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USD 1 & USD 6:

Updated Report

Current state of knowledge of the extent, causes and population effects of unusual mortality events in Scottish seals

Sea Mammal Research Unit
Report to
Scottish Government

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Contents

1 Executive summary

This report summarises the available information on a newly identified cause of seal deaths around the Scottish coast.

All of the seals had a characteristic wound consisting of a single smooth edged cut that started at the head and spiralled around the body. In most cases the resulting spiral strip of skin and blubber was detached from the underlying tissue. The wound was identified as the cause of death in all cases for which a detailed post mortem examination was carried out.

To date (January 2015) a total of 127 seals with confirmed spiral injuries have been recorded in Scotland; 73 grey seals, 51 harbour seals (*Phoca vitulina*), 1 hooded seal (*Cystophora cristata*) and 2 seals of indeterminate species. These numbers are minimum estimates and will probably represent only a proportion of those animals killed close to shore.

Geographical and seasonal distributions of dead seals with these characteristic wounds are patchy in Scotland. Two concentrations are apparent; one around the Scottish south east coast (mainly comprising the area around the Tay and Eden estuaries and the coast of the Firth of Forth) and the other in Orkney. These patterns indicate strong selectivity in the causal mechanism. The presence of similar injuries around Europe and in Canadian waters is presented, showing that this is a widespread problem.

A range of causal mechanisms have been investigated and the list of potential causes has been reduced to the most likely cause being a rotating blade in a tunnel or housing, i.e. ducted.

The circumstances leading to the injuries and their possible population consequences are discussed.

2 Introduction

This report describes the state of knowledge regarding unusual mortality events in seals as of January 2015. It describes the geographical extent of reports and sightings of dead seals with characteristic spiral wounds and the limited information available on the history of this type of mortality in Scotland, in the UK and in the rest of the world. It describes the current view of the pathology, the possible causal mechanisms and describes the limited evidence available to confirm the causal mechanism.

3 Background

In 2009 and 2010, both harbour and grey (*Halichoerus grypus*) seals carcases were found on the coast of Fife and Tayside with injuries consisting of a single continuous curvilinear skin laceration spiralling down the body. Marine Scotland commissioned the Sea Mammal Research Unit (SMRU) to investigate this issue in Scotland. The initial response to the appearance of these unusual mortality events and results of preliminary investigations were reported in Thompson *et al*., (2010). At that stage, a number of severely damaged seal carcasses had been found on beaches in eastern Scotland (St Andrews Bay, Tay and Eden Estuaries and Firth of Forth), along the North Norfolk coast in England (centred on the Blakeney Point nature reserve), and within and around Strangford Lough in Northern Ireland.

4 Pathology

All of the seals had a characteristic wound consisting of a single smooth edged cut (Figure 1) that started at the head and spiralled around the body (Figure 2). In most cases the resulting spiral strip of skin and blubber was detached from the underlying tissue. The wound was identified as the cause of death in all cases for which a detailed post mortem examination was carried out. Post-mortem examinations of 20 harbour seals revealed they had been alive and healthy when the injuries were sustained, with no evidence of any underlying disease or disability (Bexton *et al.*, 2012).

Figure 1. Photograph of the wound on a juvenile harbour seal. The smooth edged cut through the skin and tearing of the blubber by a lateral shearing force was common to all carcasses examined.

Figure 2. Harbour seal juvenile showing typical spiral wound. Collected in the Eden estuary, St Andrews Bay, July 2009.

The wound patterns were the same in necropsied seals from Norfolk (RSPCA and AHVLA), Scotland (SRUC) and Northern Ireland (AFBI). Necropsy findings from all three areas are presented in Bexton et al (2012) and are summarised below (Table 1) to give the characteristic features of spiral lacerations. Twenty harbour seals were subjected to intensive necropsy. The proportion of animals exhibiting the characteristic features of spiral lacerations is shown. Note that only eight seals were x-rayed and four subjected to detailed histopathological examination.

Table 1. Summarised Necropsy results from 20 seals (12 from Norfolk, 4 from Scotland and 4 from Northern Ireland)

	Characteristics	No. (%)
1.	Continuous helical skin laceration originating at the head and spiralling down the body terminating between the ribcage and pelvic area (corkscrew wound)	20 (100%)
2.	Skin and blubber sheared from the underlying fascia with connective tissue attachments torn caudo-laterally	20 (100%)
3.	Scapular attachments to the axial skeleton severed and the fore flipper partially de-gloved	18 (90%)
4.	Wound edge smooth and perpendicular or angled slightly caudally to the axis of the body, with hairs immediately adjacent to the wound uncut	20 (100%)
5.	Bruising, notably to the neck, thoracic inlet, and/or sternum consistent with blunt trauma to the chest area	9 (45%)
6.	Animals in good physical condition with adequate blubber reserves	18 (90%)
7.	Food remains in the stomach consistent with recent feeding activity prior to death	10 (50%)
8.	Radiographic confirmation of the absence of foreign material such as metal fragments, hooks, gunshot, or embedded tooth fragments	8 (100% of those radiographed)
9.	Absence of any additional significant gross pathological changes indicative of underlying disease or injury	20 (100%)
10.	Absence of any significant histopathological changes	4 (100% of those examined)
11.	No significant tissue loss associated with wounds	20 (100%)
12.	Lesions to the head, including slice wounds on the muzzle or skull fractures with lesion orientation consistent with a frontal impact	19 (95%)
13.	Patterned injuries comprising a series of linear or triangular wounds or abrasions 15 mm in length and 12 to 15 mm apart	5 (25%)

5 Conclusion

Based on the pathological findings it was concluded that mortality was caused by a sudden traumatic event involving a strong rotational shearing force (Bexton *et al.*, 2012). The extremely neat edge to the wound strongly suggested the effects of a blade with a smooth edge, applied with considerable force, while the spiral shape of the wound is consistent with rotation about the longitudinal axis of the animal. The separation of a large section of the skin and blubber layer from the front of the carcass and avulsion of the shoulder blades in most cases was evidence of the application of a powerful lateral force pushing the body past a rotating blade.

By a process of elimination, the initial investigations concluded that the injuries were consistent with the seals being drawn through a ducted propeller such as a Kort nozzle or some types of Azimuth thrusters. No other mechanism with the required characteristics could be identified at any of the locations where these strandings were reported. Such systems are common to a wide range of ships including tugs, self-propelled barges and rigs, various types of offshore support vessels and research boats. All the other explanations of the injuries that have been proposed, including suggested Greenland shark predation (Lucas & Natanson, 2010) are difficult to reconcile with the actual observations and, based on the evidence to date, seem very unlikely to have been the cause of these mortalities.

6 Numbers of seals reported

6.1 Scotland

Seals with these spiral cuts have continued to wash ashore around the Scottish coast. In addition, various groups have re-examined their photographic records and identified spiral wounds on both grey and harbour seals at various locations around Scotland since 1985 (see section 6 below). Table 2 shows the annual records from Scotland of all seals assessed to have died of corkscrew injuries compiled by the Scottish Marine Animal Strandings scheme and SMRU.

Table 2. Numbers of seals with corkscrew wounds reported in Scotland (with some additional information from Northumberland).

Year	Grey seal	Harbour seal	Note
1985	-	2	
1998	-	1	
2004	2+*	-	* possibly up to 5 at Isle of May
2008	1	2	
2009	1	4	
2010	17*	9	*includes 2 from Northumberland
2011	13	7	
2012	14	7	
2013	8	7	
2014	6	8	*1 hooded seal and 1 seal of indeterminate species were also reported

The first definite examples were two harbour seals photographed in 1985 in Orkney. The almost total absence of reports between 1985 and 2003 and again from 2005-2007 is almost certainly due to under-reporting and/or misidentification of the cause of death.

To date (January 2015), a total of 127 seals with confirmed spiral injuries have been recorded in Scotland; 73 grey seals, 51 harbour seals, 1 hooded seal and 2 seals of indeterminate species. These numbers are minimum estimates and probably represent only a proportion of those animals killed close to shore, as not all the carcasses of all animals killed will come ashore, and not all will be found.

6.2 East Anglia

Eleven grey seals were discovered on the north Norfolk coast in the vicinity of Blakeney Point between October 2009 and March 2010. A total of 24 harbour seals and 5 unidentified seals (thought most likely to have been harbour seals based on their description), were found in the same area between April and September 2010. Two unidentified seals with similar injuries had also been reported at Blakeney in March 2009.

The mortality event in Norfolk received no new reports between early 2011 and winter 2012. Eleven weaned grey seal pups (5 female and 6 male) with spiral wounds were reported between January and March 2013 and confirmed by post mortem examination by RSPCA vets (Bexton pers. comm.).

6.3 Northern Ireland

Four confirmed cases (all identified as harbour seals) were reported in 2010, in and around Strangford Narrows. No new reports were received until 2013, at which point a further 2 harbour seals with spiral injuries stranded. The severed face and anterior sections of the skull of a freshly killed grey seal were trawled up from the entrance to Strangford Narrows in 2010, indicating that both species are/were probably being affected in the area.

6.4 SW Britain

The Marine Environmental Monitoring (MEM) and the UK Cetacean Strandings Investigation Programme (CSIP) publish annual reports on marine mammal strandings including seals from the Welsh coast. All seal strandings in recent years have been grey seals. Prior to 2011 only the dates, locations, species, sex and age of each occurrence was noted. However, in 2011 two photographs clearly showed head trauma and one was a typical spiral wound. In total one spiral and three head trauma cases (two with head removed) were recorded. However, the cause of death was not recorded for 91 out of the total of 95 seals reported to the end of 2011. The report authors plan to re-examine archived photographs to assess the level of such injuries in the recent past.

The Cornwall Wildlife Trust Marine Stranding Network record seal strandings in Cornwall and the Scilly Isles and identify cause of death where possible. Out of a total of 69 strandings in 2011, one weaned grey seal pup was photographed with injuries that were probably a spiral injury and one other weaned pup with face trauma was identified as a possible "boat strike."

6.5 Europe

In both Germany and the Netherlands there are intensive strandings reporting and necropsy programmes for all marine mammals. These are of particular relevance in that they cover the Wadden Sea and its associated water ways. Osinga *et al*. (2012) reported approximately 1300 strandings (both live and dead) of grey and harbour seals on the Dutch coast between 1979 and 2008; 379 of these animals were necropsied. Only 3% of the harbour seals (8 of 186) and 5% of grey seals (5 of 93) were identified as having died from trauma. Only one grey seal was identified as a likely victim of a propeller strike.

Siebert *et al*., (2007) necropsied 355 harbour seals found around the German coast between 1996 and 2005. Trauma identified as wounds to skin or fractures was observed in around 11% of seals, but was not necessarily the direct cause of death. Only one animal was identified as a possible victim of a ship's propeller on the basis of a 30cm slash wound.

The almost total absence of spiral seal injuries along the Dutch and German coasts is both interesting and somewhat puzzling.

6.6 Canada

Seals with similarly characteristic spiral injuries have been reported from Atlantic Canada for at least the last 15 years. For example, large numbers of grey, harbour and harp (*Pagophilus groenlandica*) seals with these types of injuries have washed ashore on Sable Island in Canada. Examination of sample photographs confirms that these injuries are the same as those observed in the UK. Researchers in Canada have attributed

the injuries to predation by Greenland sharks (*Somniosus microcephalus*) (Brodie & Beck, 1983; Lucas & Stobo, 2000). After a detailed examination of the published data and further discussion with seal and shark biologists it is apparent that there is no direct evidence to support this assertion. Since publication of the preliminary findings of the UK investigations in 2010, the shark predation theory has been rejected by other Canadian research groups with direct knowledge of the biology and feeding behaviour of Greenland sharks (www.geerg.ca/gshark_1.html#Prey and www.geerg.ca/edit_20101006.html).

Similar injuries were also seen on large numbers of juvenile harp seals and smaller numbers of hooded seals in a single mass stranding in the Gulf of St Lawrence in 1997. Approximately 1400 seal carcasses washed up along the shore of Prince Edward Island after the breakup of the ice on the seal breeding grounds (Daoust & Lucas, 1998). Approximately 1000 of these animals suffered wounds described as "either the head region or the cranial third or half of the body had lost some of, or all, its skin and blubber (sculp), the edges of the remaining portions of skin being very straight. Some carcasses had a complete circumferential cut/tear of the sculp around the body, with the entire cranial portion of the sculp missing. In others, the cranial portion of the sculp was in rags, but its repositioning over the carcass showed the cuts/tears to be in a spiral shape, sometimes going almost twice around the circumference of the body" (Daoust & Lucas, 1998). Similar mass strandings of spiral injured harp, hooded and grey seals occurred on Prince Edward Island in 2005 and on the west coast of Cape Breton Island in 2006. Again, examination of sample photographs of harp, hooded and grey seals confirms that these injuries were the same as those observed in the UK.

Although not yet confirmed, it appears that groups of juvenile grey seals with similar injuries stranded in Nova Scotia in 2009 and 2010.

6.7 Anecdotal and press reports

Several examples of probable spiral injuries have been reported, or posted on, social media web sites. In most cases it is not possible to confirm the identification, but there are likely examples from sites in the Pacific Northwest and North East coasts of the USA. However, it appears that such events are rare or at least unusual around the coast of North America with the exception of eastern Canada.

6.8 Conclusion

Seals showing these injuries are still being observed around Scotland and most likely around the rest of the UK. Reporting appears to be sporadic and efforts by SRUC and SMRU staff are currently underway to expand the reporting network in Scotland. It is likely, however, that seals are still being missed and that there has been under-reporting in the past so it is not possible to estimate the true scale of the problem.

It is clear that the problem is not new. Seals with these injuries have been seen since 1985 in Scotland and large scale mortality events have been happening in Canada since 1997.

The absence of any reports from East Anglia between the end of 2010 and early 2013 suggests that it was specific boat activity during 2010 that was the most probable cause and that all of the observed mortality may have been due to a small number of vessels.

The data from Wales are unclear, and it may be that significant numbers of such seals have been recorded. However, the data from Cornwall and from two major studies along the Dutch and German coasts suggest that there are few if any examples of spiral injuries in those areas. Given the large seal populations in the Wadden Sea and the large amounts of shipping activity there is a clear difference between the Wadden Sea and both Scottish and Canadian situations. This clearly requires further investigation.

7 Distribution

7.1 Scotland

7.1.1 Scotland wide distribution

Figure 3 shows the distribution of confirmed spiral seal strandings around Scotland. The majority of these were recorded since 2009. Two concentrations are apparent; one around the south east coast of Scotland (mainly comprising the area around the Tay and Eden estuaries and the coast of the Firth of Forth) and the other in Orkney.

Only four confirmed cases have been recorded in western Scotland and so far there have been no confirmed and only one likely case in Shetland.

The distribution of spiral injuries does not reflect the density of seals around Scotland nor does it clearly reflect the density of ship traffic. The concentration in certain areas means that there must be some particular set of circumstances leading to these mortality events or that the environmental conditions mean that the events are more likely to be observed in particular areas.

7.1.2 Seasonal distribution patterns

The distribution of spiral mortalities in south-east Scotland shows interesting and potentially informative seasonal and geographical patterns. Figures 4 and 6 show the records for the summer months (defined here as April to September). Summer recorded strandings between 2010 and 2012 were restricted to the coast north of Fife Ness and 95% of them were found north of St Andrews. In addition, over 95% of the recorded strandings were harbour seals. 58% of summer records for 2013-2014 were harbour seals.

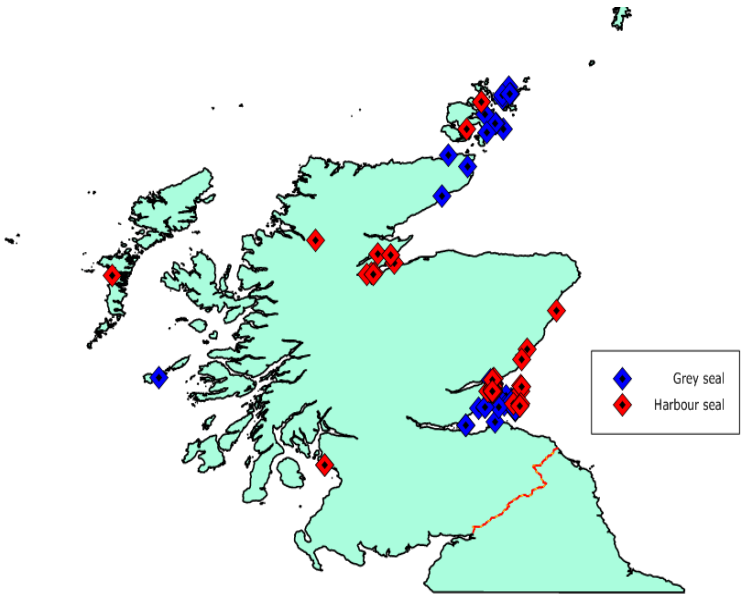

Figure 3. Distribution of all 80 recorded corkscrew seal recoveries in Scotland (all records from 1985 to 2014).

Figures 5 and 7 show the records for the winter months (defined here as October to March). Winter records were mainly in the Firth of Forth with only four records north of St Andrews and 93% south of Fife Ness, i.e. in the Firth of Forth. Only two spiral cut harbour seals have been recorded during the winter in south-east Scotland. Of the 38 grey seals found, 35 were juveniles, most within the first two months after weaning.

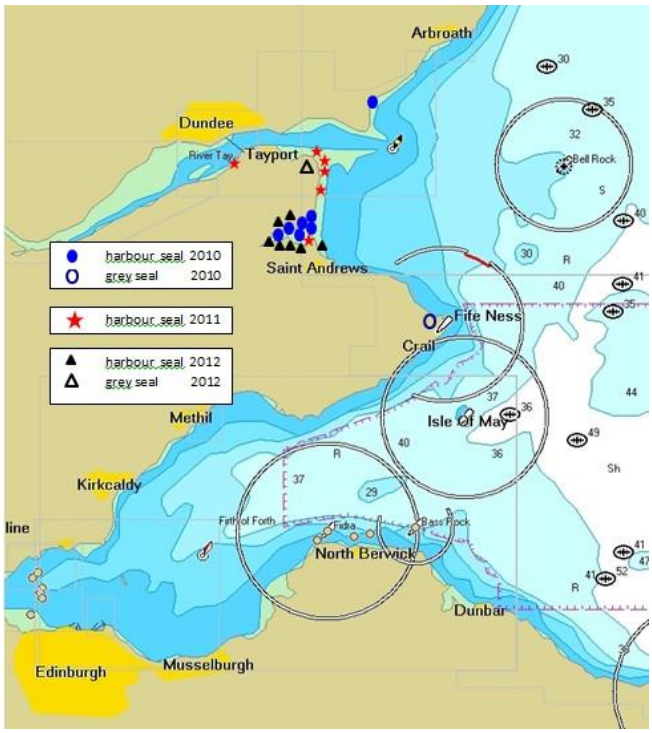

Figure 4. Distribution of spiral seal recoveries SE Scotland during summer (April to September) in 2010, 2011 & 2012. Twenty (>90%) were adult harbour seals, two were grey seals.

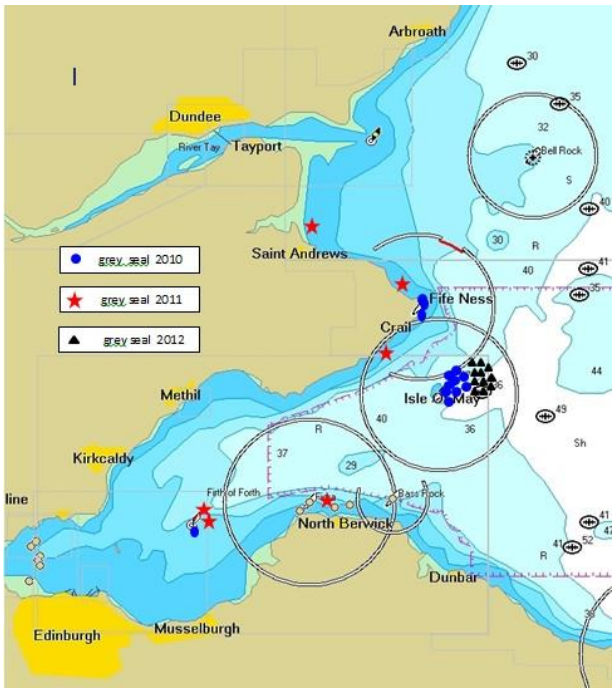

Figure 5. Distribution of spiral seal recoveries in SE Scotland during winter (October to March) in 2010, 2011 & 2012. All were grey seals, 26 juveniles and 4 adults.

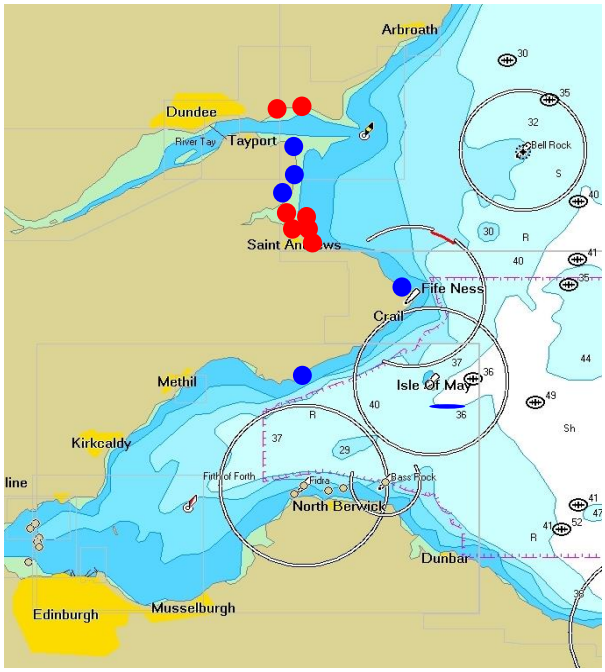

Figure 6. Distribution of spiral seal recoveries SE Scotland during summer (April to September) between 2013 and 2014. Seven were harbour seals and five were grey seals. Harbour seals locations are marked in red and grey seals in blue.

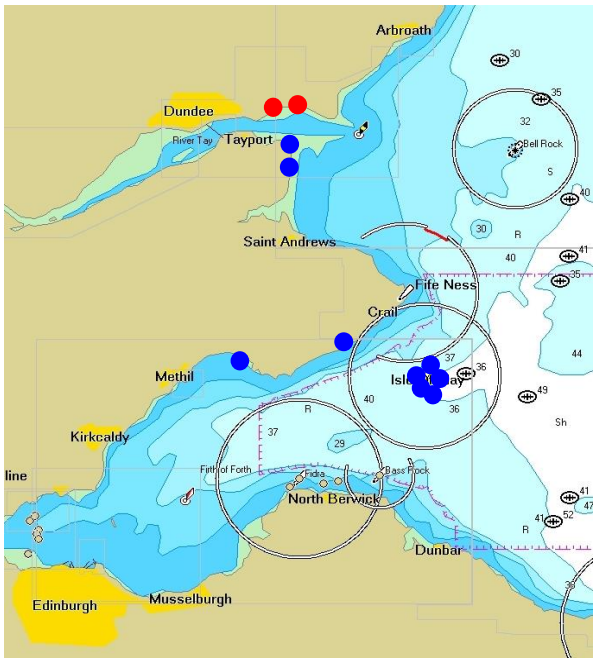

Figure 7. Distribution of spiral seal recoveries SE Scotland during winter (October to March) between 2013 and 2014. Two were harbour seals and nine were grey seals. Harbour seals locations are marked in red and grey seals in blue.

This seasonal and geographical pattern contains useful information. The preponderance of harbour seals in the summer and their concentration in and around St Andrews Bay may simply reflect the fact that harbour seal haul-out sites are located in the Eden estuary and the Firth of Tay. However, during the summer months

in 2009 to 2014 there were far more grey seals than harbour seals at the haul-out sites in the mouth of the Tay and in the Eden.

The prevalence of grey seals (mainly juveniles) during the winter months and their concentration in the vicinity of the Isle of May and the upper Firth of Forth probably reflects the arrival of large numbers of naïve, recently weaned grey seal pups from the large breeding colony at the Isle of May and the smaller colony on Inchkeith.

7.1.3 At sea locations of corkscrew injury events

An analysis of the tidal and wave induced surface current in north Norfolk was carried out by K.Pye Associates to assess the extent of the area within which the seals could feasibly have been killed. The times of stranding for two seals were known to within a few hours and they were thought to be relatively fresh kills. Results suggested that these two particular seals died within 5 km of the shore, somewhere between Scolt Head (20km west of Blakeney Point) and Weybourne (12km east of Blakeney Point) with the area between Holkham/Wells and Blakeney the most likely. Furthermore, as the Norfolk seal bodies have all washed ashore along a relatively small stretch of coast, it is reasonable to assume they may have died in the same general area in close proximity to the shore.

A detailed description of the analysis can be found in the full report (available from K.Pye@kpal.co.uk).

A similar analysis was conducted by STATOIL to determine the likelihood of seals drifting ashore from the Sheringham Shoals development site. Although the methods apparently differed, the conclusions were broadly similar, i.e. that seals washing ashore at Blakeney were probably killed close to shore and within a few kilometres of Blakeney Point.

7.2 Conclusion

The distribution of records of spiral injuries around Scotland, the UK and eastern Canada suggest that this is a widespread problem. The patchiness of the distribution may indicate either that the problem is due to particular local conditions and circumstances or that the opportunity to observe the results is due to those conditions. At present it is not possible to differentiate between these alternatives.

There is no simple direct mapping of spiral injuries to either seal population densities or ship traffic concentrations. The knowledge of the distribution of these events is limited. It is clear that records will be heavily biased towards seals that have been killed close to shore.

8 Mechanism of Injury

It has previously been argued that the most likely cause of death for the seals from the UK is injury associated with the seals being drawn through a ducted (or cowled) propeller, such as a fixed Kort or Rice nozzle or a ducted azimuth thruster (Thompson *et al*,. 2010; Bexton *et al.*, 2012).

The principal reasons for this conclusion are:

- The presence of a single, continuous, smooth edged cut appears to be the result of contact with a single blade. The absence of cut hair suggests that the blade was only sharp enough to cut the skin when applied with sufficient force but not razor sharp.
- To produce the spiral cut the seal must have rotated relative to the blade. Although a seal in contact with a large open propeller may rotate, it will also be thrown out laterally away from the centre. The multiple rotations of the spiral cut suggest that the carcasses were prevented from being thrown out. This is consistent with the propeller being in some form of duct or cowling. In such a situation the carcass would be expected to roll around the inside of the cowling while being drawn past the blade by the movement of water through the duct.
- The spacing and number of rotations of the cuts on the seals is consistent with the architecture of some ship drive systems. An adult harbour seal or juvenile grey seal can be approximated as a 0.4 m diameter by 1.6 m long cylinder. Drawing this through a cowling containing a 1.8m diameter propeller (i.e.

approximately the size of propeller likely to be fitted on a 1000kw thruster) with a pitch of 1.0 to 1.7 times the diameter would produce a cut that spiralled round the cylinder between 2.2 and 3.7 times along the length of the object. The successive cuts would be approximately 0.4 to 0.7 m apart (Pearce, *pers. comm.*). The force of water pushing the seal between the angled blades would be large, irresistible, and easily capable of forcing the skin/blubber layer off the underlying muscle and skeleton. The angle of the cuts is consistent with this architecture.

- The presence of patterns, matching the rope cutters that are present on some of these types of propeller systems, on the side of the head of several animals may also be indicative of them being drawn through propellers.
- Ducted propellers and azimuth thrusters are used for the dynamic positioning of vessels, towing and for general low speed manoeuvring where high thrust is needed at low speeds. These boats maintain their position by altering the speed and direction of their thrust. This can involve an almost stationary vessel repeatedly starting or reversing its rapidly rotating propellers, a situation that used to be relatively rare. This may increase the opportunities for animals to approach propellers and be drawn into them.
- Simple trials using model seals with a solid core and a soft plasticine blubber layer were reported in Thompson *et al*., (2010). These showed that the rotation of a propeller within a tunnel could produce wounds with some of the characteristics of a corkscrew injury. Those trials used a simple hand turned propeller and the model was pushed through the duct.

  Since then two additional and more realistic scale model trials have been carried out:

  1. A marine engineering propeller manufacturer (Voith Turbo) has conducted preliminary trials using engineering scale models of a ducted Azimuth pod drive and a model of a Voith Schneider propulsion system. Those trials used a simple, solid plasticine model of a seal. Trials showed that at some speeds and entry points the model passed through the propeller and rotated around the duct resulting in a spiral cut similar to those seen on the seals. Collisions with the Voith Schneider drive did not produce similar marks, producing one impact mark at the site of the initial contact.
  2. SMRU have constructed accurate scale models of both juvenile grey and adult harbour seals based on morphometrics taken from images of swimming seals. The models have been constructed in two parts, a semi rigid core made from paraffin wax and an outer layer of softer wax (cheese wax). The outer layer is again scaled to represent a realistic blubber thickness. The models are held in a 30˚C water bath to keep the "blubber layer" pliable. These have been passed through a 20cm diameter, 3 bladed propeller on a 5Hp electric motor inside an ABS tunnel. Over a range of rotation speeds these models passed through the propeller and received cuts that penetrated the "blubber layer" and peeled it away from the core.

SMRU are collaborating with Voith on a series of scale tests to confirm the range of sizes and speeds of ducted propellers that inflict these injuries on the models to assess the sizes of propellers likely to be involved in a real situation.

A comprehensive list of the more reasonable alternative mechanisms was presented in Thompson *et al*., (2010) (the list of alternative mechanisms and arguments for their exclusion are presented in Appendix 1 for information). The previous report concluded that none of these alternatives was able to inflict the injuries at all of the times and locations at which spiral seals had been observed. Despite the publication of a report ascribing the injuries in Canada to Greenland sharks, there do not seem to be any reasons to alter the conclusion that injuries were most likely inflicted by some sort of ducted propeller.

8.1 Conclusion

The pathology of these injuries suggests that they result from seals swimming into a fast spinning propeller inside some form of duct or cowling. The only such mechanisms that could have been present at all locations and times were ships propellers in something like a Kort nozzle or an azimuth pod drive.

9 Circumstances leading to injuries

Distributions of seals and shipping activity and the pattern of spiral seal strandings show that only a small proportion of potential fatal interactions actually occur. This suggests that under certain conditions the seals are responding inappropriately to some aspect of the operation of these devices.

The localisation in space and time of these events makes it unlikely that the seals are being hit as a result of random coming together of swimming animals and fast moving vessels. The concentration of carcasses in each locality suggests that the vessels must be either stationary or slow moving but operating their propellers, such as when using motors for dynamic positioning, towing or simply holding station in a current. If correct this suggests that some aspect of the operation of these devices is attracting the seals to within a danger zone from which they do not appear to be able to escape, or do not try to escape.

At present it is not known what the attraction is. Two possible mechanisms would be; 1) attraction to concentrations of food associated with the vessel, or 2) an inappropriate response to an acoustic signal from the motor/ship/propeller. The pattern of mortality in the summer in the Tay and Eden area suggests that food concentration is not the main attraction. To date nearly all the seals killed in summer are harbour seals but the local haul-out sites contain far greater numbers of grey seals than harbour seals. As they have similar diets it would be expected that both species exploit such a food source. Therefore, if prey concentrations were the main attraction it would be expected that large numbers of grey seals would be killed in that area at that time.

An acoustic cue is suggested by the fact that almost all of the seals killed during summer month have been harbour seals, which are thought to be attracted by underwater calls of breeding males.

Juvenile grey seals, which are the main victims during winter months in Scotland and Norfolk, have also been shown to be attracted by conspecific calls with a pulsing rhythmic pattern. Again it may be that grey seal juveniles are responding inappropriately to an innate attraction to such sounds.

9.1 Conclusion

The pathology of the injuries, e.g. the initial impact point always being on the face of the seal suggests that they are voluntarily approaching to within a short distance of active propellers without taking any avoiding action. This clearly suggests that there is some form of inappropriate attraction to operating ducted propellers. The seasonal, geographical and species composition patterns of the recorded spiral injured seals suggests that they are likely to be the result of interactions with slowly manoeuvring or stationary vessels and that prey concentration is unlikely to be the main attraction. By a process of elimination the most likely attraction would seem to be some aspect of the acoustic output of the device.

10 Population Consequences

10.1 Tay and Eden harbour seal population

In St Andrews Bay and the Firth of Tay the harbour seal population has declined dramatically over the past decade. The causal factors for this decline are not known, but the current level of observed spiral mortality is unsustainable in this area. If, as expected, only a small proportion of the spiral casualties are being recorded then it is possible that this has been the major factor in the dramatic decline in the Tay & Eden harbour seal population. Lonergan & Thompson (2010- Report to SNH under Advice section of MMSS/001/11) used simple models to examine the recent declines in the numbers of harbour seals counted in the Firth of Tay and Eden Estuary Special Area of Conservation (SAC). These suggest that the continuation of current trends would result in the species disappearing from this area within the next 20 years. The rate of decrease indicates that whatever the cause of decline it must be reducing adult survival. The corkscrew seal deaths were primarily adult females between 2009 and 2014.

The results of studies in Canada indicated that the observed mortality due to such spiral wounds, and the bias towards adult females in the observed mortality, was sufficient to explain the decline in the Sable Island

harbour seal population. Pup production in that population declined from around 600 pups per annum to around 40 pups per annum over an eight year period 1989 to 1997 (Lucas & Stobo, 2000).

10.2 Wider population effects

The relatively small numbers of spiral cut seals found elsewhere would be unlikely to have a significant impact on large seal populations. However, there is no way of estimating what proportion of the casualties are being seen and it is highly unlikely that all the mortalities are being recorded.

The full extent of the problem is not known. Particular carcasses may be recorded because they were struck under a set of conditions that allowed them to wash ashore and be recorded. It is not known if these conditions are necessary for the mortality to occur or just that the particular conditions mean that a small proportion of the results of what may be a more widespread, but generally unobserved, occurrence are being seen. If it is the former, then the problem may be a local phenomenon with limited population scale consequences. However, it is known that only a small proportion of the seals that die each year in UK waters are washed ashore and reported. The probability of observing a seal that dies at sea is therefore low. It cannot be ruled out that these stranded carcasses represent fortuitous observations of a more general and widespread process.

The problem may extend to other marine mammal species. Harbour porpoises (*Phocoena phocoena*) exhibiting large lacerations have stranded around the UK and southern North Sea in recent years. In the light of the seal strandings, photographic records of these harbour porpoise strandings are being re-examined.

10.3 Conclusion

It is likely that the spiral seal mortalities observed in south-east Scotland have to some extent contributed to the decline of the Tay and Eden SAC population of harbour seals. The current observed level of mortality is unsustainable and is likely to be an under-estimate of the total being killed.

We do not have sufficient information to be able to estimate the mortality rates due to this mechanism in any population, but evidence from Sable Island in Canada suggests that a small number of vessels may be able to have a large impact on relatively large harbour seal populations.

11 Data Gaps and Future Research

The following is a list of research topics/data gaps that need to be addressed before appropriate management or mitigation strategies can be developed.

There are a large number of potential research questions and it is important to prioritise the issues and concentrate on those which are most likely to provide useful information. There are four distinct but interrelated aspects to the problem that need further investigation. For each of these aspects the main questions are presented and a specific work programme is suggested:

1. **Assessing the scale and extent of the problem**
   - **a. Determine the true geographical extent and intensity of the problem,**
     - i. All seal carcasses washed ashore in Scotland should be examined for signs of these wounds. Where possible wounds should be documented and photographed and where appropriate and practicable the carcasses should be collected and necropsied. The Scottish Marine Animal Strandings Scheme (SMASS) is working on this task in Scotland, and SRUC and SMRU staff are attempting to extend the seal reporting effort of the strandings network.
     - ii. A retrospective analysis of photographic records of seal strandings should be undertaken wherever such data exist. Within Scotland this is happening under USD5 of MMSS/001/11 and discussions with other strandings groups are continuing.
   - **b. Characterise the geographical, biological and oceanographic features of the locations where it occurs.**
     - i. An in-depth analysis of wind, wave and tidal current induced movements of carcasses, should be completed for specific strandings of confirmed spiral wounds where one or more of the following is true:

- Carcasses are concentrated in a small area.
- Time since death can be estimated to within a small time window.
- There is a reasonable chance of identifying vessels in the area.

ii. Information on the distributions of seal haulouts and foraging patterns, bathymetry and boat/industrial usage characteristics should be compared across sites to identify common features, and an analysis of ship and seal distributions at sea should be conducted to identify areas of high risk. Work under MR5 of the MMSS/001/11 project will address this issue.

c. Assess the intensity of the problem, i.e. assess the number of animals involved

i. Methods for estimating the intensity of the problem will be developed in light of information from a & b above.

ii. One potential method of estimating the scale of the problem is to monitor the propeller outwash on a number of vessels to detect such events. Cameras on propellers would be expensive and difficult to install/maintain but observations or video recordings from the decks of suitable vessels may be feasible. The infrequent nature of these events means that a large and expensive effort would be required to produce useful data. At present it is not clear that these events would produce any useable visual signal. Trials with specially prepared, fresh seal carcasses and ducted propellers could be conducted to characterise the visual cues available when seals pass through ducted propellers to assess the feasibility of such a monitoring project.

2. Identifying and then testing the most likely causal mechanisms.

These topics are currently being investigated as part of MMSS/001/11.

a. Use literature, expert advice and presence/absence to identify candidate mechanisms

i. Continue the current investigations and expand the network of researchers/engineers contributing information and suggestions.

b. Test the candidate mechanism

i. Scale models of seals (using appropriate materials) should be tested in scale models of ducted propellers and other candidate mechanisms of injury. A series of such trials is currently underway with a propeller manufacturer. The results will allow permit determination of what further work will be required.

ii. If the results of scale model trials indicate that they are necessary, full scale carcass tests should be carried out on those mechanisms identified by scale tests. These mechanisms are expected to be ship propellers in the first instance. Availability of suitable seal carcasses in good condition will be a major restriction on such a study.

c. Use ship and industry records to identify specific devices where possible.

i. Use AIS ship tracking software, costal and port radar services and shipping /offshore industry records to determine the locations and operation patterns of vessels with candidate mechanisms for comparison with estimated locations of spiral events wherever and whenever suitable strandings occur (see 1bi above).

3. Determining the conditions under which the mechanisms become lethal to seals

The most likely attractive mechanism is some form of acoustic cue or perhaps less likely attraction to concentrations of prey associated with boats. Topic **a**. is currently being investigated as part of MMSS/001/11.

a. Characterise the acoustic signatures of the potential causal mechanisms

i. Collaborate with industry to obtain a comprehensive set of recordings of acoustic signals from candidate mechanisms identified above.

ii. Use a combination of captive animal studies and tests on wild free ranging seals to identify which if any of these signals are strongly attractive to seals.

b. Collaborate with fisheries scientists and technologists to determine the likelihood that specific mechanisms or the vessels themselves may act as fish concentration devices.

4. Identifying and testing potential mitigation measures.

It would be premature to suggest the development of specific mitigation measures before the research projects detailed above have identified the causal mechanism and the conditions under which these events

become more likely. However, it is essential that appropriate actions are taken as soon as sufficient information is available. This will be taken forward under USD7 of MMSS/001/11.

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13 Appendices

Appendix 1

13.1 Alternative explanations of the injuries

A large number of alternative mechanisms have been suggested by other research groups and the general public. All of these have been considered at length. In response to the wide public and press interest in some of these alternatives are presented them along with a brief explanation as to why it is not thought that they are the causal mechanism in this situation.

13.1.1 Deliberate killing

- The cuts would have been very difficult to inflict manually. Necropsy results indicate that the seals were killed by the cuts, but it would be extraordinarily difficult to produce the single smooth edge cut by hand even on a dead seal and completely impossible on a conscious live animal. The force required to cut the skin with a blade that was not sufficiently sharp to also cut the hair would be well beyond the force that could be applied by a person or even a group of people working together. The consistent nature of the injuries also suggests that those carrying out the cutting would need to have been highly practised.
- One recurring suggestion has been the existence of purpose built traps/underwater snares. Noting that such traps have not been found and are not known to exist, the mechanism of injury requires that any such device would need to be large, robust and contain a mechanically driven blade of some sort. It is hard to see how such a device could be built, deployed and operated in St Andrews Bay without being observed or detected. There is no evidence for such a device ever having been constructed or deployed anywhere. The simultaneous and secret deployment of similar devices in eastern Scotland, eastern England, Northern Ireland and Sable Island in Canada seems extremely unlikely.

13.1.2 Fishing activity

- Fish lift/pump systems are used on large pelagic trawlers and seine net boats. These are known to have killed seals in the past by sucking them up into the pump mechanism. Extensive discussion with fisheries technologists, local fishery officers and coast guards confirmed that there were no large-scale fishing operations in the inshore areas within 10 to 15 km of either Blakeney or St Andrews Bay.
- Long line fishing was highlighted as a potential source of spiral cuts. In order to cause such an injury, a line would need to wrap around the seal and then be pulled tight enough to cut through the skin. The suggested mechanism involved the seal taking the bait or a caught fish and itself becoming caught on the hook.
    - The consistency of the wound is unlikely to result from such a random event.
    - There were no apparent points where the blade cut deeper. A spiral line drawn tight might be expected to "bite" at certain points and produce cuts of different depth. Hooks are designed to grip rather than cut, and so would seem unlikely to produce clean cuts.
    - There are no long-line fisheries near St Andrews Bay and no long-line fisheries near Blakeney were identified.
    - There was no evidence of fishing line in any of the wounds.
- Dredging for shellfish
    - Shell fish dredging is practised in Norfolk, occasionally off St Andrews and around Sable Island. However, the gear employed does not contain any mechanism capable of producing the consistent spiral cut wounds.
- Fishermen cutting seals from nets.
    - This is not feasible given the consistency and the smooth continuous nature of the wound.

- Repeated references to fishermen removing seals heads and/or slicing them around the body to get them out of nets do not make sense. Such cuts would not help remove nets and would be extremely messy in terms of blood and oil discharge.
- The absence of any large scale fishing operations in the fishery exclusion zone around St Andrews Bay and close to Blakeney means that there is no supporting evidence from the localities in which most of the dead seal have been found.

13.1.3 Self-inflicted injury during escape attempts

- Suggestions that seals are spinning in attempts to escape and cutting themselves on a blade are not feasible given the consistency and severity of the injuries. For example the two juvenile harbour seals in St Andrews Bay in 2009 suffered instantaneous, massive head trauma that was immediately fatal. All carcasses show that the body was dragged past a blade with sufficient force to remove the blubber and skin from underlying tissue. It would be impossible for a seal to maintain the swimming actions needed to inflict such an injury on itself.

13.1.4 Water Extraction and Dredging

- There are no known fixed mechanical devices with rotating parts large enough to cause these injuries in either area and no dredging activity other than simple bucket dredging in the Tay and Wells harbours. Bucket dredges do not involve the use of any rotating devices other than the ship propellers on the dredgers themselves.

13.2 Predators

13.2.1 Killer whales

- Killer whales do not possess cutting teeth capable of inflicting cuts like those observed.
- Tearing seals apart would not produce the consistent spiral wounds observed in all seals.
- Although occasionally seen off the Fife coast, killer whales do not occur frequently enough in either St Andrews Bay or off north Norfolk to be responsible for even a small fraction of the seals found.

13.2.2 Greenland sharks

- There has been extensive speculation in the media that the spiral cuts are the result of predation by Greenland sharks. This stems from reports from Sable Island where the similar laceration injuries occurred and researchers have suggested that they are inflicted by Greenland sharks. There does not appear to be any direct evidence from Sable Island that Greenland sharks are the principal cause of spiral lacerations to seals. It is highly unlikely that shark predation is not the cause of these wounds in the UK and there is scepticism over a connection to Greenland sharks in the Canadian case.
- The wounds observed in the UK are inconsistent with shark predation. It is a single smooth edged continuous cut. Although a smooth edged cut can be produced by the small cutting teeth in the lower jaw of a Greenland shark there is no indication that they are capable of producing a continuous spiral cut. There is no evidence at all that Greenland shark bites produce such wounds on carcasses of seals and no plausible mechanism for them to inflict such wounds. An alternative suggestion that Greenland sharks tear the skin by biting the faces of seals and then thrashing or spinning around is inconsistent with the wounds on UK seals (it requires that the razor sharp slicing teeth leave no marks during the violent thrashing) and implausible (the wounds are identical and clearly caused by a blade cutting in from the outside, in one seal at Blakeney the end of a fore flipper in line with the cut was crushed and cut). It is also noted that there is no direct observation of Greenland sharks involved in this behaviour. No evidence has been found to support the argument that the spiral tear results from some regular lattice structure in the collagen fibres of the skin and blubber in seals as suggested by some Canadian researchers.
- There are no known observations of Greenland sharks in inshore waters in the UK. They are primarily a cold water species and are thought to move into shallower waters in winter. They are not known in the shallow, relatively warm waters of the southern North Sea in July and August.

- There is no explanation for why any predator would kill large numbers of seals without eating any part of any of the carcasses. Video footage of Greenland sharks clearly shows them removing and swallowing large sections of skin, blubber and muscle from scavenged seal carcasses.
- The shark hypothesis at Sable Island was proposed in part because of a perception that there were few boats in the surrounding area. However, this is not consistent with the construction, continued development and operation of an extensive network of gas rigs in the coastal waters off Sable Island, e.g. one rig is only 5km from the island's shore. The development and maintenance of such an industry will have involved a wide range of shipping activity. The presence of these types of vessels appears to be a common feature of the UK and Canadian experiences of spiral cuts to seals.

1.1 Tidal turbines

- Spinning blades on tidal turbines were suggested as likely culprits. They cannot be responsible for any of the seal mortalities on the Scottish or English east coasts because there are no tidal turbines in those regions. The closest operating devices are in the inner channels of the northern Orkney Islands, several hundred miles from the locations at which the, freshly killed, carcasses have been discovered.

1.2 Military activities

- The presence of submarines in the shallow water off Norfolk and within St Andrews Bay is very unlikely. For obvious reasons submarine do not operate normally within shallow waters and the regions concerned are not recognised naval exercise areas.