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Interactions between humans and leopard seals

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Abstract: In July 2003 Kirsty Brown, a marine biologist at Rothera Research Station (West Antarctic Peninsula), was attacked and drowned by a leopard seal (*Hydrurga leptonyx*). As a direct consequence, a study was initiated to analyse interactions between humans and leopard seals over the last thirty years utilising humanistic and observational data. The response of leopard seals to humans in different situations was considered using a categorical response scale. Location of the leopard seal and human had the greatest influence on the response of the leopard seal. More specifically, interactions occurring at the ice edge, where leopard seals seek out prey, resulted in the highest response from leopard seals. 'In water' interactions, examined through SCUBA dive and snorkelling logs, generally described the seal's behaviour as displaying curiosity and occurred most frequently at the surface. Although leopard seals approached close to observers and displayed behaviour that appeared aggressive, there were no records of interactions where 'curious' leopard seals showed subsequent hunting, or attack behaviour. In contrast, in most interactions (only a few occasions) where physical contact was initiated by a seal, in the form of an attack, the seal was not seen prior to the attack. Kirsty's incident is the only known account of its kind, given that physical contact occurred at the surface of the water, and the seal had not been seen prior to the attack. This suggests that the commonly cited descriptions of leopard seals interacting with humans in the water are a distinctly different behaviour to that displayed in the attack on Kirsty. Although leopard seal behaviour was generally described by divers as curious, the death of Kirsty Brown indicates that leopard seals can display predatory behaviour towards humans.

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Introduction

As with any large, predatory species human perceptions of leopard seals *Hydrurga leptonyx* Blainville are inevitably shaped by the historical accounts of interactions with humans that have occurred since the Heroic Age of Antarctic exploration. Several historic accounts of interactions have been published, as well as more contemporary anecdotal accounts, which have portrayed leopard seals as 'evil', 'feared creatures', 'beasts', resembling 'small dinosaurs' with a 'sinister reputation' (e.g. Lansing 's (1959) account of leopard seal encounters in 1916 during Shackleton's expedition). De Laca *et al.* (1975) and Erb (1993) provide accounts of leopard seal interactions with humans that have a more balanced perspective. The experiences of De Laca *et al.* (1975) diving at Palmer Station, Antarctic Peninsula, during a four year period from 1971 led them to conclude that a 'prey-capture' scenario of behaviour did not seem to apply because the seals never made an attempt to seize divers. However, they did find that unusual noises and vibrations in the water often attracted leopard seals and that leopard seals confronting submerged SCUBA divers may become aggressive after prolonged interactions. Erb (1993) reported interactions on land at Heard Island and on sea-ice on the Antarctic continent near Mawson, East Antarctica from 1992–93; providing details of physical contact between humans and leopard seals that occurred primarily at the ice edge. In his account, Erb (1993) described the leopard seal on land as generally unresponsive to the presence of humans, whereas at the ice edge he experienced a number of hostile encounters including some where the seal actually attempted capture.

Leopard seal distribution, diet and hunting techniques

Leopard seals are generally solitary and pagophilic, distributed within the circumpolar pack ice surrounding the Antarctic continent (Bonner 1994) with a population estimated to be 222 000 to 440 000 (Rogers 2002). In addition to the normal distribution in relation to the Antarctic pack ice they disperse northwards to sub-Antarctic islands such as South Georgia (Walker *et al.* 1998, Jessopp *et al.* 2004) and Macquarie Island (Rounsevell & Eberhard 1980) during the winter. In general these extra-limital records involve juveniles that appear to move further north during the winter (Rogers 2002). Leopard seals have also been recorded in Chile, Argentina, the Falkland Islands, South Africa, New Zealand and Australia (Bonner 1994, Rodriguez *et al.* 2003). The most northerly recordings of leopard seals have been from the Cook Islands 20°S (Rogers 2002).

Leopard seals are catholic feeders and their diet, which varies with season and location, includes penguins, seals, krill, fish, cephalopods and crustaceans (Kooyman 1965, Kooyman 1981, Laws 1984, Bonner 1994, Rogers & Bryden 1995, Walker *et al.* 1998, Hiruki *et al.* 1999, Hall-Aspland & Rogers 2004, 2005, Ainley *et al.* 2005,). Although detailed behaviour varies greatly between individual leopard seals, distinct hunting techniques have been observed, mainly in the water and at the ice edge (Penny & Lowry 1967, Rogers & Bryden 1995, Hiruki *et al.* 1999). Most observations of hunting have been of leopard seals preying on penguins or seals either by ambush (wherein the seal lies at the surface, often with only its nostrils breaking the surface, in a place where prey are known to be abundant), by stalking under thin ice and breaking through the ice with their head to capture penguins, or by pursuit hunting where the seal makes no attempt to hide itself and relies on swimming speed to capture its prey.

Human activities where interactions with leopard seals may occur

Humans are likely to encounter leopard seals while undertaking directed scientific research on them or during activities that take place either in the water or at the coast/ice edge of the Antarctic region. Perhaps the most obvious situation where such interactions may be of particular concern is during diving. In addition, the requirement to maintain detailed records of diving, with frequency and details of interactions as well as occasions where no interactions occurred, means that it provides a particularly useful source of information on human-leopard seal interactions. Diving in Antarctic waters is currently (or has historically been) undertaken by the national Antarctic programmes of Argentina, Australia, Brazil, Canada, Chile, France, Germany, Italy, Korea, New Zealand, Russia, United Kingdom and the United States, and has typically been for scientific research.

Recreational diving has become an increasingly popular tourist activity in the Southern Ocean over the last two decades as Antarctic tourism has increased dramatically. An estimated 19 700 tourists visited Antarctica in 2003/2004 season, with in excess of 21 200 predicted for 2004/2005 (www.iaato.org, accessed 20 April 2005), but only a small proportion of Antarctic tour operators undertake diving activities. Thus it would appear that there is the potential for an increase in interactions between humans and leopard seals.

An attack by a leopard seal

On 22 July 2003 Kirsty Brown, a 28 year old marine biologist with the British Antarctic Survey (BAS), was snorkelling with her partner (buddy) 20 m from shore studying iceberg scouring at South Cove and Ryder Bay, Rothera Research Station, Adelaide Island (67°34'S, 68°07'W). The conditions were calm and overcast (wind 2 knots from 80 degrees, cloud cover 7 octas and increasing). The air temperature was -8.1°C and the local sea-surface was covered by grease-ice (< 1 cm thickness). Water visibility was recorded as good (> 30 m). The two snorkellers had entered the water at 15:10 local time, whilst two personnel maintained a safety watch from ashore. A few minutes later, when both snorkellers were within 20 m of the shore and were *c.* 15–20 m apart, Kirsty screamed and disappeared from view. As her snorkelling partner started to swim towards where Kirsty disappeared, the shore party saw Kirsty briefly resurface together with a leopard seal. The shore party immediately made a MAYDAY call to the research station operations room (at 15:25) and a rescue boat was launched. As the snorkelling partner reached the point at which Kirsty was last seen he could see her submerged at 5 m with a leopard seal holding her fin. At this point the snorkelling buddy returned to join the shore party.

At 15:35 the seal resurfaced, approximately 1 km from where it had last been seen. It was holding Kirsty, who was face down in the water, by the head. As the rescue boat approached one of the members of the boat party began hitting the water and the leopard seal with a shovel. The leopard seal released Kirsty and remained in the vicinity of the boat. Kirsty was then pulled into the boat and emergency first aid was administered. The boat immediately returned to shore where Kirsty was transferred to the Rothera surgery under the direction of the station doctor. After full assessment and prolonged attempts at resuscitation, CPR was stopped and Kirsty was pronounced dead at 16:50 hours.

The Falkland Islands Coroner, Mr N.P.M. Sanders, acting in his capacity as HM Coroner, British Antarctic Territory, visited Rothera and met with BAS personnel who were involved in the incident. The Coroner's Inquest took place on Friday 14 November 2003 at Stanley, Falkland Islands. The Inquest recorded a verdict of accidental death, caused by drowning due to a leopard seal attack. The Coroner paid tribute to Rothera personnel, and said that he had been very impressed by the professionalism and skill of everyone involved, in particular those directly involved in the incident. He stated that the tragedy was a reminder of the dangers encountered when conducting research in the Antarctic.

Kirsty was 156 cm tall and weighed 55 kg, and she was wearing a black drysuit and black fins. Her dive computer, which had been reset prior to entering the water, recorded a maximum depth of 70.1 m. The sex of the leopard seal was not determined, but it was estimated to be 4.5 m in length, measured with reference to the rescue boat. This length indicates that it may well have been an unusually large female based on the size distribution described by Rogers (2002).

Safety review and risk assessment

In response to the death of Kirsty Brown BAS temporarily suspended SCUBA diving (herein diving) and snorkelling activities while a review of diving and snorkelling safety was undertaken. Diving recommenced in January 2004, with a number of revisions to the diving procedures, although snorkelling is now prohibited These revisions include a 30 minute period of observation of marine mammals prior to a diver entering the water, a boat party to accompany all dives and the use of diver-to-surface communications.

Whilst undertaking this safety review it became apparent that there was a lack of detailed information on the nature (location, activity and timing) of interactions between humans and leopard seals. Thus making an informed assessment of the risks involved with operations in areas where humans may potentially come into contact with leopard seals was difficult. The aim of this study was to investigate the available information on human-leopard seal interactions in order to quantify the likelihood of interactions and to provide information to enable more appropriate assessment of the hazards and risk associated with leopard seals.

Methods

This study was conducted over a 12 month period beginning in April 2004, and included 3 months each for questionnaire design, data acquisition, data analysis and report writing. Humanistic and observational data were used to aid examination of the effect of different covariates on the response of leopard seals to the presence of humans. The humanistic data essentially comprised the shared experiences of those who have had encounters with leopard seals. This was gathered using an Internet-based questionnaire, two discussion forums held at BAS, in-depth interviews with individuals who had considerable experience with leopard seals, and anecdotal responses. In order to compare the nature and extent of each reported interaction, each were categorised according to the description of the response level of the leopard seal. This response level, termed the 'Leopard Seal Response Index' (LRSI), was on a scale from 1–5 as follows:

5 - Contact
4 - Close approach
3 - Active approach
2 - Movement
1 - Passive / Flight

Observational data was collected from diving and snorkelling logs at BAS (hereafter BAS logs), the detailed records from a single Antarctic diver and from the long-term monitoring of leopard seal abundance at Antarctic research stations. BAS dive and work related snorkelling logs from 1970 to December 2004 spanned operations at Grytviken (South Georgia), Signy Island (South Orkney Islands) and Rothera. BAS logs are not separated, and sometimes it was not clearly stated whether a log had been raised for a dive or a snorkel. From 1970–2004 work-based snorkelling was rare so there were relatively few snorkels (compared to diving) logs. The logs also contain information on marine mammals, including leopard seal, sightings and interactions. A total of 8947 dives were analysed from 1970 for Grytviken, Signy and Rothera. Although data on sightings for Rothera included 2004 data, this data was not included in further statistical analysis, as an increased vigilance in sightings of marine mammals occurred following Kirsty Brown's death.

The second source of observational data was the detailed descriptive dive logs of one of the authors (DKAB) from January 1991 to December 1992 inclusive that provided additional information to that required in the routine dive logs. The third set of observational data was the long-term monitoring of leopard seal abundance at Bird Island, South Georgia (see Walker *et al.* 1998, Jessopp *et al.* 2004) and from the routine zoological records of Antarctic wildlife from Rothera. In addition to the interactions reported in questionnaires, forums and in depth interviews, some observations of leopard seal behaviour in captivity were offered. This information was not included in the analysis but it did provide useful context for the interpretation of the results.

This study required the involvement of observers who have had personal experience of interactions with leopard seals. Therefore a targeted potential sample with experience of leopard seal interactions was established that included scientists, tour operators, tourists and wildlife filmmakers. The nature and timing of our research, following the death of Kirsty Brown, meant that the use of such a purposive sampling approach probably produced a greater response than may have been the case otherwise as many respondents expressed a desire to participate as a direct result of hearing about the tragedy.

Humanistic data used in social research is by its very nature, subjective (Sarantokos 1998) and this was an important consideration throughout this research. In particular the experience and familiarity of observers with leopard seals, the 'experience effect', was considered as potentially important to interpreting descriptions of experiences. Furthermore inter-observer differences were likely in the level of effort in recording and recollecting leopard seal experiences, known as the 'effort effect'. By recognizing the potential limitations of humanistic data, and by combining both humanistic and observational data, the subjectivities inherent in this type of research can be accommodated.

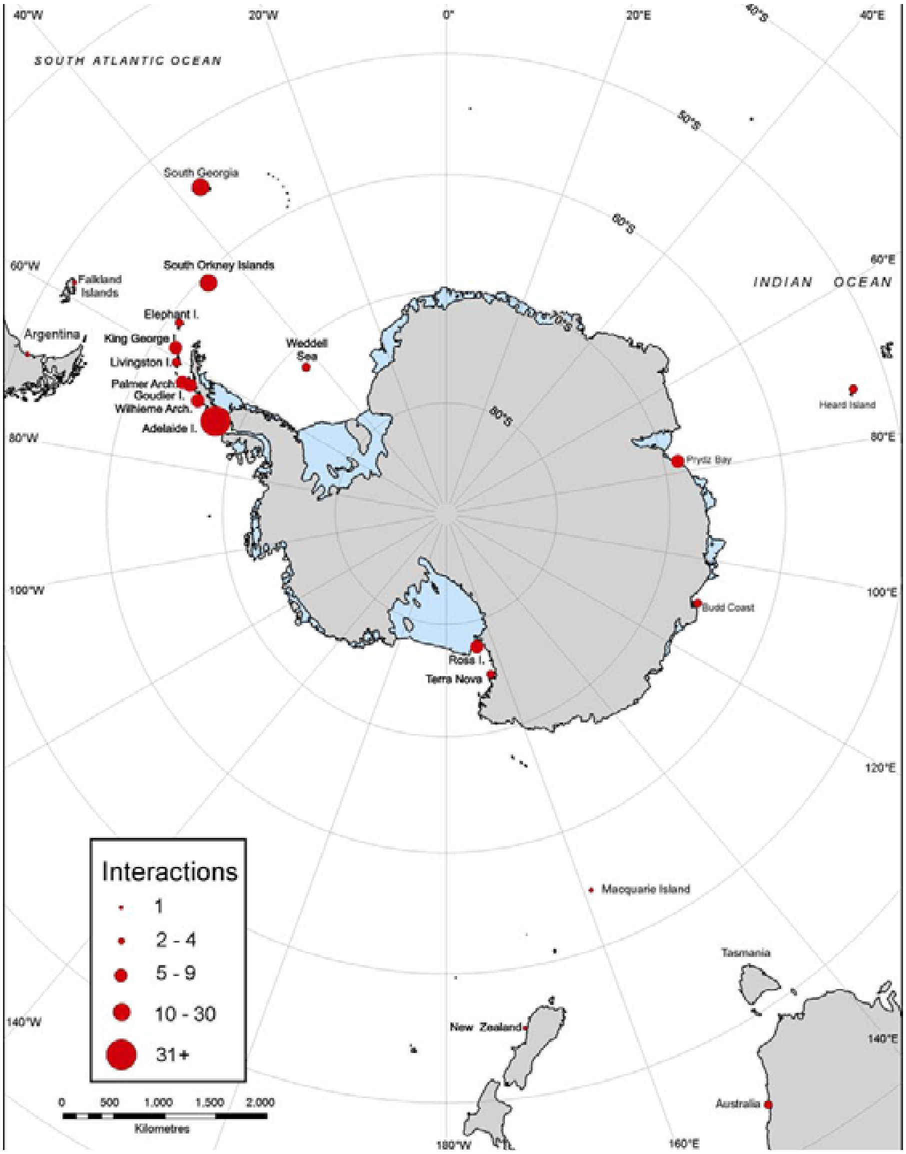

Fig. 1. Distribution of leopard seal interactions reported in questionnaires. The numbers for each location correspond to the number of interactions described at that location.

Results

Completed questionnaires, from 70 individual respondents, provided details of 137 leopard seal-human interactions, of which 93 were single interactions and 44 involved two or more interactions. A total of 17 people with personal experience of interactions with leopard seals attended the forums, a further nine gave in-depth interviews; anecdotal correspondence was received from a further eight individuals. Information was supplied from all sectors of the target audience with scientists, logistic support staff, tour operators and wildlife filmmakers from 10 nations (Argentina, Australia, Canada, Chile, Germany, France, New Zealand, Sweden, UK and US) submitting questionnaires or attending interviews or forums.

The interactions that were reported in completed questionnaires took place primarily in the Scotia Sea/ Antarctic Peninsula, Ross Sea, Prydz Bay and Budd Coast in East Antarctica, Heard Island and on the southern coasts of South America, New Zealand and Australia (Fig. 1).

All categories of response of leopard seals to observers (LSRI) were reported in single and multiple interactions

Table I. LSRI for total interactions, single interactions and groups of multiple interactions.

LSRI (Leopard seal response index)	Total no. interactions	Total interactions (%)	Single interaction (%)	Group interactions (%)
1 – Passive / flight	9	6.6%	6.5%	6.8%
2 – Movement	34	25.5%	29.0%	18.2%
3 – Active	41	29.9%	29.0%	31.8%
4 – Close approach	27	19.0%	15.1%	27.3%
5 – Contact	26	19.0%	20.4%	15.9%
Total	137	100%	100%	100%

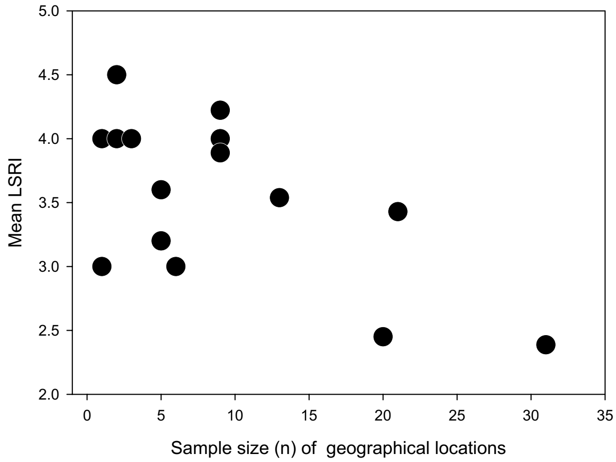

Fig. 2. Mean leopard seal response index (LSRI) per sample size (*n*) of individual geographic locations.

Table II. Observer location and mean LSRI.

Observer location	*n*	Mean LSRI	SD
On land	36	2.611	0.871
On ice	17	3.824	0.883
In the water	40	3.175	1.238
In boats	44	3.455	1.320

(Table I). There was no effect of LSRI reporting interactions as groups of multiple interactions, compared to single interactions(one-way ANOVA, $P = 0.233$). However, there were significant differences in the LSRI between geographic locations for which there was more than a single record (one-way ANOVA, $P < 0.001$). On further analysis, a significant negative correlation was found between the LRSI and the number of incidences (n) reported from a site ($r^2 = 0.34$, $P = 0.013$; Fig. 2). Thus sample size (n) at geographic locations was a strongly confounding variable to

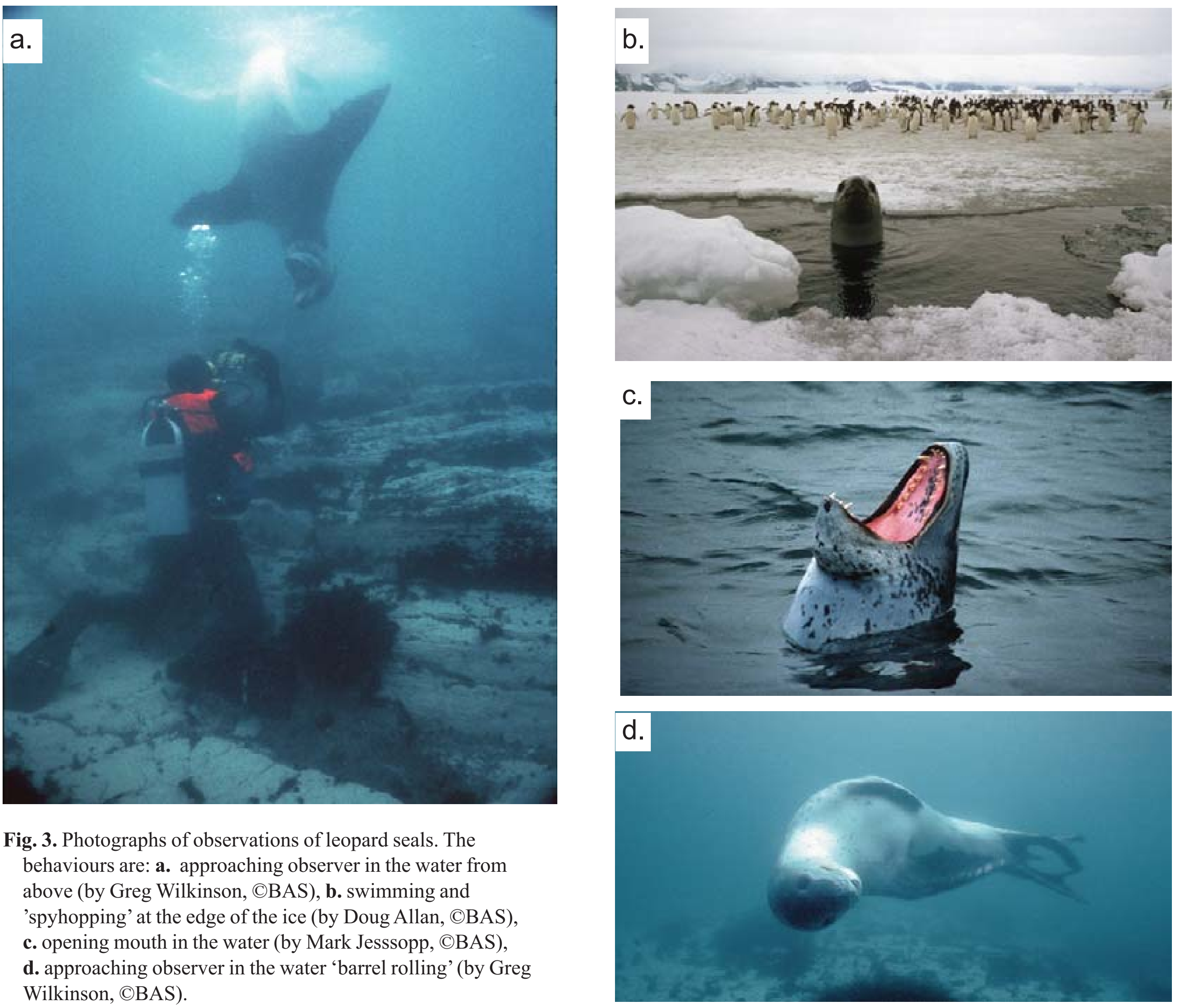

Fig. 3. Photographs of observations of leopard seals. The behaviours are: **a.** approaching observer in the water from above (by Greg Wilkinson, ©BAS), **b.** swimming and 'spyhopping' at the edge of the ice (by Doug Allan, ©BAS), **c.** opening mouth in the water (by Mark Jesssopp, ©BAS), **d.** approaching observer in the water 'barrel rolling' (by Greg Wilkinson, ©BAS).

Table III. Leopard seal location and Mean LSRI.

Leopard seal location	*n*	Mean LSRI	SD
On land	36	2.85	0.871
On sea ice	17	4.125	0.883
On iceberg	44	2.1	1.320
In the water	40	3.289	1.238

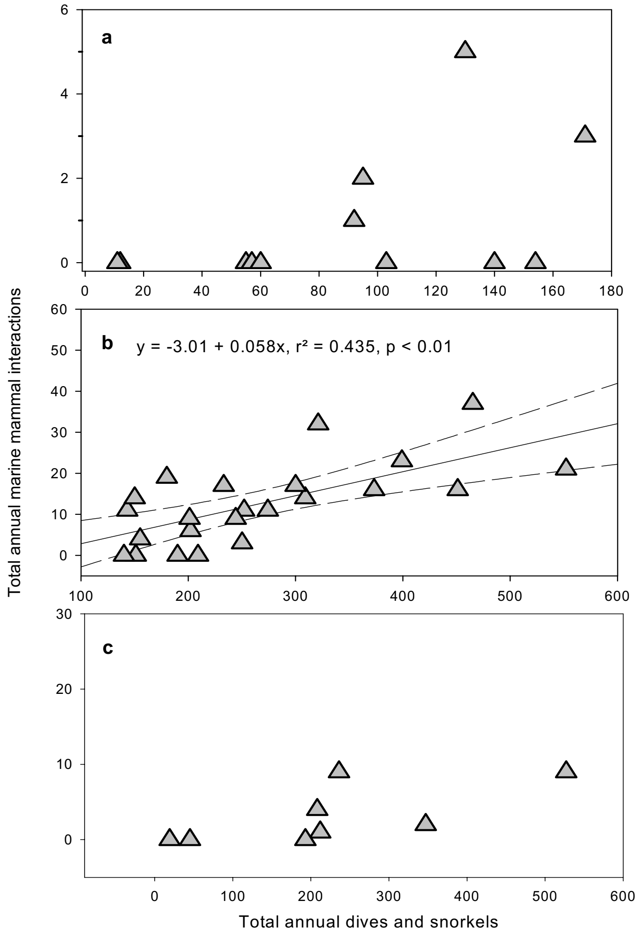

Fig. 4. Total numbers of reported human–marine mammal interactions with total number of dives and snorkels for three research stations. The stations are **a.** Grytviken, **b.** Signy Island and **c.** Rothera. A significant regression is shown (solid line) with 95% confidence interval (dashed line).

differences in the mean LRSI since the mean LSRI at those sites with large numbers of observations was lower than at sites with fewer observations.

Habitat type and location of interaction

Of the categories of observer location, the LSRI was highest for those on ice (Table II). Observer location had a significance influence on LSRI (ANOVA, $F_3 = 5.61$, $P = 0.001$). Mean LSRI for an observer on land was significantly lower than for one on ice (Tukey Simultaneous Tests, Difference of means = 1.2124, SE 0.3363, Adjusted T-value = 3.605, $P = 0.0025$) or in boats (Tukey Simultaneous Tests, Difference of means = 0.8434, SE = 0.2568, Adjusted T-value = 3.284, $P = 0.0071$). Similarly, seal location had a significant effect on LSRI (one-way ANOVA $P = 0.001$); with the LSRI where the leopard seal was on sea-ice being highest (Table III). Tukey post hoc tests indicated that when the seal(s) was on land, the LSRI was significantly lower than when it was on sea-ice (Tukey Simultaneous Tests, Difference of means = 1.2750, SE = 0.4769, Adjusted T-value = 2.674, $P = 0.0416$). Furthermore the LSRI for seals on sea ice was significantly higher to those on icebergs (Tukey Simultaneous Tests, Difference of means = -2.025, SE = 0.5407, Adjusted T-value = -3.745, $P = 0.0015$), and seals in water had a significantly higher LSRI to those on icebergs (Tukey Simultaneous Tests, Difference of means = 1.189, SE = 0.3786, Adjusted T-value = 3.139, $P = 0.0111$).

On land, where leopard seals were most often observed resting, if a leopard seal responded at all to the presence of humans, it would raise its head or enter the water. Leopard seals often (>50% of reports) pursued humans on sea-ice and on occasion actually made contact with the observer. A frequently described behaviour followed a pattern of the leopard seal being initially in the water (Fig. 3b) and then launching out of the water in an attempt to rapidly get onto the ice. In most of these instances the leopard seal was not seen by the observer prior to the interaction.

Observers varied considerably in the detailed patterns they reported for interactions where both the seal and the observer were in the water, but approach and circling of the observer was most commonly described. The seal would often approach from above (Fig. 3a), and it was common for the leopard seal to lift or shake its head and to open its mouth (Fig. 3c). Several instances were reported where the leopard seal appeared and then receded from view. As the time the observer spent in the water increased, the leopard seal was inclined to disappear from view, and then re-appear, circle in closer, barrel rolling (Fig. 3d) and repeating a striking action, opening and shutting its mouth and shaking its head.

The most commonly reported pattern of behaviour of leopard seals in response to small boats was that the seal(s) approached boat, spy-hopped (raised head out of water, Fig. 3b), lingered in the vicinity of the boat, circled the boat and pursued the boat. In addition there were 13 instances of a leopard seal making some form of physical contact with small boats including puncturing the side of rubber boats.

Human activities and 'in water' interactions

There was no significant influence of the nature of the observer activity (i.e walking, boating, or in-water activities) on LSRI (one-way ANOVA, $P = 0.447$). From the 40 responses from observers that were in the water with

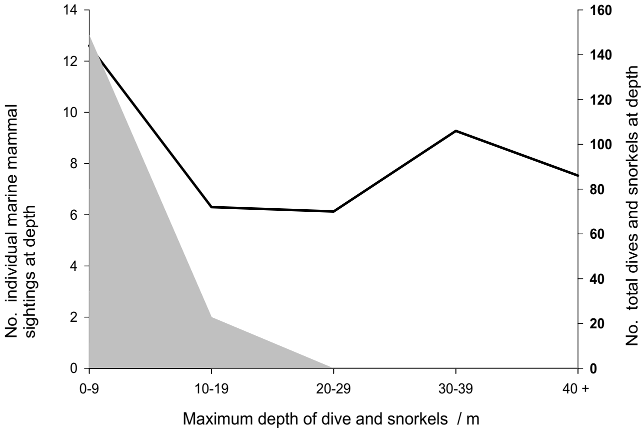

Fig. 5. Number of marine mammal sightings and numbers of SCUBA dives with depth of dives, at Signy Island 1991–92. Shaded area is number of marine mammal sightings and solid line is number of dives per depth.

leopard seal(s) there was no significant difference in leopard seal response between a snorkelling or a diving observer (one-way ANOVA, $P = 0.260$). Further analysis of more specific human activities in the water (ie: inshore and off shore snorkelling and SCUBA diving and under ice diving) indicated no significance difference for specific types of in-water activities (one-way ANOVA, $P = 0.173$). There was no influence of depth of dive on the LRSI. (one-way ANOVA, $P = 0.142$).

To aid analysis of the total dives from 1970 for Grytviken, Signy and Rothera, the data was split according to the total number of dives, sightings and interactions per year (Table IV). The number of marine mammal interactions increased significantly as a function of the total number of dives each year at Signy ($r^2 = 0.43$, one-way ANOVA, $P < 0.01$; Fig. 4b). However, no such significant relationship was found for the Grytviken ($r^2 = 0.15$, one-way ANOVA, $P = 0.110$) (Fig. 4a) or Rothera data ($r^2 = 0.38$, one-way ANOVA, $P = 0.058$) (Fig. 4c), although the forms of the relationship was suggestive of a similar trend but the sample sizes were smaller for both than at Signy.

Based on the total number of dives and interactions, the likelihood of a diver interacting with a leopard seal was *c*. 0.3% at both Grytviken and Rothera (number of interactions = 2) (Table V) whereas at Signy it was more than twice this (0.7%, number of interactions = 42) with an overall likelihood of interacting with a leopard seal of about 1 in 200 dives. Most interactions appeared to occur at shallow depths, but analysis of this using the questionnaires was complicated by the lack of data on the depth at which the interaction actually occurred compared to the maximum depth of the dive. The detailed dive logs of 1991 and 1992, where sufficient information was available, revealed the average depth of interaction with marine mammals to be less than 8 m. Sightings of marine mammals were disproportionately frequent at shallow depths, as no interactions were reported on dives to 20 m or deeper despite 56% of dives being in this depth category (Fig. 5). Of the four leopard seal sightings in these detailed logs three were between the surface and 9 m, and one was at a depth between 10 and 19 m. This notwithstanding, the probability of interaction will depend upon the time spent at a particular depth by the diver rather than the dive depth. Taking into account decompression stops and dive procedures at the surface at the beginning and end of dives, it is likely that more time is spent at shallow depths.

Table V. Mean number of dives reporting an interaction with marine mammal and leopard seals.

	Grytviken (1970–82)	Signy (1970–92)	Rothera (1997–mid 2003)	Mean of 3 stations
Marine mammals	0.73%	4.51%	1.42%	2.95%
Leopard seals	0.32%	0.73%	0.27%	0.50%

Frequency of physical contacts, fatalities and likelihood of injury

In total, at BAS research stations, from January 1970–July 2003, physical contact with a marine mammal during diving and snorkelling has been reported on 17 occasions of which four were with a leopard seal. At Grytviken there was a single instance of physical contact and that was with a southern elephant seal (*Mirounga leonina*). At Signy of the 14 instances of physical contact with a marine mammal 11 were with Antarctic fur seals (*Arctocephalus gazella*) and three were with leopard seals. Since 1997 at Rothera there has been one instance of physical contact with a crabeater seal (*Lobodon carcinophagus*) and one with a leopard seal

Table IV. Total dives, range of the number of sightings and interactions for Grytviken, Signy and Rothera.

	Grytviken	Signy	Rothera	Total of 3 stations
Total dives and snorkels	1080 (1970–82)	8088 (1970–95)	2010 (1997–2004)	11178
	1080 (1970–82)	6144 (1970–92)	1723 (1998–2003)	8947
Range of the number of sightings per year	0–6	0–46	2–54	
Range of the number of interaction per year	0–5	0–36	0–10	

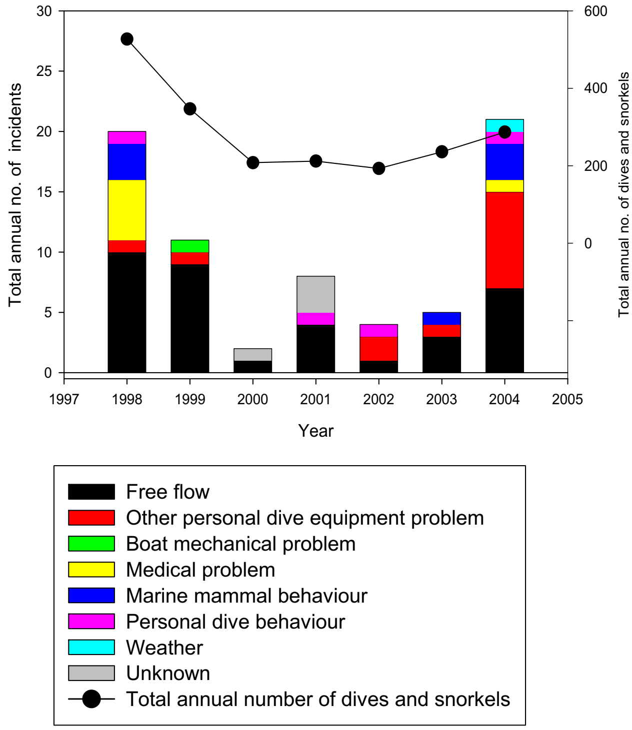

Fig. 6. Incidents and total dives and snorkels at Rothera, 1998–2004.

(which led to the fatality of Kirsty Brown).

Antarctic diving safety: Rothera diving and snorkelling incidents 1998–2004

There was no relationship between the number of incidents reported and the total number of dives and snorkels at Rothera for the period 1998–2004 (ANOVA, $F_6 = 6.27$, $P = 0.054$). However, upon removal of the data in the period after Kirsty Brown's death, the relationship was significant (ANOVA, $F_5 = 43.38$, $P = 0.003$).

The 71 reported incidents represented less than 4% of the total number of dives and snorkels. The annual total and causes of these incidents varied considerably from 1998 to 2004 (Fig. 6). The major (49.3%) cause of incidents was SCUBA demand valve (regulator) second stage 'free flows'. Other equipment failures (such as dry-suit direct feed, VHF radio or other malfunctions) caused 18.3% of incidents. Marine mammal encounters caused 10 % ($n = 7$) incidents. In three (1998, 2003 and 2004) of the seven years, diving or snorkelling incidents were recorded involving a marine mammal.

The consequences of incidents ranged from minor, in the event of second stage free flow, where once corrected, a dive was able to re-commence, to more serious incidents, termed accidents, where there was an elevated risk of injury. Separate analysis of BAS' health and safety records indicated that four injuries have occurred from a total of 2565 BAS logs since 1998. Three of the four injuries were not related to marine mammals, whilst the fourth was the fatal attack on Kirsty Brown.

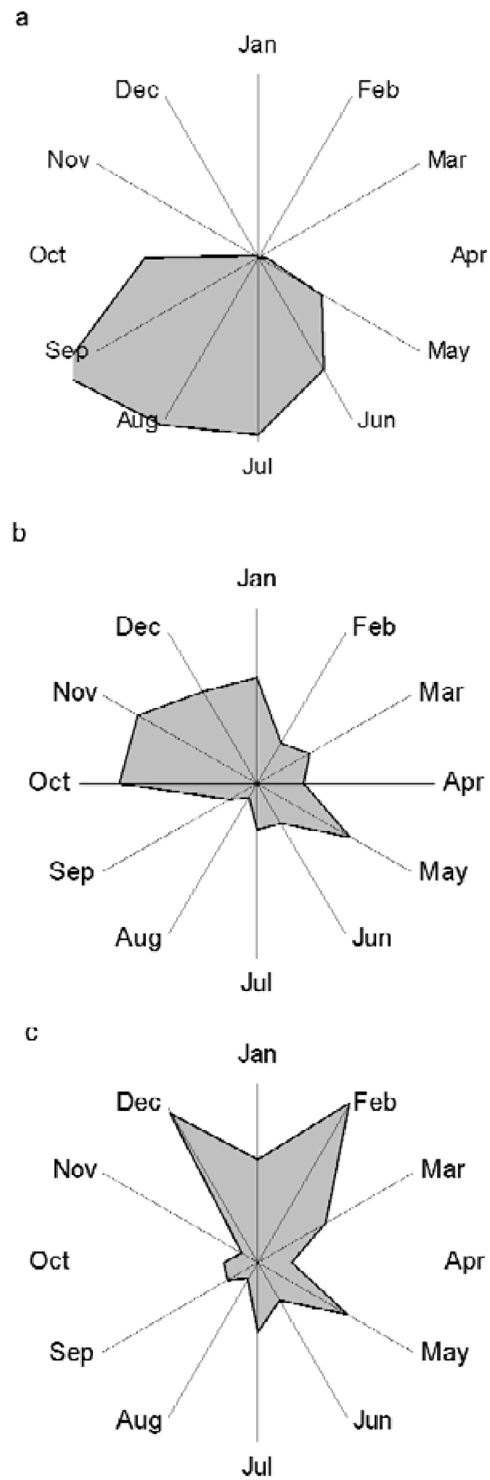

Fig. 7. Relative percentage sightings of leopard seals at **a.** Bird Island (BAS Long Term Monitoring Reports, 1994–2004), **b.** Signy (BAS dive logs 1970–92), and **c.** Rothera (BAS Long Term Monitoring Reports, 1996–2004).

Monthly sightings of leopard seals at Bird Island, Signy and Rothera

The inter-annual pattern of leopard seal sightings was consistent at each of the three study localities (Bird Island, Signy and Rothera research stations), but there was little overlap in the time of peak abundance between them (Fig. 7). At Bird Island (Fig. 7a), leopard seals were sighted from May to October, with the highest numbers from July to September. In contrast, at Signy (Fig. 7b) peak numbers of leopard seals were seen mainly from October to January (from dive log data) and at Rothera (Fig, 7c), they were seen mainly from December to February.

Discussion

Large marine predators, potentially capable of causing human fatalities, occur in all oceans and seas of the world. In polar environments these are principally leopard seals (south), polar bears *Ursus maritimus* Phipps (north) and killer whales *Orcinus orca* L. (both). In the wild, killer whales have never been known to cause a human fatality[1], leopard seals are only known to have caused one (discussed here) and polar bears have been implicated in *c.* 40 (Davids 1982, Risholt *et al.* 1998). On the basis of recorded injuries or fatalities the most dangerous large marine predators are sharks. Yet in Australia, the country with most fatalities, they are responsible for less than a single death per year and are in the lowest category of sources of mortality at sea (Australian Bureau of Statistics figures cited in Caldicott *et al.* 2001).

Although the threat posed by large marine predators is relatively small, the perception of this risk is generally quite different. In the case of the southern polar region, humans have very little experience or interactions with either killer whales or leopard seals, indeed most leopard seals may have never encountered a human. Human propensity for unprovoked attack means that our anthropomorphic interpretation of the response of large predatory species often fails to account for naturally risk averse behaviour. Leopard seals clearly pose some degree of threat to humans, but the awareness of potential threat can lead to biases in non-expert interpretations of leopard seal behaviour.

In order that these risks can be properly assessed there is a need to collate relevant information so that those people who are potentially likely to encounter leopard seals have appropriate information with which to make more informed decisions with respect to the hazards posed by leopard seals. In the current study trends at three Antarctic localities are presented from observational, and categorical data and anecdotal information gained from shared personal experiences from a number of locations, provides some important additional context to human-leopard seal interactions.

The response of an individual leopard seal to a human will depend upon a range of factors that make every interaction unique and thus impossible to predict with absolute certainty. It is nonetheless useful to describe and propose a potential interpretation of the general scenarios of seal behaviour that have been identified during this research. Observations of a leopard seal's response to humans differed depending on whether the observations were made from land, on ice, or in the water. In examining these differences it is important to recognise that water is the environment to which leopard seals are most adapted. It is therefore not surprising that most leopard seals will enter the water after encountering a human on land. Although there were thirteen accounts of a leopard seal making some form of contact with equipment, this behaviour is not uncommon amongst all marine mammals.

Behaviour scenarios that may influence locational differences

Two quite distinct and dissimilar behaviour types emerged when comparing the behaviour of leopard seals towards humans at the ice-edge and in the water. These were either an attack with little or no prior observation of the seal, which was interpreted as an ambush/hunting behaviour, or swimming around the observer in a variety of movement patterns but not mounting any sort of attack, which is interpreted as curiosity. Although some were described as aggressive, no interactions with divers in the water subsequently led to actual attacks. The majority of attacks have occurred at the ice-edge and the account of the wildlife cameraman, Doug Allan (July 2004) may represent typical hunting behaviour; *'A group was approaching fast ice edge where we knew leopard seal(s) were present which could be actively hunting emperors. A leopard seal was seen briefly approx 100 m away as we approached the edge, it spy hopped once or twice, then went down underwater. When we carried on walking and were close to edge (3 m), the seal suddenly reappeared to immediately launch itself out of the water and onto the ice, slithering across the ice towards us. This is classic hunting strategy by the seal, to take advantage of unwary penguins standing too close to the ice edge. The seal slithered back into the water, no more attempts that day but showed same behaviour as we approached the edge on the following day. This behaviour was interpreted as seal opportunistically trying out an attack strategy on prey which I guess it assumed to be emperor penguins'* Similarly (Erb 1993) recalls an incident involving a leopard seal attack whilst standing at the ice edge; '*And yet, had that leopard really intended to get (me), he could have picked me off the ice and into the water with one single flick of that huge head. ... I have.. been*

[1]Two human fatalities are known to have occurred in captivity as a result of interactions with killer whales. These fatalities occurred in 1991 at Sealand of the Pacific, Canada, and in 1999 at Sea World, Florida (Williams 2001).

absolutely convinced… attacks on people are results of the animal's mistaking us for penguins. This is quite easy to do, as leopards, when in the water, have a view on a horizon on which people stand out as dark upright shapes: penguins!' Various authors have documented similar hunting strategies to that described by Allan (July, 2004) and Erb (1993) at other localities (Penny & Lowry 1967, Rogers & Bryden 1995, Hiruki *et al.* 1999). An explanation for such attacks by leopard seals at the ice-edge could be the mistaken identity of humans as prey or simply identification as prey. Given the numbers of penguins in the Antarctic compared to the very limited number (and distribution) of people it is hardly surprising that such mistakes occur. Erb (1993) suggested that once a seal realises a mistake has been made, the attack would be likely to be discontinued. In this case we are lacking sufficient data to evaluate this suggestion.

Research into human/shark interactions has indicated that mistaken identity is a likely cause of a high proportion of shark attacks. Caldicott *et al.* (2001) suggested that by avoiding areas where sharks feed, and actions that mimic their normal prey, risk of attack can be minimised. Clearly there are a very much larger number of attacks by sharks than by leopard seals yet the advice of Caldicott *et al.* (2001) is pertinent for leopard seals, especially given that the only thing other than humans that stands vertically at the ice-edge is one of the most frequent prey of leopard seals.

In contrast to the frequency of attacks at the ice-edge there were no attacks where both the seal and the observer were in the water (apart from that on Kirsty Brown). In the water, the impression of many observers was that the leopard seal was behaving in a curious or inquisitive manner. Curiosity is essential to the acquisition of knowledge and is fundamental to ensure that individual animals are optimally adapted to their environment (Berlyne 1960). Observations of inquisitive behaviour are often described as curiousness and playfulness, and questionnaire responses from a wide range of experiences with leopard seals indicated curiosity as a frequent explanation for the behaviour of leopard seals. Marine mammals in particular are well known for 'playing' with inanimate objects. Scheer *et al.* (2004) documented several behaviours of short finned pilot whales towards humans, including a 'headshake' behaviour, which was interpreted as non-aggressive, although it should be recognised that relatively little is known of about the behavioural signals of aggression in pilot whales, or in marine mammals generally, while they are in the water.

Many respondents reported that leopard seals approached with an open mouth and suggested that this represented aggressive behaviour. However, Rogers *et al*. (1995) describes open mouth displays as part of agnostic (aggressive–defence) displays between leopard seals. In other species of seals (e.g. Antarctic fur seals and southern elephant seals) an open mouth is often a sign of submissive behaviour, particularly shown by male seals immediately after losing a fight (Reid personal observation). As such this response can also be representative of an animal that feels threatened and hence may be prone to unpredictable behaviour.

Factors affecting the likelihood of sighting and interacting with leopard seals

Any assessment of the probability of interacting with a leopard seal is predicated upon three primary criteria, namely where, when and what activity is being undertaken. For the first two criteria it is clear that there is a very strong spatio-temporal pattern in the periods when leopard seals were present at Antarctic localities. Data of the current study showed very different patterns of abundance at Bird Island, South Georgia (July to September), Signy Island, South Orkney (October–January, and in May) and Rothera, Antarctic Peninsula (December to January). At Admiralty Bay, South Shetland Islands, Salwicka & Sierakowski (1998) found that leopard seals were most abundant from September to October, supporting the pattern described. Such a distribution pattern reflects the seasonal advance and retreat of the pack ice, the preferred habitat of leopard seals. A recent analysis of the long-term study of leopard seals at Bird Island showed a strong positive relationship between seal numbers and the distance to the edge of the pack ice (Jessopp *et al.* 2004). Although there was a strong seasonal trend and high inter-annual variability in the occurrence of leopard seals in these three locations there was no evidence of any long-term trends in numbers (neither increases nor decreases). Notably the timing of Kirsty Brown's fatality does not fit with the typical spatio-temporal pattern described as it occurred in July, outside the normal occurrence of leopard seals at Rothera.

In addition to the seasonal movements of leopard seals, the human population of Antarctic regions is also highly seasonal with numbers in summer far exceeding those in winter. As technology and logistic support makes human travel and presence in Antarctica easier, that presence is increasing and inevitably humans are likely to encounter leopard seals more frequently. The potential for such encounters is highest in the vicinity of research stations and along popular tourist destinations, particularly along the Antarctic Peninsula. In other regions of the Antarctic the potential for encounters exists even in areas where leopard seals have not previously been recorded. For example, it had been generally assumed that leopard seals occurred infrequently and only in summer in small numbers in the Prydz Bay region (near to the Australian Davis Station). Directed research on the pack-ice seals in this region revealed that leopards seals did indeed occur in this region in considerable numbers (Rogers *et al*. 2005).

Human activities, other than actually conducting research on the seals themselves, which are most likely to bring about an encounter with a leopard seal are 'in water' activities. Due to the data available, this report focussed on BAS work-related diving and snorkelling as examples of 'in water' activities. The analysis of sightings of leopard seals whilst diving at Signy and Grytviken showed an increase in sightings as a function of the dives and snorkels, i.e. as more time was spent in the water more seals were encountered. Similarly the relationship between sightings and interactions suggested that interactions increased as a function of sightings at all three stations.

Based on the analysis of the extensive BAS dive logs, the likelihood of having an interaction with a leopard seal whilst diving and snorkelling was of the order of once every 200 dives. Furthermore, the chances of that interaction involving actual physical contact with a leopard seals is of the order of once in every 2200 dives, as physical contacts had been recorded on 4 of 8947 dives.

The nature of the reported physical contact took many forms but the current study had few reports of actual physical injuries to divers as a result of physical contact with leopard seals. Even if the proportion of contacts that produce actual injuries was as high as 25%, which is probably a considerable overestimate, this would equate to a likelihood of sustaining a physical injury from a leopard seal of the order of one in 9000 dives. Since there are always a minimum of two people on a dive this risk is equivalent to one in every 18 000 person dives. Putting these figures into context is complicated by the lack of comparability in diving conditions in different environments and the different risks and hazards faced in different situations.

We compared the risk value we found to two risk figures, firstly that for the UK work diving community and secondly to that of the UK sport (recreational) diving community. Work diving statistics from the Health and Safety Executive (HSE 2005, unpublished) reveal that of the 24 fatalities (none of which were scientific diving) and 452 accidents reported since 1996, decompression related illness was the major cause. This is a fatality rate of about 1/15600 work related dives per year. Sport diving records (we used the British Sub Aqua Club Diving Incidents Report) have questionable accuracy as are self reported and they do not provide total dive figures. Nevertheless a total of 24 fatalities and 400 incidents were reported for 2004 (www.bsac.org/techserv/increp04/intro.htm, accessed 20 April 2005). Decompression Illness (DCI) accounted for the highest number of incidents. Further analysis of recreational and scientific diving by Sayer & Barrington (2005) indicated that the rate of DCI was lower for scientific diving than for sport diving. The level of 0.12 DCI incidents per 1000 dives was within the range for previous studies on SCUBA diving (0.07–0.14) but below reported incident rates for wreck and/or multi-day recreational diving (0.25–0.49). A previous study trying to analyse scientific diving specifically (Paras 1997) concluded that fatalities and accidents were typically too infrequent to properly assess the risk. We found that even for a sport in which documentation is good, such as diving, accessing data in a format that quantitative comparisons can be made across places or communities (scientific vs sport) is not easy.

In the context of interactions with marine mammals an analogous situation is that of humans interacting with polar bears in the Arctic. Over a similar time period to that of leopard seal interactions in the current study, Risholt *et al.* (1998) recorded 88 interactions, six injuries and four fatalities resulting from polar bears on the Arctic archipelago of Svalbard. Other studies from the Arctic suggest these values are reasonably representative for other Arctic localities (Davids 1982, Risholt *et al.* 1998, Cox personal communication 2005). Clearly these rates of interactions, injuries and fatalities are considerably higher than with leopard seals in Antarctica. This probably reflects the difference in human populations and hence the encounter rate in the two polar regions. In comparison with other causes of death both are low; for example, polar bears cause considerably fewer fatalities around the Arctic than dogs or snowmobiles (Middaugh 1987).

Possible influences on the risk of interactions

The consequences of sustaining injuries caused by a leopard seal may be amplified by the typically extreme conditions of the Antarctic. Leopard seal hunting and predatory behaviour, possible precursors to attack and human behaviour should be taken into consideration to potentially reduce the risk to humans involved in interactions with leopard seals.

Caldicott *et al.* (2001) indicate that knowledge of the behaviour of predators, including prey choice and hunting techniques, may provide insights that allow the risk of human attacks (by sharks) to be reduced. Although the surface is where the evidence of a leopard seal's kills are most apparent, as they 'flay' their prey (see Hiruki *et al.* 1999) extended observations of leopard seal hunting and feeding at South Georgia indicate that the Antarctic fur seals were dead before the flaying started (Reid personal observation). In addition leopard seals were not observed at the surface immediately prior to the flaying, suggesting that their Antarctic fur seal prey had been killed below the surface (Reid personal observation). The behaviour of the seal that killed Kirsty Brown i.e. capture, followed by prolonged submersion and then a return to the surface at a location some distance from the initial submersion site, along with the bite marks on Kirsty's head, are consistent with the leopard seal hunting behaviour described above. The information from the dive computer that Kirsty was wearing is the first piece of information on the sub-surface behaviour of leopard seals during a feeding attack. The rapid descent to 70 m and ascent suggests that leopard seals may undertake rapid, deep dives whilst holding large prey items before returning to the surface at some point remote from the point of initial capture.

In all of the accounts of interactions between leopard seals and divers there were no examples of the response level of the seal escalating to a point where a physical attack was launched. Indeed, in the incidences where a leopard seal attacked people at the ice edge there was often no sighting of the seal prior to the attack. The leopard seal that killed Kirsty was not seen by the shore party or Kirsty's snorkelling buddy. Furthermore, Kirsty gave no indication of sighting the seal prior to the attack. One of our initial aims was to investigate whether Kirsty's relatively small size was a factor in the attack. Our analysis of the effect of the size of divers on the response of leopard seals showed no effect, but this analysis only included seals displaying a 'curiosity' type response while the seal that killed Kirsty was not 'curious', it was hunting. Therefore, taking into account the distinct role of seal behaviour, it is not possible to make any inferences about the role of size in the attack on Kirsty.

Based on the description of hunting behaviour and the account of the fatal attack on Kirsty Brown it would appear that, whilst it is a very rare event, leopard seals can display predatory behaviour towards humans. It is axiomatic that large predators, which are known to sample novel prey, may consider humans as a potential prey. This has been well documented in many parts of the globe especially where human populations are expanding into new areas and thus providing new opportunities for interactions with predator species e.g. tigers in India (Saberwal *et al.* 1994), crocodiles in northern Australia (Kofron 2004), mountain lions in California, (Conrad, 1992) and polar bears in the Arctic (Davids 1982, Bromley *et al.* 1992, Risholt *et al.* 1998). Curio (1976) suggests that mountain lions (cougars) in California have come into contact with two new potential prey items, humans and domestic pets, as residential areas expand into their habitat. They further suggest that the initial interactions are often prompted by curiosity (Curio 1976) and it is only after a number of interactions that the cougar attempts predation; the first few attempts at predation are often unsuccessful. There would appear to be something of a learning curve before the mountain lion becomes familiar with the new prey item (Bromley *et al.* 1992). Interestingly the attacks by mountain lions on domestic pets and humans were not associated with food shortages and the attacking animals appear to be adults and healthy.

The research of the current study also aimed to investigate whether there was any evidence of seal behaviours that may act as precursors to a higher level of aggression during interactions with humans. Although personnel that have worked extensively with leopard seals in captivity, on ice and on land, suggested a range of behaviours that may precede an escalation in aggression, no conclusive evidence was found to support these. Rogers *et al.* (1995) suggested that such behaviour types that may be precursors of aggression include sudden head movements or jabs, extensions of the neck vocalizations, including a snort in of air, and a blast out of air, and intentionally making eye contact. Precursors to heightened behaviour 'in water' may be circling in towards the person in the water, approaching towards the head, and blowing air or bubbles. However, as with all interpretation of animal behaviour, the perception of aggression by an observer may not actually reflect an increase in aggression from the seal.

Similarly there was no conclusive evidence that specific human behaviours may result in an increased response from a leopard seal. However, respondents suggested a number of human behaviours that may result in an increased response from the leopard seal including blowing bubbles, trapping/blocking the exit of the seal, moving rapidly away and turning away. In addition a number of respondents provided suggestions of human behaviours that may result in a decreased response from a leopard seal. These included being constantly vigilant of leopard seals, as awareness of their presence is crucial to reacting without panicking, doing nothing but remaining facing the leopard seal and retreating slowly facing the seal, if the interaction escalates. As in the case of leopard seal behavioural signals no evidence or multiple references to the same behaviour was received upon which to specify the most important precursors or the most influential response to an encounter.

Conclusions

The current study attempted to collate and analyse existing information on human interactions with leopard seals in order to provide an improved basis for risk assessment of activities where such interactions may occur. The results suggest that there is a distinct separation between encounters where seals repeatedly interacted with divers, displaying a range of behaviours that appear to be curiosity led, and an attack where there was no prior indication of the presence of a seal

The detailed analysis of dive records suggests that the number of sightings of, and interactions with, marine mammals was simply a function of the total number of dives and there was no evidence of a change in frequency of interactions over time. Detailed dive log data indicated that sightings and interactions with leopard seals have most frequently occurred at or near the surface. On the basis of >30 years of BAS dive data there is a likelihood of interacting with a leopard seal on approximately 1 in every 200 dives, and the likelihood of sustaining a physical injury from a leopard seal is of the order of 1 in 9000 dives.

The seal that attacked Kirsty Brown displayed hunting behaviour and this is the only account of its kind where the person that was attacked was in the water. That the attack occurred at a time of year when leopard seals are generally uncommon at Rothera suggest that this seal was atypical in a number of ways. In this analysis, data has been presented as it relates to the most frequently observed behaviour types. However, as in any evaluation or risk there is always the possibility of unavoidable events that could not have been predicted on the basis of existing knowledge. In the majority of interactions between divers and leopard seals in the water described the response of seals as curious or inquisitive. Nevertheless the death of Kirsty Brown does show that leopard seals can display predatory behaviour towards humans.

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