South Georgia. Different areas are as follows: SR = Shag Rocks, NG = north South Georgia, EG = east South Georgia, SG = south South Georgia, and 200 m, 1 000 m and 3 000 m bathymetry is shown. Inset shows the position of the study area in relation to the South Atlantic.

actual time of sunset and sunrise depended on the latitude and longitude of the fishing location and the time of the year. During the longline season (May to August), sunset ranged from 1845 to 2040 h and sunrise ranged from 0656 to 0851 h. Nautical dusk and dawn were about an hour longer. Visibility during night-time was restricted leading to a certain degree of bias in estimating abundance and activity around the vessels.

The effect on catch rates

Toothfish catch rates were calculated for the six vessels selected in the 2001 season, and expressed as green weight (kg) per hook and also as the number of toothfish caught per 1 000 hooks. Catch rates (CPUEs) for hauls where no sperm whales or killer whales were observed were compared to those for which either sperm whales or killer whales or both species were present. Paired *t*-tests were used to determine whether the presence of either one of the cetaceans, or both, in the vicinity of vessels during hauling had an impact on catch rates. For these analyses the catch rates of lines with no cetacean presence were independently compared to those for which killer whales were present, those where both killer and sperm whales were present and to those where sperm whales were observed around the vessels.

Detailed studies on a specific vessel

On one of the vessels fishing at South Georgia in the 2001 season (voyage 'L', Table 2), detailed studies were conducted on the interactions taking place between cetaceans and fishing operations (Purves, 2001). On previous voyages it had been noted that toothfish lips and jaws were more prevalent on returning hooks when sperm whales were present. From these anecdotal observations, as well as comments from other observers and fishers, it seemed as if sperm whales mostly took toothfish 'cleanly' off the hooks, sometimes leaving the lips or jaws as evidence of depredation. In order to

Table 2: The frequency of marine mammal interactions for different voyages as reported by observers during longline fishing operations at South Georgia in the 2001 and 2002 seasons. KIW = *Orcinus orca*, SPW = *Physeter macrocephalus*, SEA =*Arctocephalus gazella*.

Voyage	Number of Observations	KIW Present		SPW Present		SEA Present	
		(*n*)	(%)	(*n*)	(%)	(*n*)	(%)
A	374	71	19.0	194	51.9	0	0
B	149	19	12.8	43	28.9	0	0
C	496	32	6.5	87	17.5	73	14.7
D	338	20	5.9	138	40.8	6	1.8
E	209	12	5.7	34	16.3	75	35.9
F	403	23	5.7	63	15.6	6	1.5
G	295	14	4.7	35	11.9	11	3.7
H	302	14	4.6	46	15.2	0	0
I	319	14	4.4	78	24.5	20	6.3
J	712	30	4.2	119	16.7	14	2
K	346	12	3.5	18	5.2	7	2
L	238	8	3.4	167	70.2	2	0.8
M	254	8	3.1	49	19.3	10	3.9
N	659	17	2.6	85	12.9	212	32.2
O	356	6	1.7	100	28.1	42	11.8
P	345	4	1.2	144	41.7	25	7.2
Total	5795	304	5.2	1400	24.2	503	8.7

examine whether sperm whale depredation could thus be quantified, the number of toothfish lips and jaws on returning hooks were noted, and these were correlated with the abundance of different cetacean species in the vicinity of the vessel during hauling.

Results

Plots correlating whale presence with fishery locations

The positions of longline fishing operations at South Georgia are shown in Figure 2. Fishing occurred all along the 1 000 m depth contour of South Georgia Island and Shag Rocks.

When comparing the sightings of killer whales (Figure 3) to the positions of longliners (Figure 2), it can be seen that in some areas overlap occurred more frequently. On west Shag Rocks both fishing effort and killer whale interactions were quite high. Similar areas of high fishing effort and increased interactions could be identified at north South Georgia and east South Georgia. Fishing effort was, however, also high at south South Georgia, but comparatively few interactions with killer whales occurred in this area. A similar situation was also observed on north Shag Rocks. From the geographic mapping analyses it does seem as if interactions generally occurred in areas similar to those in which fishing took place, but some areas seemed to be more prone to interactions with killer whales than others.

The positions at which sperm whales were observed during hauling operations can be seen in Figure 4. These interactions also seemed to occur most often in areas of greatest fishing effort. Unlike killer whales, sperm whales were often sighted at fishing grounds at south South Georgia, but were not so common at east South Georgia (Figures 3 and 4). At Shag Rocks, sperm whales were more prevalent in the north and west, although fishing effort here was spread more evenly along the 1 000 m depth contour (Figure 2). Both cetacean species were quite active next to fishing vessels at west Shag Rocks and north South Georgia, but it is not known how many of these interactions occurred simultaneously.

Marine mammal presence and evidence of depredation

Observers monitored 78% of hauls for marine mammal interactions during the 2001 and 2002 seasons. Sperm whales were the most abundant marine mammals observed in the vicinity of vessels when lines were being hauled (Table 2). During 24% of the 5 795 observations sperm whales were present, but a large variation was noted between voyages. During the 2001 season, 70% of the haul observations during voyage ‘L’ recorded a sperm

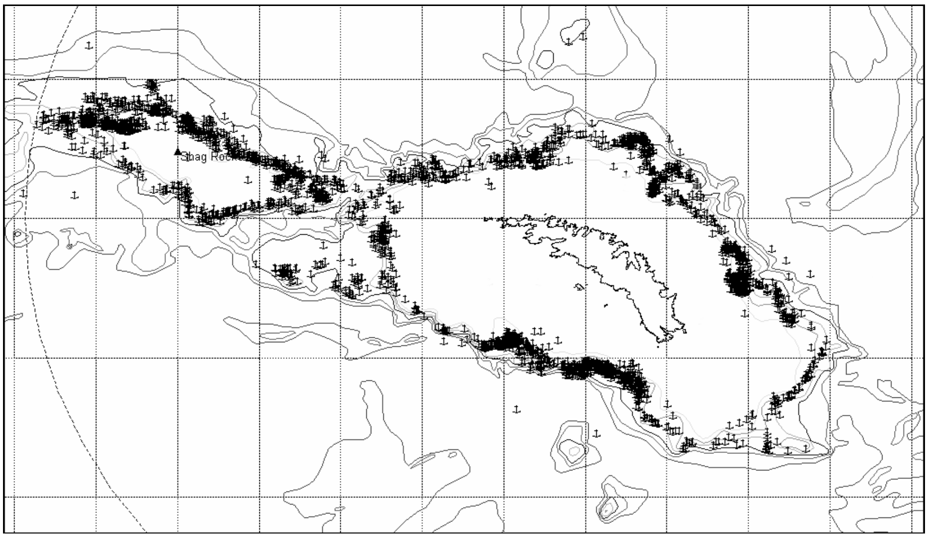

Figure 2: Map of South Georgia showing the mid-positions of all the hauls of vessels used for data analyses during the 2000, 2001 and 2002 seasons.

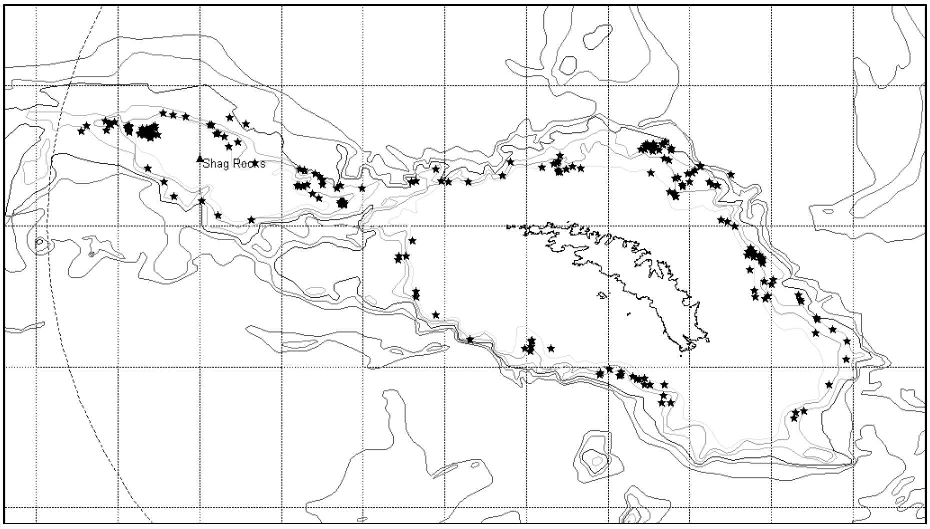

Figure 3: Map of South Georgia showing positions where killer whales were sighted during hauling of longlines during the 2000, 2001 and 2002 seasons.

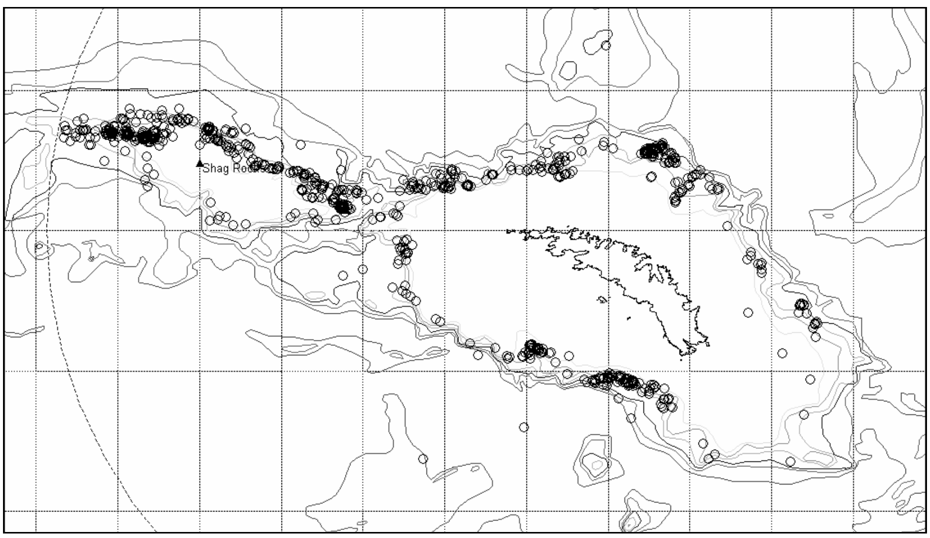

Figure 4: Map of South Georgia showing positions where sperm whales were sighted during hauling of longlines during the 2000, 2001 and 2002 seasons.

whale presence, whereas sperm whales were present at only 5% of observations of voyage 'K' in the same season.

Killer whales were the second most abundant cetaceans observed around longline vessels fishing at South Georgia, being present during 5% of haul observations. A notable difference also occurred between vessels, with 19% of the hauls of voyage 'A' in the 2002 season occurring when killer whales were present. In contrast, for only 1% of the observations of voyage 'P' in the same season were killer whales present. Antarctic fur seals were the only other mammal species observed as interacting in high numbers. Interactions with leopard seals (*Hydrurga leptonyx*), always as solitary animals, were reported on three different occasions.

Group sizes and temporal differences

The frequencies at which different group sizes of killer whales were observed are shown in Table 3. Small groups, consisting of two to three animals, were most commonly seen (25% of observations). Larger groups, consisting of 15 or more animals, were relatively scarce (8% of observations). Solitary animals were observed in the vicinity of fishing vessels in 13% of observed killer whale interactions (Table 3).

Sperm whales were most often solitary when interacting with fishing vessels (43% of observations; Table 3). Two (32%) or three (18%) animals together were also relatively common, but seven or more animals were only observed on 7% of occasions. A maximum of 12 sperm whales was once observed in the vicinity of a vessel when hauling.

Interactions with killer whales were most often observed in the afternoon after midday (46% of interactions; Table 4). Morning interactions, between 0800 and 1200 h, were also common, comprising 33% of sightings. Killer whale interactions with fishing operations still occurred after sunset, being present for 18% of observations up to midnight. Only occasional interactions were noted after midnight and before sunrise (3.4%; Table 4). Interactions with sperm whales followed a similar pattern, with most interactions occurring in the afternoon (56%) and in the morning after sunrise (43%). Interactions at night made up less than 1% of observations (Table 4). It should, however, be kept in mind that the same level of accuracy of observations as was achieved during the day was not possible at night.

Effect on catch rates

The catch rates of toothfish were significantly lower when killer whales were present during the hauling of lines when compared to the catch rate of lines hauled when no cetaceans present (*t*-test: df = 17, $t = 3.7$, $P = 0.0016$, Table 5). Catch rates were also significantly lower when both killer whales and sperm whales were present (*t*-test: df = 8, $t = 4.3$, $P = 0.0025$, Table 5). The same trend was, however, not observed for catch rates when sperm whales were present during hauling (*t*-test: df = 128, $t = 1.4$, $P = 0.1624$). As can be seen in Table 5, a slight increase was noted in catch rates in the presence of sperm whales. When data from the area around southeast Shag Rocks, where high toothfish catch rates were recorded, were excluded from analyses, a slight but not significant decline in catch rates was noted.

Detailed studies on a specific vessel

During 66% of the 238 hauling observations made on voyage 'L' during the 2001 season, no mammals were observed in the vicinity of the vessel. The most abundant mammal species present during hauling operations were sperm whales, which was the case during 31% of observations. A maximum of five sperm whales was sighted at any one time. Sperm whales were observed more frequently to the southeast of Shag Rocks, when fishing took place at depths of around 550 to 700 m. Killer whales were observed during four hauls (1.5% of mammal observations).

During hookline observations it was noted that hooks with toothfish lips or jaws were more prevalent when sperm whales were in the vicinity of the vessel. During 84% of observations where lips were found on the hooks, sperm whales were also observed, often diving near the line. The presence of lips might indicate that sperm whales rip whole fish from the line, as no mutilated fish (heads) were observed when they were present during hauling (Purves, 2001).

During 3% of direct line observations where lips where recorded on hooks, killer whales were in the vicinity of the vessel, and during the remaining 13% of these observations no marine mammals were present.

Sixty-eight lips were recorded during the 31 observation periods (29 hauls) when sperm whales were present. When extrapolating these observations to all the hooks hauled during these specific hauls, and assuming that all lips observed were due to sperm whale depredation,

Table 3: The frequency at which specific group sizes of killer whales (n = 186) and sperm whales (n = 836) were observed at South Georgia in the 2001 and 2002 seasons.

Killer Whales			Sperm Whales		
Group Size (n)	Number of Observations	% of Total Observations	Group Size (n)	Number of Observations	% of Total Observations
1	25	13.4	1	361	43.2
2–3	47	25.3	2	265	31.7
4–5	25	13.4	3	146	17.5
6–8	34	18.3	4–5	56	6.3
9–10	20	10.8	6–10	7	0.8
11–15	21	11.3	>10	1	0.1
16–20	12	6.5			
21–30	2	1.1			

Table 4: The times at which interactions occurred with killer whales and sperm whales at South Georgia during the 2001 and 2002 seasons. KIW = *Orcinus orca*, SPW = *Physeter macrocephalus*.

Period (hh:mm)	Number of KIW Interactions	% of KIW Interactions	Number of SPW Interactions	% of SPW Interactions
00:00–06:00	7	3.4	2	0.2
06:00–12:00	68	32.9	374	43.1
12:00–18:00	95	45.9	489	56.4
18:00–00:00	37	17.9	2	0.2
Total	207		867	

Table 5: The catch rates of toothfish in the 2001 season, for hauls during which interactions occurred with killer whales and with sperm whales, compared to the catch rate of hauls where no cetacean interactions with fishing operations occurred. KIW = *Orcinus orca*, SPW = *Physeter macrocephalus*.

	CPUE (kg/hook)	CPUE (fish/1 000 hooks)	Number of Observations
KIW interaction	0.15	21.47	27
SPW interaction	0.32	51.87	129
SPW interaction (without southeast Shag Rocks data)	0.25	33.89	74
No cetacean interaction	0.29	48.46	556
No cetacean interaction (without southeast Shag Rocks data)	0.28	46.09	491

it is estimated that 265 toothfish, of an estimated weight of approximately 2 tonnes, were taken by sperm whales (Purves, 2001). This is likely to be a conservative estimate as some fish are probably ripped from hooks leaving no trace of lips or jaws. The maximum number of hooks with lips observed during a specific period was 11 (1 124 hooks observed), and on this occasion four sperm whales were present in the area. On another occasion, when five sperm whales were present, seven hooks with lips were observed (768 hooks observed).

Discussion

The high inter-vessel difference in the percentage of hauls where cetaceans were present (Table 2) was probably mainly due to the differences in fishing grounds and the occurrence of sperm and killer whales in these areas. Some fishers and vessel operators have, however, also claimed that certain vessels seem to incur more cetacean interactions than others. Factors that might play a role in this are differences in levels of noise emitted by the line haulers and of engine noise of specific vessels. Francine and Awbrey

(1993) and Jefferson and Curry (1996) reported that in Alaska, where killer whale–longline interactions were a problem, the focus was on making fishing operations less noisy, and thus less detectable to killer whales from a distance. This might be done by noise masking (using fire hoses and bubble screens) and acoustically decoupling the vessel's engine from the hull (with rubber pads between the engine mount and the hull). The effectiveness of these measures has not yet been assessed (Jefferson and Curry, 1996). Methods of isolating the winch from the vessel hull, allowing hauling of fishing gear to be quieter, have also been proposed to mitigate killer whale–longline interactions in the New Zealand fishery (Visser, 2000).

Although it seems as though cetacean interactions are generally restricted to daytime, it should be kept in mind that the times at which interactions were recorded as having occurred (Table 4) were based on observed data, and were therefore probably biased towards daylight observations. It is often difficult or even impossible to note any mammal interactions occurring at night around the vessel, unless these interactions happen in the direct vicinity of hauling lights which illuminate the area, or during nights with clear skies and full moon conditions. Due to the fishing regime at South Georgia, where lines are required to be set at night, the majority of hauling operations happen during daylight hours and it is therefore more likely that observers would note cetacean interactions at these times. Anecdotal observations do, however, suggest that interactions with hauling operations at night do not occur often. It was noted on some occasions that killer whale interactions became less frequent after sunset, but this was not always the case.

The slightly higher catch rates found for hauls during which sperm whales were present as compared to those for lines hauled with no cetacean presence (Table 5) was unexpected. It was further noted that the catch rates were particularly high in the southeastern part of Shag Rocks (Figure 1), despite the constant presence of sperm whales in this area. If it is assumed that the high catch rates in these areas also attracted sperm whales, and the data for this area is ignored for this analysis, catch rates in the rest of the areas combined did show a slight decrease when sperm whales were present (Table 5). This difference was, however, not significant. The relatively high catch rates recorded when sperm whales were present at southeast Shag Rocks might indicate that these animals congregate in areas of high toothfish density. As such they could, in some cases, be indicators of 'good catches' rather than a nuisance. This does, however, only seem to be true in areas with high catch rates. Observations from the Prince Edward Islands, south of South Africa, where catch rates are generally much lower than at South Georgia, indicated that the added depredation of catches by sperm whales can become a significant problem (Watkins, unpublished data). Similarly, catch rates seem to be affected by sperm whales in the Falkland/Malvinas Islands toothfish fishery (Pompert, pers. comm.).

It was noted that during 13% of observations on voyage 'L' toothfish lips were present on hooks, but no marine mammals were sighted in the vicinity of the vessel. It is likely that some fish were torn off the hooks during hauling, either due to bad weather, the lines dragging on the bottom or entanglements, thus accounting for some of those instances where lips were found on hooks without any mammals being present. Another possibility would be that depredation occurred at deeper depths, making direct observations impossible. This could have been done either by cetaceans or other predators such as Greenland shark (*Somniosus cf. pacificus*) which are known to prey on toothfish (Pequeño et al., 1991).

Photographic evidence of sperm whale flukes, used to identify individuals, have indicated that some sperm whales might be interacting more frequently with fishing vessels in Alaska, although the sample size was small (Hill et al., 1999). Anecdotal reports by some observers in the South Georgia fishery, where the same individuals were repeatedly observed interacting with hauling operations, seem to substantiate this, although further investigations are necessary.

Interactions between sperm whales and killer whales have been reported by Pitman et al. (2001), from the Falkland/Malvinas Islands (Nolan et al., 2000), and at South Georgia (Ashford et al., 1996). At the Prince Edward Islands, Tilney and Purves (1999) reported a pod of four killer whales attacking a sperm whale, following which a large quantity of blood was seen in the water around the whale. Observers at South Georgia also reported interactions between these two cetaceans during the past three years, but the nature of these interactions was not always clear. On one occasion a sperm whale was observed to drive off six long-finned pilot whales (*Globicephala melas*) that were in the vicinity of the vessel.

Incidental catches of marine mammals in fisheries are of concern, but have hardly ever been reported by observers in toothfish fisheries in the South Atlantic, South Indian and Southern Oceans

(SC-CAMLR, 1999, 2000, 2001). Entanglements with sperm whales have occasionally been reported from South Georgia (Ashford et al., 1996) and from the Prince Edward Islands (Watkins, pers. comm.). Another interesting phenomenon that has been noted by observers in the Falkland/ Malvinas Islands is that killer whales take only toothfish off the lines, while leaving by-catch untouched (Pompert, pers. comm.). At South Georgia by-catch such as grenadiers (Macrourids) and *Antimora rostrata* were also left on the line when killer whales took toothfish. Visser (2000) reported that in New Zealand killer whales selectively took certain species, but not others, off longlines. Observers in the South Georgia fishery did not report seeing sperm whales take either offal or discarded by-catch.

Sperm whale depredation is usually very difficult to observe and quantify. In most cases damaged or mutilated fish are not observed, although damage to fishing gear, occasional fish heads and the occurrence of toothfish lips and jaws seem to indicate that fish have been taken off the line. Sperm whales have often been observed diving down directly next to the vessel as the lines were being hauled. Nolan et al. (2000) noted that killer whales could be seen on the depth sounder, swimming below the vessel at depths of between 50 and 100 m, taking fish off the line. This predation-at-depth behaviour of both species often makes it difficult for observers to say with certainty that depredation has occurred, unless mutilated fish are hauled aboard.

One of the main problems when quantifying cetacean interactions in the Patagonian toothfish fishery is that, despite the legal fishery having 100% coverage by independent scientific observers, protocols for these interactions are not standardised and comparisons between vessels and between fisheries in different areas are not always possible. This is something that might warrant further attention by CCAMLR when setting observer protocols.

Most of the vessels fishing at South Georgia over the past two seasons (2001 and 2002) did not employ mitigation measures to reduce interactions with cetaceans. The following mitigation measures were, however, employed on some vessels, although no quantitative studies were conducted to measure their effectiveness:

- acoustic harassment devices (AHDs) or seal scarers, emitting irregular broad-band sound pulses, were deployed on either side of one of the vessels during hauling operations;
- a number of small magnets were randomly spaced and tied onto the fishing line of the same vessel;
- the on-board acoustic equipment of some vessels was turned off during line hauling as this was seen as a possible attractant to cetaceans;
- toothfish heads and other offal were retained on board during line hauling and discarded away from the hauling site;
- sometimes when killer whales were observed during line hauling, hauls were interrupted, the lines were buoyed-off, and the vessel would steam away from the hauling site.

The observer on the vessel using the AHDs and magnets reported that both measures seemed to have little effect on depredation by killer whales. The effect of switching off on-board echo sounders, and the retention of offal during hauling might prove worthy of further investigation. The mitigation method that seemed to be the most effective, however, was the interruption of hauling operations and steaming away from the hauling site. Observers reported that when vessels steamed away for between 20 and 30 n miles, killer whales were often absent from the hauling site when hauling was resumed. Observers also reported that in some cases, vessels being followed by killer whales would pass close by another vessel engaged in fishing in an attempt to 'shake off' these animals and 'pass' them on to this other vessel.

Some of the other methods proposed to mitigate against killer whale–longline interactions are the use of rubber bullets to shoot at the whales, sparkler devices that emit sound and light when fish are removed from the hooks, the electrification of lines to shock whales and bubble screens to interfere with whale acoustics (Dahlheim, 1988).

Many studies of the effect of noise on whales have been carried out (Richardson et al., 1995; Jefferson and Curry, 1996). Morton and Symonds (2002) found that the frequency of killer whale occurrence between two adjacent shallow water areas, one of which had AHDs installed for an intermediate period, seemed to indicate that killer whales were displaced due to the deliberate introduction of noise into their environment. How effective these high amplitude devices would be when deployed next to a fishing vessel or on longlines is not known, but Carlström et al. (2002) noted that the displacement effect of acoustic alarms is likely to be more effective in coastal waters where access to bodies of water is limited.

André (1997) found that sperm whales were resistant to acoustic deterrents and that the level of acoustics that would be required to deter a sperm whale could possibly inflict permanent damage.

Conclusion

Future research should concentrate on evaluating and solving the problems of longline–cetacean depredation, the standardisation of observer protocols to ensure the collection of the required data, and assessing and implementing mitigation strategies under controlled experimental conditions. Further research is also needed on the population structure and ecology of cetaceans at South Georgia. Offal retention, switching off acoustic devices during hauling and the deployment of AHDs next to the vessel during line hauling may be worth testing for their effectiveness in reducing depredation.

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Liste des tableaux

Liste des figures

Список таблиц

Список рисунков

Lista de las tablas

Lista de las figuras