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Biological findings and causes of death in harbour porpoises (*Phocoena phocoena*) collected between 2006 and 2019 in Sweden

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Sammanfattning

Tumlare (n = 109) som samlats in mellan 2006 och 2019 har obducerats av Naturhistoriska riksmuseet i samarbete med Statens Veterinärmedicinska Anstalt (SVA). Denna sammanställning ger data om biologiska parametrar, sjukdom och dödsorsak och utgör grunden för vidare utveckling av hälsoindikatorer för dessa djur.

Bifångst och sannolik bifångst (32%) var den vanligaste dödsorsaken bland tumlarna i denna studie, följt av infektionssjukdomar, särskilt lunginflammation (16,5%). De flesta var kalvar eller ungdjur (67%). Näringsstatus skiljde sig i allmänhet mellan bifångade tumlare och de som dog av infektionssjukdomar.

Några av tumlarna visade tecken på predation. Gråsälspredation har blivit en vanlig dödsorsak för tumlare i Nordsjön, men det återstår att utvärdera huruvida tumlare blir dödade i Sverige av gråsälar, späckhuggare eller något annat rovdjur.

Tumlare är en utmärkt miljöindikator. Tumlares hälsa och sjukdomsstatus återspeglar deras miljö och visar förekomsten av sjukdomsframkallande smittämnen och andra hot mot djur- och människors hälsa i våra marina miljöer. Strandade och bifångade tumlare ger utmärkt och kostnadseffektiv information om tumlares hälsa och biologi och kan också användas för att upptäcka förändringar i populationsdynamiken. Emellertid krävs ett mycket större antal undersökta djur än vad vi har idag för att kunna utvärdera tumlarnas allmänna hälsa.

På samma sätt är livshistoriska parametrar, näringsstatus, reproduktiv framgång och sjukdomsstatus potentiella hälsoindikatorer och vår sammanställning av obduktionsdata ger grundläggande data för vidare utveckling av dessa. Framtida utveckling av lovande indikatorer som kroppsindex och ett index över sjukdomsstatus med både historiska data och framtida studier behövs.

Slutligen ger resultat från ett fortsatt och utökat hälso- och sjukdomsövervakningsprogram för tumlare en grund för rapportering om Sveriges miljökvalitetsmål "Hav i balans och levande kust och skärgård" och "En rik flora och fauna" samt rapportering inom regionala havskonventioner som ASCOBANS.

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Bycaught juvenile female from Landskrona, Öresund. (Photo SVA).

Background

The Swedish Museum of Natural History (NRM) has in collaboration with the National Veterinary Institute (SVA) performed necropsies on porpoises for over a decade. From 2008 to 2019, 109 porpoises have been necropsied by NRM and SVA, with funding from the Swedish Agency for Marine and Water Management the last few years. It has now been possible to compile the information from the necropsies and a detailed report including pathological examinations has been published in a report to the Swedish Agency for Marine and Water Management (Neimanis, Stavenow et al. 2020). A summary of findings including biological parameters and causes of death is presented here.

Introduction

The harbour porpoise (*Phocoena phocoena*) is one of the smallest toothed whales and belongs to the family *Phocoenidae*. There are seven species in this family. The harbour porpoise (from now on called porpoise), occurs in sub-arctic and temperate waters in the North Pacific, North Atlantic and Black Seas. It is the most common whale in the North Sea (Lockyer 2003). The porpoise is the only whale that is found regularly in Swedish waters all year round. While it is common on the west coast, the Baltic porpoise population is classified as critically endangered on the IUCN Red List. The porpoise was protected in Sweden in 1973.

There are three populations of porpoises in Swedish waters: the North Sea population found in the Skagerrak and in the northern part of the Kattegat, the Belt Sea population found in the southern part of the Kattegat, the Sound and the Belt Sea, and the Baltic Sea population in in the Baltic Sea. Periodically, population boundaries may partially overlap, especially in winter. The Baltic porpoise is critically endangered and is estimated at around 500 animals, but the uncertainty is large (95% confidence interval is between 100-1000 animals approximately, according to calculations from the SAMBAH project (Static Acoustic Monitoring of the

Baltic Harbor Porpoise)) (SAMBAH, 2016). The Belt Sea and the North Sea populations are significantly larger and not endangered.

Until the 1960s, the porpoise also used to be common in the Baltic Sea. Historically, porpoises have also been intensively hunted. During the 19th century, 1000–2000 animals were caught annually in the Little Belt, and they were also hunted in the Baltic Sea. During 1922–1933, more than 700 porpoises were caught in Polish waters alone (Species Data Bank: https://artfakta.se/artbestamning/taxon/phocoena-phocoena-100106).

Time of conception was calculated for porpoises in the Kattegat and Skagerrak and the Baltic Sea. It was concluded that conception peaks approximately three weeks earlier in the Kattegat and Skagerrak seas compared to the Baltic Sea. Furthermore, assuming a gestation length of 318 days, peak parturition was estimated to around 8 June in the Kattegat and Skagerrak seas, calculated from foetal size, and three weeks later in the Baltic (Börjesson and Read 2003). However, these calculations were based on historic data, and more recent research need to confirm if this is still the case.

Adult porpoises are usually smaller than 1.8 m and weigh between 45 to 70 kg. Newborn calves are about 70 to 90 cm and weigh around 5 kg. The porpoise becomes sexually mature usually at around 3-4 years of age for both sexes, age at first ovulation is >3 years and the female can give birth to a calf every one or two years, usually during the first half of the summer (Lockyer 2003). The female is pregnant for 10-11 months and the calf stays with its mother for 8-12 months, but starts eating fish from 3-4 months of age. Mortality is highest during the first year of life, and <5% of the population live beyond 12 years. Although porpoises rarely live longer than 12 years, they can reach twice that age (Lockyer 2003).

The porpoise usually lives alone or in small groups that may consist of one or more females with their calves, or a group of young males. However, they sometimes are seen in very large groups as well. In these occasions, it is probably several smaller groups searching for food in the same place.

Porpoises are native top predators in Swedish waters, just as seals, otters and sea eagles. A previous study based on stomach content of 112 bycaught porpoises from the Kattegat and Skagerrak revealed that their dominant prey item was Atlantic herring (*Clupea harengus*) among both juveniles and adults, and that hagfish (*Myxine glutinosa*) was an important prey specially among adults (Börjesson, Berggren et al. 2003), but the diet includes a large variety of species.

The often coastal habitat of porpoises makes them particularly vulnerable to anthropogenic activities, such as environmental contaminants, marine traffic, wind turbines, noise, and unintentional bycatch in fishing activities (van Elk, van de Bildt et al. 2019). Therefore, porpoises can be used as an indicator of the marine environment. In addition, they have a relatively short life span, yet do not have a high reproductive rate, so environmental changes that affect the porpoise negatively may quickly result in decreases at population level. Therefore it is important to monitor health conditions, identify threats and monitor population size.

Because porpoises live relatively secluded, they are difficult to study. Stranded animals and those caught in fishing gear provide opportunities to gather important information about, among other things, their life spans, diet, health status- and reproductive status. Studies on stranded animals in other parts of northern Europe have been used to investigate causes of death, disease and other threats to the porpoise (Siebert, Wünschmann et al. 2001, Jauniaux, Petitjean et al. 2002, van Elk, van de Bildt et al. 2019). Although porpoises from Swedish waters have been used to study various life history parameters in the past (Börjesson and Read 2003), further studies with more recent data are needed.

The Swedish Museum of Natural History (NRM) has studied stranded and bycaught porpoises for several decades. Tissue samples are saved in the museum´s Environmental Specimen Bank (ESB) which now contain samples from over 1300 porpoises collected between 1972 and 2019, enabling unique studies on contaminant trends etc. In 2009, a collaboration to study porpoises was initiated between NRM and SVA. Currently, some 15 animals per year are collected for necropsy and sampling to our saved in the museum´s Environmental Specimen Bank at NRM and the tissue biobank at SVA. The number of animals that are collected is not yet enough to draw conclusions about the health status of the porpoise populations in Swedish waters, but provides a baseline information to build upon.

In this study we have compiled data collected from necropsies of porpoises that were either found dead on the beach (n = 98) or caught in fishing gear (n = 11) between 2006 and 2019. We provide information on the causes of death and basic biological parameters for these animals.

Material and methods

We have performed necropsies of 109 porpoises between 2009 and 2019 (including six porpoises collected from 2006-2008, but kept frozen until our collaboration began). Two of the 109 porpoises were females in late stage pregnancy and their full-term fetuses were also necropsied (i.e. a total of 111 porpoises were examined). The necropsies were performed in teams of at least one veterinary pathologist and one biologist. A number of standardized protocols were followed to facilitate systematic collection of data and samples. It was not possible to collect full data sets from all animals, so the sampling was modified depending on the degree of decay of the carcass and / or if it had been scavenged.

In almost all cases, the porpoises had been frozen before for the necropsy. Most animals originated from the Swedish west coast and were stored in a freezer at Gothenburg Natural history museum before being shipped to Stockholm or Uppsala for necropsy. During the first two years, necropsies took place at NRM but since 2011 the necropsies are performed at SVA in Uppsala (Figure 1).

Figure 1. Necropsies are performed at SVA, Uppsala, with a team of at least one pathologist and one biologist to each porpoise. Two to four porpoises are necropsied at the same time (Photo SVA).

External examination

Before necropsy, several biological data were collected including sex, length, weight as well as age group: calf (less than one year old), juvenile (sexually immature) or adult (sexually mature). Blubber thickness was measured and an external assessment was made for signs of disease, human interaction (such as net marks, mutilation) and lesions from predation, scavenging, or other changes. For 36 of the porpoises, the age was determined by counting annual growth lines in the teeth root cementum (AgeDynamics, Denmark), or was set as 0 (zero) for animals that were assessed as calves based on size, tooth eruption and date found.

Most body measurements and organ assessments needed to make a diagnosis become less reliable with increasing decay status. Additionally, missing tissue from scavenging or predation also affects measurements and organ assessment. Therefore, not all data could be collected for all animals.

Nutritional status was graded as emaciated (1), below average (2), average (3) and above average (4), based on blubber thickness in relation to age group and what is expected for the season in which the porpoise died. Body Mass Index (BMI) was calculated based on whole body weight and length squared, to evaluate possible tools for evaluating nutritional status. BMI was calculated from the porpoises where the ratio between full body length and weight was reliable (n = 54). Calves were excluded because body proportions vary during different phases of growth, and therefore variations in BMI do not only correlate with health (Peig and Green 2010). Porpoises that were too decomposed, lacked body parts or were pregnant were also excluded. In the analysis, we compared the BMI with other assessments of nutritional condition, and how the BMI of porpoises in normal nutritional status varied over time of year.

Internal examination

Macroscopic changes were documented and if the degree of decay was not too severe, samples were fixed in formalin for later microscopic examination and a set of tissues was saved for SVA's biobank and NRM's Environmental Specimen Bank (ESB). The presence of parasites was noted and, in some cases, representative sets of parasites were saved in 70% ethanol. The parasite burden was graded for lung- and heartworms and for liver trematodes as none, mild, moderate and severe in 97 and 86 porpoises, respectively. The occurrence was not documented in a systematic way for all animals.

To study the diet of the porpoises, the gastrointestinal tract was examined either during necropsy, or saved for later examination at NRM. Since 2015, samples for DNA analysis (environmental DNA, so called eDNA) have been taken from the stomach and/or colon and food items are examined macroscopically for diet studies.

The reproductive organs were measured, ovaries were examined macroscopically for the presence of follicles, *corpus luteum* (CL) or *corpora albicans* (CA, scar tissue from older *corpus luteum*), and the uterus was opened to check for the presence of fetuses. In earlier years, systematic documentation of corpora was not done. All adult females were checked if they were lactating or not. In recent years, direct smears of samples from testicles, epididymis and cervix have been examined microscopically for presence of sperm. Testicles and epididymis were weighed and measured.

Cause of death

Cause of stranding or death was assigned for each individual. In cases where the cause of death could not be determined, the cause was set as 'not determined'. Bycatch in fishing gear is very difficult to diagnose if the animal is found dead in the water or on the beach because the presence of net marks are used as the decisive, specific finding to make this diagnosis. Some fishing gear, such as a trawl, leaves no marks, and often scavenging and decay obscure any net marks. Porpoises caught in fishing gear are usually in good body condition, and have froth in the airways indicating drowning, varying degrees of hemorrhage in the subcutaneous tissue, and no signs of disease or other causes of death. In cases where these criteria were met but no net marks could be seen, the cause of death was set as 'probable bycatch'.

Cause of death for each porpoise was classified in the following categories: Bycatch, probable bycatch, infectious disease, non-infectious disease, trauma, emaciated, abandoned, probable predation, not determined, and inappropriate material. The bycatch diagnosis was made either if the porpoise was bycaught and handed in by fishermen (n = 11) or if the background was unknown, but characteristic net marks on the head and or extremities were found (n = 9, Figure 2). 'Probable bycatch' is defined above. 'Abandoned' was used only for newborns (found dead in June and July) with empty gastrointestinal tract and no other signs of disease. 'Probable predation' was used when clear bite wounds after predators could be seen but the body was too rotten or scavenged to enable confirmation that the attack took place in connection with death and not later when the carcass was scavenged. 'Inappropriate examination material' was used for carcasses that were severely rotten and or extensively scavenged, and in cases where many organs or tissues were missing.

Figure 2. Presence of penetrating net marks are indicative of entanglement, and bycatch (Photo SVA)

Results

Forty-four porpoises (40%) originated from the area of the Skagerrak/North Sea population, 57% from the area of the Belt Sea population (n = 62) and 3% from the overlapping area of the Belt Sea and Baltic proper populations (n = 3) (Sveegaard, Galatius et al. 2015, Carlén, Thomas et al. 2018) (Figure 3). Although the population distribution areas overlap and vary over the year, the sites of carcasses are plotted in relation to the regions that each population inhabits to provide an overview of the origin of the necropsy data. In addition to the abovementioned porpoises, one porpoise was found upstream in the Nissan river. Fifty-eight males, and 50 females were necropsied during the study period as well as two fetuses. One porpoise could not be sexed since most organs were missing.

Porpoises were found during all months of the year, with slightly more found during the summer months. Of the porpoises examined, 26% were classified as calves (less than a year old) (n = 28), 41% as juvenile (sexually immature) (n = 45) and 33% as adults (sexually mature) (n = 36, Figure 4).

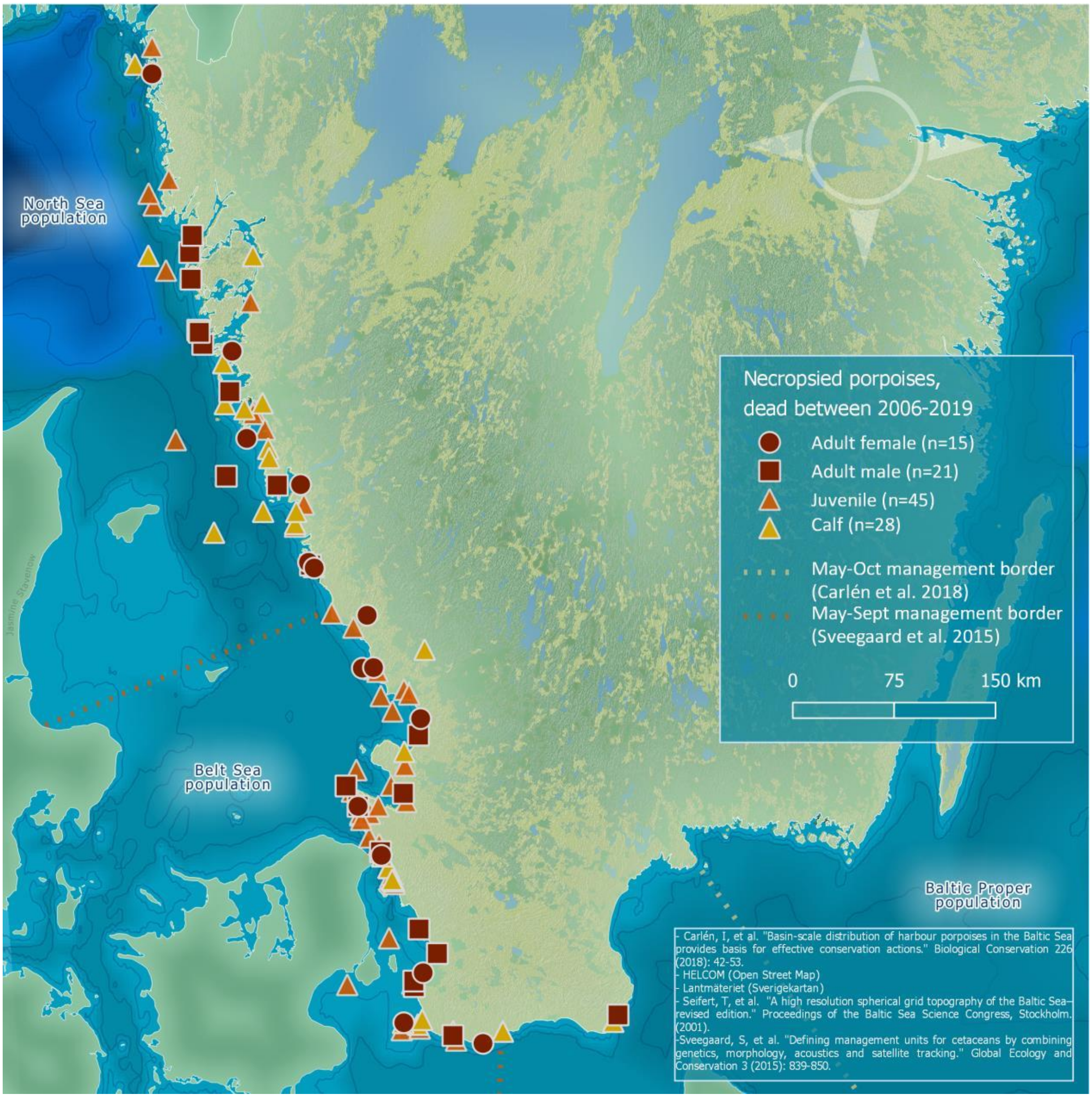
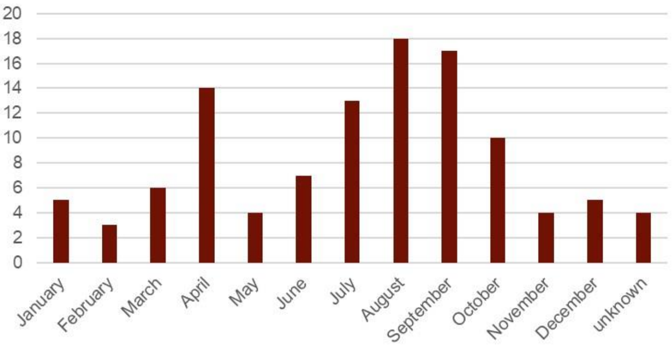


Figure 3. Most porpoises in this study were collected on the Swedish west coast. Only three were found in the Baltic, in the area where the Baltic and the Belt Sea populations overlap. Also, most porpoises were calves or juveniles (n=73).



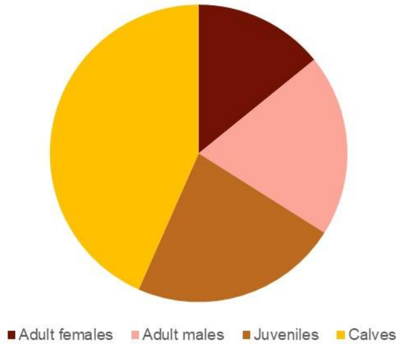


Figure 4. Porpoises were collected during all months of the year, but more during the warmer months (left). Most of the porpoises were calves or juveniles in this study (right).

Causes of death

Cause of death could be determined for 78 of the animals (72%). Twelve porpoises (11%) were unsuitable for examination due to decay or heavy scavenging, and no cause of death could be determined in the remaining 19 animals (17%). In 16 of these latter 19, however, bycatch could not be ruled out. Either the animals had froth in the lungs but were in poor nutritional condition, or they were in normal nutritional condition but did not have froth in the lungs. Bycatch (18%) and probable bycatch (14%) are together the most common primary diagnosis in our material (32%), followed by unknown cause of death (17.5%), infectious diseases (15%), unsuitable material (11%), emaciation (10%), trauma (7%), non-infectious diseases (3.5%), abandonment (2%) and probable predation (2%). Cause of death in relation to age class are presented in Table 1.

Table 1. Cause of death in relation to age class among the porpoises in this study.

Cause of death	Calf	Juvenile	Adult	Total
Bycatch	1 (5%)	13 (65%)	6 (30%)	20
Probable bycatch	3 (20%)	7 (47%)	5 (33%)	15
Infectious disease	3 (15%)	6 (30%)	11 (55%)	16
Non-infectious disease	2 (50%)	0 (0%)	2 (50%)	4
Trauma	1 (12.5%)	6 (75%)	1 (12.5%)	8
Emaciated	6 (55%)	3 (27%)	2 (18%)	11
Abandoned	2 (100%)	0 (0%)	0 (0%)	2
Probable predation	2 (100%)	0 (0%)	0 (0%)	2
Undetermined	6 (31.5%)	6 (31.5%)	7 (37%)	19
Unsuitable	5 (42%)	4 (33%)	3 (25%)	12

The proportion of each cause of death category was also determined for the stranded animals only (n = 98), i.e. excluding the 11 porpoises sent directly from fishermen. The most common diagnoses for stranded animals were bycatch (9%) and probable bycatch (15.5%), unknown (19.5%), infectious disease (16.5%), unsuitable material (12.5%), emaciation (11%), trauma (8%), non-infectious disease (4%), abandonment (2%) and probable predation (2%).

After bycatch and probable bycatch, disease was the most common cause of death (n = 20) and of these, infectious diseases dominated (n = 16). Eleven of the 16 animals with infectious diseases had pneumonia.

In the case of non-infectious diseases, three of the four cases were related to complications around giving birth.

Of traumatic cases, four were classified as blunt trauma. One animal died of acute peritonitis after a penetrating wound in the abdomen and another had a so-called corkscrew-wound along the body axis that penetrated the chest and abdomen. In the remaining two cases, there was major tissue damage and it was not possible to rule out predation. In an additional two porpoises, wounds seen on the body were consistent with predation (classified as 'probable predation'), but the predator was not identified.

Nutritional condition

Nutritional condition class seemed to correlate well with blubber thickness BMI and circumference. BMI appeared to be a promising indicator of nutritional status for juvenile and non-pregnant adult animals. However, it was not possible to calculate BMI for all animals since several of them were scavenged, and therefore it is valuable to have different parameters to assess nutritional status (Table 2).

Table 2. Nutritional status vs. blubber thickness, BMI, and circumference (mean values) of juvenile and adult porpoises for which data were available.

Nutritional status	Blubber thickness (mm)	BMI (weight/length^2)		Circumference (cm)	
Emanciated	12 (n=6)	15.4	(n=6)	67.3	(n=5)
Below average	15 (n=16)	18.6	(n=19)	75.6	(n=6)
Average	24 (n=31)	20.9	(n=27)	77.2	(n=31)
Above average	27 (n=5)	23.1	(n=5)	78.7	(n=5)

Parasite prevalence

Sixty-four of 97 porpoises (66%) had at least one roundworm (nematode) in the lungs and or heart and 36 of 86 (42%) had at least mild presence of liver trematodes. Parasite infection generally increased in frequency and severity in older age groups (Table 3). Although 18 porpoises had roundworms in the stomachs (*Anisakis complex*) and 12 had roundworms (*Stenurus minor*) in the inner ear, data were not collected and recorded consistently or systematically, which prevented a full interpretation of the presence and significance of these parasites.

Table 3. Prevalence of lung- and heartworm and liver trematodes in porpoises in different age groups.

		Calf	Juvenile	Adult	Total
Lung and heartworm	none	19	14	0	33
	mild	3	19	16	38
	moderate	0	8	13	21
	severe	0	2	4	6
Liver-trematode	none	19	28	3	50
	mild	0	6	20	26
	moderate	0	0	10	10
	severe	0	0	0	0

Reproductive status

Of the 15 adult females in this study, at least three were pregnant, two of which had full-term fetuses. Several females were found dead during summer/early fall or were very decomposed and scavenged and hence were difficult to evaluate if they were pregnant or not. Both females with full-term fetuses were five years old and died in June, which is the season when female porpoises normally give birth (Börjesson and Read 2003). One female died due to complications giving birth (dystocia) (Figure 5) and the other was bycaught. Another female was pregnant with an 11 cm long fetus. She was three years old and was bycaught in October. A female who died in August had a corpus luteum and was possibly pregnant, but no fetus was found.

Figure 5. Female found dead on the island of Vrångö, south of Gothenburg. She died from complications from giving birth (Photo NRM).

We examined two stillborn calves within this study. One was found the 28th of June 2018, and weighted 6,6 kg. The second was heavier, 8,5 kg. It was found in mid-August and was severely decomposed, indicating an earlier date of death. Both were 78 cm long females. For comparison, the pregnant female with a full-term 83 cm long male fetus was found dead the 26th of June.

Of the six adult females whose ovaries were examined more closely, all had corpus albicans, scars in the ovary (CA) and five had corpus luteum (CL). Two other females had CL but presence of CA was not examined. CA in the ovaries is formed at positions where a CL has degenerated. Corpus luteum indicates that ovulation has occurred. One of the females from 2009 had more than ten CA. She was 12 or 13 years old. Of the other females with CA, two females had at least three CAs, and two others had an undefined number. A two-year-old female who died in early July had several follicles in the ovary, but no visible CL or CA, and thereforewas not quite sexually mature since she had not ovulated.

Presence of milk in the mammary glands (lactation) indicated that a female had an accompanying calf or carried a full-term fetus at the time of death. Eight of the 15 adult females were lactating (53%), of which two were the above-mentioned females with full-term fetuses.

All three adults (out of four females examined) had sperms in the vagina, which shows that they had recently mated. The mating season for porpoises in Swedish waters is between June and August, which correlated well with the time of death, (July and August) for these females. The three adult females were also lactating. The fourth female was not sexually mature.

Five of nine examined adult males examined had sperm production. They died between June and September, while those without sperm died in August, September and December. The weight of the adult male testicles varies with the season and is greatest during the summer months, which corresponds to the reproductive season also seen in other areas (Neimanis, Read et al. 2000) (Figure 6).

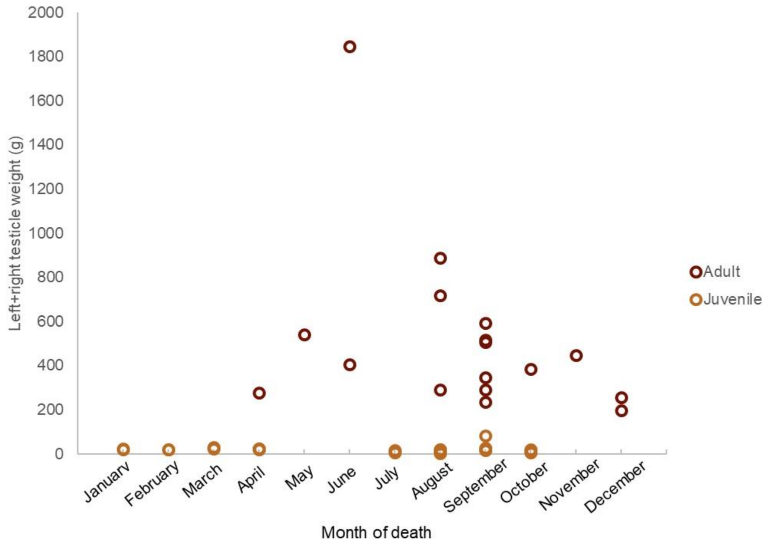


Figure 6. Testicular weight according to age group, with consistent low testicular weight for juveniles. The testicle weight of adult males varies between seasons.

Age and size

Of the porpoises for which age was determined, juvenile porpoises were between 0–2 years old and 101.5–133 cm long. Adult porpoises were between 3–19 years old and 136–169 cm long. Weight was a more uncertain measure because many carcasses had been scavenged. Figure 7 shows length, weight, and age among the porpoises in this study where information is available.

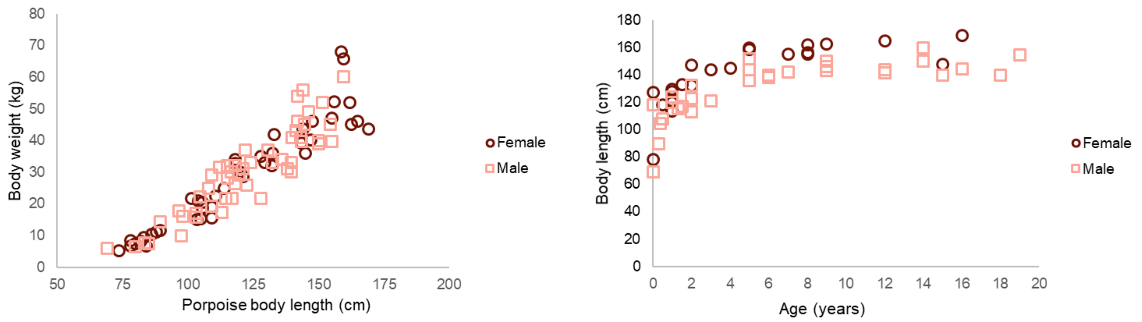


Figure 7. Diagram of weight vs. length (left) and length vs. age (right) of the porpoises in this study.

Discussion

The occurrence of porpoises differs greatly between the population areas, and the necropsy cases generally reflect the differences in porpoise density and frequency in Swedish waters. This conclusion is consistent with other studies, where stranding data have been shown to provide information on density in porpoises within a certain area (Peltier 2013). Therefore, changes in the frequency of reports of dead animals in areas are also important to follow, as they can provide indications of population growth, decline, and geographical fluctuations, which are difficult to monitor.

Only three of the porpoises in this study might belong to the Baltic Sea population, as they were collected in the overlapping population area between the Baltic Sea and the Belt Sea population. Genetic analyses of the animals need to be performed to know which population they belong to, but regardless, we can state that our compilation contains either very little or no data from porpoises from the endangered Baltic Sea population. The results from the necropsies therefore mainly apply to the Skagerrak/North Sea and Belt Sea populations. The cause of death and parasitism reported here are indications of what could be found in the Baltic Sea population, but the habitats differ between the populations.

Most porpoise calves were found dead between June and October. As females give birth around the month of June, this likely represents a time when calves are most vulnerable. Similar to calves, adults and juveniles were also found in larger numbers during the summer months. However, it cannot be ruled out that the seemingly higher mortality rate during the period reflects increased effort during summer months when there are more people present along the coast to find and report dead animals. A surveillance network with year-round, regular observational capacity would be needed to confirm seasonal variation in strandings.

In this study, confirmed bycatch accounts for 9% of the stranded animals. As mentioned earlier, bycatch is very difficult to diagnose with certainty in stranded animals and is probably underestimated. Almost a quarter (24.5%) of all stranded animals (*i.e.* not submitted by fishermen) were diagnosed as bycatch. This is lower than the 38% described for stranded porpoises on the English and Welsh coasts (Kirkwood, Bennett et al. 1997), but higher than the 15% described for Belgian and French coasts from 1990–2000 (Jauniaux, Petitjean et al. 2002). In a more comprehensive summary of the causes of death of stranded porpoises from 1990–2017 in Belgium, bycatches accounted for 35% of cases (Jauniaux, Delrez et al. 2019). In studies from German waters, bycatch was also the most common cause of death for stranded porpoises from the Baltic Sea, while it was rarely documented (7% of cases) in animals from the North Sea (Siebert, Wünschmann et al. 2001, Siebert, Tolley et al. 2006). A recent study from German, Danish, Polish and Latvian waters also concluded that bycatch was the main cause of death (around 50%) (Siebert, Pawliczka et al. 2020). Since bycatch accounts for a significant number of stranded animals, it confirms that stranding data can be a useful indication of fishing-related mortality in coastal waters. More reliable estimates of the size of bycatch mortality require well-designed fishery observer programs at sea (Cox, Read et al. 1998).

Diseases

Infectious and non-infectious diseases was the second most common cause of death. As in other studies, pneumonia was the most common infectious disease (Kirkwood, Bennett et al. 1997, Jauniaux, Petitjean et al. 2002). Most pneumonias were bacterial in origin and pneumonia was always seen in association with lungworm infection. However, the parasites are fairly ubiquitous and often were considered to be secondary or incidental findings. Bacteria that caused pneumonia are consistent with reports from other European countries (Jepson, Kuiken et al. 2000, Siebert, Wünschmann et al. 2001, Jauniaux, Petitjean et al. 2002, van Elk, van de Bildt et al. 2019, Siebert, Pawliczka et al. 2020)

Nutritional status

Nutritional status generally differed between bycaught porpoises and those that died of infectious diseases, which was consistent with other studies (Kuiken, Bennett et al. 1994). Similar analyses (e.g. BMI) performed for juvenile and adult porpoises could also be performed for calves, but taking into account that it would represent both their physiological developmental stages and health (Peig and Green 2010).

Depending on the status of the carcass, different measurements are relevant for assessing nutritional condition. Blubber thickness and girth are good alternatives and, if full body length and weight are measureable, BMI calculation can be useful. Optimally, if the porpoise is very fresh, all three options can be used to provide as complete a picture as possible. Our preliminary results show promise in using these measures as relevant for assessing nutritional status. More necropsies of fresh animals are needed so that the different measurements can be compared with each other and investigate seasonal trends. We need more carcasses in good condition along with historical data from NRM to establish what the normal curve for a healthy porpoise looks like at different times of the year.

By analyzing and classifying the ranges of BMI, blubber thicknesses, and girths for each nutritional condition class in relation to what is a normal range is for the time of year, a tool could be created to categorize the nutritional status of an examined carcass. Combining historical data to data collected prospectively means that both past and future necropsies can yield improved quality of body condition assessment.

Parasites

As in other studies, lung- and heartworms were a common finding in porpoises. These infections can lead to severe pneumonia (Jauniaux, Petitjean et al. 2002). Some roundworms (nematodes, e.g. *Pseudalis inflexus*) were found to be particularly pathogenic to porpoises (van Elk, van de Bildt et al. 2019). Identification of worms and systematic registration and grading of the infection is needed to be able to follow trends regarding parasitic infections in Swedish waters. Porpoises from waters in Norway, Iceland, and Greenland showed decreased lungworm incidence associated with milder pathological findings than animals from German waters and appear to reflect differences in porpoise populations or environmental conditions (Siebert, Tolley et al. 2006).

Emaciation

Emaciation was the most common diagnosis in calves, and most dead calves were reported from June to October. At that time, the calves are still suckling and most probably were separated from their mothers. The underlying cause of emaciation in the older age groups was not determined.

Predation

Tissue damage consistent with predation was seen in two cases and diagnosed as probable predation. In addition, of the eight cases diagnosed as trauma, predation could not be ruled out in at least two cases. In recent years, gray seals have increased in importance as predators of porpoises in the North Sea (Leopold, Begeman et al. 2015, Stringell, Hill et al. 2015) and the distribution areas of gray seals and porpoises overlap in Swedish waters. A group of killer whales are also regularly seen in the waters off the Swedish west coast. Swabs have been taken and saved from skin lesions on porpoises that are suspected to have been killed by a predator for future genetic analysis in an attempt to identify the predator.

Age at sexual maturity

One female classified as almost sexually mature was two years old and the youngest sexually mature female was three years old, which is young for porpoises (Lockyer 2003). Age of sexual maturity can, among other things, vary depending on density within the population (Read and Gaskin 1990), environmental contaminant burden, food availably and quality, etc. To determine the age of sexual maturity, establish growth curves and other life history parameters for these populations, all necropsied porpoises need to be aged. Calculation and monitoring of these parameters over time is highly warranted as they can act as indicators for health assessment.

Age of sexual maturity is an important health parameter but varies between regions. For porpoises it is usually between 3-4 years for both sexes but there seem to be regional differences (Lockyer 2003 and references therein).

Health indicators

Since the porpoise is a top consumer, is sensitive to anthropogenic threats and has a relatively short lifespan compared to other marine mammals, it is an excellent indicator of environmental conditions. Life history parameters, nutritional status and disease status are all possible health indicators. Size and age at sexual maturity are two life history parameters that are sensitive to changes in food supply (Read and Gaskin 1990, Read and Hohn 1995). Shifts in these parameters can be the result of changes in the food web, in the density of porpoises or in the marine environment that affect the food supply. Dietary studies, including trends from fatty acids or stable isotopes, can also provide insights into the shifts within marine food webs (Moore 2008). Changes in porpoise's nutritional status can reflect both shifts in the prey as well as prey quality but it can also indicate changes in disease incidence (Moore 2008). Porpoises that have died of infectious diseases are generally in poorer nutritional status than those caught in fishing nets (Kuiken, Bennett et al. 1994), as was also seen in this study. Finally, careful and continuous documentation of diseases, infectious agents, and parasites, as well as their absence, allow trends to be detected. Because the health status of porpoises reflects the ecosystem in which they are a part, changes in disease patterns in porpoises often signal changes in the ecosystem.

Contaminants

One of the strengths of the cooperation between SVA and NRM is the collection of data on both diseases and environmental contaminants. Many studies have suggested links between environmental contaminants and the health of marine mammals (Olsson 1975, Helle, Olsson et al. 1976, Jepson, Bennett et al. 1999, Bredhult, Bäcklin et al. 2008, Jepson, Deaville et al. 2016, Desforges, Hall et al. 2018, Williams, Doeschate et al. 2020). Similarly, the reproduction of seals in the Baltic Sea has been negatively affected by environmental contaminants (Bergman 1999). Even today, reproductive failure in porpoises in British waters is suggested to be linked to elevated concentrations of PCBs (Murphy, Barber et al. 2015).

Comparing health and disease conditions and reproductive data with environmental contaminant levels in porpoises in Swedish waters will help to fill knowledge gaps about the significance of environmental contaminants for these animals. A study on contaminants in Swedish porpoises was initiated in 2019 with funding from the Swedish EPA.

Recommendations

- More carcasses, especially fresh ones, need to be necropsied for a better understanding of porpoise health. Also, more adult animals need to be examined.
- Continued and expanded collaboration between NRM and SVA and other actors to create a better knowledge base regarding the health, diseases, and causes of death of porpoises.
- Increased and continued monitoring of infectious agents in Swedish porpoises to understand the significance of them for porpoises, to monitor trends and to identify which agents are present in marine ecosystems that may also have significance for domestic animals and humans
- Systematic macroscopic and microscopic examination and genetic analyses of bite wounds to investigate the extent of predation on porpoises in Swedish waters.
- Develop a coordinated national stranding program in Sweden to maximize data collection and contribute to the collection of porpoises from the Baltic Sea.
- Develop the opportunity to perform necropsy of selected porpoise cases at the facilities of our partners to promote sampling and data collection of fresh carcasses and strengthen collaboration with coastal communities.
- Standardization and further development of protocols for necropsies and field sampling should be done to ensure that the same data is collected regardless of who is handling a case.
- Continue to harmonize protocols with national and international actors for the exchange of information, including within the regional maritime conventions.
- Additional protocols to be produced when needed, for example to investigate the presence of plastic in the gastrointestinal tract.
- Additional and continuous analyses of PCB and other contaminants are urgently needed.

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