

# Investigation into the long-finned pilot whale (*Globicephala melas*) mass stranding event, Tolsta, Isle of Lewis, July 2023

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Compiled by the [Scottish Marine Animal Stranding Scheme](#)  
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## Executive summary

Long-finned pilot whales (*Globicephala melas*) demonstrate among the highest stranding frequencies observed globally. This species exhibits pronounced social cohesion and matrilineal structure that are thought to predispose populations to collective stranding, though proximate causal factors often remain elusive. These events, often involving substantial numbers of individuals, can generate considerable public and media attention and inquiry into underlying causative mechanisms. They also offer invaluable research opportunities for studying an otherwise elusive deep-water cetacean species.

Two large-scale strandings of long-finned pilot whales occurred in Scottish waters during 2023 and 2024, presenting the opportunity for a multidisciplinary investigation. This report details the comprehensive analysis into the mass stranding event (MSE) of long-finned pilot whales that occurred in Tolsta Bay, Isle of Lewis, Scotland, on 16 July 2023.

Necropsy examinations indicated good overall health of all individuals, with good nutritional condition despite no indication of recent feeding. Microbiological and histological analysis indicated no major underlying diseases. No viral infections were identified, bacterial infections, where isolated, were considered likely to be incidental and parasitic burden was considered to be within normal limits for this species. There was indication of elevated heavy metal contamination in several individuals although the biological significance is unclear and it is considered unlikely this contributed directly to the stranding event. No algal toxins were detected.

Environmental factors were investigated, including wind, tide and bathymetric aspects. The shallow, steeply shelving nature of the bay, potentially combined with onshore winds present during the stranding event, was identified as having had a potential role in hindering the pod's navigation. This species usually occurs in deep, offshore and shelf edge waters and have been rarely reported in the inshore waters of the Northern Minch as evidenced by the scarcity of previous visual sightings records from the region. Their presence in this region was a highly unusual occurrence.

The presence of dystocia - a difficult birth typically caused by a large or poorly positioned calf - in a mature female was noted and suggests a possible social trigger for the stranding. Strong social cohesion may have then led the entire group to follow the distressed individual into shallow waters. Once stranded, the animals were unable to refloat themselves due to a combination of surf generated by onshore winds and the soft sand substrate on the beach. Drowning was determined as the primary cause of mortality for many of the stranded animals.

Long-finned pilot whales are highly social animals, and behavioural responses to disturbance, whether natural (e.g., predators) or anthropogenic (e.g., vessels, underwater noise) are well documented in this species. Consequently, the potential role of other factors, including underwater noise were considered in this investigation. A full analysis of impulsive and continuous noise data collected from hydrophones deployed near the stranding site to assess the presence of cetaceans

around the time of the event and potential anthropogenic sound sources has been published and is summarised in the [pilot whale stranding acoustic analysis report](#).

This investigation emphasises the importance and value of taking an integrated ecological approach, integrating health assessments, infectious disease screening, toxicological and environmental data analysis, and social behaviour considerations. Data produced by this investigation will improve our understanding of potential factors that could influence pilot whale strandings and inform pilot whale ecology.

## Acknowledgements

This investigation, supported by Marine Directorate, Scottish Government, Defra through the Healthy and Biologically Diverse Seas Evidence group and the Joint Nature Conservation Committee, involved collaborative networks spanning the Universities of Aberdeen, St Andrews, Heriot-Watt, and the Scottish Universities Environmental Research Centre.

Undertaking necropsies on this number of animals was logistically challenging, time critical and was only made possible due to the significant help and support provided by a large number of people from the Western Isles community, SMASS volunteers and collaborators and colleagues from the UK and the international marine science community. Expert pathology and necropsy input was provided by teams from the Dutch (University of Utrecht) and England and Wales (CSIP) stranding networks and the depth and breadth of necropsy examinations undertaken were only possible due to Lonneke IJsseldijk, Rob Deaville and Simon Spiro offering essential assistance to this phase of the investigation. Manuel Fuentes Veterinary Diagnostic Services Unit at the University of Glasgow for undertaking the bacteriological investigation. Mara Rocchi, Moredun Research Institute for undertaking morbillivirus investigations.

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## Section 1: Background and context

A mass stranding event (MSE) is described as ‘a stranding event involving two or more cetaceans of the same species, other than a mother and calf, stranding at the same time and place’ (IWC, 2016).

On 16 July 2023 one of the UK’s largest fatal mass stranding for decades, comprising 55 long-finned pilot whales (LFPW) (*Globicephala melas*) occurred on Traigh Mhòr beach, North Tolsta, Isle of Lewis.

The first report from a member of the public was made, via Police Scotland, at around 07:00 to British Divers Marine Life Rescue (BDMLR). The initial report indicated approximately 55 dead animals, including both adults and calves, however, it was subsequently confirmed that 15 of these animals were still alive.

The live animal stranding response was hampered by Tosta's remote location, creating logistical challenges including poor or absent mobile phone communication, difficult vehicle and personnel access and equipment and transport limitations. Poor weather conditions with heavy rain and strong winds further compromised operations, making human safety the overriding priority throughout the incident and ultimately limiting rescue options for the stranded animals. Only one of the 55 animals was successfully refloated and the remainder either died or were euthanised on welfare grounds.

Long-finned pilot whales are an offshore (pelagic) dolphin species known to form matrilineal pods with strong intergenerational bonds and strong social cohesion. This species is known to mass strand; in some cases, such events can involve many hundreds of animals. This MSE offered an opportunity to explore questions of disease prevalence, feeding ecology and contaminant burdens within a large group of animals with a shared recent history. Such data can help inform an understanding of potential factors leading to the stranding and wider questions of ecology and human impact on this species.

This report presents the pathological findings of the investigation and examines broader ecological factors to identify probable causal drivers of the event. More detailed data on specific ecological and life history aspects will be published in due course through the peer review process.

## Section 2: Investigation outline

With 54 deceased animals, this MSE was the third largest recorded mass stranding event in the UK behind a subsequent long finned pilot whale MSE in Sanday, Orkney in July 2024 involving 77 animals and a false killer whale stranding event involving 130+ animals almost a century earlier in 1927 in the Dornoch Firth<sup>1</sup>.

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<sup>1</sup> [Natural History Museum: 104 years of collecting whales](#)

The reasons as to why cetaceans mass strand are complex, multifactorial and species- and location-specific. Any investigation into possible causal factors that, in isolation or in combination, led to the stranding therefore needs to cover several key components. In this situation, the investigation aimed to address the following questions: why was this typically pelagic species found close to shore, what factors might have led them to strand, and what can be inferred about their ecology and life prior to the stranding? This investigation sought to assess the disease status of the stranded animals and attempt to identify any processes that may have contributed to this specific stranding. The necropsies undertaken have helped identify potential underlying health issues and external injuries, and information derived from gross necropsy has been supported by diagnostic testing to identify or exclude known pathogens and disease processes known to impact these species.

The analysis encompassed a comprehensive suite of techniques; diagnostic necropsies supported by histopathological, toxicological, and microbiological analysis; environmental data analysis (sea currents, weather, geomorphology); dietary analysis (stomach contents, fatty acid and stable isotope studies) and genetic analysis.

Comprehensive sampling of all stranded individuals, including maternal and foetal tissues, enabled population level analyses of health parameters, contaminant loads, dietary ecology, and metabolic profiles that would be otherwise impossible to obtain from free-ranging animals. These data represent a baseline for understanding both the proximate causes of this mass stranding event and the broader physiological status of a species that remains largely inaccessible to sampling due to its offshore distribution.

Long-finned pilot whales rely on complex vocalisations, utilising clicks and whistles for communication, echolocation, and social cohesion. The potential for anthropogenic noise to disrupt, disorient, or injure cetaceans is well-documented (Harding and Cousins 2022; Weilgart 2007; Richardson et al., (1998) 2013; B. L. Southall et al., 2007). [A separate report on analysis into continuous and impulsive noise sources in the area has been published.](#)



Figure 1: Map of stranding location, Isle of Lewis, UK (inset shown in red).

### Section 3: Overview of stranding event

On 16 July 2023, a mass stranding of long-finned pilot whales occurred at Tolsta beach on the Isle of Lewis (Fig 1 & 2). The incident was first reported to BDMLR as "a pod of several dolphins," but when the first medic arrived, they discovered a group of pilot whales with only 15 still alive among a larger number of dead animals. The stranding presented numerous challenges including poor weather conditions with heavy surf, a receding tide, difficult vehicle access, limited mobile coverage, and soft sand that made logistics difficult.

Cetacean mass stranding events (MSEs) represent extreme, time-critical situations where public safety, animal welfare, and scientific research priorities must be clearly defined and managed under a constant pressure of emergency.

Rescue teams arrived around 08:40 to find animals scattered along the shoreline. BDMLR medics supported by Stornoway Coastguard, Fire and Rescue Services, Police, SMASS staff and local volunteers began the task of triaging live animals and implementing emergency care protocols. This involved, where possible, putting animals in mid sternal recumbency (upright), and utilising wet, pale coloured towels and sheets to cover the skin to prevent dehydration and overheating. This was possible for all but one animal (M371.44/23) which was too large and heavy to move.

Refloating attempts were considered for two male pilot whales (M371.55/23 and M371.54/23) based on size and the assumption that juvenile males have a higher likelihood of rejoining other groups at sea. One animal (M371.55/23) was successfully refloated, swimming strongly seaward and surfacing multiple times at increasing distances from shore. However, the second animal (M371.54/23) immediately re-stranded despite rescue efforts. Attempts to refloat additional animals were abandoned due to their size and the limited personnel available under increasingly dangerous sea conditions.

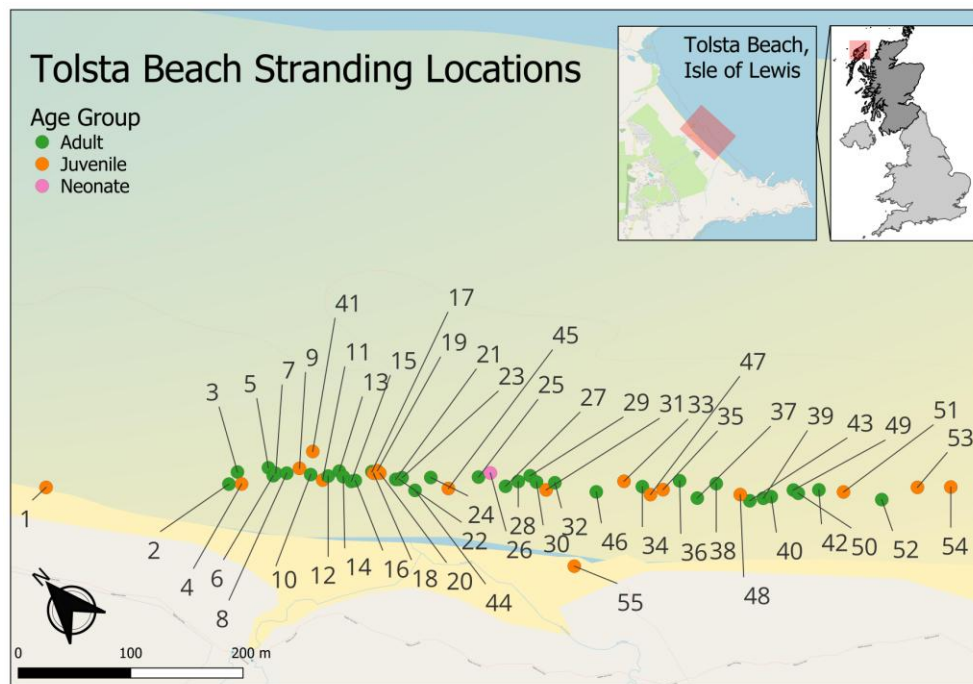


Figure 2: Stranding location of individual animals on Tolsta beach.

By 11:00 the coastguard terminated all refloat attempts due to worsening weather and unsafe water conditions for rescue personnel. The decision to euthanise the remaining live animals was reached through multi-agency consultation at 13:00, involving the local veterinarian, SMASS team, coastguard, BDMLR volunteers, and fire brigade. This decision was based on the impossibility of further rescue attempts given the deteriorating environmental conditions, the animals' compromised condition after prolonged stranding, and human safety. The veterinarian arrived at 14:15 to carry out the euthanasia procedures, with protocols established for volunteer safety and immediate postmortem sampling. The 12 whales that were still alive were euthanised by a local veterinarian using a modified .308 calibre rifle.

All euthanised animals were measured and sampled for skin, blubber, and muscle the same day of stranding, and arrangements made with Western Isles Environmental Health teams to have all carcasses recovered the following day to the Stornoway landfill site for examination and disposal. Data and tissue samples were collected from all animals and between 17 and 21 July, the SMASS team and collaborators examined all cases and undertook a complete diagnostic necropsy on a subset of 23 cases.

#### Section 4: Stranding group composition

The mass stranding event involved animals from all sex and age classes (six adult males, 30 adult females with six pregnant and nine recently post-partum, 11 juvenile males, seven juvenile females, and one newborn calf). "Juvenile" here refers to sexually immature animals, including those dependent on mothers and those nearing

sexual maturity. An overview of the age, sex and reproductive status of the animals is given in Figure 3 and Tables 1 & 2.

The individuals exhibited a range of reproductive states. In total, 12 females were in a "resting" state, likely recovering from the energetic demands of gestation and lactation. Three non-pregnant lactating females may have been nursing a calf at the time of stranding. The six pregnant females showed varying stages of pregnancy ranging from a full-grown foetus at birth length (210cm) presenting as a suspected dystocia (difficult birth, typically caused by a large or awkwardly positioned foetus), to early-stage embryo (< 2cm long). Nine females showed signs of recent birth and were lactating. Three pregnant females were also lactating, suggesting recent conception and potential weaning of a previous calf. Age and kinship analysis is detailed in Figure 3 and Tables 1 & 2.

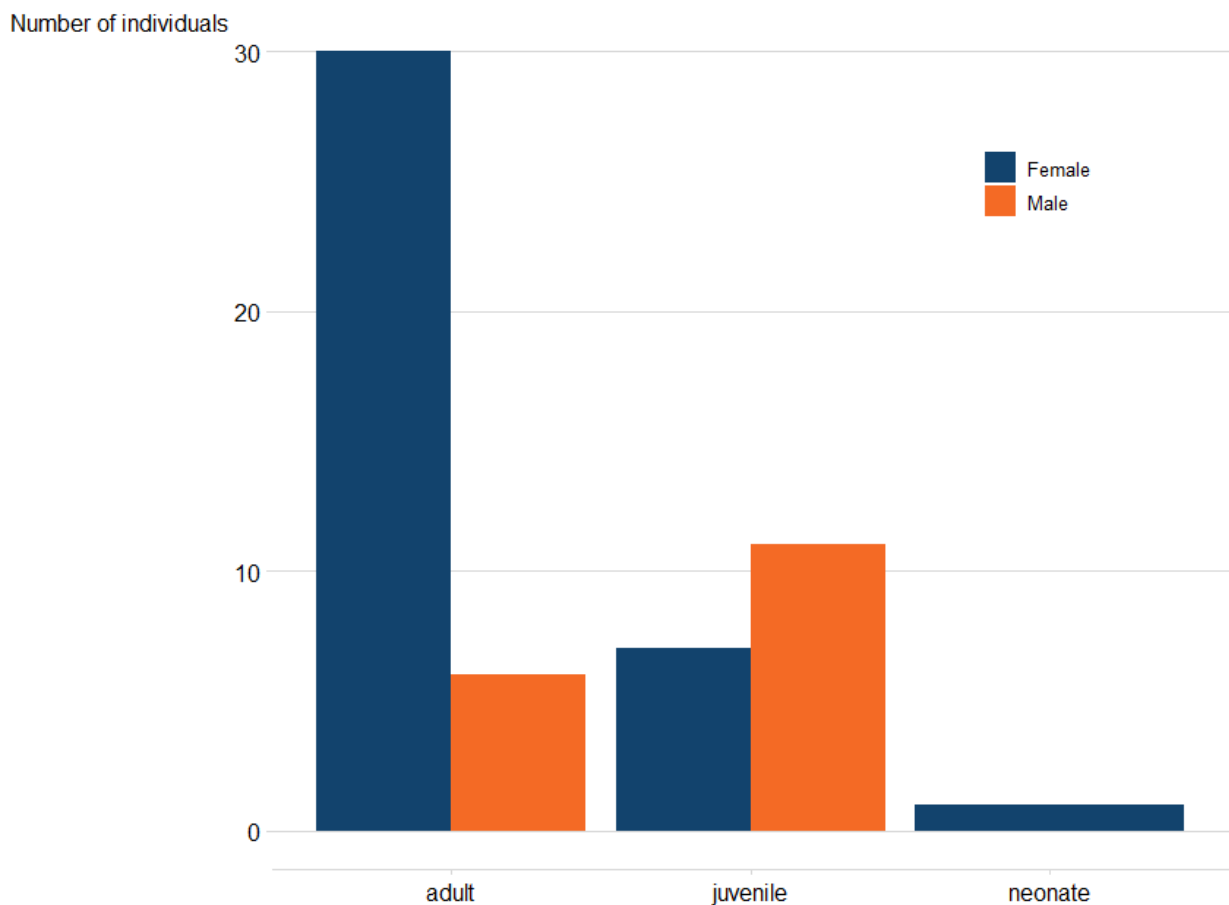


Figure 3: Summary overview of age group and sex of the 2023 MSE of long-finned pilot whales.

Table 1: Age and sex distribution of the 2023 MSE of long-finned pilot whales not including the refloated animal.

<b>Age/Sex</b>	<b>Adult</b>	<b>Adult %</b>	<b>Juvenile</b>	<b>Juv %</b>	<b>Calf</b>	<b>Total</b>
<b>Female</b>	30	73%	7	54%	1	38
<b>Male</b>	11	27%	6	46%	0	17
<b>Total</b>	41	-	13	-	1	55

Table 2: Demographics of the 55 animals involved in the mass stranding event.

<b>M reference</b>	<b>Age class</b>	<b>Sex</b>	<b>Length (cm)</b>	<b>Sexual maturity (Y/N)</b>	<b>Pregnancy status</b>	<b>Lactating</b>
M371.2/23	Adult	F	415	Yes	Not pregnant	No
M371.3/23	Adult	F	406	Yes	Not pregnant	No
M371.5/23	Adult	F	390	Yes	Not pregnant	No
M371.7/23	Adult	F	391	Yes	Not pregnant	No
M371.12/23	Adult	F	365	Yes	Not pregnant	No
M371.14/23	Adult	F	396	Yes	Not pregnant	No
M371.16/23	Adult	F	385	Yes	Not pregnant	No
M371.17/23	Adult	F	426	Yes	Not pregnant	No
M371.21/23	Adult	F	350	Yes	Not pregnant	Yes
M371.24/23	Adult	F	419	Yes	Not pregnant	No
M371.29/23	Adult	F	400	Yes	Not pregnant	No
M371.30/23	Adult	F	390	Yes	Not pregnant	No
M371.34/23	Adult	F	375	Yes	Not pregnant	Yes
M371.37/23	Adult	F	410	Yes	Not pregnant	No
M371.49/23	Adult	F	384	Yes	Not pregnant	Yes
M371.22/23	Adult	F	376	Yes	Pregnant	Yes
M371.27/23	Adult	F	444	Yes	Pregnant	Yes

M371.39/23	Adult	F	426	Yes	Pregnant	No
M371.40/23	Adult	F	450	Yes	Pregnant	Yes
M371.42/23	Adult	F	374	Yes	Pregnant	No
M371.43/23	Adult	F	399	Yes	Pregnant	No
M371.13/23	Adult	F	430	Yes	Recent parturition	Yes
M371.15/23	Adult	F	472	Yes	Recent parturition	Yes
M371.25/23	Adult	F	447	Yes	Recent parturition	Yes
M371.32/23	Adult	F	404	Yes	Recent parturition	Yes
M371.36/23	Adult	F	398	Yes	Recent parturition	Yes
M371.38/23	Adult	F	400	Yes	Recent parturition	Yes
M371.46/23	Adult	F	423	Yes	Recent parturition	Yes
M371.50/23	Adult	F	425	Yes	Recent parturition	Yes
M371.52/23	Adult	F	415	Yes	Recent parturition	Yes
M371.1/23	Juvenile	F	300	No	Not pregnant	-
M371.18/23	Juvenile	F	233	No	Not pregnant	-
M371.33/23	Juvenile	F	258	No	Not pregnant	-
M371.35/23	Juvenile	F	360	No	Not pregnant	-
M371.41/23	Juvenile	F	277	No	Not pregnant	-
M371.48/23	Juvenile	F	293	No	Not pregnant	-
M371.53/23	Juvenile	F	226	No	Not pregnant	-
M371.26/23	Neonate	F	175	No	Not pregnant	--
M371.6/23	Adult	M	459	Unknown	-	-
M371.8/23	Adult	M	450	Unknown	-	-
M371.10/23	Adult	M	602	Yes	-	-
M371.20/23	Adult	M	435	Yes	-	-

M371.23/23	Adult	M	465	Yes	-	-
M371.28/23	Adult	M	510	Yes	-	-
M371.44/23	Adult	M	529	Yes	-	-
M371.4/23	Juvenile	M	412	Unknown	-	-
M371.9/23	Juvenile	M	435	No	-	-
M371.11/23	Juvenile	M	283	No	-	-
M371.19/23	Juvenile	M	290	No	-	-
M371.31/23	Juvenile	M	380	No	-	-
M371.45/23	Juvenile	M	302	No	-	-
M371.47/23	Juvenile	M	406	No	-	-
M371.51/23	Juvenile	M	227	No	-	-
M371.54/23	Juvenile	M	240	No	-	-
M371.55/23	Juvenile	M	Na	Na	-	-

## Section 5: Sightings data for long-finned pilot whales in the Northern Minch

Alice Walters, Whale and Dolphin Conservation.

Dr Lauren Hartny-Mills, Hebridean Whale and Dolphin Trust.

Long-finned pilot whales are primarily offshore cetaceans, and their sightings in nearshore waters outside of stranding events are uncommon but not necessarily abnormal or indicative the animals are out-of-habitat (Waggitt et al., 2020) (Figure 4). To investigate the observed incidence of this species in the Northern Minch, their regular habitat use patterns in the area was assessed. Disorientation or navigational errors are potential causes, but it is important to understand their usual behaviour, particularly the use of nearshore waters.

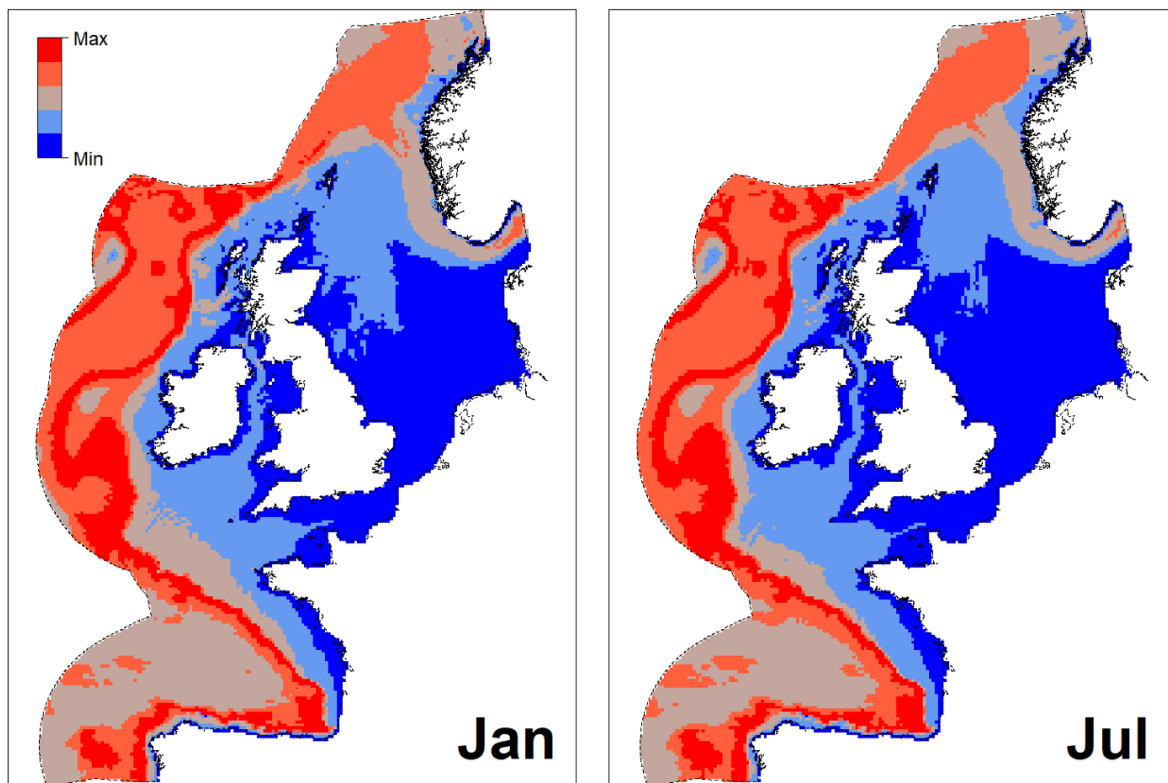


Figure 4: Modelled distribution of long-finned pilot whale around British Isles (Waggitt et al., 2020).

### 5.1 Hebridean Whale and Dolphin Trust Surveys

Since 2002, HWDT has conducted more than 100,000 km of dedicated acoustic and visual surveys for marine mammals off the west coast of Scotland from their research vessel, [Silurian](#). Despite this extensive survey effort, there has only been one confirmed sighting of long-finned pilot whales. This sighting was of a group of 25 individuals recorded on 1 October 2018, to the northwest of the Summer Isles in The Minch.

Analysis of data from Whale Track recorded between 2017 and 2023, showed there had been no sightings of long-finned pilot whales recorded during 3,400 at-sea excursions and 265 land-based watches. During this time, 23,962 casual sightings were recorded and only 22 sightings were identified as long-finned pilot whales.

### 5.2 WDC Shorewatch

Between 2010 and 2023, WDC recorded over 14,000 Shorewatch efforts from specific land-based survey locations along the west coast and Western Isles, equating to approximately 2,349 hours of dedicated observation across 2,677 days surveyed during this period. These consistent, long-term shore-based surveys resulted in very few sightings of long-finned pilot whales across the survey period. Sightings occurred only on a single day in each of 2011, 2013, 2015, and 2019 – demonstrating the rarity of encounters despite sustained monitoring efforts.



Figure 5: Screenshot from short video taken by local surfer the day before the strandings showing a group of long-finned pilot whales milling close to shore (kindly provided by BDMLR).

A sighting of approximately 30 long-finned pilot whales was observed at 19:06 on 15 July 2023, the day prior to the stranding. The whales sighted off Tolsta may represent the same group that subsequently stranded. The animals were observed milling in close formation and were reported to BDMLR by a local surfer (Figure 5). No additional reports were received from that area either before or after this observation.

The data presented above from HWDT and WDC demonstrates that the west coast is not often frequented by long-finned pilot whales. These findings support previous abundance and distribution studies which highlight the rarity of long-finned pilot whales in inshore Scottish waters, particularly in the Northern Minch where the mass stranding event occurred.

## Section 6: Pilot Whale MSE Summary and Trends

Rachel Lennon; SMASS and University of Glasgow.

Understanding trends and patterns in previous strandings is essential for contextualising the significance of mass stranding events such as this. Data collected by SMASS over the three decades of the scheme's operation was analysed. Incidence data for reports to SMASS were examined to assess temporal and spatial trends and patterns, providing a framework for evaluating whether this stranding event was anomalous in scale, timing, or location.

### 6.1 Summary Statistics

Between 1992 and 2023, a total of 480 long-finned pilot whales were reported stranded. Of those, 180 were part of mass stranding events (MSEs), of which there have been a total of 13. A map showing both density of long-finned pilot whales single strandings and MSE's is given in Figure 9.

### 6.2 Temporal Trends

To test for annual trends, generalised linear models (GLMs) were fitted to counts of stranding events as a function of year with an interaction of event type. The model was fit with a Poisson error distribution and log-link function.

Both single stranding events ( $z = 3.70$ ,  $p < 0.001$ ) and MSEs ( $z = 10.53$ ,  $p < 0.001$ ) have increased over time (Figure 6). The magnitude of MSEs has also increased, with more individuals being involved in events in more recent years ( $z = 6.89$ ,  $p < 0.001$ ). The Tolsta beach mass stranding was the largest UK based stranding event on record, in terms of individuals involved, until the Sanday MSE in July 2024 ( $n = 77$  animals).

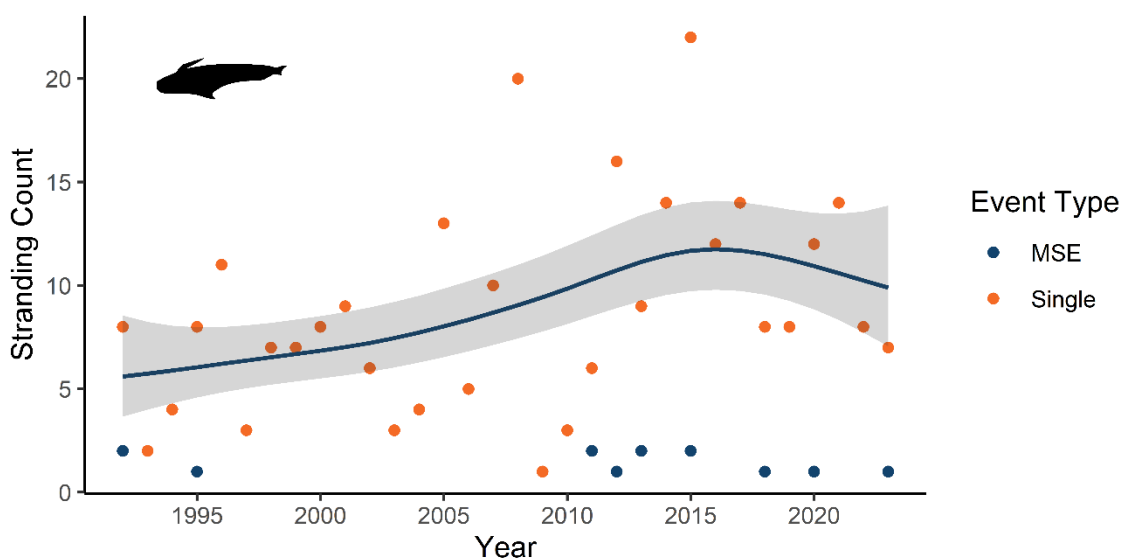


Figure 6: Annual trends in stranding rates of long-finned pilot whales from 1992 – 2023 with black curve generated from general additive modelling and grey band

representing 95% confidence intervals. Orange points show single events, blue points show mass stranding events.

To test for seasonal trends, GAMs were fitted to counts of strandings with covariate smooths of month with a cyclic cubic spline and year with a thin plate regression spline. Event type was fitted as an interaction term for both smooths. Models had a Poisson error distribution and log-link function.

For single stranding events, long-finned pilot whales display no seasonality with strandings occurring all year round (edf = 0,  $p > 0.05$ ). This contrasts to MSEs, which display a clear peak in the summer months around June and July, though there are events recorded in every season (edf = 2.04,  $p < 0.05$ ). The largest magnitude events also occur in the summer months ( $z = 4.16$ ,  $p < 0.001$ ). July has the highest magnitude of MSEs including the Tolsta MSE. The 2024 Sanday MSE also occurred in July.

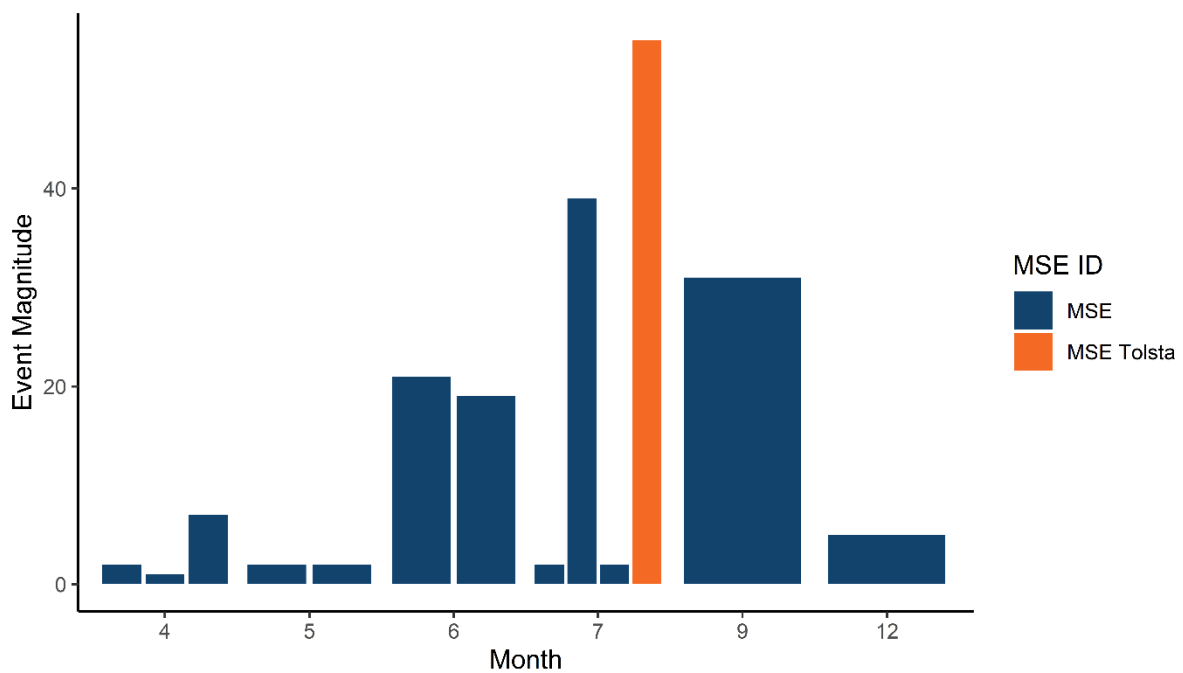


Figure 7: Magnitude of Mass Stranding Events in Scotland by month of occurrence. Multiple events are displayed as staggered bar plots for the same month, and the Tolsta beach MSE is coloured in orange.

It is important to note here that reporting effort has increased over time with wider mobile phone use and growing citizen science and public engagement, improving detection of single strandings. Although robust effort metrics are not yet available for Scottish strandings, mass strandings are so conspicuous that they were likely reported even historically, making them less sensitive to changes in effort. Thus, rising MSE frequency likely reflects a real trend.

### 6.3 Body Condition Trends

Body condition assessment provides a useful metric for evaluating the health status of stranded cetaceans, as chronic disease, injury, or insufficient feeding all negatively impact energy reserves and tissue deposition. Animals in good body condition are therefore assumed to have been in generally better health prior to stranding, making body condition indices valuable for identifying animals potentially compromised by underlying health issues. For this mass stranding event, assessing body condition across the group helps determine whether these animals were healthy individuals subject to a relatively acute process, or whether poor health may have contributed to the stranding.

Body condition index (BCI) scores were used as a proxy for health by indicating available energetic reserves. A BCI for long-finned pilot whales was generated from the residuals of a generalized additive model (GAM) fitted to girth as a function of body length. The GAM accounted for non-linear relationships between body size and length, whilst residuals quantified relative BCI. A linear model was then fitted to BCI with event type as a covariate to test for differences between stranding events.

The modelling found that mass stranding events had a better BCI than single stranding events ( $t = 2.84, p < 0.01$ ), whilst individuals from the Tolsta MSE had higher body scores than other mass stranding events ( $t = 2.05, p < 0.05$ ) (Figure 8). This supports the hypothesis that mass stranding events predominantly comprise healthy animals, which, aside from the acute impacts of the stranding event, are physiologically normal.

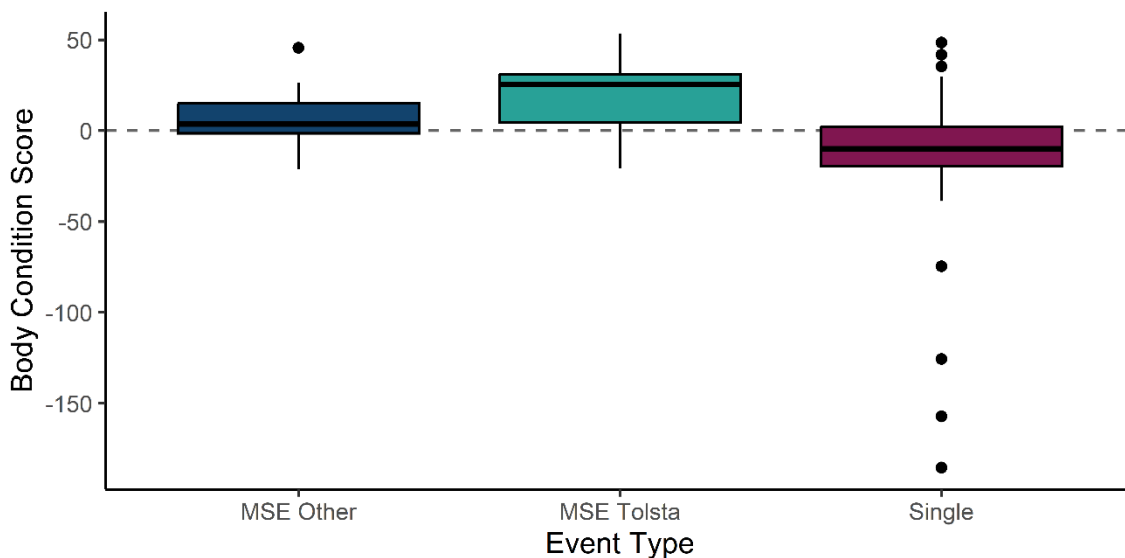


Figure 8: Body condition index (BCI) scores of stranding event types for long-finned pilot whales stranded in Scotland between 1992 to 2023. Each box represent interquartile ranges with median lines. Upper and lower limits shown by whiskers with black points depicting outliers. Dashed line shows the baseline value of the BCI.

## 6.4 Spatial Trends

To conduct spatial analysis of recent mass stranding events, the latitude and longitudes of each event was used to generate point data. A heatmap was created using a kernel density estimation in QGIS across a 50km search radius.

Long-finned pilot whale strandings occur across Scotland but exhibit a clear hotspot on the west coast, particularly in the Outer Hebrides, where both the frequency and magnitude of mass stranding events are highest (Figure 9). This spatial pattern is consistent with the known offshore distribution of long-finned pilot whales in the northeast Atlantic, with animals occurring in oceanic waters west of Scotland. The concentration of strandings around the Western Isles likely reflects both the proximity of suitable pilot whale habitat and the complex bathymetry and hydrography of this coastline, which may increase stranding risk for highly social, deep-diving species navigating these waters.

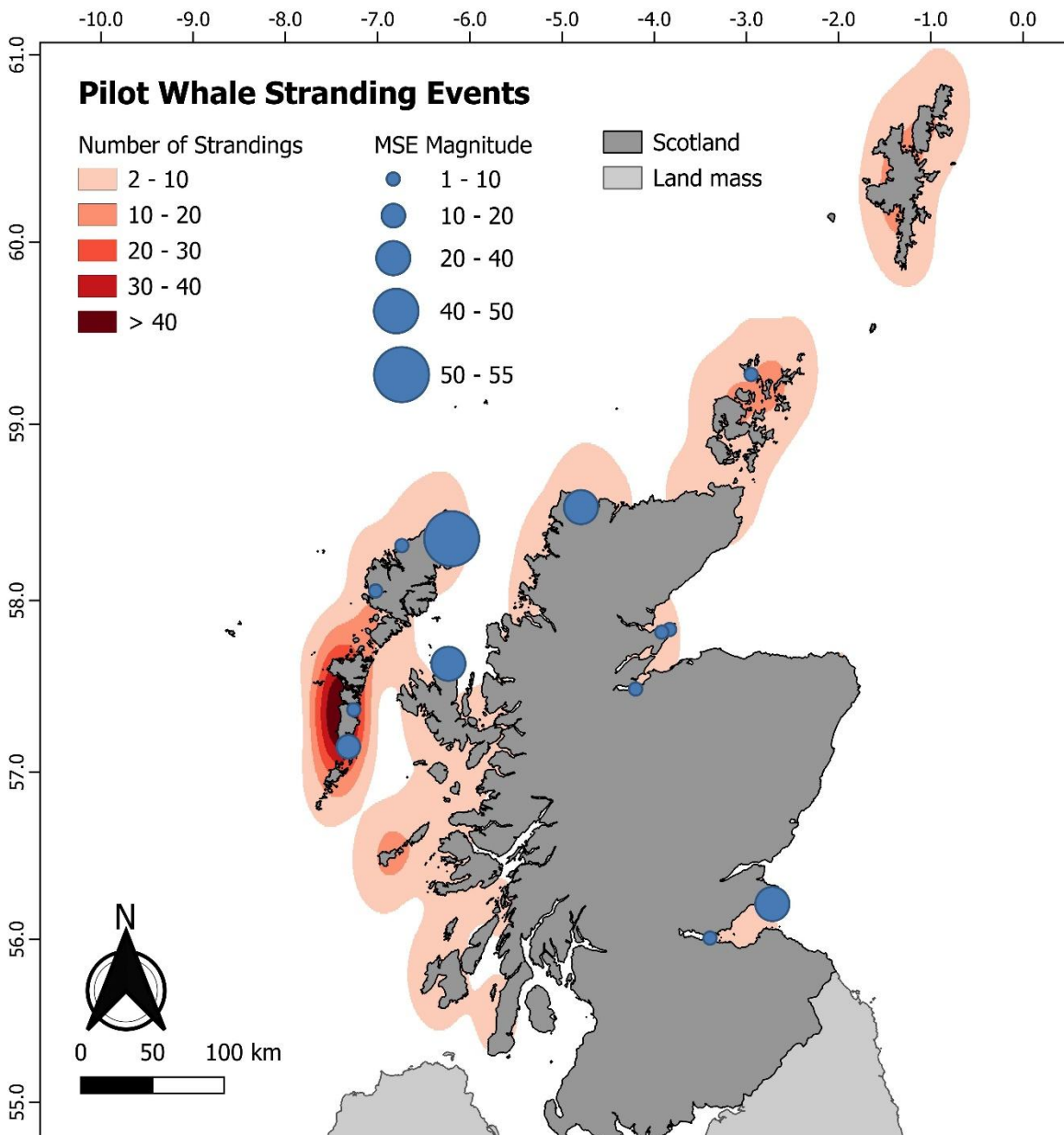


Figure 9: Stranding abundance map of long-finned pilot whale stranding events in Scotland between 1992-2023 using a kernel density estimate with a 50km radius. Darker red colouring shows a higher density of single stranding events. Blue dots show location of mass stranding events, with the size correlating to the magnitude of the event.

## Section 7: Postmortem (Necropsy) Examinations

Diagnostic necropsies form the foundation of marine mammal stranding investigations. Their primary objective is to evaluate individual health and identify factors contributing to stranding, with a secondary objective of collecting samples for further analyses. These samples are used to investigate causes of morbidity and mortality at the individual level and to assess population-level metrics of ecology, physiology, and health, including diet, contaminant exposure, and life-history parameters. Necropsies are often conducted under significant time and logistical constraints, particularly when working with large carcasses outside dedicated facilities, necessitating rapid recovery of data and samples before decomposition degrades information quality. All examinations followed internationally agreed protocols (Ijsseldijk et al., 2019).

A comprehensive suite of tissues and measurements were collected to support diagnostic assessment and downstream analyses. Such systematic tissue sampling is essential for identifying acute pathological processes and chronic health stressors, while also contributing to broader understanding of population dynamics, foraging ecology, vital rates, and anthropogenic impacts. Selected tissues were archived to enable future investigations as new research questions arise.

### 7.1 Sample Collection

All animals had the following data recorded and samples taken:

- Detailed morphometrics including total length, girth (both in front of the dorsal fin, and behind the pectoral fins), and blowhole-to-dorsal fin measurements.
- Photographs.
- Age class determined.
- External examination for trauma, bycatch or entanglement marks.
- Blubber thickness.
- Sex and, where possible, reproductive status.
- Stomach contents and evidence of recent feeding.
- Samples of skin, blubber, muscle, and liver.
- Teeth (for ageing)

Most of the animals which were examined at necropsy also had the following additional data recorded and samples taken:

- Weight.
- Bacteriology (lung, liver, kidney, brain, spleen as minimum).
- Formalin-fixed samples for histopathology.
- Body condition scoring (good/moderate/poor).
- Cochlea (eight animals).
- Urine and faeces.

## 7.2 Health assessment parameters

In addition to the samples outlined above, the following assessments were made on all animals taken to necropsy:

- Bruising patterns (subcutaneous, sub-mandibular)- an indicator of live stranding.
- Lung asymmetry detection.
- Water/sand aspiration and ingestion.
- Evidence of hepatic lipidosis (fatty liver).
- Parasite burden, including subcutaneous cysts/abscesses (scored for severity).
- Reproductive status assessment (if pregnant or evidence of recent parturition). This was also done for animals not necropsied.
- Ovary evaluation inclusion.
- Foetal size measurement.
- Lactation status.

All carcasses were sampled (skin, blubber, and muscle) the day after stranding prior to being transported to Stornoway landfill site for necropsy. (Figure 10 to Figure 12). Between 17 and 21 July, SMASS conducted full necropsies on 23 individuals, representing 43% of the group. This was the maximum feasible number before decomposition compromised diagnostic quality. The remaining 31 cases (57%) were photographed, measured, and sampled for liver, muscle, and where possible, brain tissue to enable toxicological analysis, age determination, and reproductive assessment. Cases were prioritised for full necropsy based on decomposition status, targeting the freshest individuals while maintaining representative age and sex distributions.

All animals were evaluated for external indicators of poor body condition, disease, or pre-existing injury that might suggest a sick or compromised individual could have led otherwise healthy animals ashore.



Figure 10: The SMASS trailer proved beneficial in curating the necropsy data and samples. Over 1000 individual tissue samples were taken during the five days of necropsy work.



Figure 11: Necropsy site at Stornoway waste disposal centre. The site kindly allowed the SMASS team to repurpose an oil bund for the necropsies.



Figure 12: Carcasses were transported to landfill site prior to necropsy or examination.

### 7.3 Necropsy Findings

All necropsied animals were in good nutritional condition with adequate blubber reserves. External body shape, blubber thickness, and back muscle mass were within normal ranges, and free lipid was evident on cut section in all cases, indicating sufficient energy stores. No animals showed evidence of significant or prolonged negative energy balance; in particular, there were no metabolic hepatic lesions such as jaundice or fatty liver.

Of the 23 animals examined, ten had been euthanised. Among the remaining 13 animals, the proximal cause of death in ten cases was either drowning or pathology consistent with hyperthermia associated with the stranding process. Drowning was diagnosed by the presence of sand or silt in the airways, consistent with aspiration of seawater and sediment, most likely in the surf zone. Stranding-related pathology was identified by lung asymmetry, deep tissue bruising, and/or myoglobinuria. These findings strongly indicate that the animals were alive at the time of stranding but succumbed either during the initial beaching or shortly thereafter.

Twelve animals exhibited chronic subcuticular parasitic infections, evident as multifocal, well-demarcated abscesses up to 30 cm in diameter containing white purulent material. These lesions were likely of parasitic origin, with possible secondary bacterial infection, but showed no evidence of dissemination, sepsis, or systemic compromise. All animals were in good nutritional condition with adequate blubber reserves and no indication of infectious disease, significant trauma, fisheries interaction, or proximity to underwater explosions. Stomachs contained seawater but no recent ingesta, suggesting regurgitation prior to death. In non-euthanised animals, drowning due to aspiration of seawater and sand on the shallow beach was

the primary cause of death. Euthanasia by ballistic trauma (n = 12) was effective, producing extensive cranial injury consistent with instantaneous death.

One female (M371.40/23), initially suspected to have a uterine prolapse, was found to have prolapsed placental tissue, consistent with ongoing, possibly prolonged parturition. The cervix was dilated, and a full-term male foetus in normal (tail-first) presentation occupied the left uterine horn. Although no physical obstruction to delivery was present, placental separation, pulmonary oedema, and meconium expulsion indicated foetal distress, suggesting dystocia. The placental tissue appeared otherwise normal, and the foetus was likely alive at or near the time of maternal death, implying that the stranding event may have precipitated or exacerbated parturition difficulties. No other animals showed evidence of acute disease or injury on gross examination, though undetected pathology in non-necropsied cases cannot be excluded.

#### 7.4 Reproductive Status

Several females were noted to be pregnant in various stages of gestation. Estimated, from foetal size, females had either recently conceived (in the past few weeks) or were pregnant with at-term foetuses. In the latter case there were two animals with prolapsed placenta from the right (non-gravid) horn during the stranding process. There were additionally nine females showing evidence of recent parturition. These findings align with a gestation time estimated to be approximately 12 months. Given the strong matrilineal, intergenerational bonds in this species, it is possible the group had clustered around one or more females who were in the process of giving birth and this may have contributed to so many animals coming ashore.

#### 7.5 Fisheries Interactions

There was no evidence of recent or historic trauma to any of these animals which may be attributed to bycatch, entanglement or ingestion of significant marine debris. This included no indication of either recent or historical skin lesions or scarring consistent in pattern to those caused by either net or line entanglement or entrapment. One animal had a small loop of green braided polyethylene twine in the stomach consistent with a type widely used in fishing and some land-based industries, but this was not causing problems and was considered an incidental finding.

#### 7.6 Microbiological Analysis

Comprehensive microbiological and histological examinations were undertaken on all necropsied cases to assess pathogen carriage, prevalence, and potential subclinical infection as a component of evaluating overall health status. This investigation included microbiological culture of at least five organs (brain, lung, spleen, liver, and kidney), histological examination, and viral PCR screening for

morbillivirus. High pathogenicity avian influenza virus (HPAIV) was not suspected in any of the cases based on clinical presentation or gross pathological findings.

### 7.6.1 Bacteriology Screening

Nick Davison and the Veterinary Diagnostic Services (VDS); University of Glasgow.

Samples from various organs collected during necropsy were stored frozen until screened by standard microbiological culture techniques for any potential bacterial infections likely to be implicated in the mass stranding event. Given the 'sick leader' hypothesis has often been raised as potential cause for these events and a bacterial infection of the central nervous system (CNS) would not always be evident on gross necropsy and hence bacterial culture was indicated. Additionally, given the observed subcutaneous abscesses in a number of cases, the investigation sought to ascertain if any animals showed indication of pathogenic bacterial infection or disseminated bacteraemia or sepsis.

Tissues from 23 animals were subjected to bacteriological examination (15 adults, seven juveniles and one calf). Isolates were recovered from all cases subjected to culture. Routinely lung, liver, spleen, brain and when available CSF (cerebrospinal fluid) cultures as standard. Molecular techniques were not used.

Bacteriological culture was carried out as per Foster et al (2002). Briefly, tissue samples were inoculated directly onto Columbia sheep blood agar (CSBA) (Oxoid) and Farrell's medium (Animal and Plant Health Agency), incubated at 37°C in a capnophilic (5% CO<sub>2</sub>) atmosphere and examined daily for 14 days. Samples were also inoculated directly onto MacConkey agar (Oxoid) and incubated at 37°C in air. This investigation included specialised cultures for *Brucella* species given the known association with brucella infection and meningoencephalitis in cetaceans, including long-finned pilot whales, which has been implicated in live strandings (Davison et al. 2015). Lung was cultured in all cases. Liver was cultured in 22 cases. Spleen was cultured in 21 cases. Brain was cultured in 13 cases and CSF was available for culture in four animals. Lesions with purulent material were observed on 12 animals and cultured in five cases.

**Results:** Most recovered isolates were *Edwardsiella tarda* and *Enterococcus faecalis* followed by *E. coli*, *Aeromonas sp.*, and *Vibrio sp.* These isolates were considered to be incidental and are likely postmortem invaders. A single case involving *Brucella ceti* was isolated in mixed culture from the purulent abscess caudal/cranial to abdominal in M371.43/23 (Figure 13). The significance of this isolate is uncertain, but in the absence of associated pathology it was considered an incidental finding. The other abscesses cultured either proved sterile or revealed postmortem invaders such as *Enterococcus sp.*, *Edwardsiella sp.*, and *E. coli*.

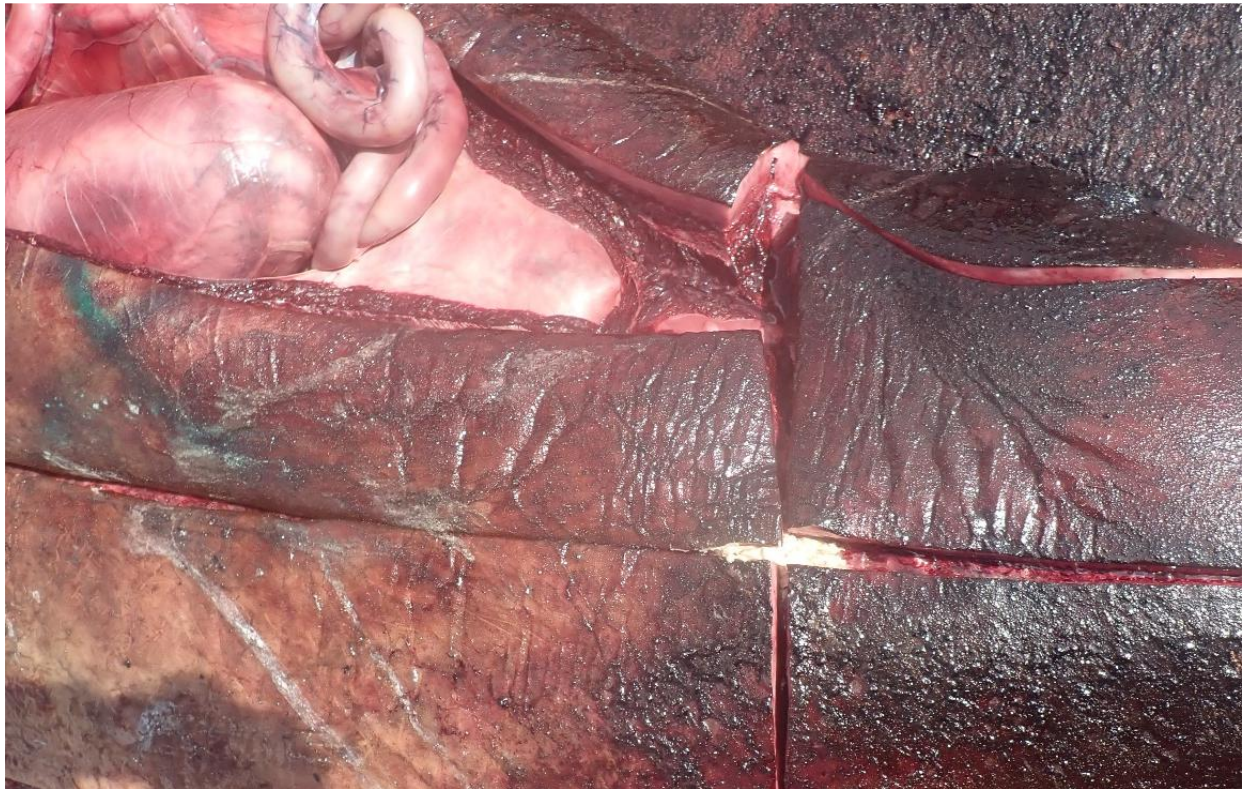


Figure 13: Photo of M371.43/23 showing position of subcuticular inspissated abscess from which *Brucella ceti* was cultured.

### 7.6.2 Viral Screening

Madeleine Maley & Mara Rocchi, Moredun Research Institute.

Cetacean morbillivirus (CeMV), the etiological agent of distemper in cetaceans, is a significant cause of morbidity and mortality globally and has been associated with several epizootic events (Sierra et al., 2020; Van Bressemer et al., 2008).

To investigate the potential involvement of CeMV involvement in the MSE, total RNA was extracted from frozen (-80 °C) lung and pooled tissue samples (n = 23). Reverse transcriptase polymerase chain reaction (RT-PCR) assays targeting the conserved N-terminal region of the morbillivirus nucleoprotein (N) gene were performed in duplicate (Grant et al. 2009).

**Results:** No cetacean morbillivirus CeMV RNA was detected. In addition, necropsy findings revealed no macroscopic or histological lesions consistent with morbilliviral infection. Consequently, cetacean morbillivirus was excluded as a differential in this stranding event.

## 7.7 Histopathology

Mark Dagleish and the Veterinary Diagnostic Services (VDS), University of Glasgow.

Histological analysis of stranded pilot whales was constrained by tissue autolysis and only 14 of the 18 cases examined histologically were considered diagnostic.

**Results:** Histological examinations revealed a range of pathological lesions commonly encountered in cetacean strandings. These included mild tissue swelling (oedema) of brain, lung and heart tissue, and brain and lung haemorrhages consistent with live stranding and associated hyperthermia. There was also evidence of liver changes including fatty deposits and iron accumulation, muscle degeneration, localised inflammatory skin conditions, and parasitic infections affecting the stomach and mammary glands. However, the extent and severity of these lesions were insufficient to be considered a primary cause of morbidity or mortality. Overall, the group appeared to be in good health with no major underlying diseases identified. This supports the notion that the animals were healthy prior to stranding.

## 7.8 Teeth aging

Dr Ailsa Hall, Prof Simon Northridge and Simon Moss; Sea Mammal Research Unit, University of St Andrews.

A modified acid etching method based on Pierce and Kaijmura (1980) and Martin et al. (1987) was used to investigate age-length relationships. Teeth were bisected longitudinally and a 0.5mm central section was etched in 5% formic acid for 1-2 hours. Growth layers were counted from digital images taken under light microscopy at 2.5x magnification and enhanced using microscope camera software or Adobe Photoshop where necessary.

A subset of 16 teeth were independently counted by a second reader, with ages differing by a maximum of  $\pm 4$  years (average difference 16%, or 3% excluding two worn teeth from older animals). Teeth were also weighed as an additional parameter for estimating age and body size. Gompertz growth curves were fitted to total length (tip of upper jaw to tail notch) and age data.

**Results:** A significant linear relationship between tooth mass and age was found ( $p < 0.001$ ) but low  $R^2$  values (0.40 and 0.55 for females and males respectively) suggest tooth mass is not a good predictor but might be used as a rough guide

The distribution of ages in the sample for males and females is shown in Figure 14 with a mean age of 10  $\pm$  5 years for females and 7  $\pm$  4 years for males.

Previous studies had found that maximum length for the males was 630 cm and 546 cm for the females with the oldest male in the sample being 20 years and the oldest female being 25 years. Mature females were generally  $> 400$  cm and older than 12 years. The data from this MSE corresponds to these results, with mature females (as determined from their reproductive tracts) showing sexual maturity around 400 cm in length and at a minimum age of 10 years. The minimum age for mature males in this group was 9 years old.

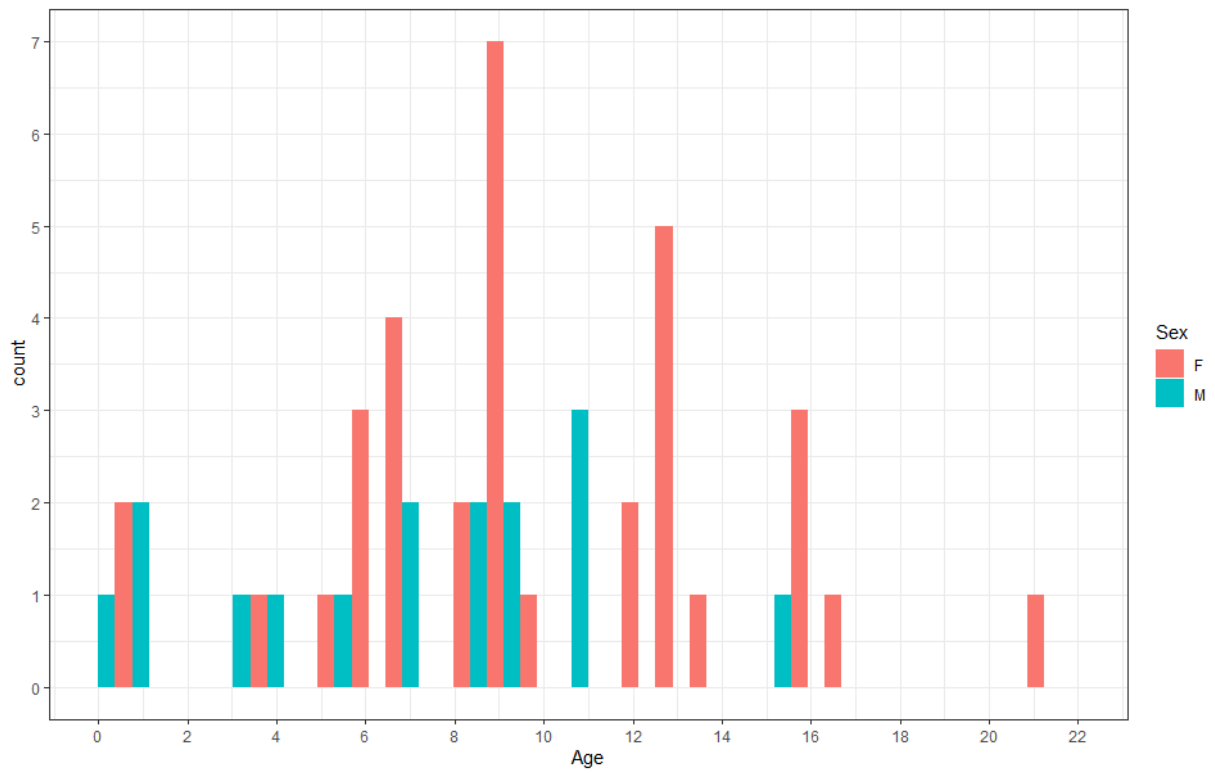


Figure 14: Age distributions by sex as derived from teeth.

## Section 8: Influence of wind and tide

Wind and tidal influences were investigated as potential contributing factors to the stranding event. Wind data for the 48 hours (Figure 15 & Table 3) preceding the stranding revealed a dominant northerly airstream, with a shift from northeasterly winds in the 24 hours prior to stranding, to more northerly and north-westerly winds in the six hours leading up to the event. Wind speeds remained moderate, not exceeding ten knots until the six hours prior to stranding, when gusts of 15-20 knots were recorded from the north. While these wind speeds are not uncommon for the area, the presence of a sustained northerly wind during this critical period could have played a role in pushing animals towards the shore and generating onshore surf. This may explain the high number of drowned individuals found during the early hours of 16 July 2023.

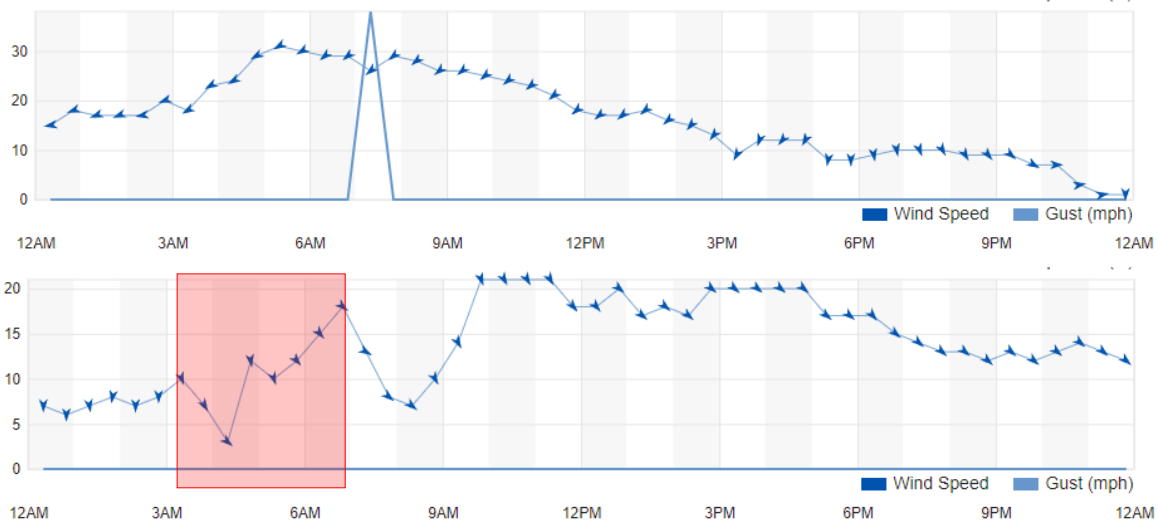


Figure 15: Wind strength and direction 15/06 (upper panel) and 16/06 (lower panel) Red box shows likely period of stranding. Data from [Wunderground website](#).

Table 3: Windspeed and direction at Stornoway airport, 16 July 2023. Red rows show likely period of stranding. Data from [Wunderground website](#).

Time	Wind	Wind Speed	Wind Gust	Pressure	Precip.	Condition
12:20 AM	N	7 mph	0 mph	29.09 in	0.0 in	Light Drizzle
12:50 AM	N	6 mph	0 mph	29.12 in	0.0 in	Cloudy
1:20 AM	N	7 mph	0 mph	29.12 in	0.0 in	Cloudy
1:50 AM	N	8 mph	0 mph	29.12 in	0.0 in	Cloudy
2:20 AM	N	7 mph	0 mph	29.15 in	0.0 in	Cloudy
2:50 AM	N	8 mph	0 mph	29.15 in	0.0 in	Cloudy
3:20 AM	NNW	10 mph	0 mph	29.15 in	0.0 in	Cloudy
3:50 AM	NNW	7 mph	0 mph	29.15 in	0.0 in	Cloudy
4:20 AM	NW	3 mph	0 mph	29.18 in	0.0 in	Cloudy
4:50 AM	N	12 mph	0 mph	29.18 in	0.0 in	Light Rain
5:20 AM	NNW	10 mph	0 mph	29.18 in	0.0 in	Mostly Cloudy
5:50 AM	NW	12 mph	0 mph	29.18 in	0.0 in	Cloudy
6:20 AM	NW	15 mph	0 mph	29.21 in	0.0 in	Cloudy
6:50 AM	NW	18 mph	0 mph	29.21 in	0.0 in	Cloudy
7:20 AM	WNW	13 mph	0 mph	29.21 in	0.0 in	Cloudy
7:50 AM	NW	8 mph	0 mph	29.24 in	0.0 in	Cloudy

Detailed information on tidal processes at the specific stranding site on Tolsta Beach, Isle of Lewis, is limited. However, [tidal data](#) suggests a moderate mean spring tidal range of 3.5-4.0 meters, potentially increasing slightly towards the inner part of Broad Bay. Flood currents travel northwards up the Minch, with high tide occurring roughly synchronously across the area. The main tidal stream across the mouth of Broad Bay is weak, with a peak spring rate of less than 0.3 m/s. Currents within the bay are similarly weak. Ebb tide currents flow south off Tolsta Head, exhibiting a weak anticlockwise rotation within the bay. Flood tide currents are minimal along the north coast of the Eye Peninsula, with a weak NNE-flowing stream existing along the north coast of the bay, strengthening towards Tolsta Head (Ramsay and Brampton 2000). These findings suggest that tidal processes likely played a minimal role in directly influencing the stranding event.

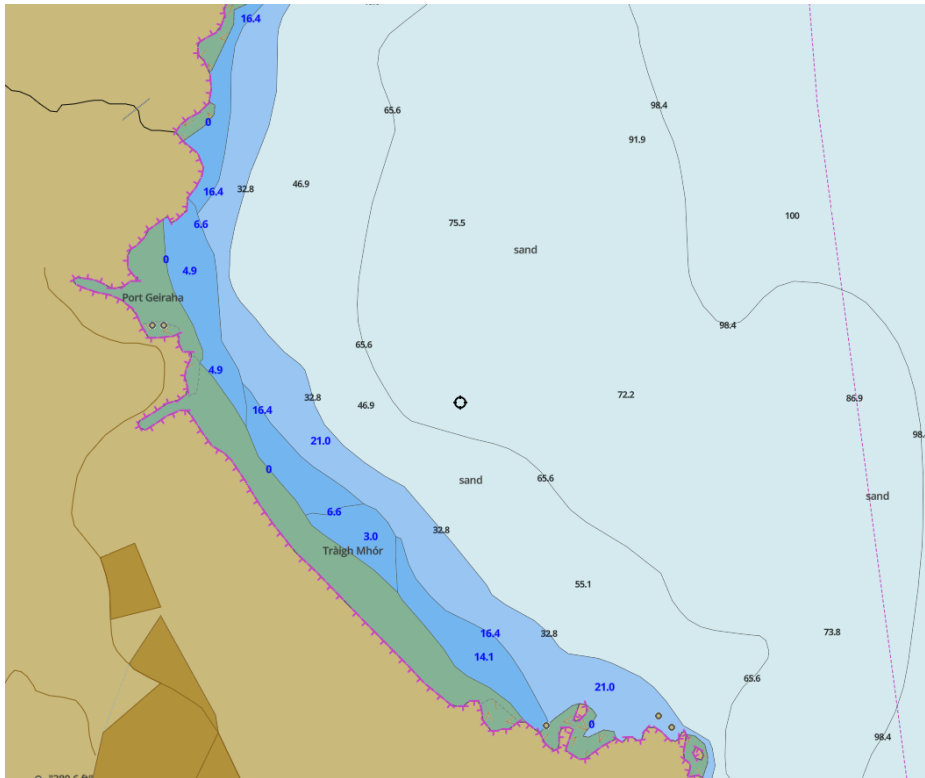


Figure 16: Bathymetry of Tolsta beach (data from NMPi).

The stranding occurred on Tolsta Beach (Traigh Mhòr), a linear sandy beach with fine-grained sand, oriented northeast and facing the Minch. The beach extends uninterrupted for around 2.3 km, exhibits a gentle offshore gradient and is bounded to the south by a rock headland (Figure 16). Water depth drops gradually to around 25 meters within a few hundred meters offshore and only averages 50 meters around 4 km from shoreline. The geomorphology of this beach, comprising soft sand a shallow gradient and a headland-bay formation is consistent with mass stranding sites elsewhere (Hamilton and Lindsay 2014). Soft sand substrates are hypothesised to disrupt echolocation in cetaceans through a process termed "sonar termination" (Chambers and James 2005). This phenomenon suggests that pilot whales' biosonar signals may become attenuated or scattered in shallow waters with soft sediment, potentially hindering their ability to navigate effectively and locate deeper channels. Once the stranding event occurred, the combination of soft sand and potential onshore surf would have created a challenging environment for self-refloating. The animals limited manoeuvrability due to their large size and body shape, coupled with the lack of a firm substrate for propulsion and heavy surf would likely have significantly contributed to the high number of drowned mortalities observed.

## Section 9: Contaminants and Toxins

There are several natural and anthropogenic toxins and contaminants that are known, or suspected, to have impacts on cetacean health, immune status or reproduction. These include, polychlorinated biphenyls PCBs and polycyclic aromatic hydrocarbons (PAHs) and other persistent organic pollutants (POPs), toxins from

harmful algal blooms (HABs), sewage, radionuclides, toxic elements and tri-butyl tin (TBT).

Previous investigations have shown that long-finned pilot whales tend to have lower levels of POPs than some odontocete species (Jepson et al., 2016; Brownlow et al., 2011; Weihe et al., 1996) likely due to their predominantly pelagic habitat and feeding at relatively low trophic levels. Samples for POPs have been archived for future screening, however based on previous analysis and the understood feeding ecology of this species, it is not expected that the levels of POPs will be particularly elevated (Weihe et al., 1996; Dam and Bloch 2000). The results for two contaminants of potential significance (harmful algal blooms and heavy metals) are summarised below. These data are part of wider ecotoxicological studies which will be published separately.

### 9.1 Contaminants: Biotoxin Screening

Dr. Jo Kershaw and Dr. Holly Armstrong; Sea Mammal Research Unit, University of St Andrews.

Harmful algal bloom (HAB) toxins consumed by marine predators through fish prey can pose significant health threats, impact behaviour and acute high exposure levels can be lethal. Mass mortalities and strandings among marine mammals due to biotoxin exposure resulting in HAB toxicosis have been regularly reported since the late 1990s worldwide. The two major HAB toxins found in fish around Scotland are domoic acid (DA, produced by *Pseudo-nitzschia* species), and saxitoxins (STX), produced by *Alexandrium* species) (Kershaw et al., 2021). These can be detected in the urine and faeces of marine mammals following consumption of contaminated prey (Hall et al., 2024; Jensen et al., 2015). Concentrations of these two toxins were quantified in the urine of the pilot whales to investigate potential exposure in these animals.

**Results:** In the week leading up to the mass stranding (10 to 16 July 2023), *Alexandrium* species were present at high levels (> 20,000 cells/L) in the Outer Hebrides, while *Pseudo-nitzschia* species were also present but at much lower levels (Habreports . Figure 17). Commercially available ELISAs previously validated for use with marine mammal samples were used for urine analysis (Jensen et al., 2015). Small urine volumes resulted in 15 samples assayed to determine STX concentrations, and 22 samples assayed to determine DA concentrations. All samples were below the assay limit of detection for both toxins.

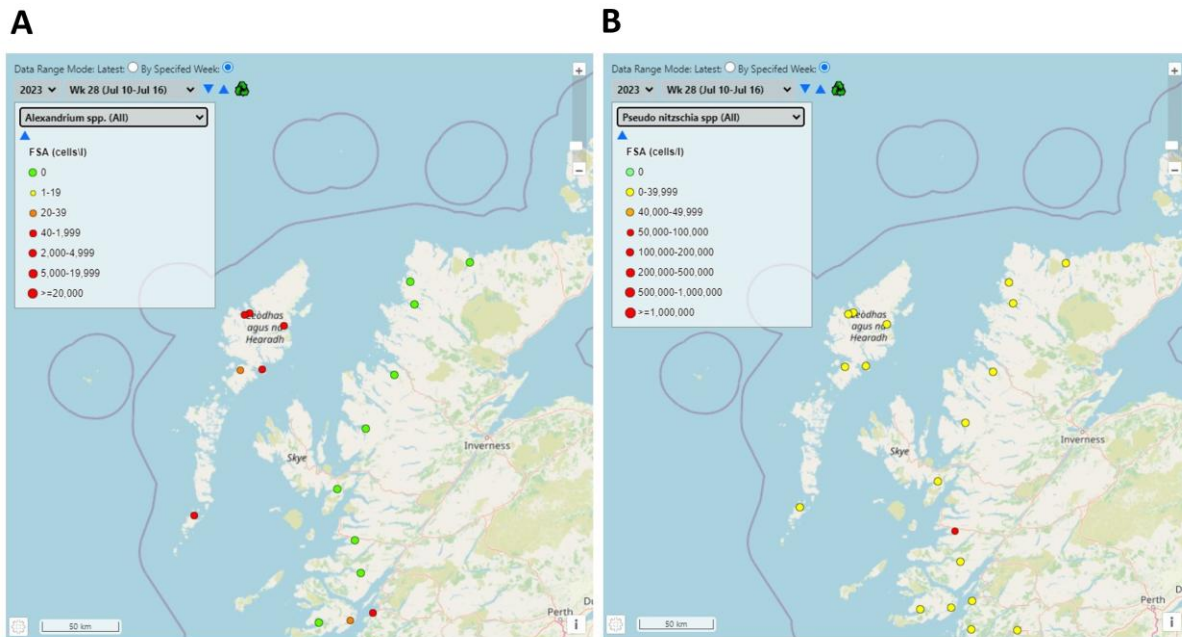


Figure 17: HAB Reports. Harmful Algal Bloom, Biotoxin Monitoring and Risk Assessment map of the west coast of Scotland for the period of the 10 – 16 July 2023. (A) *Alexandrium* species cell counts. (B) *Pseudo-nitzschia* species. Source: [Habreport website](#).

These data suggest that the pilot whales were likely not exposed to high levels of STX or DA through their diet immediately before the stranding event, even though cell counts of *Alexandrium* species were high, and *Pseudo-nitzschia* were present in the inshore waters around the Isle of Lewis over this period.

## 9.2 Contaminants: Heavy Metals

Ryan McCarthy, Dr Christoph Gade, Dr Rebecca von Hellfeld; University of Aberdeen.

In marine ecotoxicology, mercury (Hg) exists in various forms, of which methylmercury (MeHg) is the most toxic and bioavailable. MeHg is a neurotoxic organic mercury compound formed primarily through microbial methylation of inorganic Hg in aquatic sediments. It biomagnifies through marine food webs, leading to high concentrations in top predators, including cetaceans (Dietz et al., 2022).

In long-finned pilot whales mercury exposure is particularly well-documented due to their position as long-lived, high trophic level predators. Studies from the Faroe Islands have shown total Hg concentrations in liver tissue exceeding 100 µg/g wet weight, with MeHg comprising the majority of Hg in muscle (>90%) (Weihe et al. 1996; Hoydal, Erenbjerg, and Dam 2024). Due to their feeding ecology, long-finned pilot whales can exhibit physiologically elevated levels of heavy metals (mercury, Hg and cadmium, Cd). Interpreting metal burden is complex as these species have well-developed detoxification mechanisms to deal with naturally high exposure to these metals.

**Results:** Mercury concentrations varied markedly among tissues, with the highest levels detected in the liver, consistent with hepatic detoxification processes. Significant positive correlations were observed between skin, liver, and muscle concentrations. Adults exhibited higher burdens than juveniles, reflecting cumulative exposure, and females consistently exceeded males. Measured concentrations were within global ranges reported for long-finned pilot whales indicating similar contaminant loads across populations. While some individuals approached thresholds thought to induce mercury-induced liver damage, it is unlikely that the observed burdens were sufficiently elevated to contribute to the stranding event.

More details on this work are available in McCarthy et al (in prep). Future work will integrate  $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$ , and  $\delta^{34}\text{S}$  isotope analyses from skin, muscle, and liver tissues of stranded adult *Globicephala melas* (See section 11.2) with mercury (Hg) concentration data to elucidate ecological drivers of contaminant variability across populations. This will involve assessing differences in isotopic niche space and trophic position among Northeast Atlantic populations to determine whether variations in feeding ecology and habitat use explain Hg burden disparities.

## Section 10: Metabolic Stress and Proteomic Analysis

Dr Davina Derosus<sup>1</sup>, Alexandra Tranganida<sup>1</sup>, Dr Joanna Kershaw<sup>2</sup>.

<sup>1</sup>School of Biological Sciences, University of Aberdeen.

<sup>2</sup>Sea Mammal Research Unit, Scottish Oceans Institute, University of St Andrews, St Andrews, Fife KY16 8LB, UK.

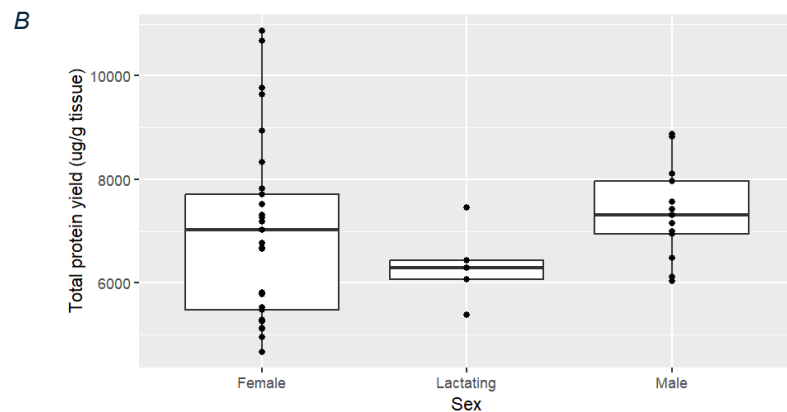
Cetaceans can become stressed by a range of factors which may impact individual and population resilience and predispose them to illness or stranding. Assessment of stress indicators is challenging but initial work into cetacean proteomics has been recently piloted by the University of Aberdeen. Proteomics is emerging as a powerful tool for understanding cetacean health, offering insights into antemortem metabolic processes and overall well-being and these signals can persist after death and exhibit low between sample variability in subsampling from the same tissue. Part of this investigation looked at the proteomic profiles of different blubber layers in a subset of animals from this MSE to gain a better understanding of their metabolic profile and identify health markers.

The primary objective was to identify protein-based biomarkers that could be used to assess health in free-ranging cetaceans. Blubber samples were collected from various groups (lactating females vs. non-lactating females, males, foetuses, juveniles, adults) and layers (outer, middle) to evaluate metabolic stress and blubber development. Initial analyses revealed no significant difference in total protein content between the outer blubber of females and males, while juveniles displayed a higher total protein content in the outer compared to middle blubber layer.

**Results:** Proteomic profiling of outer blubber in cetaceans revealed high inter-individual variability in total protein content and abundance, even within sex- and age-matched groups (Figure 18). Juvenile males displayed distinct proteomic signatures compared to adult males, reflecting blubber tissue expansion and

developmental processes. In contrast, juvenile and adult females showed minimal proteomic differences attributable to growth, though adult females exhibited markers suggestive of tissue damage, potentially linked to hyperthermia at the time of sampling. Reproductive state had little influence on the blubber proteome of adult females, and euthanasia was not associated with proteomic changes. Overall, age emerged as the primary driver of proteomic variation, with signatures indicating tissue remodelling, inflammation, and coagulation processes.

This proteomic analysis offers novel insights into physiological processes in cetaceans, specifically age related and strandings related (e.g. hyperthermia) changes. At scale, this has potential to improve interpretation of blubber condition in stranded individuals, enhancing assessments of health status and identification of the physiological impact of stressors.



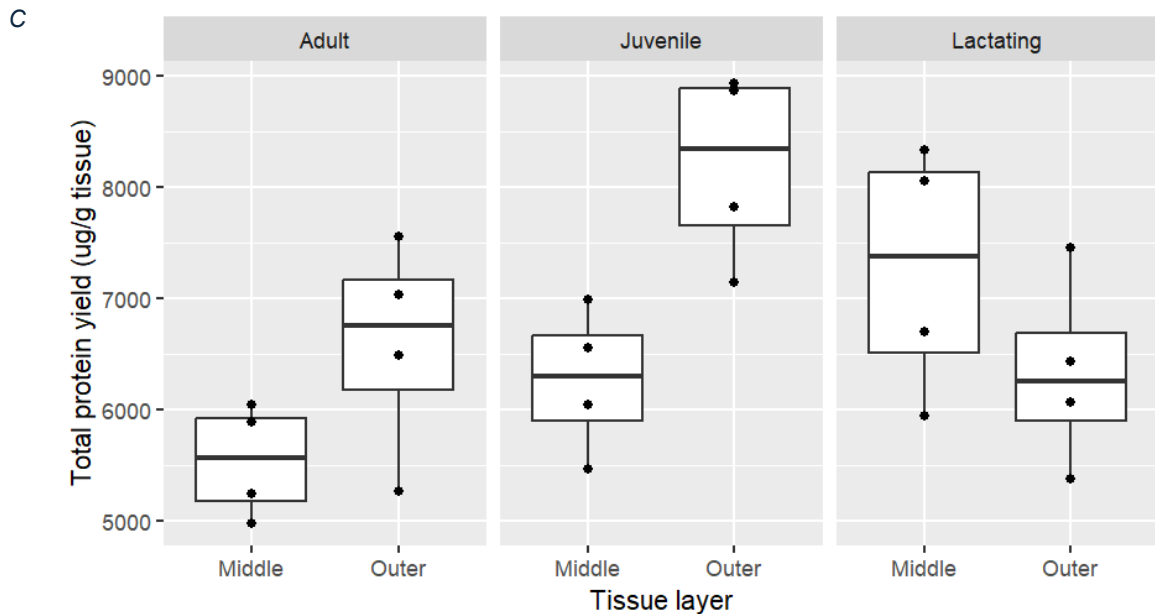


Figure 18: Blubber protein extractions of the mass stranded pilot whales. A. Frozen blubber tissue on dry ice to avoid defrosting. B. Total protein yield ( $\mu\text{g/g}$  tissue) for sex and energy-demanding groups. Each point represents an observation; boxplots with upper and lower quartiles and  $1.5 \times$  interquartile range. C. Total protein yield ( $\mu\text{g/g}$  tissue) vs tissue layer and categorised by age group and lactating females. Each point represents an observation; boxplots with upper and lower quartiles and  $1.5 \times$  interquartile range. Data and plots created and owned by Davina Derous, University of Aberdeen.

## Section 11: Feeding ecology and population structure

This event presented an opportunity to investigate broader questions around population structure and feeding ecology of a deep-diving cetacean species. The necropsy response enabled the collection of high-quality biological samples from 56 individuals (including three foetuses), allowing analyses across genetics, stable isotopes and fatty acids and metabolomics. This component of work was funded by Defra through the Healthy and Biologically Diverse Seas Evidence group and supported by JNCC. A summary of this work is presented in sections 11.1 & 11.2 with detail provided in a separate report (Plint et al in prep).

The question being addressed here was whether the animals had similar diets and foraging areas prior to stranding, whether multiple pods were involved in the larger group (otherwise known as a pod aggregation or clan gathering), whether foraging ecology had recently shifted, and whether the whales were in good nutritional condition.

## 11.1 Population Structure

Dr. Rachel Ball; University of Glasgow.

Dr. Niall McKeown; Aberystwyth University.

Long-finned pilot whales are the species most frequently involved in mass stranding events worldwide (Sergeant, 1962; Evans et al., 2005). Their social structure is characterised by bisexual natal philopatry, where both males and females remain in their natal groups for life.

Behavioural studies indicate that long-finned pilot whale pods typically consist of 3–14 closely bonded individuals, which are composed of long-term social companions (Augusto et al., 2017b; De Stephanis et al., 2008; Ottensmeyer & Whitehead, 2003). These pod units aggregate to form pod complex larger social groupings within pod complexes; alloparental care has been observed from both males and females (Augusto et al., 2017a).

At an even broader social level, clans may form, consisting of temporary aggregations of over 150 individuals. Mating behaviour observed within these clan gatherings supports the hypothesis that exogamy (outbreeding between pods) occurs in these larger assemblages (De Stephanis et al., 2008).

Although genetic studies on free-ranging long-finned pilot whales are scarce, research on the Faroese *grindadráp* (pilot whale hunts) provides valuable insights into their social genetics. These hunts typically involve entire groups, presumed to represent pods although, with median group sizes of 57 individuals these are indicative of pod complexes rather than single pod units ((Nichols et al., 2020)). Genetic analyses of these captures have revealed extended family structures in which males remain within their natal groups but avoid breeding with closely related individuals (Amos et al., 1993).

### **Results:**

Genetic analysis of this mass stranding event revealed that the long-finned pilot whales involved belonged to multiple, unrelated pod units, consistent with a multigroup association likely related to breeding. Although relatedness within maternal clusters was high, the average relatedness across the entire group was low, indicating the presence of several genetically distinct family units. No evidence of inbreeding or heterozygosity deficiency was detected in the MSE group, conforming to patterns observed across the broader eastern North Atlantic population. Furthermore, four unique (private) alleles were detected in some individuals within the group, which were not found in any other single or mass strandings, highlighting the potential for such events to result in the loss of rare genetic variants.

Additionally, 53% of juveniles in this MSE were missing their mothers. Some juveniles were assigned to maternal clusters, suggesting potential alloparental care behaviours such as babysitting prior to the MSE. Critically, spatial separation of

related individuals across the stranding site demonstrated that physical proximity on the beach did not reflect genetic relatedness. This finding has important implications for rescue operations: responders should not assume that a calf nearest to an adult female is her offspring, and live animal incident management decisions should account for the complex social structure of mixed-pod aggregations rather than treating stranded groups as single family units. Widespread spatial disruption of kin, including separation of most mother–juvenile pairs, may have led to social confusion upon entering shallow waters, contributing to the stranding.

## 11.2 Stable Isotope and Fatty Acid Analysis

Dr Tessa Plint & Anna Kebke: University of Glasgow, Heriot-Watt University.

Stable isotope and fatty acid analyses are powerful tools in remote ecological monitoring, offering valuable insights into the foraging niche, diet composition, and habitat use of marine mammals. These analytical techniques provide critical information, including trophic position within the food web, habitat preferences (such as coastal, pelagic, or benthic zones), estimations of preferred prey species and their proportional contributions to the diet, as well as seasonal and ontogenetic dietary shifts. Furthermore, they are useful in assessing nutritional condition and foraging success.

The principle underlying stable isotope analysis is encapsulated in the concept "you are what and where you eat," which describes how isotopic signatures integrate information about diet and habitat into animal tissues over time. These isotopic signatures accumulate at varying rates depending on the tissue being analysed, enabling the reconstruction of dietary history over different temporal scales. For instance, liver tissue reflects dietary information over a matter of days, skin over weeks, muscle over months, and bone over years (Connolly et al., 2004; Deniro & Epstein, 1978, Teixeira et al., 2022).

The objective of this analysis was to employ stable isotope and fatty acid analyses to reconstruct the ecological niche, diet, and habitat use of long-finned pilot whales involved in the 2023 Isle of Lewis mass stranding event. By analysing stable isotopes of carbon ( $\delta^{13}\text{C}$ ), nitrogen ( $\delta^{15}\text{N}$ ), and sulphur ( $\delta^{34}\text{S}$ ) across a time series of tissues with different dietary incorporation rates (liver, skin, muscle) and blubber fatty acids, it was possible to gain insights into the trophic level, foraging, and nutritional condition of these animals in the weeks to months preceding the event. The resulting data were compared with samples from single-stranded individuals affected by chronic illness or starvation to identify contrasting values between healthy and compromised individuals, enabling a more comprehensive understanding of the health status of the stranded group.

**Results:** Results from stable isotope and fatty acid analysis showed that the animals involved in the 2023 Isle of Lewis MSE were in good nutritional condition and exhibited no evidence of a recent dietary shift indicative of a change in foraging depth or habitat use. This finding contrasts with one hypothesis that the whales may have been exploiting prey in shallower waters prior to stranding and suggests there

was no sudden (i.e., days prior) alteration in their foraging ecology. This project demonstrated that stable isotope and fatty acid analysis is a viable tool for long-term, remote monitoring of data-deficient cetacean species.

## Section 12: Impacts of Underwater Noise and Hearing

As light attenuates rapidly underwater, cetaceans inhabit an environment where sound is the primary sensory modality. Hearing is thus essential to the survival and ecological fitness of these deep-diving species, which depend upon acoustic cues for vital biological functions including prey detection, orientation, predator evasion, and communication. Consequently, any degree of hearing loss or impairment can have consequences, disrupting essential behaviours and potentially compromising individual fitness and population viability.

### 12.1 Cochlear (ear) analysis

Maria Morell; University of Hannover

Hearing impairment can be caused by several factors, such as noise exposure, age, ototoxic drugs exposure, pollutants, infections, and congenital disorders (Southall et al., 2019; Morell et al., 2020; Rohner et al., 2022; Siebert et al., 2022). Similar to documented hearing loss in humans and terrestrial mammals, repeated exposure to loud noises of specific intensity and frequency can cause temporary or permanent hearing loss in cetaceans. Permanent hearing loss is associated with structural alterations within the organ of Corti (Figure 19), including damage to hair cell stereocilia and degeneration/loss of sensory cells. Unlike some organisms, mammalian hair cells lack regenerative capacity, with neighbouring cells actively participating in scar formation upon cell death. Additionally, loud noise exposure can induce morphological changes on the tectorial membrane, altering the imprints left by healthy hair cells. These imprints can remain even after hair cell disappearance and can be assessed through electron microscopy. High-intensity sources like active sonar and underwater noise from shipping, gas exploration, or seismic surveys could potentially cause such severe lesions that they become directly or indirectly lethal, e.g. gas embolism (Epson et al., 2005), hearing compromise (Southall et al., 2007) or displacement.

Examining the cochlea for scarring patterns and stereocilia imprints can be a valuable tool for identifying past acoustic trauma in whales, despite potential artefacts arising from tissue decomposition. Furthermore, the location of damage within the cochlea can provide clues about the frequency range of the sound that caused the injury. However, obtaining reliable data requires rapid cochlea fixation (ideally within 15 hours postmortem) to minimise postmortem changes that can obscure these vital indicators of noise exposure.

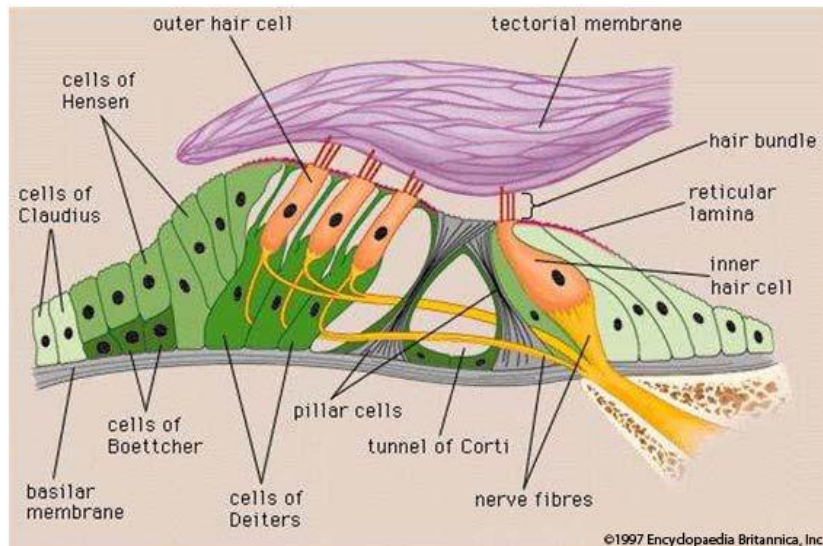


Figure 19: Schematic representation of the organ of Corti or hearing organ in mammals, formed by one row of inner hair cells (IHCs) and three rows of outer hair cells (OHCs).

Due to the time required to recover the stranded animals, only the freshest carcasses ( $\leq 40$  hours post-mortem) had their ears preserved for examination. While autolysis may hinder definitive diagnostics, ultrastructural assessment can still provide valuable insights into potential noise-related pathology and inner ear condition. However, the delay in preservation may limit the ability of analyses to determine whether noise exposure contributed to this stranding event (Morell et al., 2017).

**Results:** Necropsy examination did not reveal evidence of direct blast trauma. Several animals did appear to have haemorrhage in one or both ears, however, this may have been caused by agonal congestion which can occur during stranding. The analysis of cochlea by scanning electron microscopy takes several months due to lengthy decalcification processes. Initial results did not detect overt pathology consistent with acoustic trauma although substantial autolysis precluded assessment of fine structural detail. More specialist diagnostics are currently underway and if applicable will be published in due course.

## 12.2 Underwater Noise Assessment

Underwater sounds have been shown to injure or disturb cetaceans, and around the world, cases have been documented of cetacean mass strandings that have been linked to underwater noise, across many species.

The Scottish Government's Marine Directorate-Science, Evidence, Data and Digital (MD-SEDD) Portfolio has reviewed several acoustic information sources available around the time of the pilot whale mass stranding at Tolsta on the east of the Isle of Lewis in July 2023. This includes analysis of passive acoustic data collected through existing co-deployed broadband and click detector recorders at two different locations, one at a site approximately 12.5 km offshore of the beach where the stranding occurred (Tolsta site), and another one at a site on the west of the Lewis

(Garenin site). Data from the week prior to, and the day of the stranding were analysed. Both broadband acoustic data and cetacean click detections were available around the time of the stranding event and the report seeks to provide an account of (1) the presence of cetaceans around the time of the stranding, and (2) the presence of any identified sounds from presumed anthropogenic sources, acknowledging the limitations of inferring any conclusions from single underwater recorders. It also summarises activities that were taking place in the region at the time, that may have generated underwater noise.

At the Tolsta site, cetaceans were detected regularly throughout the analysis period on both the broadband and click detector recorders. However, these detections could not be attributed to specific cetacean species, except to delphinids or porpoises. A total of 1,330 unique cetacean detection events were identified throughout the analysis period in the broadband data. Shipping noise was commonly encountered at the Tolsta site, and impulsive sounds were found in the recordings at around 01:00 UTC and 05:00 UTC (02:00 and 06:00 British Summer Time) on 16 July. Impulsive sounds were not found at other times. Given the frequencies and pulse patterns of these sounds, and that they decreased in amplitude over the duration of the recording, the sounds appear to be consistent with echosounders which are commonly found on vessels throughout Scottish waters, which would decrease in amplitude if the vessel was moving away from the acoustic recorder. However, the source of the detected sounds cannot be verified given the lack of vessel presence at the time in the Automatic Identification System (AIS) and Vessel Monitoring System (VMS) evidence. The area of the sea in which the sounds detected by the recorders were audible is also unknown. From the data gathered, combined with the uncertainty around the time of the stranding, it is not possible to determine whether the pilot whales were in the area to hear these sounds, or what effect they may have had on their behaviour if they were. However, echosounders are widely used by vessels, and would not be unusual sounds in the marine environment.

The recordings from the Garenin site on the west of Lewis included high levels of shipping noise and cetacean detections, but at much lower levels than those seen at the Tolsta site. Other biological sounds were also recorded, including sounds that are considered likely to have been from fish such as haddock.

In reviewing activities that could have produced underwater noise, MD-SEDD approached the Ministry of Defence (MOD), which reported activity in the area. However, the information provided by the MOD does not suggest any obvious activity that may have been a factor in the strandings, such as the use of active sonar or explosives, which have previously been linked with cetacean strandings around the world. Activities taking place under licence included a geophysical survey at a wind farm lease area on the west of Lewis. Much of that activity was carried out at very high frequencies, well outside of pilot whale hearing ranges. Sounds from the geophysical survey were not detected in the acoustic data collected by MD-SEDD at the Garenin site.

The results of this work are presented in the publication: [\*Report on Passive Acoustic Underwater Monitoring Data and Potential Sources of Noise in Relation to a Mass\*](#)

## Section 13: Conclusions

Although mass strandings are unfortunate events, they offer rare opportunities to examine large groups of individuals sharing a common ecological context, and gain data around the health, behaviour and ecology of an otherwise largely inaccessible species.

This investigation into the mass stranding of 54 long-finned pilot whales at Tolsta, Isle of Lewis demonstrates the value of a multifactorial, multidisciplinary approach for assessing complex events such as this. To understand the role and impact of factors potentially causal to this event, it is necessary to be able to reliably distinguish what is normal from what may not be. This in turn relies on detailed baseline data across a suite of metrics describing health, reproduction, and toxin burden. These provide the context necessary to collate and interpret the findings. Integrating data from detailed necropsies, supported by extensive histopathology and microbiological screening enabled detailed evaluations to be made about individual body condition and disease status. The addition of data on feeding ecology, reproductive status and toxicological burden, combined with an appraisal of environmental and oceanographic factors, offered a robust dataset for evaluating both proximate and ultimate causes of mortality. A summary evaluating plausible causal factors is given in Table 4.

These examinations, conducted across multiple individuals, revealed no significant evidence of infectious disease, traumatic injury, or pathological abnormalities. The animals were in generally good nutritional condition, with low parasite burdens and no substantial toxin or contaminant burdens for the most likely agents. It is therefore possible to exclude disease or poor health as likely primary drivers of the event.

It is likely significant that one animal showed signs of dystocia, which may have acted as a social or behavioural trigger. This species' well documented strong social cohesion may have contributed to group following behaviour, exacerbated by local environmental conditions, including shallow bathymetry, onshore winds, and a soft substrate; all factors likely to have impaired navigation. These environmental variables, in conjunction with social dynamics, plausibly culminated in a high mortality rate once stranding occurred.

Harmful algal bloom screening for saxitoxin and domoic acid tested below the limit of detection for both toxins, indicating that harmful algal blooms were not a contributing factor to the stranding event.

Heavy metal analysis revealed that the adult animals involved in the stranding exhibited higher contamination levels than juveniles, consistent with expected bioaccumulation patterns over time. Measured concentrations fell within ranges reported in previous studies of similar cetacean populations. Although some individuals approached established thresholds for mercury-induced hepatotoxicity,

overall contamination levels were unlikely to have contributed to the mass stranding event.

Feeding ecology analysis results suggested the animals showed no evidence of recent dietary shifts, suggesting that prey pursuit in unfamiliar shallow waters was unlikely to have triggered the event.

Genetic and isotopic data revealed the presence of multiple unrelated pod units, some with distinct isotope signatures, suggesting that the whales were aggregating prior to the stranding event (O'Callaghan, 2023; Oremus et al., 2013). Widespread spatial disruption of kin, including separation on the beach, notably among mother–juvenile pairs, might be an indication that that social disorganisation and confusion during entry into shallow waters may have been a contributory factor in the stranding.

Kinship analysis revealed distinct resource-use patterns among pods and the absence of certain members (e.g., juveniles without mothers), suggesting that not all individuals present in the area stranded. When integrated with reproductive assessments which indicated that several females were pregnant with near-term or recently conceived fetuses or had recently given birth, these findings support the hypothesis that the event represented a clan-level aggregation of multiple genetically distinct pods, potentially assembled for breeding and calving. Although data from Scotland are limited, observations from Norway and the Faroe Islands suggest that higher latitudes are used as calving areas by this species. (Donovan et al., 1993; O'Callaghan, 2023) Historical sighting data do not indicate large coastal aggregations for this species, and thus further research would be required to understand if the distribution or presence of these whales may be changing, for example, in response to drivers such as climate change or prey availability.

Acoustic analysis of two underwater recorders located at a site approximately 12.5 km offshore of Tolsta, and at a site on the west of the Lewis, indicated the presence of routine shipping noise and echosounder signals consistent with typical background conditions in Scottish coastal waters. No noise sources of unusual character, magnitude, or duration, such as those known to influence cetacean behaviour, were detected in the data. Furthermore, no marine activities were reported in the area during the relevant period that would be expected to generate acoustic disturbance of sufficient intensity to cause a mass stranding event. It remains possible, however, that disturbance sources not detected may have occurred.

Although no single factor was identified as the definitive cause of the event, it is plausible that once the animals approached the shore, a combination of factors contributed to the stranding. These include the presence of a female experiencing dystocia, the associated social milling behaviour observed the previous day, and the bay's bathymetric features, which may have made navigation difficult. This pattern aligns with the species' strong social cohesion, in which individuals tend to remain close to a compromised conspecific. The circumstances are therefore considered more likely to have arisen from a combination of interacting biological and environmental stressors, rather than from a single causative factor.

This study also highlights the value of combining genetic and dietary markers to distinguish pod units in future stranding events. Investigating changes in long-finned pilot whale distribution and habitat use around the UK and understanding seasonal changes on their distribution should be part of future research.

The work summarised in this report will be further disseminated through peer-reviewed publications, expanding on elements of the 2023 stranding event and broader aspects of pilot whale ecology and population health. Together, these data offer a valuable reference point for future stranding assessments and contribute to a deeper understanding of long-finned pilot whale conservation in a changing marine environment.

Table 4: Summary table of potential factors in the mass stranding event.

	Factor	Why was this offshore species close inshore	What factors might have led them to strand	Once stranded, why was the mortality rate so high?
<b>Acute anthropogenic impact</b>	Boat strike	1	1	1
<b>Acute anthropogenic impact</b>	Bycatch or entanglement	1	1	1
<b>Acute anthropogenic impact</b>	Impulsive underwater noise (any source)	1	1	1
<b>Acute anthropogenic impact</b>	Fishing activity	1	1	1
<b>Acute anthropogenic impact</b>	Disturbance by vessel traffic	1	1	1
<b>Acute anthropogenic impact</b>	Detonation of underwater explosives	1	1	1
<b>Environmental factors</b>	Biotoxins from algal blooms	1	1	1
<b>Environmental factors</b>	Toxic heavy metal burden	1	1	1
<b>Environmental factors</b>	Weather, wind or tide influence	2	2	2
<b>Environmental factors</b>	Beach morphology	1	2	2
<b>Environmental factors</b>	Earthquakes	1	1	1
<b>Environmental factors</b>	Inshore foraging	1	1	1
<b>Environmental factors</b>	Predator attack/presence	1	1	1
<b>Health, physiological or behavioural factors</b>	Physiological compromise	1	1	2
<b>Health, physiological or behavioural factors</b>	Dystocia	2	2	1
<b>Health, physiological or behavioural factors</b>	Bacterial infection	1	1	1
<b>Health, physiological or behavioural factors</b>	Poor body condition	1	1	1
<b>Health, physiological or behavioural factors</b>	Viral infection	1	1	1
<b>Health, physiological or behavioural factors</b>	Gas/ fat embolism	1	1	1
<b>Health, physiological or behavioural factors</b>	Infectious disease	1	1	1
<b>Health, physiological or behavioural factors</b>	Navigational error	2	2	1
<b>Health, physiological or behavioural factors</b>	Social bonds	2	2	1

1 (green) = No or limited evidence; 2 (orange) = Plausible influence.

## Section 14: Bibliography

- Amos, B., Schlötterer, C., & Tautz, D. (1993). [Social Structure of Pilot Whales Revealed by Analytical DNA Profiling](#). *Science*, 260(5108), 670–672.
- Augusto, J. F., Frasier, T. R., & Whitehead, H. (2017a). [Characterizing alloparental care in the pilot whale \(\*Globicephala melas\*\) population that summers off Cape Breton, Nova Scotia, Canada](#). *Marine Mammal Science*, 33(2), 440–456.
- Augusto, J. F., Frasier, T. R., & Whitehead, H. (2017b). [Social structure of long-finned pilot whales \(\*Globicephala melas\*\) off northern Cape Breton Island, Nova Scotia](#). *Behaviour*, 154(5), 509–540.
- Brownlow, A., Baily, J., Dagleish, M., Deaville, R., Jensen, S., Krupp, E., Law, R., Penrose, R., Read, F., & Jepson, P. (2011). *Investigation into the long-finned pilot whale mass stranding event, Kyle of Durness, 22 nd July 2011*. (July), 1–59.
- Connolly, R. M., Guest, M. A., Melville, A. J., & Oakes, J. M. (2004). [Sulfur stable isotopes separate producers in marine food-web analysis](#). In *Oecologia* (Vol. 138, Number 2, pp. 161–167).
- Dam, M., & Bloch, D. (2000). [Screening of mercury and persistent organochlorine pollutants in long-finned pilot whale \(\*Globicephala melas\*\) in the Faroe Islands](#). *Marine Pollution Bulletin*, 40(12), 1090–1099.
- Davison, N. J. N. J., Brownlow, A., McGovern, B., Dagleish, M. P. M. P., Perrett, L. L. L. L., Dale, E. J. E.-J., Koylass, M., & Foster, G. (2015). First report of *Brucella ceti*-associated meningoencephalitis in a long-finned pilot whale *Globicephala melas*. *Diseases of Aquatic Organisms*, 116(3), 237–241.
- De Stephanis, R., Verborgh, P., Pérez, S., Esteban, R., Minvielle-Sebastia, L., & Guinet, C. (2008). [Long-term social structure of long-finned pilot whales \(\*Globicephala melas\*\) in the Strait of Gibraltar](#). *Acta Ethologica*, 11(2), 81–94.
- Deniro, M. J., & Epstein, S. (1978). *Influence of diet on the distribution of carbon isotopes in animals\** (Vol. 42).
- Dietz, R., Letcher, R. J., Aars, J., Andersen, M., Boltunov, A., Born, E. W., Ciesielski, T. M., Das, K., Dastnai, S., Derocher, A. E., Desforges, J. P., Eulaers, I., Ferguson, S., Hallanger, I. G., Heide-Jørgensen, M. P., Heimbürger-Boavida, L. E., Hoekstra, P. F., Jenssen, B. M., Kohler, S. G., ... Sonne, C. (2022). [A risk assessment review of mercury exposure in Arctic marine and terrestrial mammals](#). *Science of the Total Environment*, 829.
- Donovan, G. P., Lockyer, C., & Martin, A. R. (1993). *Biology of Northern Hemisphere Pilot Whales: A Collection of Papers*. International Whaling Commission.
- Foster, G., MacMillan, A. P., Godfroid, J., Howie, F., Ross, H. M., Cloeckert, A., Reid, R. J., Brew, S., & Patterson, I. A. P. P. (2002). [A review of \*Brucella\* sp. infection of sea mammals with particular emphasis on isolates from Scotland](#). *Veterinary Microbiology*, 90(1–4), 563–580.

- Foster, G., Whatmore, A. M. A. M., Dagleish, M. P. M. P., Baily, J. L. J. L., Deaville, R., Davison, N. J. N. J., Koylass, M. S. M. S., Perrett, L. L. L. L., Stubberfield, E. J. E. J., Reid, R. J. R. J., & Brownlow, A. C. A. C. (2015). [Isolation of \*Brucella ceti\* from a long-finned pilot whale \(\*Globicephala melas\*\) and a sowerby's beaked whale \(\*Mesoploden bidens\*\)](#). *Journal of Wildlife Diseases*, 51(4), 868–871.
- Grant, R. J., Banyard, A. C., Barrett, T., Saliki, J. T., & Romero, C. H. (2009). [Real-time RT-PCR assays for the rapid and differential detection of dolphin and porpoise morbilliviruses](#). *Journal of Virological Methods*, 156(1–2), 117–123.
- Hall, A. J., Kershaw, J. L., Fraser, S., Davidson, K., Rowland-Pilgrim, S., Turner, A. D., & McConnell, B. (2024). [Estimating the risks of exposure to harmful algal toxins among Scottish harbour seals](#). *Harmful Algae*, 136.
- Harding, S., & Cousins, N. (2022). [Secretariat of the Convention on Biological Diversity \(CBD\)](#). In *International Regulatory Co-operation* (Number 99). OECD.
- Hoydal, K. S., Erenbjerg, S. V., & Dam, M. (2024). [Mercury speciation in pilot whale from Faroe Islands, 1977–2015](#). *Environmental Pollution*, 356.
- Ijsseldijk, L. L., Brownlow, A. C., & Mazzariol, S. (2019). *Best practice on cetacean post mortem investigation and tissue sampling Joint ACCOBAMS and ASCOBANS document Editors*.
- IWC. (2016). *Report of an IWC Workshop Developing Practical Guidance for the Handling of Cetacean Stranding Events*. 1–23.
- Jensen, S.-K., Lacaze, J.-P., Hermann, G., Kershaw, J., Brownlow, A., Turner, A., & Hall, A. (2015). [Detection and effects of harmful algal toxins in Scottish harbour seals and potential links to population decline](#). *Toxicon*, 97.
- Jepson, P. D., Deaville, R., Patterson, I. A. P., Pocknell, A. M., Ross, H. M., Baker, J. R., Howie, F. E., Reid, R. J., Colloff, A., & Cunningham, A. A. (2005). [Acute and chronic gas bubble lesions in cetaceans stranded in the United Kingdom](#). *Veterinary Pathology*, 42(3), 291–305.
- Jepson, P. D. P. D. P. D., Deaville, R., Barber, J. L. J. L., Aguilar, À., Borrell, A., Murphy, S., Barry, J., Brownlow, A., Barnett, J., Berrow, S., Cunningham, A. A. A. A., Davison, N. J. N. J., ten Doeschate, M., Esteban, R., Ferreira, M., Foote, A. D., Genov, T., Giménez, J., Loveridge, J., ... Law, R. J. R. J. (2016). [PCB pollution continues to impact populations of orcas and other dolphins in European waters](#). *Scientific Reports*, 6(November 2015), 1–17.
- Kershaw, J. L., Jensen, S. K., McConnell, B., Fraser, S., Cummings, C., Lacaze, J. P., Hermann, G., Bresnan, E., Dean, K. J., Turner, A. D., Davidson, K., & Hall, A. J. (2021). [Toxins from harmful algae in fish from Scottish coastal waters](#). *Harmful Algae*, 105.
- Morell, M., Brownlow, A., McGovern, B., Raverty, S. A., Shadwick, R. E., & André, M. (2017). [Implementation of a method to visualize noise-induced hearing loss in mass stranded cetaceans](#). *Scientific Reports*, 7.

- Morell, M., Raverty, S. A., Mulsow, J., Haulena, M., Barrett-Lennard, L., Nordstrom, C. A., Venail, F., & Shadwick, R. E. (2020). [Combining Cochlear Analysis and Auditory Evoked Potentials in a Beluga Whale With High-Frequency Hearing Loss](#). *Frontiers in Veterinary Science*, 7.
- Nichols, H. J., Arbuckle, K., Fullard, K., & Amos, W. (2020). [Why don't long-finned pilot whales have a widespread postreproductive lifespan? Insights from genetic data](#). *Behavioral Ecology*, 31(2), 508–518.
- O'Callaghan, S. A. (2023). [Observations of long-finned pilot whale \(\*Globicephala melas\*\) calves less than one year old, including neonates and a very recently born calf, in northern Norway](#). *Polar Research*, 42.
- Oremus, M., Gales, R., Kettles, H., & Baker, C. S. (2013). [Genetic evidence of multiple matriline and spatial disruption of kinship bonds in mass strandings of long-finned pilot whales, \*Globicephala melas\*](#). *Journal of Heredity*, 104(3), 301–311.
- Ottensmeyer, C. A., & Whitehead, H. (2003). [Behavioural evidence for social units in long-finned pilot whales](#). *Canadian Journal of Zoology*, 81(8), 1327–1338.
- Ramsay, D. L., & Brampton, A. H. (2000). *Coastal Cells in Scotland: Cells 8 & 9 -The Western Isles*. (Number 150).
- Richardson, J. W., Greene Jr, C.R., Malme, C.I. and Thomson, D.H., (1998) 2013. *Marine mammals and noise*. Academic Press.
- Rohner, S., Morell, M., Wohlsein, P., Stürznickel, J., Reiter, E. B., Jahnke, A., Prenger-Berninghoff, E., Ewers, C., Walther, G., Striwe, L. C., Failla, A. V., & Siebert, U. (2022). [Fatal aspergillosis and evidence of unrelated hearing loss in a harbor porpoise \(\*Phocoena phocoena\*\) from the German Baltic Sea](#). *Frontiers in Marine Science*, 9.
- Siebert, U., Stürznickel, J., Schaffeld, T., Oheim, R., Rolvien, T., Prenger-Berninghoff, E., Wohlsein, P., Lakemeyer, J., Rohner, S., Aroha Schick, L., Gross, S., Nachtsheim, D., Ewers, C., Becher, P., Amling, M., & Morell, M. (2022). [Blast injury on harbour porpoises \(\*Phocoena phocoena\*\) from the Baltic Sea after explosions of deposits of World War II ammunition](#). *Environment International*, 159(November).
- Sierra, E., Fernández, A., Felipe-Jiménez, I., Zucca, D., Díaz-Delgado, J., Puig-Lozano, R., Cámara, N., Consoli, F., Díaz-Santana, P., Suárez-Santana, C., & Arbelo, M. (2020). [Histopathological Differential Diagnosis of Meningoencephalitis in Cetaceans: Morbillivirus, Herpesvirus, Toxoplasma gondii, Brucella sp., and Nasitrema sp.](#) *Frontiers in Veterinary Science*, 7(September).
- Southall, B. L., Bowles, A. E., Ellison, W. T., Finneran, J. J., Roger L. Gentry, Jr., C. R. G., Kastak, D., Ketten, D. R., Miller, J. H., Nachtigall, P. E., Richardson, W. J., Thomas, J. A., & Tyack, P. L. (2007). Marine mammal noise-exposure criteria: initial scientific recommendations. *Aquatic Mammals*, 33(4).
- Southall, E. B. L., Finneran, J. J., Reichmuth, C., Nachtigall, P. E., Ketten, D. R., Bowles, A. E., Ellison, W. T., Nowacek, D. P., & Tyack, P. L. (2019). [Marine mammal noise exposure criteria: Updated scientific recommendations for residual hearing effects](#). *Aquatic Mammals*, 45(2), 125–232.

- Teixeira, C. R., Troina, G. C., Daura-Jorge, F. G., Simões-Lopes, P. C., & Botta, S. (2022). [A practical guide on stable isotope analysis for cetacean research](#). In *Marine Mammal Science* (Vol. 38, Number 3, pp. 1200–1228). John Wiley and Sons Inc.
- Van Bresseem, M. F., Raga, J. A., di Guardo, G., Jepson, P., Duignan, P., Siebert, U., Barrett, T., de Oliveira Santos, M. C., Moreno, I., Siciliano, S., & others. (2008). Emerging and recurring diseases in cetaceans worldwide and the role of environmental stressors. In *DISEASES OF AQUATIC ORGANISMS*.
- Waggitt, J. J., Evans, P. G. H., Andrade, J., Banks, A. N., Boisseau, O., Bolton, M., Bradbury, G., Brereton, T., Camphuysen, C. J., Durinck, J., Felce, T., Fijn, R. C., Garcia-Baron, I., Garthe, S., Geelhoed, S. C. V., Gilles, A., Goodall, M., Haelters, J., Hamilton, S., ... Hiddink, J. G. (2020). [Distribution maps of cetacean and seabird populations in the North-East Atlantic](#). *Journal of Applied Ecology*, 57(2), 253–269.
- Weihe, P., Grandjean, P., Debes, F., & White, R. (1996). [Health implications for Faroe islanders of heavy metals and PCBs from pilot whales](#). *Science of the Total Environment*, 186(1–2), 141–148.
- Weilgart, L. S. (2007). [The impacts of anthropogenic ocean noise on cetaceans and implications for management](#). *Canadian Journal of Zoology*, 85(11), 1091–1116.



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