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Sowerby's Beaked Whales (*Mesoplodon bidens*) in the Skagerrak and Adjacent Waters: Historical Records and Recent Post-Mortem Findings

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Abstract: In contrast to sparse historical observational records, five Sowerby's beaked whales (SBW) stranded and died in Swedish waters between 2015 and 2020. Here we summarize historical records of SBWs in the Skagerrak basin and adjacent waters. The three recent stranding events from Sweden are described, and the post-mortem findings, including diet analysis, from the five SBWs are presented. Of 30 historical records of SBWs observations since 1869, 13 (43%) were documented between 2010 and 2021, and records between July and November were the most frequent. The recent stranding events occurred in October 2015 ($n = 1$), August 2019 ($n = 3$) and July 2020 ($n = 1$). Four of the SBWs were examined through necropsy, and one was sampled in the field. They were all sub-adults and included a single female and four males. The causes of death were emaciation, euthanasia due to traumatic injury, and live stranding of undetermined cause. Two SBWs each had a focal bone lesion consistent with osteomyelitis. Other findings included pox-like dermatitis, trauma, focal granulomas in a lymph node and intestine, and ulceration of the stomach. CT scans were performed on the heads of two animals, with inconclusive results. Three SBWs had hard parts in the gastrointestinal tract that mainly consisted of otoliths from several fish species. An eDNA-analysis confirmed and supplemented the diet analysis, revealing 17 fish species in total, including species not previously described as prey for SBW, such as *Pleuronectidae* spp. The apparent increase in observational records since 2010 may indicate a shift in SBW distribution or changing threats to these animals. Our results support and expand theories on SBW movements and provide data on the biology and health of this poorly known species, which are valuable for conservation and legislation efforts.

Keywords: Sowerby's beaked whale; *Mesoplodon bidens*; pathology; stranding records; beaked whales; marine mammal; diet



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1. Introduction

Sowerby's beaked whales (*Mesoplodon bidens* (Sowerby, 1804), SBW) have the most northerly range of *Mesoplodon* beaked whale species in the Atlantic Ocean, but their distribution, biology and threats are not fully understood [1,2]. Recent studies have found morphological differences between SBWs from the western and eastern North Atlantic, suggesting a metapopulation structure or several populations within the species [3,4]. Thus, intra-species differences regarding their ecology, behaviour or migrations may exist.

In the Northeast Atlantic, observations of SBWs have been recorded as far north as the polar seas of northern Norway [5] to the south and east around the Azores, in the Tyrrhenian Sea, in the Mediterranean, and by the Canary Islands [6–9]. An abundance estimate, although based on a few sightings of SBWs and grouped together with other

beaked whale species, showed sighting concentrations in a hot spot south of Iceland and northwest of Ireland [10]. Observations of SBWs with calves off western Ireland in May further support this as an important area, possibly for calving and breeding [11]. There is also support for the year-round presence of SBWs and other beaked whales, with greater intensity in the summer months, in the Bay of Biscay [12].

The most frequent records of SBWs in the Northeast Atlantic have come from the coasts of the UK and Ireland as stranded dead specimens. Between 1803 and 2021, over 160 records have been filed [13]. Most strandings in the Northeast Atlantic have involved juveniles and occurred during the summer to fall months [14]. These trends may reflect population distribution patterns or seasonal migration routes [14]. As pelagic, deep-diving animals, it is theorised that their natural diving behaviour is constrained by the shallow continental shelves southwards, and they, therefore, are confined within the deeper trenches when they migrate south [1,14,15]. Deep water basins, or deeper canals, within these continental shelves may work as a corridor, and in some cases, ‘trap’ deep-diving whales in their attempt to find deeper waters [1,14,16]. It is suggested that this may be more problematic for inexperienced juveniles than for adults that may have learned the geographical and bathymetrical barriers [15]. The theory is supported by the many beaked whale strandings in the North Sea and the UK that have occurred in estuaries [14]. If SBWs have seasonal migration routes to reach proposed hot spots and breeding and calving areas [10,11], the southward route could lead them into these deeper canals that are surrounded by shallow continental shelves.

The southern part of the roughly 200 m deep Norwegian trench leads into the Skagerrak, a deep-water basin surrounded by the coasts of Sweden, Denmark and Norway. The Skagerrak is the only route connecting the Atlantic Ocean to the Baltic Sea, through the sea basins of the Skagerrak, the Kattegat, the Sound and Great and Little Belts. Records of several beaked whales have been documented along the Skagerrak coastline. Through a compilation of known observations, this paper presents the sparse historical records and the apparent increase in the frequency of observations of SBWs in recent years.

Because beaked whales inhabit deep, pelagic waters, they are difficult species to study. Findings from examinations of carcasses, therefore, are important sources of information. Causes of death of SBWs determined through necropsy examination include entanglement in fishing gear, trauma including ship strike and neurobrucellosis [17–20]. Several beaked whale strandings have coincided with naval activities and active sonar use, indicating that the physiological impact of loud underwater noise is a threat to them [17,21–24]. However, the decomposition of carcasses makes the physiological impacts of loud noise, such as auditory trauma in the cochlea and gas embolism, challenging to diagnose [22,24].

There is a proposed niche separation between beaked whale species in the North Atlantic through diet, where Northern bottlenose whale (*Hyperoodon ampullatus*, NBW) and Cuvier’s beaked whale (*Ziphius cavirostris*, CBW) mainly prey on larger squid species at depths below 1000 m, while *Mesoplodon* spp. mainly feed on smaller fish, and to some degree on smaller squid species, between 200 and 1000 m in depth [25–27]. It is also proposed that SBWs feed opportunistically, and with plasticity, supported by the variety of prey species found in diet studies [25–27]. However, relatively few accounts of stomach contents have been published from SBWs and more data is needed to confirm the ecological role and trophic level of SBWs and investigate if these vary between areas [25].

The three main objectives of this paper are (1) to contextualise the recent stranding frequency by summarising the historical records and data of SBWs in the Skagerrak basin and adjacent waters; (2) to describe the three SBW stranding events in Sweden between 2015 and 2020; (3) to present the biological and pathological findings from the five SBWs examined from those strandings, including the macroscopic and eDNA analyses of stomach contents.

2. Materials and Methods

2.1. Historical Records

Records of SBWs were collected from the land and waters in proximity to the Skagerrak and the southern Norwegian trench, the ‘deep water corridor’, that extends from the deep waters of the Northeast Atlantic to the deepest trench of Skagerrak, ‘Bratten’ (Figure 1). Records from the Kattegat, the Sound, Great and Little Belt, and the Baltic Sea were also collected, because the SBWs most likely passed through the Skagerrak to reach these areas. In practice, observations from the waters and coasts of Sweden, east- and north coast of Denmark, southern Norway and Baltic coasts of Germany and Poland were included.

Observational records from Sweden were collected from the Swedish Museum of Natural History (NRM), Gothenburg Museum of Natural history, and Lund university through personal contact and extraction from their databases. From Denmark and the Baltic Sea, unpublished and published records were made available by one of the authors (C.C.K.) [28–30]. Records from Norway were collected from the Norwegian Species Observation Service [31]. Records presented in Waller et al. 2014 [32] were also used to complement data from nineteenth-century records.

For each observation, available information on the location, date, length, sex, age class and other relevant information were compiled. Records of both live and dead SBWs were included. If the same individual was observed several times, only the last observation was used. Any stranding consisting of two or more individuals, excluding cow/calf pairs, was considered a mass stranding [33,34].

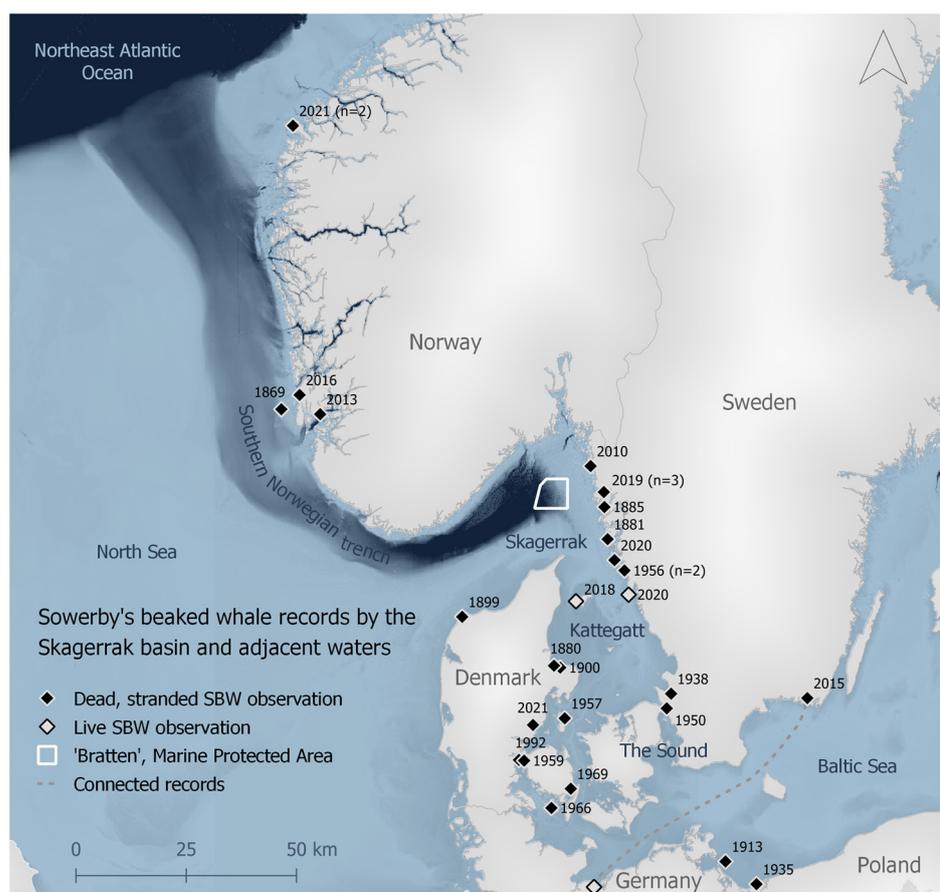


Figure 1. Geographical distribution of observational records of Sowerby's beaked whales (*Mesoplodon bidens*) in the Skagerrak basin and adjacent waters. GeoData from HELCOM (Open Street Map) [35], EMODnet Digital Bathymetry [36] and Lantmäteriet (MPA) [37].

2.2. Stranding Events 2015–2020

Three stranding events (2015, 2019 and 2020) were qualitatively described, including when the SBWs were first observed, how the animals were handled prior to and after death, before post-mortem examination. The information was collected from people involved in the stranding events, from archived records, and from valar.se [38], the Swedish network for cetacean surveillance.

2.3. Post-Mortem Examinations

Complete necropsies were carried out on four out of five SBWs, and field sampling was performed on the fifth. The necropsies were conducted at the National Veterinary Institute (SVA) in Uppsala, Sweden in three cases, and the fourth was performed in the field. Necropsies were performed two to five days after the animal was found dead in the field.

Necropsy examinations followed procedures outlined by Kuiken and Hartman [39] and ASCOBANS best practices [34]. Briefly, necropsy involves detailed, systematic examination of all organ systems accompanied by standardized sample and data collection and any ancillary diagnostic analyses needed to document abnormalities, assess general health status, and try to establish cause of death. After a thorough external examination, blubber is removed and examined before opening the body cavities to evaluate internal organs. Musculature is removed from the skeleton to assess any bony abnormalities. Decomposition codes of the carcasses were assigned from DCC1, representing very fresh to DCC5, only skeletal remains of the animal. Body measurements and blubber thickness were taken according to ASCOBANS best practices, including annexe 2 additional measurements for rare species [34]. Nutritional status was also qualitatively assessed based on contour of the dorsal musculature. The only body measurement collected from the SBW that was sampled in field 2019 was total length and blubber thickness, that was measured on the lateral side of the animal under the dorsal fin.

Gross lesions were documented and when suitable, tissues were collected in 10% neutrally buffered formalin for histopathological examination. Formalin-fixed tissues included skin, lymph nodes, lung, liver, adrenal glands, muscle, kidney, spleen, pancreas, intestine, reproductive organs, heart, and brain. Not all tissues could be collected from all animals. Tissue samples from all five SBWs were collected and stored in biobanks at NRM and SVA. Complete skeletons were collected from all five SBWs and saved at NRM and Gothenburg Natural History Museum. Formalin-fixed tissues were processed and embedded in paraffin and 3–4 μm sections were stained using Mayer's haematoxylin and eosin [40].

Stage of maturity was assessed based on gonadal development, and in males if teeth had erupted. Ovaries and testes were weighed and measured (length \times width \times height). Ovaries were examined for presence of corpus luteum and corpora albicans, and the width of the uterine horns was measured at the widest point.

Parasitic infections were scored as none (no parasites observed), mild infections, moderate or severe [41,42].

Two of the SBWs from the stranding in 2019 were investigated for evidence of trauma to the auditory system using high-resolution computerized tomography imaging (CT-scan). Due to severe decomposition, none of the inner ears were examined microscopically for evidence of acoustic trauma.

2.4. Diet Analysis

Diet analyses were performed both by gross visual hard part analysis and eDNA (environmental DNA)-analysis. For the hard-part analysis, the gastrointestinal tracts of all five SBWs were opened from stomach to anus, the content was washed until clean, and hard parts were collected. Otoliths were morphologically identified as close to species level as possible [43]. Due to erosion the otoliths were not identified to species level. The

otoliths were counted (n) to estimate the number of identified prey consumed (N), and the Numerical frequency (%N) of the fish species identified was calculated.

To complement the hard-part analysis, eDNA analysis was performed on stomach content of all five SBWs. eDNA extraction of Specimen 1 was performed by Rodrigo Esparza-Salas at NRM in 2018 with an ‘InviMag stool DNA kit KF96’ following the recommendations of the manufacturer for maximising DNA recovery for eukaryotes, and a Kingfisher duo instrument using a custom run protocol provided by Strattec. Two fragments of the mitochondria (16S short and 16S long) were targeted using primers (Table 1). eDNA extraction of Specimens 2–5 was performed by the Center for Genetic Identification (CGI) at NRM using a Kingfisher flex extraction robot, and a ‘Kingfisher Cell and Tissue’ DNA extraction kit, as described by the manufacturer. For the analysis, a short piece of the mitochondria (12S) was amplified using primers (Table 1) described in an earlier study [44].

Table 1. Forward and reverse sequences of the primer that was used for detection of eDNA in the gastrointestinal tract of Sowerby’s beaked whales (*Mesoplodon bidens*).

Gene Fragment	Primer Name	Primer F	Primer R
16S long	16sPreyF	CGTGCRAAGGTAGCG	GTCGCCCAACCRAAG
16S short	16sFiskF	GAAGACCCTWTGGAGCTTWAG	GTCGCCCAACCRAAG
12S	MiFish	AAACTCGTGCCAGCCACC	GGGTATCTAATCCCAGTTTG

The raw sequence data from all specimens were filtered and trimmed from primer sequences using the program cutadapt [45] and the remaining data were analysed with the R-package dada2 [46]. Remaining sequence variants were traced to species level through the tool BLAST (Basic Local Alignment Search Tool) [47] and the sequences were compared with the NCBI open nucleotide collection database. The sequence comparison of Specimens 2–5 was performed on 24 February 2022 and Specimen 1 on 20 March 2022.

3. Results

3.1. Historical Records

A total of 27 SBW observational events in proximity to the Skagerrak basin and adjacent waters were compiled. The reports spanned from 1869 to 2021, with a total of 30 individual whales (Table A1, Appendix A). Of these, 28 were dead or live stranded but died, one was a sighting of a live, seemingly healthy individual, and one was live stranded and assisted offshore, with no subsequent observation. There were two events defined as mass stranding (>1 individual), with two (1956) and three (2019) individuals, respectively. Additionally, a calf and a possible adult were stranded in close spatiotemporal proximity near the northern mouth of the southern Norwegian trench in 2021. One report was of skeletal remains (2010), with an unknown date of death.

The historical observations of SBWs varied between months (Figure 2), with a peak in August and September and a tendency of increasing numbers between June and November, and another peak in February. Twelve of the historical records were adults, of which four were females, seven were males and one from 1969 was described in historical records as ‘probably’ a female. Adult female lengths ranged between 4.19 and 5.02 m (mean = 4.77 m, median = 4.88 m) and adult males ranged between 4.40 and 5.00 m (mean = 4.56 m, median = 4.50 m). One female that was stranded in October 1900 was pregnant with a 70 cm long fetus. Eleven records were juveniles (five females and five males), of which one from July 2021 was a calf of unknown sex. Juvenile females with known length ranged between 3.20 and 3.62 m (mean = 3.40 m, median = 3.38 m), and juvenile males between 3.85 and 4.55 m (mean = 4.28 m, median = 4.27 m). The method used and the accuracy of the historical measurements are unknown. Seven SBWs were of an unknown age class.

The observational records were not evenly distributed over the years (Figure 3). Thirteen of the 30 records (43%) occurred over twelve years between 2010 and 2021. Seven records (23%) were between 1869 and 1913 (a 44-year span), and nine records (30%) were between 1935 and 1969 (a 34-year span). One SBW was reported in 1992.

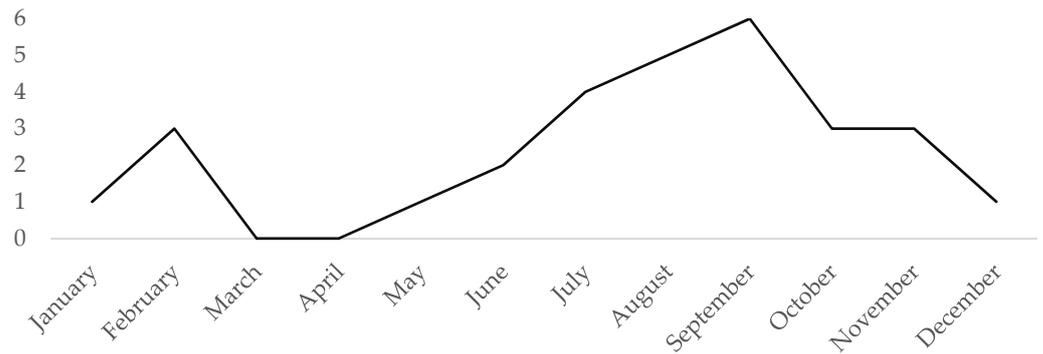


Figure 2. The monthly dispersal of Sowerby’s beaked whale (*Mesoplodon bidens*) records, in the Skagerrak basin and adjacent waters, 1860–2021. The record of skeletal remains from June 2010 is not included, since the month of death is unknown.

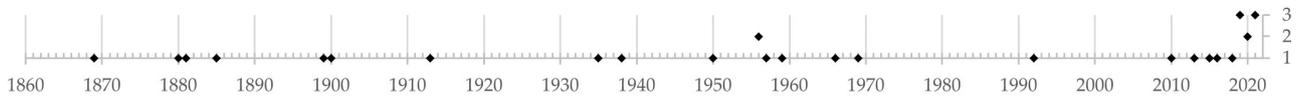


Figure 3. Timeline of Sowerby’s beaked whale (*Mesoplodon bidens*) observational records in the Skagerrak basin and adjacent waters.

3.2. Description of Recent Stranding Events 2015–2020

3.2.1. October 2015

In September 2015, several observations of a live SBW were recorded in the southern Baltic Sea. It was stranded near the town of Wismar, Germany, on 26 September, and was assisted out to open water. The whale stayed in the area and was observed breaching on 10 October. On 21 October the same whale was found dead by Joggesö, close to Karlshamn southeast of Sweden (Figures 1 and 4). It was transported to SVA for necropsy, which was performed on 23 October. This individual is hereafter referred to as Specimen 1.



Figure 4. The Sowerby’s beaked whale (*Mesoplodon bidens*) that was found in June 2015 (Specimen 1) was emaciated and had severe atrophy of the epaxial muscles along its back. Photo: Robert Ekholm (left) and SVA (right).

3.2.2. August 2019

On Sunday 28 July, three whales were observed breaching deep in the Gullmarfjord on the west coast of Sweden. A week later, on Sunday 4 August, a group of three SBWs was found in nearby Åbyfjord in the shallow waters by Nordens Ark, a wildlife foundation park (Figures 1 and 5). Two of them appeared to be in good condition, while the third was weak and had wounds on its belly. Several attempts to assist the animals offshore were made, and after about an hour, they swam out to deeper waters. That evening, the first SBW was found exhausted, and bleeding nearshore in Åbyfjord and was found dead the next morning of Monday the 5th. Later the same day, the second SBW was found in the shallow waters of the Gullmarfjord, appearing distressed. It disappeared but was found dead on Wednesday the 7th. The third SBW was found dead in the Åbyfjord on Thursday the 8th. The two latter carcasses were transported to SVA for necropsy (hereafter Specimen 2 and 3) on 12 August. The first SBW to be found dead was sampled in the field by NRM on 6 August (hereafter Specimen 4).



Figure 5. Two of the three Sowerby's beaked whales (*Mesoplodon bidens*) that were found in shallow waters of the Åbyfjord on the Swedish west coast in 2019. Photo: Lena Lundin.

3.2.3. July 2020

On Saturday 11 July 2020 an SBW was observed alive, apparently disoriented, and confused, swimming into rocks and boats within a small boat harbour in Öckerö kommun, on the West coast of Sweden (Figures 1 and 6). The whale bled from wounds on the left side of the head and on its tail (Jan-Erik Bäck pers. commun. 2020). Because of its debilitated condition, the animal was euthanized on animal welfare grounds by a gunshot to the head. On Tuesday 14 July, pathologists and biologists from SVA and NRM performed a field necropsy at the stranding site. This individual is hereafter referred to as Specimen 5.

3.3. Necropsy Findings

See Table 2 for a comparative summary and overview. See supplementary material, Table S1, for the body measurements and organ weights.

3.3.1. Specimen 1, ID 15-VLT002234

The subadult female was emaciated based on severe atrophy of the epaxial muscles and prominent vertebral processes (Figure 4). The blubber thickness was 24 mm laterally in front of the dorsal fin. Externally, there were moderate to abundant pock marks up to 1.5 cm in diameter along the sides of the animal, indicative of possible pox-like dermatitis. Older, irregular scars and two lesions consistent with lamprey attachment were also seen. Post-mortem decomposition prevented evaluation of all surfaces for net marks, but no evidence of net or rope marks indicative of entanglement was found. Internally, a focal

granuloma was found in the mesenteric lymph node. There was mild gastric ulceration in the main stomach, which was empty except for a small amount of plant-like material. Stomach anatomy was consistent with descriptions provided in Mead, 2007 [48]. There was no forestomach, only a main stomach partially divided into two segments, followed by a series of connecting chambers, which emptied into the pyloric stomach. No other abnormalities or parasites were found. The ovaries were inactive and the uterus was small. Emaciation was assigned as the cause of death.



Figure 6. Field necropsy of a Sowerby's beaked whale (*Mesoplodon bidens*) (Specimen 5). Note the wound on the left side of the jaw. Photo: Anna Bisther.

Table 2. Summary of the postmortem findings of the five Sowerby's beaked whales (*Mesoplodon bidens*) that died in Swedish waters 2015–2020.

	Specimen 1	Specimen 2	Specimen 3	Specimen 4	Specimen 5
Date found dead	2015-10-23	2019-08-07/08	2019-08-07/08	2019-08-05	2020-07-11
Location	Karlshamn (Baltic Sea)	Fiskebäckskil (Skagerrak)	Fiskebäckskil (Skagerrak)	Fiskebäckskil (Skagerrak)	Öckerö (Skagerrak/Kattegatt)
Sex	Female	Male	Male	Male	Male
Age class	Sub-adult	Sub-adult	Sub-adult	Sub-adult	Sub-adult
Length	3.42 m	4.55 m	4.24 m	4.47 m	3.85 m
Weight	340 kg	826 kg	730 kg	N/A	N/A
DCC1–5	3	4	3–4	N/E	3–4
Cause of death	Emaciated	Live stranding, undetermined cause	Live stranding, undetermined cause	Live stranding, undetermined cause	Euthanized, traumatic wounds
Other findings	Pock marks, gastric ulcerations	Pock marks	Focal osteomyelitis (maxilla), pock marks, gastric ulceration, tooth rake marks	Osteomyelitis (vertebrae)	Possible pock marks
Parasites			30–40 nematodes in stomach		Few trematodes in a bile duct

3.3.2. Specimen 2, ID: 19-VLT001658

This subadult male was in normal nutritional condition. Teeth were unerupted. The blubber thickness was 35 mm laterally in front of the dorsal fin. Externally, pock-like marks were observed. No evidence of net or rope marks, indicating entanglement, was found, but severe decomposition precluded thorough examination. Internally, organs were liquefied due to severe decomposition. Generalized gas bubbles were also observed and attributed to severe decomposition. A 5 × 5 cm haemorrhagic and gas-filled swelling was seen surrounding the right flipper insertion, indicative of possible injury, and a focal granuloma was observed in the intestine. The stomach was empty except for 42 otoliths (Table 3). No other abnormalities or parasites were seen. Screening for *Brucella*, morbillivirus and influenza A virus yielded negative results. The radiological examination was inconclusive. Although fluid suggestive of haemorrhage was observed in the left middle ear cavity, the change could not be distinguished from post-mortem decomposition artefact. There were no signs of sperm production in the testes microscopically. The cause of death was assigned as live stranding of undetermined cause.

Table 3. Summary of the hard part analysis of the Sowerby's beaked whales (*Mesoplodon bidens*) that died in Swedish waters 2015–2020 and had hard parts in the gastrointestinal tract. Due to erosion the otoliths could not be assessed to species level. n is number of otoliths; N is the minimum number of prey estimated from otolith count and %N is the numerical frequency of the number of prey in the stomach.

Prey List of Lower Taxa	Specimen 2			Specimen 3			Specimen 5			Total		
	n	N	%N	n	N	%N	n	N	%N	n	N	%N
Gadidae												
<i>Gadidae</i> spp.	6	3	13.63				115	58	25.55	121	61	24.60
<i>Trisopterus</i> sp.	37	19	86.36	1	1	100.00	234	118	51.98	272	136	54.84
Pleuronectidae												
<i>Pleuronectidae</i> spp.							76	38	16.74	76	38	15.32
Gobiidae												
<i>Gobiidae</i> spp.							23	12	5.29	23	12	4.84
Ostreidae												
<i>Ostridae</i> sp.							1	1	0.44	1	1	0.40
Total	43	22	-	1		100	449	227	-	493	248	-

3.3.3. Specimen 3 ID: 19-VLT001659

The subadult male was in normal nutritional condition. Teeth were unerupted. Blubber thickness was 34 mm laterally in front of the dorsal fin. Externally, parallel linear marks spaced 1 cm apart and consistent with tooth rakes were seen. This animal also displayed numerous pockmarks. No evidence of net or rope marks was observed, but the skin was not intact on all surfaces, precluding complete examination. Internally, moderate, acute to subacute gastric ulceration was seen in the main stomach (Figure 7). No other abnormalities or parasites were observed macroscopically. Tissues were screened for *Brucella*, morbillivirus and influenza A infections with negative results. Radiographic imaging revealed a focal 2.5 cm lesion in the right maxilla consistent with osteomyelitis. Like Specimen 2, the right middle ear cavity showed changes consistent with haemorrhage, but this could not be differentiated from a postmortem decomposition artefact. There were no signs of sperm production in the testes microscopically. The cause of death was assigned as live stranding of undetermined cause.



Figure 7. Ulcerations found in the main stomach during the necropsy of a Sowerby's beaked whale (*Mesoplodon bidens*) that died in 2019 (Specimen 3). Photo: SVA.

3.3.4. Specimen 4, ID: NRM A2019/05472

This sub-adult male was sampled in the field in proximity to the stranding site, and it was in normal nutritional condition. Teeth were unerupted. Blubber thickness was 35 mm laterally in front of the dorsal fin. No parasites were found. Following cleaning of the skeleton, lesions consistent with osteomyelitis were found on two adjacent vertebrae and the vertebral body was fractured in one (Figure 8). The stomach was macroscopically empty. No other abnormalities were observed.



Figure 8. Probable osteomyelitis in vertebrae in a Sowerby's beaked whale (*Mesoplodon bidens*) that died in 2019 (Specimen 4). Photo: Peter Nilsson, NRM.

3.3.5. Specimen 5, ID: 20-VLT001629

This subadult male was in normal nutritional condition. Teeth were unerupted. The blubber thickness was 40 mm laterally in front of the dorsal fin. A large gash 30 × 10 cm long was seen on the left side and under the jaw (Figure 6), and another 6 cm wound at the base of the tail extended through the skin and into the underlying cartilage. The wounds corresponded to sites of haemorrhaging before the whale was euthanized. The head and skull could not be evaluated for other traumatic lesions because tissues were destroyed

when euthanised by gunshot. Externally, pockmarks and circular scars consistent with lamprey attachment were seen. There was no evidence of lines or net marks indicative of entanglement. Internally, haemorrhage and torn muscle fibres were found in the right epaxial musculature over the thorax, but no broken ribs or vertebrae were noted. Focally, mild trematode infestation was noted in a thickened intrahepatic bile duct. No other abnormalities or parasites were observed. The testes were small and inactive. The stomach contained 449 otoliths (Table 3) and part of an oyster shell. The cause of death was euthanasia following traumatic injuries.

3.4. Diet Analysis

The hard part analysis showed prey species of the families *Gadidae*, *Pleuronectidae*, *Gobiidae* and *Ostreidae* (Table 3). No squid beaks or marine debris were found. The number of otoliths in stomachs was 43, 1 and 449, representing at least 22, 1 and 227 prey fish (2 otoliths from one identified prey were counted as 1 fish) (Table 3). The *Gadidae* were the most frequent prey item, followed by *Pleuronectidae* and *Goobiidae*.

The eDNA-analysis of the SBWs revealed 17 fish species (Figure 9). The sequences from the emaciated Specimen 1 resulted in a total of 6087 sequences that contained appropriate primers and were of good enough quality to be used in downstream analysis. Out of these, 6030 sequences belonged to fish. Those sequences originated primarily (>99%) from Atlantic herring (*Clupea harengus*), whiting (*Merlangius merlangus*), caplin (*Mallotus villosus*) and salmon (*Salmo salar*) (Figure 9). Small traces (<1%) were identified from Arctic cod (*Boreogadus saida*), lumpfish (*Cyclopterus lumpus*), Greenland halibut (*Reinhardtius hippoglossoides*) and sand eel (*Ammodytes* sp.). The remaining sequences were of low quality or were traces of other organisms.

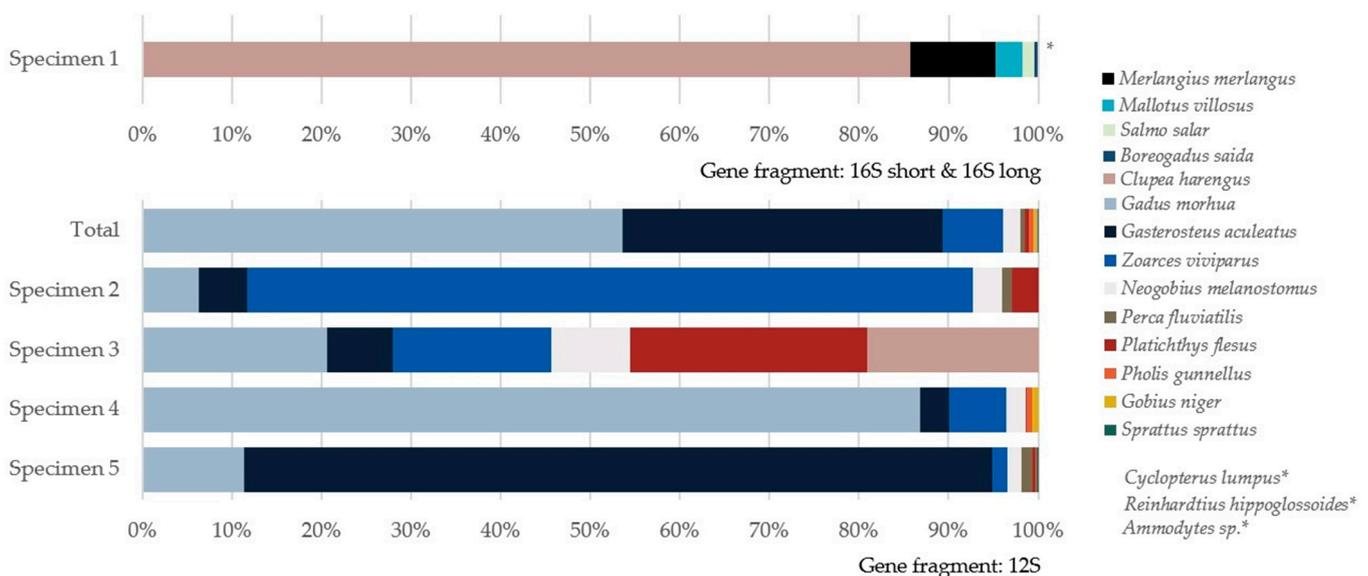


Figure 9. Overview of the eDNA-analysis results from the five Sowerby's beaked whales (*Mesoplodon bidens*) that died in Swedish waters 2015–2020. The most common prey species were Atlantic herring (*Clupea harengus*), European eelpout (*Zoarces viviparus*), cod (*Gadus morhua*) and three-spined stickleback (*Gasterosteus aculeatus*). The results from Specimen 1 are separated from Specimens 2 to 5 because different gene fragments were analyzed. * Traces of species detected.

Considering only the analysis of Specimen 2–5, which were analysed with the same gene fragments, the total number of raw reads after sequencing was 18.1 million, and single samples had between 4.1 and 6.1 million sequences. In all, 17.0 million of the sequences contained expected primers and were of good enough quality to be used in downstream analysis. From these, a large proportion (16.2 million sequences), 95% of the sequences that contained appropriate primers, were of whale origin, which likely means that a lot of DNA

from the host was incorporated into the analysis. A smaller portion (<1%) of the sequences belonged to fish. The fish sequences belonged to ten different species (Figure 9), where cod, three-spined stickleback (*Gasterosteus aculeatus*), and European eelpout (*Zoarces viviparus*) were represented by the highest number of sequences (Figure 9). The other species found were round goby (*Neogobius melanostomus*), European perch (*Perca fluviatilis*), European flounder (*Platichthys flesus*), rock gunnel (*Pholis gunnellus*), black goby (*Gobius niger*), Atlantic herring (*Clupea harengus*) and European sprat (*Sprattus sprattus*). The remaining sequences were of low quality or were traces of other organisms.

4. Discussion

4.1. Historical Records of SBWs

Observations of animals in this study were opportunistic, and there are biases associated with using stranded animals as data sources [49]. These data should be interpreted with caution, particularly regarding older records where supplementary data is often scarce or if monitoring effort has changed over time. However, our results indicate that there is an apparent, substantial increase in the frequency of records of SBWs around the Skagerrak basin and adjacent waters since 2010. Forty-three per cent of all the observed SBWs from 1869 to 2021 (152 years) came from the last twelve years. Using a long-term reporting system, changes in record frequencies of any species may be indicative of changes in population size or distribution [50], ecosystems or threats to the species. Therefore, the apparently increased intensity of recent strandings in proximity to the Skagerrak basin may imply changes in SBW populations. For example, an increase in the numbers of SBWs, a shift in their southward migration, or new or more frequent threats, could lead to more observations of stranded individuals. In the Northwest Atlantic, in the Gully submarine canyon, an increase of 21% in SBWs was found between 1988 and 2011 [51]. The authors discuss that these findings might represent an increase in the numbers of SBWs, perhaps in this area or in general. If this reflects an increase in overall SBW population size, that strengthens the probability of an increase in SBWs in the Northeastern Atlantic as well since the 1980s. Similarly, although based on a low sample size, observations of SBWs in the Bay of Biscay have been increasing between 2006 and 2018 [12].

To reach the Skagerrak basin, animals that inhabit deep waters will likely travel from the pelagic open waters in the Northeast Atlantic through the southern Norwegian trench. The trench is roughly 200 m deep and has similarities to other deep-water corridors that are proposed to act as 'traps' for beaked whales within the continental shelves surrounding the UK [1,14]. In the Skagerrak basin, within a Natura 2000 marine protected area, there is a deep canyon area called 'Bratten' (Figure 1). It is a few hundred metres wide, has steep and varied topography and is 560 m at its deepest [52]. The depth makes the abiotic conditions stable; it is a high biodiversity hot spot, and a rich habitat for *Gadidae* sp. and *Pleuronectidae* spp. [53], prey items identified in the SBWs in this study. In addition to 'trapping' beaked whales on migrations, perhaps deep-water corridors can also lead them to suitable habitats within a given season or life history period.

Knowledge of population structure, ecology and migration routes is important for conservation and legislation efforts, and recently, information about SBWs in Northeast Atlantic has increased, through data from both live and dead animals. Tagging of SBWs has described diving and feeding behaviour [54]. Important summer areas have been identified using bottom-mounted autonomous acoustic recorders. Possible calving areas have been described off Western Ireland [11,55,56] and stable isotope analysis suggests that there may be several populations of SBWs [3,4]. Efforts to study live and dead SBWs in proximity to the Skagerrak basin would provide additional insights into SBWs in the Northeastern Atlantic. Due to difficulties in studying beaked whales, and thus little available data, data from *Mesoplodon* species are sometimes grouped together in the literature [10,25]. While this is necessary when data is scarce, it limits our understanding of individual *Mesoplodon* species. This underlines the need for continued collection and reporting of

data on SBWs and other beaked whale species to identify any differences in the species and even population levels.

MacLeod et al. 2004 found that most SBW strandings on the coasts of the UK and the Republic of Ireland have occurred between July and November, which corresponds with our findings. It has been proposed that SBW have seasonal movements, moving southwards in the summer [14]. This would explain the higher frequencies of strandings during the summer months in the Northeast Atlantic. Of the SBWs with known age class and sex presented in this paper, no age class or sex was more frequently recorded than others. However, eleven of the 12 adult SBWs were recorded prior to 1969, and 8 of the 11 juveniles (including the calf) were recorded from 1992 and onwards. To confirm the apparent recent increase in the frequency of observational records of SBWs in proximity to the Skagerrak basin and study the underlying factors responsible, continued monitoring, investigation and reporting of these events are highly warranted.

Life history data of beaked whales is key for understanding their habitat requirements and conservation needs, and models have been constructed for several beaked whale species [57]. Here we present additional data that can complement existing data for such models, such as the length of adult females, foetal size, and dietary habits. Continued data collection from stranded SBWs, especially from adult females and calves, is needed to piece together the life history of SBWs.

Since deep water corridors are hypothesised to guide beaked whales [1,14,15], we chose to collate records from a 'sea basin perspective' instead of allowing country borders to regulate the area of collection. Hopefully, collecting records from the southern Norwegian trench to the Skagerrak basin, and onwards towards the Baltic Sea, provides a more holistic perspective on whale records that better represents their distribution.

4.2. Necropsy Findings

The causes of deaths of SBWs provide insight into the threats that they face and therefore warrant investigation. Despite relatively frequent stranding records of SBWs in the Northeast Atlantic, relatively few individuals have been examined by necropsy to investigate the cause of death or other pathology. A recent report showed that of 571 beaked whale strandings in the Northeast Atlantic between 1990 and 2020, 72% were not necropsied, most often due to significant decomposition [24]. Of the beaked whales with diagnosed causes of death ($n = 109$), a majority (73%) of them died of live stranding [24]. The diagnosis was given to cases where no underlying reason for stranding was found but the whale was alive at the time of stranding. Five per cent were suspected bycatch, two per cent were entangled, and seven per cent had infectious diseases [24]. Diagnosed auditory trauma is likely underestimated as a cause of death [24]. The SBWs examined in this study died from emaciation ($n = 1$), live stranding of undetermined cause ($n = 3$) and euthanasia following trauma ($n = 1$).

Mass strandings of beaked whales have been correlated with exposure to anthropogenic sonar signals [17,21–23]. From the mass stranding of three SBWs in 2019 described here, the cause of the live strandings could not be established due to the state of decomposition, but acoustic trauma could not be ruled out. Two of the three animals (Specimen 3 and 4) also had evidence of focal osteomyelitis in the jaw and a vertebra, respectively. These findings were not severe enough to result in the death of the animals but may have negatively impacted locomotion, feeding or general health. Specimen 5 was euthanized because of its behavioural state and traumatic wounds. The cause of the wounds could not be determined, but they were the result of something sharp. Lastly, Specimen 1 was found emaciated in the Baltic and was observed alive and breaching in German waters a few weeks prior. It is possible that this individual was 'trapped' within the shallow coastal waters of the southern Baltic and was unable to sustain itself. Pox-like dermatitis was seen in a few animals, and further investigation and confirmation of an underlying viral cause are needed.

4.3. Diet Analysis

The presence of hard parts in the stomach indicates that an animal has recently fed. The time elapsed, from the feeding event until the otoliths are too broken down to be recovered, is not known for SBWs. For seals, the time for 100% retrieval has been estimated to be 0–3 h, and 0% by almost 13 h, and for harbour porpoises 10 h for 0% retrieval [58,59]. If that time frame is similar for SBWs, three of five SBWs in this study, with otoliths in the gastrointestinal tract, were fed some hours prior to their deaths. Due to the erosion, the number of fish predated is underestimated when analysing otoliths. On the contrary, squid predation based on the presence of squid beaks is proposed to be overestimated due to the longer time it takes to break down squid beaks [27]. We did not find any squid beaks in any of the SBWs examined.

Previous stomach content studies have found that SBWs are most likely generalist feeders, preying on smaller fish between 200 and 1000 m of depth with little or no squid content [25–27]. This niche allows them to compete less with, for example, NBW, which feeds at deeper depths and preys mainly on squid and larger prey [25]. There are several biases when using stomach content analysis to determine the dietary habits of cetaceans, but in cryptic, deep-diving cetaceans, it is a method that is useful because it is available [25]. The diet review by MacLeod et al. [25] discusses the lack of available data on stomach contents from Mesoplodon whales, especially from SBWs, and that there is a need for more reported data. The diet of a predator reveals its ecological role and habitat preferences, which are relevant for conservation and legislation efforts. Since the SBWs were recently fed in Scandinavian waters, this indicates that there are areas with suitable prey and perhaps habitats for this species.

The otolith hard part analysis in this study revealed prey species families of *Gadidae*, *Pleuronectidae*, *Gobiidae*, which were supported, supplemented, and identified to species level using eDNA analysis. To our knowledge, this is the first time that any species of flatfish has been described as a prey item of SBWs. Similarly, oyster hard parts have not been previously reported in the stomach contents of SBWs. ‘Suction feeding’, the feeding method presumed to be used by SBWs [60], is associated with the capture of fish or squid, and not oysters. Therefore, the finding of an oyster shell may represent incidental or secondary ingestion. The primers of the eDNA analysis targeted fish species but not invertebrates, therefore precluding identification of oysters in other SBW stomachs. European eelpout was found by eDNA-analysis in all four SBWs between 2019 and 2020, which to our knowledge is the first time this species has been described as prey. Three-spined stickleback was common in the eDNA analysis, but we consider this a secondary ingestion due to their small size and coastal habitats. Cod and European eelpout, the most common species found, are meso or benthopelagic, similar to prey species found in other studies of SBWs [25–27]. The prey species identified in this study differ from other studies, which is consistent with the belief that SBWs feed opportunistically and with plasticity, but at meso and benthopelagic depths [25,26]. Lanternfish (*Myctophids*) were a common diet from the Azores, and some individuals preyed on sea catfishes (*Galeichtys* sp.) [26]. Bycaught SBWs, from the Northwest Atlantic, had mostly codling (*Laemonema barbatulum*), Cocco’s lanternfish (*Myctophidae*), marlin-spike (*Macrouridae*), and lanternfish of several species, and few squid beaks [27]. From their analysis, the average minimum number of prey items in a stomach was more than 600 [27], indicative of the massive amount of prey a healthy SBW can consume. In our study, Specimen 5 had the most prey items in the stomach, at least 227 fish. We did not find any marine debris in any of the SBWs.

Our data support previous findings that SBWs mainly prey on fish and adds data on prey species within Scandinavian waters in proximity to the Skagerrak basin. Previous analysis of stable isotopes proposes that there are differences in foraging and feeding behaviour between SBWs in the eastern and western Atlantic [4], but exactly how their diets differ is not fully understood. More information on prey items from each region and SBW foraging behaviour is vital to learn more about this elusive species, and thus be able to provide conservation recommendations where needed.

5. Conclusions

We have presented a contextual overview of the historical observations of SBWs in the Skagerrak basin and adjacent waters and shown that there has been an apparent increase in observations in the area since 2010. This change may be indicative of changes within the SBW population. We have also described the recent stranding events in 2015, 2019 and 2020 in Sweden and presented the necropsy findings, health and diet of the five animals, including the identification of new prey items. Our presented data contributes to the knowledge we have about distribution, biology, and threats to SBWs in the Northeast Atlantic.

Supplementary Materials: The following are available online at <https://www.mdpi.com/article/10.3390/oceans3030018/s1>, Table S1: Measurements and data from the five Sowerby's beaked whales (*Mesoplodon bidens*) that died in Swedish waters during 2015, 2019 and 2020 and were examined by necropsy or sampling.

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Institutional Review Board Statement: No live animals were used in this study.

Informed Consent Statement: No human subjects in this study.

Data Availability Statement: All data presented in this study are available in Tables 1–3, Table A1 and in Table S1 in Supplementary Material.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Compilation of historical records and connected available data, of Sowerby's beaked whales 1869–2021, in proximity to the Skagerrak basin and adjacent waters.

Year	Month	Sex	Age	Length (m)	Locality	Country	Note
1869	June	Male	Adult	4.40	Nord Jan	Norway	
1880	February	Female	Adult	4.32	Hevringholm	Denmark	
1881	November	Male	Adult	4.50	Marstrand	Sweden	
1885	August	Male	Unavailable	3.87	Saltö, Lysekil	Sweden	Live stranded
1899	December	Male	Juvenile	4.27	Klitmöller	Denmark	
1900	October	Female	Adult	5.02	Hevringholm	Denmark	Pregnant
1913	July	Female	Juvenile	Unavailable	Griefswalde oie	Germany	Live stranded, killed
1935	June	Male	Adult	4.50	Wolin	Poland	Live stranded, killed
1938	September	Male	Adult	4.50	Vegehalm	Sweden	
1950	September	Male	Adult	4.47	Helsingborg	Sweden	
1956	September	Female	Juvenile	3.20	Askimfjorden	Sweden	Mass stranded
1956	September	Female	Adult	4.75	Askimfjorden	Sweden	Mass stranded
1957	November	Male	Adult	5.00	Stavsford	Denmark	
1959	September	Female	Adult	~5	Gamboerg Fjord	Denmark	
1966	September	Unavailable	Unavailable	~4	Marstal	Denmark	
1969	January	Prob. Female	Adult	~5	Lundeborg	Denmark	
1992	October	Female	Juvenile	3.34	Stenderup hage	Denmark	
2010	* June	Unavailable	Unavailable	Unavailable	Tjurpannans nature reserve	Sweden	Skeletal remains
2013	November	Female	Unavailable	Unavailable	Rogaland	Norway	
2015	October	Female	Juvenile	3.42	Karlskrona	Sweden	
2016	February	Unavailable	Unavailable	Unavailable	Rogaland	Norway	
2018	February	Male	Adult	~5	Læsø	Denmark	Live stranded, helped out
2019	August	Male	Juvenile	4.55	Fiskebäckskil	Sweden	Live, mass stranded
2019	August	Male	Juvenile	4.24	Fiskebäckskil	Sweden	Live, mass stranded
2019	August	Male	Juvenile	4.47	Fiskebäckskil	Sweden	Live, mass stranded
2020	May	Unavailable	Unavailable	~4	Tistlarna	Sweden	Alive
2020	July	Male	Juvenile	3.85	Öckerö	Sweden	Euthanized
2021	July	Unavailable	Unavailable	Unavailable	Ervik	Norway	Live stranded
2021	July	Unavailable	Calf	Unavailable	Ervik	Norway	
2021	August	Female	Juvenile	3.62	Horsens fjord	Denmark	

* Month is not representative of date of death, as skeletal remains were found.

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