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REVIEW

Understanding causes of morbidity and mortality in Southern Hemisphere small Odontoceti: a scoping review

Rebecca SOUTER* *School of Animal and Veterinary Sciences, The University of Adelaide, Mudla Wirra Road, Roseworthy, SA 5371, Australia. Email: rebecca.souter@adelaide.edu.au*
Anne-Lise CHABER *School of Animal and Veterinary Sciences, The University of Adelaide, Mudla Wirra Road, Roseworthy, SA 5371, Australia. Email: anne-lise.chaber@adelaide.edu.au*
Luciana MÖLLER *College of Science and Engineering, Flinders University, Sturt Road, Bedford Park, SA 5042, Australia. Email: luciana.moller@flinders.edu.au*
Lucy WOOLFORD *School of Animal and Veterinary Sciences, The University of Adelaide, Mudla Wirra Road, Roseworthy, SA 5371, Australia. Email: lucy.woolford@adelaide.edu.au*

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*Correspondence

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ABSTRACT

1. Marine mammals serve as sentinels for environmental health, offering insights into ecosystem health. Enhancing management and conservation strategies for these species requires a comprehensive understanding of factors contributing to their morbidity and mortality.
2. This review aims to identify reported causes of morbidity and mortality in small Odontoceti within the Southern Hemisphere.
3. A scoping review of literature was conducted, searching Scopus, PubMed, and Web of Science, with additional screening of citations for articles not captured in the search.
4. The review encompassed 198 articles, with a total sample size of 25567 deceased small Odontoceti across 20 genera. A major challenge emerged, with the cause of death undetermined or unspecified in 39% of cases. Known entanglements accounted for 47% of total mortalities. Mass strandings (11%) and infectious disease (1.1%) were also reported. The study identified 14 primary infectious pathogens in 276 animals, spanning viral (CeMV = 214, H5N1 = 1), bacterial (*Brucella* sp. = 15, *Erysipelothrix* sp. = 1, *Streptococcus iniae* = 1, *Enterobacter kobei* = 1), parasitic (*Toxoplasma gondii* = 15, *Halocercus* sp. = 17, *Clistobothrium grimaldii* = 1, *Stenurus globicephalae* = 1, *Giardia* sp. = 1), and fungal (*Aspergillus* sp. = 2, *Paracoccidioides brasiliensis* = 5, *Cryptococcus* sp. = 1) origins.
5. Anthropogenic-induced mortality emerges as a significant threat to small Odontoceti of the Southern Hemisphere, underscoring the urgent need for enhanced conservation and management strategies. Increased surveillance of infectious pathogens is imperative, aiming to deepen our understanding of pathogen distribution, prevalence, and impact on Odontoceti health.

INTRODUCTION

There is a diverse range of marine mammal phylogenetic groups represented within the Southern Hemisphere (SH), including cetaceans (whales, dolphins, porpoises), pinnipeds (seals and sea lions), and sirenians (the dugong, the Antillean subspecies of the West Indian manatee, and the Amazonian manatee; Luna et al. 2021). The group Cetacea is composed of toothed whales (Odontoceti) and baleen whales (Mysticeti). Small cetaceans are part of the Odontoceti order which consist of the families Delphinidae, Iniidae, Kogiidae, Lipotidae, Monodontidae, Phocoenidae, Physeteridae, Platanistidae, Pontoporiidae, and Ziphiidae (Wursig & Perrin 2009). Small Odontoceti generally includes all Odontoceti families except Physeteridae (Gillespie 2003). Many of these species have differing biological traits, such as migratory and non-migratory, dietary preferences, and social behaviours. There is also physiological diversity between species. It becomes difficult to generalise about the negative effects on health and abundance when exposure to certain stressors depends on the species as well as populations. However, in the Northern Hemisphere (NH), generalised threats to small Odontoceti health have been well described (Van Bressem et al. 2009b, Bossart 2011). Known threats include infectious diseases, harmful algal toxins, anthropogenic contaminant exposure and accumulation, climate change, and anthropogenic interference. In comparison to the NH, there is a perceived paucity of information on threats to the health of small Odontoceti in the SH.

Background

The ocean is under threat due to anthropogenic pressure (Bossart 2011). The human population relies on the ocean as a food resource as well as for shipping/transport, tourism, recreation, and various industries. It also serves as a sink for waste products (Stockin et al. 2021). Many of these anthropogenic practices, necessary to sustain the human population, exert pressure on the natural ecosystem by exploiting finite resources and disrupting normal processes (Bossart 2011). Extinctions and population declines have been observed across a range of marine taxa, and marine mammals are considered vulnerable to these anthropogenic pressures (Monk et al. 2014, Cagnazzi et al. 2020). Odontoceti are K-selected species characterised by their long life span, substantial maternal investment, and slow maturation, with their population numbers contingent upon the carrying capacity of their habitat (Kemper et al. 2014). Severe and chronic environmental disturbance or mortality events can impact Odontoceti populations (Kemper et al. 2016), with potential cascading negative consequences to marine food webs (Kiszka et al. 2022).

Marine mammals are considered key indicators for environmental disturbance (Bossart 2011). Their reproductive strategies, life span, and high trophic status cause their population trends to mirror the carrying capacity of the environment, highlighting key environmental concerns if populations begin to decline (Cagnazzi et al. 2013). Long-term monitoring of marine mammal population health can assist to determine primary environmental issues that can have long-term impacts on ocean health. Some Odontoceti species can display small home ranges or year-round residency, providing an ideal candidate to assess the health of local environments. Additionally, pelagic species offer a candidate to assess environmental health in a broader sense, where fewer cumulative factors are present.

Humans can impact morbidity and mortality rates in Odontoceti in several ways. Acute mortality from entanglements in fishing gear and vessel collisions has been reported extensively across multiple species (Harwood & Hembree 1987). Other human interferences can have prolonged effects eventuating in chronic stress and behavioural disturbance. Stress can trigger altered behaviour, immune suppression, disrupt the endocrine system, and adversely affect normal biological processes (Desforges et al. 2016). Stressors have also been known to have cumulative effects (Murray et al. 2021). Therefore, the number of individual stressors and the intensity of each stressor determines the associated health effects. Anthropogenic stressors are not limited to direct disturbance. Heavy metals and persistent organic pollutants (POPs) have been known to accumulate in cetaceans (Law et al. 2003, Stockin et al. 2021). Some of these contaminants, which may be waste products from industry, wastewater, agriculture, construction, or mining, have been reported to cause adverse health effects such as immunotoxicity, reproductive failure, endocrine disruption, and neuropathy in marine mammals (Schaap et al. 2023). Climatic events such as heat waves and heavy rainfall can also cause severe physiological stress, triggering mortality events (Wild et al. 2019, Duignan et al. 2020).

Due to their proximity to human civilisations, coastal species are exposed to a larger volume of stressors overall. This may pose them at an increased risk of adverse health effects such as infectious disease susceptibility (Van Bressem et al. 2009b, Bossart et al. 2019). Odontoceti have been subject to large-scale mortality events from diseases including cetacean morbillivirus (Van Bressem et al. 2014). They are also susceptible to contract and suffer adverse effects from zoonotic diseases, including brucellosis, leptospirosis, lobomycosis, and toxoplasmosis (Van Bressem et al. 2009b, Bossart 2011). Deteriorating health in Odontoceti can increase their susceptibility to infectious diseases, which may subsequently lead to zoonotic disease spillover to humans (Bossart 2011).

This scoping review explores current literature about the known anthropogenic and non-anthropogenic threats to small Odontoceti health in the SH, providing a comprehensive summary of published events, identifying knowledge gaps, and improving our understanding of the status of infectious pathogens. This will be useful for guiding future research efforts, monitoring population health, performing disease risk analyses, determining disease prevalence in populations, and identifying the emergence of novel pathogens. This information also becomes vital when identifying the steps required to achieve species conservation and management amid a changing climate.

THE REVIEW

Aim

The aim of this scoping review was to identify the reported threats to small Odontocetes in the SH. The study was limited to the SH due to the research focus of this group (located within the SH), the perceived paucity of information on threats within this region, and for logistical reasons (a comparable literature search targeting the NH revealed a large volume of studies). The principal questions we aimed to address included: 'at what level do humans contribute to mortality of dolphins', 'are natural causes of mortality represented in the literature', and 'what disease and co-morbidities have been reported?'.

Design

This review was conducted using the JBI (Joanna Briggs Institute) guidance for scoping reviews (Peters et al. 2020) and the PRISMA extension for scoping reviews (PRIMA-ScR) checklist (Page et al. 2021). This methodology was adopted with the aim to explore broad, heterogeneous literature in a growing field, and report the key characteristics and concepts identified.

The participants, concept, and context approach for inclusion criteria was adopted in our search strategy (Peters et al. 2020). Data were sourced from populations of free-ranging small Odontoceti species, which included all Odontoceti families except Physeteridae (Gillespie 2003), Ziphiidae, and Kogiidae. The concept explored included morbidity and mortality events as a way of compiling, analysing, and presenting data for future research. Morbidity and mortality events included those of non-infectious and infectious aetiologies. Morbidity events were secondary, observational, or findings of unknown significance that were not considered the direct cause of mortality. The context included research from the SH only. The types of sources eligible for our review included peer-reviewed primary articles, conference proceedings, letters to editors, government reports, and short communications that reported morbidity or mortality in small Odontoceti. No date range was applied to our search.

Search methods

Using three online data bases, Scopus, PubMed, and Web of Science, and the search phrase (dolphin* OR cetacean* OR 'marine mammal') AND (disease OR stranding* OR mortality OR infection) AND ('Southern Hemisphere' OR Oceania OR Asia OR 'South America' OR Africa OR Antarctica OR New Zealand OR Indonesia OR Australia OR Argentina OR Brazil OR Chile OR Ecuador OR Fiji OR 'French Polynesia' OR Madagascar OR Maldives OR Mauritius OR Mozambique OR 'New Caledonia' OR 'Papua New Guinea' OR 'Reunion Island' OR 'Seychelles' OR 'Solomon Islands' OR Uruguay OR Vanuatu), an initial literature search was conducted on 19 October 2022 and repeated on 18 April 2024, with the date range set to 'all time'. Reports were exported into *Covidence* (Veritas Health Innovation, Melbourne, Australia), where duplicates were removed, and screening performed by RS. Additional literature that was not captured in our initial search was sourced through screening the reference lists of eligible articles. Articles reporting tissue pollutant concentrations without concurrently assessing health parameters were excluded from the study.

Data extraction

Microsoft Excel was used to develop extraction spreadsheets that assisted with data collection. A full list of references is included in Appendix S1. Data were extracted by one reviewer (RS). Data regarding location of the study, source type (i.e. primary research article, short communication), date, sample size, species, how the data were obtained (i.e. bycaught animals, beach cast/stranded animals, observational survey), reported causes of morbidity and mortality, diseases identified, and associated contributing factors or co-morbidities were recorded.

Data analysis and presentation

Total sample sizes for causes of morbidity and mortality reported in the literature were determined. Textual data on co-morbidities and any associations made between mortality events and other factors (e.g. climatic events) reported was developed and described. Microsoft Excel was used to explore study characteristics and main findings across the literature.

RESULTS

A search of three databases using our search strategy yielded 3596 results. Once duplicates were removed, 1928 records were subject to title and abstract screening. Once irrelevant articles were identified and removed, 404 reports were retrieved and underwent full-text screening by RS. This resulted in 144 articles meeting the eligibility criteria. An additional 54 articles met the eligibility criteria through citation screening and were thus included in this review. Figure 1 displays a PRISMA flow chart detailing the selection process.

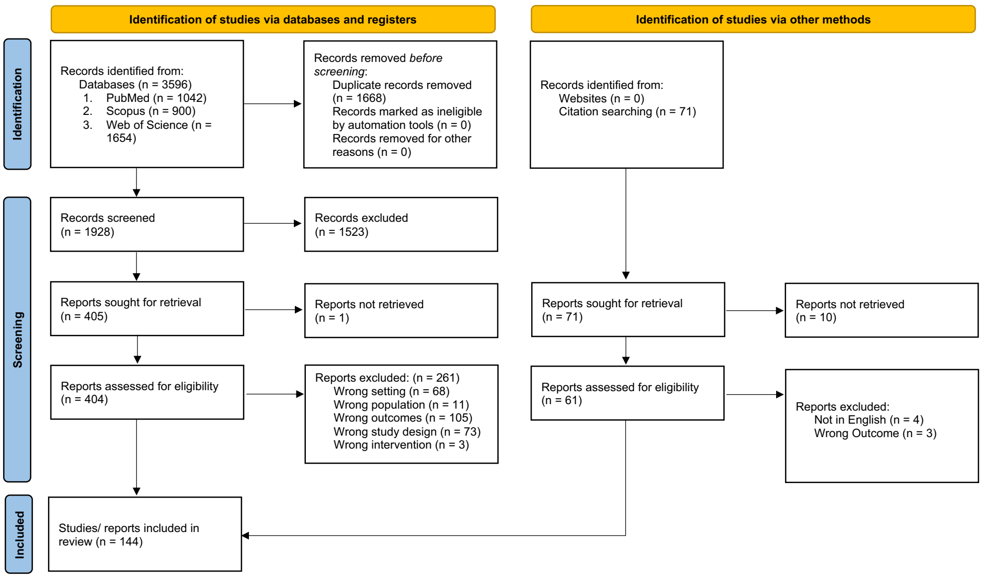

Fig. 1. PRISMA flow chart of the scope review showing number of records kept after each selection step.

Characteristics of included articles

Primary research articles made up for 75% of studies included (Table 1). The highest proportion of studies (28%) had a sample size of less than 10 individuals; however, 23% of studies had sample sizes between 101 and 500. Brazil was the most common location for the studies, accounting for 35% of the total, followed by Australia (28%) and New Zealand (10%) (Fig. 2). Approximately 36% of studies were published beyond 2016; however, many studies were retrospective and utilised data collected over large time periods, with 27% of studies utilising data that spans more than 10 years.

Various data collection techniques were reported: 52% of studies utilising stranded animals and 34% utilised bycaught animals from fishing operations or shark nets. Other methods included observational surveys (19%), live animal capture/release (5%), and interrogation of archived data (13%). Some studies (30%) used a combination of these sampling techniques.

A total of six families were identified within the review, Delphinidae, Pontoporiidae, Phocoenidae, Platanistidae, Iniidae, and Lipotidae, comprising 20 genera. A total sample size of 32481 small Odontoceti, including observation data (n = 6914), was extracted from the literature examined.

Causes of morbidity and mortality of small cetaceans in the SH

Mortality was reported for 25567 small Odontocetes (Fig. 3). Cause of death was unable to be determined or was not specified for 10057 (39%) individuals. Cause of death was assigned to 15510 individuals. Of these, 12029 were known entanglement cases. The remaining 3481 individuals were beach cast individuals where cause of mortality was categorised. Morbidity and mortality events were categorised into infectious, non-infectious (including anthropogenic impacts), and unknown aetiologies (Figs 4 and 5). Infectious aetiologies included diseases of viral, bacterial, fungal, metazoan, protozoan, or ectoparasitic origin. Non-infectious aetiologies included anthropogenic [entanglement (known and probable), vessel strike, sonar or blast effect, intentional killing, and marine debris/plastic ingestion] causes, non-anthropogenic trauma (con- or interspecific), and diseases of nutritional, metabolic, toxic, congenital/genetic, age-related/degenerative, inflammatory non-infectious, neoplastic, environmental/physiological, or miscellaneous origin. Other causes of morbidity and mortality included neonatal death and mass strandings.

Reported disease was grouped into primary, secondary, or observational findings. Primary was considered as the most likely cause of death, secondary findings included diseases that were identified in addition to primary mortality, and observational findings were diseases detected in free-ranging animals, therefore having unknown consequences to individual health. We considered findings in live animals important in understanding disease epidemiology. However, it is important to acknowledge that the significance of these findings on morbidity and mortality events is unknown.

NON-INFECTIOUS CAUSES OF MORBIDITY AND MORTALITY

Non-infectious causes of mortality were most prevalent due to the large number of known entanglement cases (n = 12029). Within beach cast individuals where mortality

Table 1. Characteristics of included articles in this analysis (n = total number of studies)

Study/article characteristics	n (%)
Type of evidence source	
Primary research article	149 (75)
Conference proceeding	2 (1)
Short communication/correspondence/dispatch	22 (11)
Note	15 (8)
Letter to the editor	6 (3)
Government report	3 (1.5)
Sampling technique	
Bycaught animals	66 (33.5)
Stranded animals	103 (52)
Observational/boat based	37 (19)
Live capture/release	10 (5)
Archived data/samples	26 (13)
Not specified	1 (0.05)
Combination of techniques	30 (15)
Date published	
<2000	27 (14)
2000–2005	32 (16)
2006–2010	32 (16)
2011–2015	36 (18)
2016–2020	47 (24)
2021–2024	24 (12)
Sample size	
<10	56 (28)
10–50	39 (20)
51–100	35 (18)
101–500	46 (23)
>500	16 (8)
Not specified	6 (3)
Region	
Africa	15 (8)
Antarctica	0 (0)
Asia	1 (0.5)
Oceania	79 (40)
South America	108 (54)
Studies with more than one region	3 (1.5)
Sampling date	
<2000	47 (24)
2000–2010	65 (33)
2011–2020	42 (21)
>2020	3 (1)
Unspecified	3 (1.5)
>10-year date range	54 (27)

could be assigned, non-infectious aetiologies accounted for 10% (354/3481), most of which were of anthropogenic origin (Fig. 4). Secondary, observational, or findings of unknown significance were also reported (Fig. 4).

ANTHROPOGENIC

Known entanglement cases were categorised into fishing gear types (Fig. 3). Approximately 35% of these could not be categorised, likely due to different sampling techniques and variation in study objectives (Van Waerebeek et al. 1997, Monteiro-Neto et al. 2000). Mortality in shark/bather protection nets were frequently reported (26%, n = 3235), followed by gillnets (20%, n = 2461), trawl fisheries (4.2%, n = 525), purse seine (<1%, n = 109), fish feedlot protection nets (<1%, n = 90), longline/shark fisheries (<1%, n = 61), and recreational fishing or decapod gear (<1%, n = 8). Entanglements in shark nets off Kwazulu-Natal, South Africa, were most frequently reported (Cockcroft 1990, 1992, Atkins et al. 2013, Lane et al. 2014, Plön et al. 2020, Van Bressem et al. 2020, Roussouw et al. 2022). Australia was the only other location reporting bycatch from shark nets (Paterson 1990, Krogh & Reid 1996). Gillnets were associated with mortalities across a large geographic distribution (Argentina, Australia, Brazil, Chile, New Zealand, Peru, Uruguay) (Harwood & Hembree 1987, Hutton et al. 1987, Dawson 1991, Torres et al. 1992, 1994, Corcuera et al. 1995, Van Bressem & Van Waerebeek et al. 1996, Ramos et al. 2001, Bertozzi & Zerbini 2002, Rosas et al. 2002, Di Beneditto 2003, Duignan et al. 2004, Franco-Trecu et al. 2009, Mangel et al. 2010, Denuncio et al. 2011, Prado et al. 2013). Trawl fisheries interactions were reported in Argentina, Australia, Brazil, New Zealand, and Uruguay (Dans et al. 1999, Crespo et al. 2000, Berón-Vera et al. 2007, Montealegre-Quijano & Ferreira 2010, Thompson et al. 2013, Allen et al. 2014, Franco-Trecu et al. 2019), and purse seine fisheries in Australia, Brazil, and Chile (Silva & Best 1996, Segawa & Kemper 2015, González-But & Sepúlveda 2016, Tomo & Kemper 2022, Kemper et al. 2023). Mortalities in fish feedlot protection nets (e.g. tuna and kingfish) were reported in South Australia and Chile (Kemper & Gibbs 2001, Kemper et al. 2005, Segawa & Kemper 2015, Espinosa-Miranda et al. 2020). Mortalities in longline fisheries were reported in Argentina and Brazil (Aznar et al. 2001, Mangel et al. 2010), as well as orca interactions in New Zealand (Visser 2000). Other accounts of entanglement mortalities included lethal fishing hook penetration from recreational fishing equipment, one of which caused a secondary septicaemia (Byard et al. 2020) and mortalities in decapod gear in South Australia (Kemper et al. 2005, Segawa & Kemper 2015).

Non-fatal anthropogenic injuries were reported in some studies, with a focus on observational data of lesions suggestive of anthropogenic origin (Kiszka et al. 2008, Nery et al. 2008, Azevedo et al. 2009). Some observational studies monitoring entanglements detected dolphins escaping from nets with physical injuries, of which the consequences to survival are unknown (González-But & Sepúlveda 2016). Other studies reported entanglements as having significant social consequences such as emigration, reduced sociality, and loss of social ranking (Félix 2021).

Vessel collisions were reported as the primary cause of mortality for eight individuals (<1%) (Visser 1999, Stone

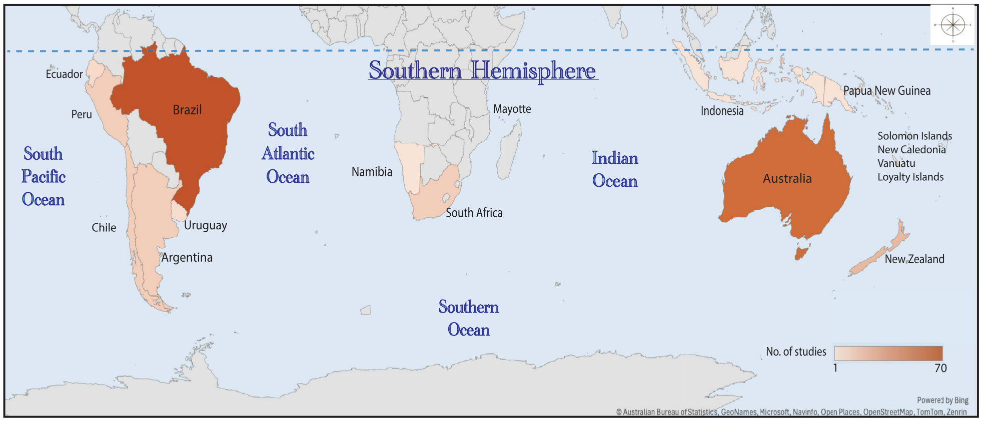

Fig. 2. Heatmap displaying the number of studies reporting data from individual countries in the Southern Hemisphere.

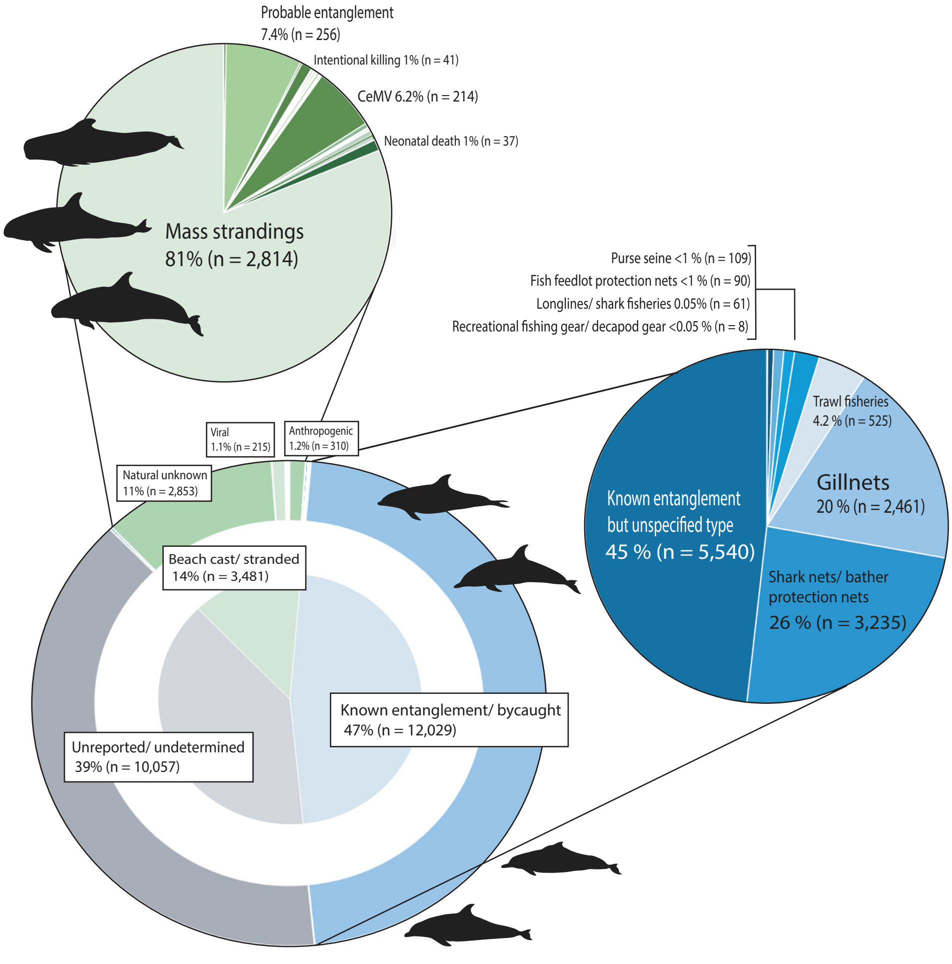

Fig. 3. Reports of mortality in genera of small Odontoceti in the Southern Hemisphere ($n = 25567$). Grey represents unreported or undetermined causes of mortality, blue displays cases of known entanglement with different equipment types, and green represents beach cast/stranded individuals where mortality was categorised.

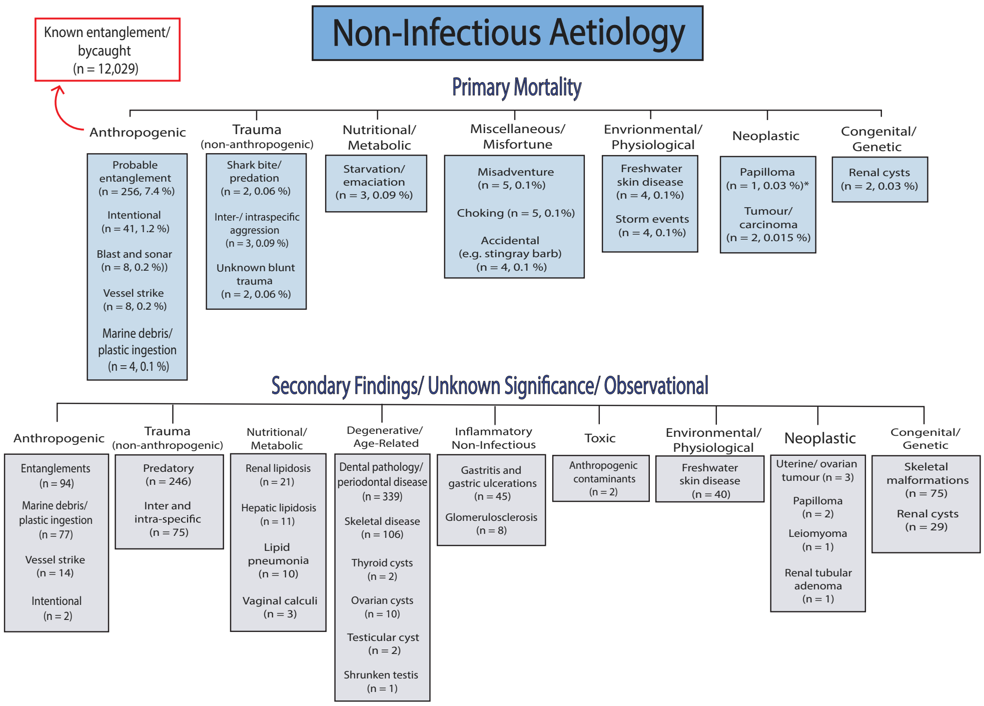

Fig. 4. Primary, secondary, and observed reports of non-infectious morbidity and mortality in stranded and bycaught small Odontoceti of the Southern Hemisphere (*n* = number of individuals reported). *Possible viral aetiology, unconfirmed (Byard et al. 2010).

& Yoshinaga 2000, Byard et al. 2013, Martinez & Stockin 2013, Domiciano et al. 2016, Adamczak et al. 2018, Tomo & Kemper 2022). Propellor wounds were also identified in observational studies (Visser 1999, Hawkins et al. 2022).

Intentional harm of small cetaceans by humans (41/3481, 1.2%) was reported in Brazil (Loch et al. 2009, Meirelles et al. 2009, Iriarte & Marmontel 2013), Australia (Gilbert et al. 2000, Byard et al. 2001, Kemper et al. 2005, Adamczak et al. 2018, Tomo & Kemper 2022), and New Zealand (Visser 2000). The motivation behind intentional killings is often unclear; however, in some regions there is a perception that marine mammals compete with humans for food, or damage fishing gear, and fisherman in New Zealand have reported shooting at *Orcinus orca* (orca or killer whale) that compete with longline fisheries (Visser 2000). Other intentional killings may be involved in cultural beliefs, bait for fishing, human consumption, and trade (Loch et al. 2009, Iriarte & Marmontel 2013).

An unusual stranding of eight dolphins [*Stenella longirostris* (spinner dolphin), *Sotalia guianensis* (Guiana dolphin), and *Stenella* sp.] was reported in Brazil following an offshore 3D seismic survey. Pathological findings included congestion of the heart, brain, and liver, and haemorrhage within the lungs, brain, and intestine, suggestive of acoustic-related trauma (Meirelles et al. 2016). This study was the only identified report of acoustic trauma in small cetaceans of the SH.

Plastic ingestion was identified as the cause of death in cetaceans from Australia (Lloyd & Ross 2015) and in an adult male *Steno bredanensis* (rough-roothed dolphin) in Brazil. The latter case was severely emaciated, and on necropsy two plastic bags were identified within the forestomach associated with mucosal ulceration (de Meirelles & do Rego Barros 2007). In other studies, plastic ingestion was an incidental finding and was not considered the primary cause of death (Duignan et al. 2003, Denuncio et al. 2011, Padula et al. 2023).

NON-ANTHROPOGENIC TRAUMA

Non-anthropogenic causes of traumatic injury were observed as the primary cause of mortality in 7/3481 (0.2%). Individual cases of death due to choking on oversized or dangerous prey items has been reported in Brazil (Domiciano et al. 2016, Mariani et al. 2020) and Australia (Byard et al. 2003, 2010, Stephens et al. 2017).

Conspecific aggression has been suggested as a cause of trauma in dolphin species from Peru (Van Bressem et al. 2006). Interspecific aggression has been reported from bottlenose dolphin (*Tursiops* spp.) aggression (García-Cegarra et al. 2024). Fatal and non-fatal shark predation has been reported (Mann & Barnett 1999, Heithaus 2001, Smith et al. 2018, Mann et al. 2021, Hawkins et al. 2022), as well as non-fatal wounds caused from cookie cutter sharks (*Isistius* sp.) (Dwyer & Visser 2011) and other marine species (Tomo & Kemper 2022).

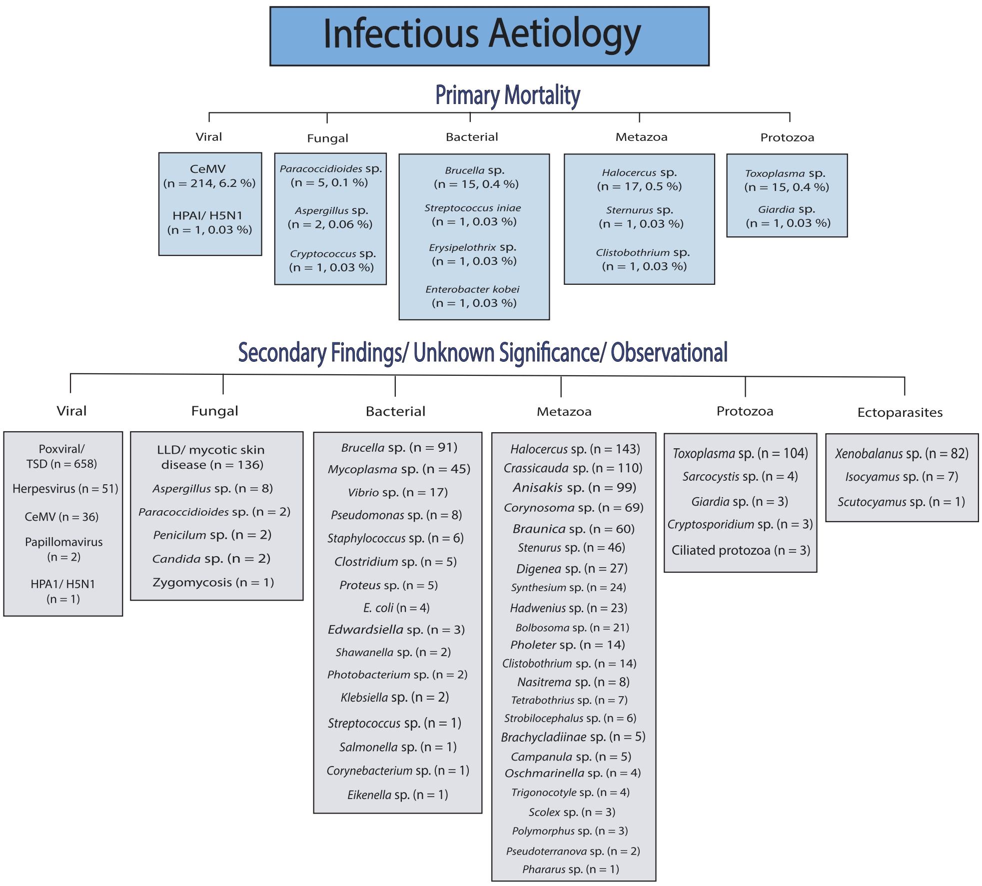

Fig. 5. Primary, secondary, and observed reports of organisms involved in infectious diseases of stranded and bycaught small Odontoceti of the Southern Hemisphere (n = number of individuals reported).

MISCELLANEOUS AND MISFORTUNE

Mortality due to stingray barb penetration has been reported in *Tursiops aduncus*, *Sousa chinensis* (Indo-pacific humpback dolphins), and *Orcinus orca* (Duignan et al. 2000, Bowater et al. 2003, Tomo & Kemper 2022). Misadventure, for example, becoming trapped while exploring (Rodrigues et al. 2018) or misjudging the tide in a shallow lagoon (McGovern et al. 2019), has also been reported.

NUTRITIONAL AND METABOLIC

Emaciation was reported in three dolphins from Brazil [*Sotalia guianensis* and *Pontoporia blainvillei* (La Plata dolphin)] (Domiciano et al. 2016). Hepatic lipidosis was identified as a pathological finding in 10/29 *Sotalia guianensis* that suffered primary CeMV infection during an *unusual mortality event* (UME) in Brazil (Groch et al. 2020a, b). In South America, vaginal calculi were identified in bycaught *Lagenorhynchys obscurus* (dusky dolphin) (Van Bressem et al. 2000) and lipid pneumonia has been reported in bycaught *Pontoporia blainvillei* (Ruoppolo et al. 2010).

ENVIRONMENTAL/PHYSIOLOGICAL

Fresh water skin disease has been confirmed on two separate occasions in four bottlenose dolphins from two estuarine environments in Australia following severe rainfall events. In one event, 40 *Tursiops* sp. were also observed with similar lesions. Salinity was reported to have rapidly declined to near freshwater (<5 parts per thousand) prior to disease incidence. The skin lesions varied in gross presentation and severity, but in general, ulcerative dermatitis with secondary bacterial, fungal, and algal infections of varying species were observed (Duignan et al. 2020).

NEOPLASTIC

Multifocal leiomyoma were identified in the gastrointestinal tract, mesentery, and liver of an adult female *Delphinus delphis* (common dolphin) from South Australia (Tomo & Kemper 2022). Female reproductive tumours (dysgerminoma, leiomyoma, and fibroleiomyoma) were reported in three bycaught *Lagenorhynchys obscurus* from Peru (Van Bressem et al. 2000) and a metastasized uterine adenocarcinoma in a *Tursiops truncatus* has been reported in Argentina (Sánchez et al. 2002). Squamous cell carcinoma and peripheral nerve sheath tumour was identified in a live stranded *Steno bredanensis* of Brazil (Alves-Motta et al. 2020). Papillomas were reported in three cases. It is possible that these lesions were of viral origin; however, no viral agent was reported. One papilloma case led to upper airway obstruction and subsequent death in a *Tursiops aduncus* from South Australia (Byard et al. 2010). Other secondary findings included a fibropapilloma in a *Sotalia guianensis* with primary CeMV (Groch et al. 2020a, b) and an oral papilloma in a *Steno bredanensis* (Sacristán et al. 2019).

CONGENITAL/GENETIC

Congenital skeletal abnormalities were identified in 65 specimens of varying species [*Lagenorhynchus australis* (Peale's dolphin), *Tursiops aduncus*, *Delphinus delphis*, *Sotalia guianensis*, *Tursiops truncatus*, and *Lagenorhynchys obscurus*]. The significance of these lesions remains unknown, however, some cases displayed lesions as adults suggesting it was unlikely to be impacting on survival (Berghan & Visser 2000, Van Bressem et al. 2006, San Martín et al. 2016, Fettuccia et al. 2013, Tomo et al. 2018).

Polycystic kidney disease (PKD) has been reported as the primary cause of mortality in two *Steno bredanensis* and renal cysts have been a secondary finding in 29 individuals (Gonzales-Viera et al. 2015, Pires et al. 2021).

AGE RELATED/DEGENERATIVE

Age-related and degenerative diseases were identified as secondary findings or having an unknown significance to health in 353 cases. Dental pathology was reported in 159 cases, periodontal disease presented in 180 cases, and ankylosis presented in 11 cases (Van Bressem et al. 2006, Loch et al. 2011, Fettuccia et al. 2013, San Martín et al. 2016, Tomo et al. 2018). The significance of these lesions is difficult to determine as cause of death was not the focus in the reporting studies.

Abnormalities of the endocrine and reproductive systems were reported as secondary findings in 15 cases. Cysts identified in the thyroid gland (2 cases), ovaries (10 cases), and testis (2 cases) were reported, as well as shrunken testis in a *Lagenorhynchys obscurus* (Van Bressem et al. 2000, Duignan et al. 2003).

INFLAMMATORY NON-INFECTIOUS

Gastric ulceration was identified in 45 specimens and was a co-morbidity with various infectious pathogens such as CeMV, brucellosis, and freshwater skin disease. Gastric ulceration associated with parasitism could not be excluded in all cases (Duignan et al. 2003). Glomerulosclerosis was also reported, but likely as a terminal stage of other diseases processes (Gonzales-Viera et al. 2015).

TOXIC

Pseudorca crassidens (false killer whales) from a mass stranding in South Africa were tested for metals in skin samples. Aluminium was found in high levels and was associated with high levels of fungal pathogens concurrently tested (Mouton et al. 2015). In South Australia, liver cadmium was elevated in a *Tursiops aduncus* with malformation of its lumbar vertebrae (Tomo et al. 2018). Long et al. (1998) detected proteinuria in *Delphinus delphis* and *Tursiops truncatus* in conjunction with renal cadmium concentrations ranging 2.1–38.2 mg kg^{-1} w.w. Copper and zinc concentrations were also elevated in a South Australian *Tursiops aduncus* which had renal and skeletal abnormalities (Lavery et al. 2009), as well as indications for reproductive pathology (Kemper et al. 2014). No reports of mortality due to harmful algal blooms were identified in this study.

INFECTIOUS DISEASE

Infectious disease was the most likely primary cause of mortality in 276/3481 cases (8%), and included organisms of viral, fungal, bacteria metazoan, and protozoal origins (Fig. 5). Major pathogens of concern were documented across multiple locations in the SH (Fig. 6).

VIRAL

CeMV was considered a primary cause of mortality in 214 cases and was a secondary or observational finding in 36 cases. CeMV has been reported in Australia (Stone et al. 2011, 2012, Stephens et al. 2014, Kemper et al. 2016), New Zealand (Van Bressem et al. 2001a), Brazil (Groch et al. 2014, 2018, 2020a, b, Domiciano et al. 2016, Costa-Silva et al. 2023), Peru (Van Bressem et al. 1998), Argentina, and South Africa (Van Bressem et al. 2001a) across a large host range. CeMV has been responsible for two UMEs, one in South Australia (Kemper et al. 2016) and another in Brazil (Groch et al. 2018, 2020a, b, Cunha et al. 2021). Cases often had concurrent bacterial, fungal, and parasitic infections, suggesting a morbillivirus-induced immune suppression. An infestation of an acorn barnacle (*Xenobalanus globicipitis*) was observed in Brazil six months after the CeMV outbreak (Flach et al. 2021).

Gammaherpesvirus and alphaherpesvirus have been confirmed in Brazil in four different species [*Pontoporia blainvillei*, *Inia boliviensis* (Bolivian river dolphin), *Stenella frontalis* (Atlantic spotted dolphin), and *Sotalia guianensis*].

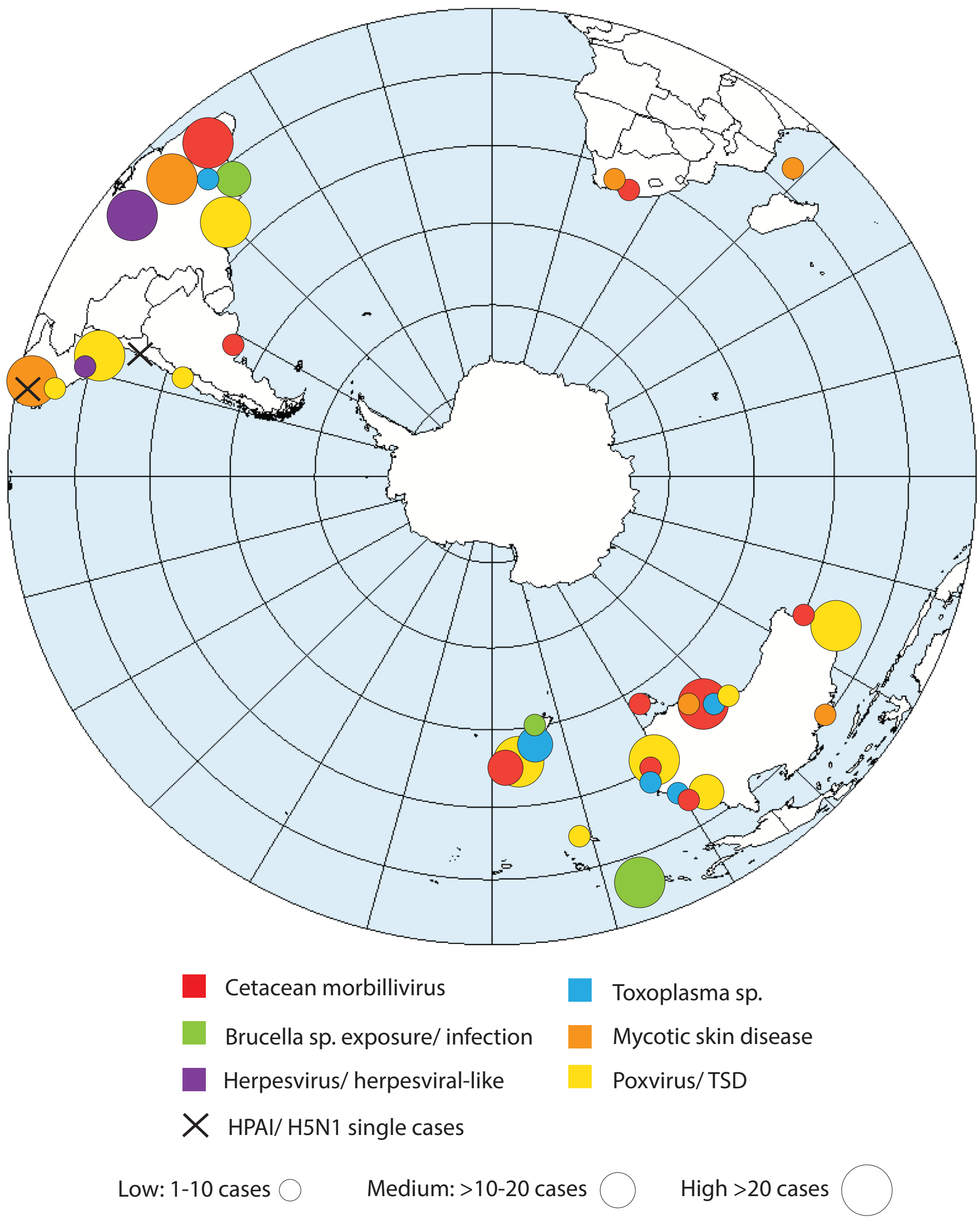

Fig. 6. Reported case numbers and distribution of CeMV, H5N1, *Brucella* sp., herpesvirus, *Toxoplasma* sp., mycotic skin disease, and poxvirus in small Odontoceti of the Southern Hemisphere. The small circles represent 1–10 reported cases, medium circles represent >10–20 reported cases, and the large circles represent >20 reported cases.

Diagnosis was made by detection of herpesviral DNA and histological evidence of viral inclusion bodies in lymph nodes and skin lesions. Clinical signs included cutaneous and mucosal lesions of the mouth and genital organs (Seade et al. 2017, Sacristán et al. 2019, Exposto Novoselecki et al. 2021). Bycaught *Lagenorhynchys obscurus* from Peru displayed herpes-like skin lesions and viral particles were confirmed by transmission electron microscopy (TEM). Skin lesions presented as multifocal, rough, dark spots over the beak in four animals and over various body surfaces in one animal (Van Bressem et al. 1994). Herpesvirus has also been detected by polymerase chain reaction (PCR) in the absence of pathological lesions (Sacristán et al. 2024).

Genital and lingual warts were reported in bycaught *Lagenorhynchys obscurus*, *Delphinus* sp., *Tursiops truncatus*, and *Phocoena spinipinnis* (Burmeister's porpoise) from Peru. Although definitive diagnosis was not attained, immunohistochemistry (IHC) recognised papillomavirus antigens in some samples and histopathological changes were observed (in the absence of viral inclusions). Warts were identified in high numbers in each species suggesting venereal transmission (Van Bressem et al. 1996). A papillomatous-like tumour was reported in the upper airway of an adult *Tursiops aduncus* from South Australia causing fatal obstruction, though viral involvement was not investigated (Byard et al. 2010).

Poxvirus, or tattoo-like skin disease, has been identified in Australia (Fury & Reif 2012, Powell et al. 2018, Tomo & Kemper 2022), South America (Van Bressem et al. 1993, Van Bressem & Van Waerebeek et al. 1996, Sanino et al. 2014, Sacristán et al. 2018a), and New Zealand (Duignan et al. 2003, Hupman et al. 2017) in *Tursiops* spp., *Sotalia guianensis*, *Stenella longirostris*, *Lagenorhynchys obscurus*, *Lagenorhynchus australis*, *Delphinus delphis*, *Cephalorhynchus hectori* (Hector's dolphin), and *Phocoena spinipinnis*. Poxvirus has characteristic tattoo-like lesions with a broad distribution over body surfaces (Van Bressem et al. 2009c). Boat-based observational and photographic surveys were the most frequently used to examine poxviral prevalence in dolphin populations (Fury & Reif 2012, Sanino et al. 2014, Powell et al. 2018, 2020). Other methods of disease detection included PCR, TEM, and histopathological evidence of inclusion bodies in deceased animals (Sacristán et al. 2018a).

H5N1 was detected in a rectal swab from a *Delphinus delphis* stranded in Peru, following an investigation into pelican (*Pelecanus thagus*) and sea lion (*Otaria flavescens*) mortalities attributed to this disease (Leguia et al. 2023). H5N1 was also reported in a serum sample from a stranded *Phocoena spinipinnis* from Chile. Necropsy was not performed on this individual due to the risk of viral spill over, therefore primary cause of death remains uncertain (García-Cegarra et al. 2024).

FUNGAL

Aspergillosis characterised by pneumonia and encephalitis was reported in *Cephalorhynchus hectori* from New Zealand (Duignan et al. 2003, Duignan & Jones 2005). In Australia, cerebral and pulmonary aspergillosis was associated with primary CeMV infection in *Tursiops aduncus* from South Australia (Stephens et al. 2014, Kemper et al. 2016). Pulmonary cryptococcosis was reported in a *Stenella coreuleoalba* (striped dolphin) stranded in Western Australia, with histological evidence of cryptococcal organisms in the lungs, lymph nodes, and gastric mucosa (Gales et al. 1985).

Lobomycosis-like disease, possibly caused by the fungal agent *Paracoccidioides brasiliensis*, has been reported in Australia (Palmer & Peterson 2013, Tomo & Kemper 2022), South Africa (Lane et al. 2014, Van Bressem et al. 2015), and South America (Simõse-Lopes et al. 1993, Moreno et al. 2008, Kiszka et al. 2009, Van Bressem et al. 2009a, 2015, Daura-Jorge & Simões-Lopes 2011, Sacristán et al. 2016, Félix et al. 2019, Soares et al. 2022). It has been reported in *Tursiops truncatus*, *Tursiops aduncus*, *Orcaella heinsohni* (Australian snubfin dolphin), and *Sousa plumbea* (Indian Ocean humpback dolphin). *Paracoccidioides brasiliensis* most commonly causes characteristic chronic granulomatous cutaneous skin lesions which can resolve on their own or cause fatality in severe cases. Most studies used observational surveys and photographic evidence of characteristic skin lesions to confirm disease prevalence. Confirmed cases have been detected through histopathology and molecular techniques (Moreno et al. 2008, Lane et al. 2014, Sacristán et al. 2018b).

BACTERIAL

Brucella sp. was the most identified bacterial pathogen. In Brazil, multiple species have been identified as positive based on PCR, IHC, and serology, and the presence or absence of characteristic lesions. Acute or chronic, asymptomatic, and exposed individuals have been identified, as well as co-infection with other pathogens (Sánchez-Sarmiento et al. 2018a, b, 2019, Sousa et al. 2021). *Brucella* has been confirmed in *Cephalorhynchus hectori* in New Zealand, with two individuals diagnosed with active brucellosis and five having an asymptomatic/latent infection (Buckle et al. 2017). Anti-brucella antibodies have been identified in dolphins of the Solomon Islands (Tachibana et al. 2006), Peru (Van Bressem et al. 2001b), and South Australia (authors personal observation). Orchitis and vertebral osteomyelitis was reported in a *Delphinus* sp. from Peru. Aetiology in this case was not confirmed; however, *Brucella* is a likely candidate based on pathological findings (Van Bressem et al. 2006). Skeletal lesions that resembled those previously described in brucellosis cases were also identified in a skeletal pathology survey in South Australian *Tursiops aduncus*, however, aetiology was not definitively confirmed (Tomo et al. 2018).

In South Australia, *Corynebacterium ulcerans* was isolated from a *Tursiops aduncus* that displayed multifocal cutaneous lesions (Kemper et al. 2005) and *Streptococcus iniae* was isolated from a *Delphinus delphis* presenting multifocal cutaneous ulcerations. In the latter, evidence of a bacteraemia and sepsis was present microscopically in skin lesions, lungs, and adrenal gland (Souter et al. 2021). *Erysipelothrix* sp. was identified as the cause of acute dermatitis with vasculitis, characterised by multifocal, well-demarcated 4–6 cm in diameter rhomboid skin lesions, in an adult *Tursiops truncatus* found stranded in Brazil (Sacristán et al. 2022). A multi-drug resistant *Enterobacter kobei* was isolated from the lung exudate of a female neonate *Pontoporia blainvillei* from Brazil that died of sepsis (Fuentes-Castillo et al. 2021).

Mycoplasma spp. DNA was detected by PCR in blood samples from stranded or bycaught *Delphinus delphis*, *Feresa attenuata* (pygmy killer whale), *Orcinus orca*, *Sotalia guianensis*, *Stenella coeruleoalba*, *Stenella frontalis*, *Steno bredanensis*, and blood and tissue samples from *Pontoporia blainvillei* (Duarte-Benvenuto et al. 2023), as well as blood samples from live sampled *Inia geoffrensis* (Amazon river dolphin) and *Inia boliviensis* from Brazil (Duarte-Benvenuto et al. 2022).

PARASITIC

Toxoplasmosis caused by *Toxoplasma gondii* has been reported in Australia (Bowater et al. 2003, Cooper et al. 2016, Kemper et al. 2016, Tomo & Kemper 2022), New Zealand (Roe et al. 2013), South Africa (Lane et al. 2014), and Brazil (Santos et al. 2011, Gonzales-Viera et al. 2013, Costa-Silva et al. 2019, Groch et al. 2020a, b). Host species include *Sousa chinensis*, *Tursiops aduncus*, *Tursiops truncatus*, *Grampus griseus* (Risso's dolphin), *Cephalorhynchus* hectori, *Inia geoffrensis*, and *Sotalia guianensis*. The most common pathological findings were the presence of *Toxoplasma gondii* cysts in the brain and tachyzoites in various tissues, and encephalitis, gliosis, focal necrosis, and concurrent disease (i.e. CeMV; Kemper et al. 2016, Groch et al. 2020a, b). Exposure to *Toxoplasma gondii* has been identified in bycaught animals from South Africa (Lane et al. 2014) and New Zealand (Roe et al. 2013), and serological evidence of exposure has been identified in Solomon Islands (Omata et al. 2005).

Giardia sp. was identified through faecal floatation and histopathological examination of the intestinal tract of a *Sotalia guianensis* calf that stranded in Brazil. The animal stranded alive with dehydration and severe emaciation. Necropsy findings included hepatic lipidosis, enteritis, pulmonary congestion, and oedema, and the presence of black viscous or liquid contents within the upper gastrointestinal tract (Altieri et al. 2007). Other protozoan parasites reported included *Sarcocystis* spp., invasive ciliate protozoa, and *Cryptosporidium* sp. (Lane et al. 2014, Borges et al. 2017, Alvarado-Rybak et al. 2020a, Byard et al. 2020).

Halocercus sp. was reported as a primary and secondary aetiological agent in a broad host range [*Sotalia guianensis*, *Stenella clymene* (Clymene dolphin), *Feresa attenuata*, *Delphinus delphis*, *Tursiops* spp.] (Marigo et al. 2010, Tomo et al. 2010, Stephens et al. 2014, Guimaraes et al. 2015, Domiciano et al. 2016, Groch et al. 2018, Sánchez-Sarmiento et al. 2018b, de Oliveira Carvalho Demarque et al. 2020, Tomo & Kemper 2022). Young animals and individuals with concurrent disease, such as CeMV and brucellosis, appear to be at an increased risk of adverse parasitosis from *Halocercus* sp. (Tomo et al. 2010, Domiciano et al. 2016, Groch et al. 2018, Sánchez-Sarmiento et al. 2018b). Other lung nematodes reported included *Stenurus ovatus* and *Phaurarus alatus* in South Australian *Tursiops* sp. (Tomo et al. 2010), and *Parafilaroides* sp. in New Zealand *D. delphis* (Stockin et al. 2009).

Parasites of the skull have been identified in South Africa (Van Bressem et al. 2020), South America (Torres et al. 1994, Van Bressem et al. 2000, 2006), New Zealand (Duignan et al. 2003), and Australia (Tomo & Kemper 2022). *Crassicauda* sp., with associated osteolysis of the cranial sinuses, has been reported in bycaught *Sousa plumbea* and *Tursiops aduncus* from South Africa (Van Bressem et al. 2020). In Peru, *Crassicauda* sp. was identified in *Delphinus delphis* and some animals displayed characteristic basket-like lesions but no adult parasites, indicating recovery from infestations (Van Bressem et al. 2006). In New Zealand, *Crassicauda* sp. has been identified in the pterygoid sinuses of *Cephalorhynchus hectori* and the mammary gland of *Lagenorhynchys obscurus* and *D. delphis* (Duignan et al. 2003, Stockin et al. 2009).

Nasitrema sp. has been reported in *Sousa plumbea* and *Tursiops aduncus* from South Africa (Van Bressem et al. 2020), *Lagenorhynchys obscurus* from Peru (Van Bressem et al. 2000), *Sotalia guianensis* from Brazil (Groch et al. 2020a, b), and *Tursiops aduncus* from South Australia (Tomo & Kemper 2022). It has been identified within cranial sinuses, tympanic bullae, and reproductive organs. These parasites have been known to have extreme migratory routes and can cause osteolysis of the cranial sinuses (Van Bressem et al. 2000, 2020). Severe osteolysis of the skull from *Stenurus globicephalae* was observed in a *Pseudorca crassidens* that was part of a mass stranding in Uruguay (Zylber et al. 2002).

Clistobothrium grimaldii (formerly *Monorygma* sp.; Caira et al. 2020) parasitosis was reported in a case of severe peritonitis in a *Delphinus delphis* from Australia. Encysted *Clistobothrium Grimaldii* (25–40 mm in diameter) were identified within the abdominal wall, uterine broad ligament, ligaments of the bladder, and within the ventral abdominal muscle. A free-living (approximately 300 mm in length) *Clistobothrium grimaldii* was identified within the peritoneal cavity (Norman 1997). Encysted *Clistobothrium delphini* (formerly *Phyllobothrium* sp.; Caira et al. 2020) (6–10 mm in diameter) were also detected within the ventral abdominal subcutaneous blubber of this animal. These parasites have been identified in a *Stenella clymene* from Brazil that had concurrent brucellosis (Sánchez-Sarmiento et al. 2018b), in *Lagenorhynchys obscurus* from Argentina (Loizaga de Castro et al. 2014), and *D. delphis* from New Zealand (Stockin et al. 2009).

Gastrointestinal parasites were often incidental findings and display diet-dependent population demographics (Dans et al. 1999, Aznar et al. 2001, Berón-Vera et al. 2001, 2007, 2008, Romero et al. 2014, Stephens et al. 2014, Domiciano et al. 2016). However, in Brazil, a *Stenella clymene* specimen with concurrent brucellosis had ulcers and haemorrhage associated with *Anisakis typica* parasitism within the stomach (Sánchez-Sarmiento et al. 2018b).

UNKNOWN

MASS STRANDINGS

Mass strandings accounted for 81% of total reported mortality events in beach cast individuals ($n=2814$). Mass strandings have been reported in Australia (*Stenella coeruleoalba*, *Tursiops* sp., *Pseudorca crassidens*, *Globicephala melas*, *Globicephala* sp., *Lagenodelphis hosei*) (McManus et al. 1984, Gales 1992, Chatto & Warneke 2000, Chambers & James 2005, Groom & Coughran 2012, Lloyd & Ross 2015, Foord et al. 2019), South America (*Pseudorca crassidens*, *Globicephala melas*) (Alonso et al. 1999, Andrade et al. 2001, Zylber et al. 2002, Alvarado-Rybak et al. 2019), South Africa (*Pseudorca crassidens*) (Kirkman et al. 2010), the Southwest Pacific (*Peponocephala electra*, *Globicephala macrorhynchus*, *Stenella longirostris*, *Feresa attenuata*) (Borsa 2006, Clua et al. 2014), Indonesia (*Globicephala macrorhynchus*, *Peponocephala electra*, *Feresa attenuata*) (Mustika et al. 2009), and New Zealand (*Globicephala melas edwardii*) (Van Bressem et al. 2001a).

JUVENILE/NEONATAL MORTALITY

Juvenile mortality was described in 37 cases, though this number is likely underestimated due to some studies not reporting specific numbers. Suggested contributing factors include predation, mismothering, trauma, starvation, disease (Steiner & Bossley 2008), climatic events (Wild et al. 2019, Mann et al. 2021), and congenital abnormalities (Kemper et al. 2005).

CONTRIBUTING FACTORS AND CO-MORBIDITIES

Contributing factors to mortality events or co-morbidities were reported in 37 studies (Table 2). Fourteen studies identified climatic events as contributing factors to morbidity or mortality events (e.g. heavy rainfall, heatwaves, storm events), six studies identified pollutants (e.g. heavy metals or noise pollution) as potential contributing factors to adverse health outcomes, and 25 studies identified co-morbidities with various pathogens.

DISCUSSION

This scoping review compiled morbidity and mortality reports in small cetaceans across the SH and identified contributing factors or co-morbidities. A total of 198 articles were considered eligible in the review, including 149 primary research articles, 2 conference proceedings, 3 government reports, 22 short communications, 15 notes, and 6 letters to the editor. A variety of infectious, non-infectious, and unknown causes of mortality were identified (Figs 5 and 6). Contributing factors or co-morbidities were also identified, including: 1) climatic events, 2) anthropogenic pollution, and 3) primary disease with concurrent viral, bacterial, parasitic, or fungal disease.

A variety of descriptive and observational study types were implemented across the reports. Notably, 52% of the studies employed stranded cetaceans as their primary data source, while 31% relied on bycaught animals from fishing operations or shark nets. This choice is primarily driven by the inherent challenges associated with conducting live sampling of marine mammals. Consequently, a substantial portion of marine mammal research hinges on opportunistic sampling, which captures a segment of the population for analysis. This evaluation of sampling technique suggests an issue with the quality of data due to potential bias, false positives or negatives, decomposition and autolysis of samples, difficulty in assessing the entire clinical picture, and significance of reported findings at a population level.

Cause of mortality was unable to be determined or was not specified for 10057 (39%) of cases. Interpretations based on 61% of mortalities should be made cautiously and highlights the need for improved marine mammal stranding response programmes across the SH that includes detailed pathological examinations and infectious disease testing. We acknowledge that reporting direct causes of mortality may not have been the scope of some studies (Chatto & Warneke 2000, Van Bressem et al. 2000, 2006, Meirelles et al. 2010, Loch et al. 2011); however, to understand the significance of anthropogenic activities on marine mammal strandings, a more specific account of mortality causes would be useful to reduce the number of unknown or unspecified cases. Assessment of deceased specimens comes with challenges (e.g. autolysis, logistics, personnel) and freezing specimens for later examination can hinder detection of subtle findings or be over-interpreted (Roe et al. 2012). However, specific criteria and case definitions to assist in categorising anthropogenic mortalities have been well described and can offer guidance during strandings investigations (Moore et al. 2013).

The most frequent determined cause of mortality in small Odontoceti was entanglements in fishing gear and bather protection nets. This accounted for 12029 mortalities from known entanglements and 256 mortalities from probable entanglements in stranded individuals. It is acknowledged that the data used in this study were collected without a date range, introducing potential bias from historical studies. In some areas, commercial fishing

Table 2. Contributing factors and co-morbidities identified in small Odontoceti of the Southern Hemisphere

Contributing factor/co-morbidities	Findings	No. of studies	References
Climatic factors			
Marine heatwave (MHW); CeMV UME	Death of approximately 50 dolphins following marine heat wave. Biotoxin testing was negative, CeMV positive	1	Kemper et al. (2016)
Marine heatwave; reduced reproductive success	Catastrophic loss of seagrass, poor body condition, and decreased recruitment rates observed in *Tursiops aduncus* post MHW	2	Wild et al. (2019), Mann et al. (2021)
High rainfall event; freshwater skin disease	Hyposalinity triggering physiological stress in *Tursiops aduncus* and *Tursiops australis*	1	Duignan et al. (2020)
High rainfall event; skin lesions	New poxvirus cases following flood events	1	Fury and Reif (2012)
High rainfall events; stranding events	Mortalities of inshore dolphins coincided with rainfall events	1	Meager and Limpus (2014)
Storm events; stranding events	Strandings and mass strandings following storm events	6	Chambers and James (2005), Evans et al. (2005), Kirkman et al. (2010), Clua et al. (2014), Alvarado-Rybak et al. (2019), Garrigue et al. (2023)
Unusually cold weather event; bacterial infection	Septic *Streptococcus iniae* in a *Delphinus delphis* specimen following abnormal cold event	1	Souter et al. (2021)
Heavy rainfall, humidity, ambient temperature between 19 and 34 °C; mycotic skin disease	Cases of mycotic skin disease (e.g. lobomycosis) associated with climatic factors	1	Moreno et al. (2008)
Pollution			
Severe noise; stranding	Eight individuals (*Stenella longirostris*, *Sotalia guianensis*, *Stenella* spp.) stranded with signs of congestion following an offshore 3D seismic survey	1	Meirelles et al. (2016)
Cd, Cu, Zn; toxicity	Moderate-to-high liver Cd, Cu, Zn was associated with potential renal damage, skeletal abnormalities, or reproductive abnormalities	4	Long et al. (1998), Lavery et al. (2009), Kemper et al. (2014), Tomo et al. (2018)
Aluminium; fungal pathogens	Higher Al levels in *Pseudorca crassidens* skin correlated with increased skin fungal colonisation	1	Mouton et al. (2015)
Co-morbidities			
CeMV; fungal infection	*Aspergillus* sp.	2	Stephens et al. (2014), Kemper et al. (2016)
CeMV; bacterial infection	*Pasturella* sp., *Salmonella* sp., *Staphylococcus aureus*, *Streptococcus* sp., *Klebsiella pneumoniae*, *Escherichia coli*, *Penicillium* sp., *Brucella* sp.	5	Stephens et al. (2014), Kemper et al. (2016), Sánchez-Sarmiento et al. (2019), Groch et al. (2020a, b), Tomo and Kemper (2022)
CeMV; parasitosis	*Halocercus* sp., *Anisakis* sp., *Pholeter* sp., *Braunina* sp., *Nasitrema* sp., *Campanula* sp., *Toxoplasma gondii*, *Isocyamus* spp.	6	Stephens et al. (2014), Domiciano et al. (2016), Kemper et al. (2016), Groch et al. (2020a, b), Marutani et al. (2021)
CeMV; other viral	Alphaherpesvirus (no viral lesions seen), poxviral	2	Groch et al. (2020a), Costa-Silva et al. (2023)
Brucella sp.; bacterial infection	*Proteus mirabilis*, *Edwardsiella tarda*, others suspected	1	Sánchez-Sarmiento et al. (2019)
Brucella sp.; parasitosis	*Halocercus* sp., *Anisakis typica*, *Clistobothrium delphini*, *Clistobothrium grimaldii*	1	Sánchez-Sarmiento et al. (2018b)
Toxoplasma sp.; bacterial infection	*Pseudomonas aeruginosa*, *Clostridium perfringens*, *Edwardsiella tarda*, *Edwardsiella hoshinae*, *Pseudomonas* sp., *Vibrio alginolyticus*, *Vibrio harveyi*, others suspected	4	Bowater et al. (2003), Cooper et al. (2016), Costa-Silva et al. (2019), Marutani et al. (2021)
Toxoplasma sp.; fungal infection	Likely *Aspergillus* sp.	1	Marutani et al. (2021)
Clistobothrium grimaldii; *Clistobothrium delphini*	Parasitosis within the blubber, abdominal wall, and urogenital ligaments	4	Norman (1997), Carvalho et al. (2010), Lehnert et al. (2017), Sánchez-Sarmiento et al. (2018b)
Neoplasia; parasitism; viral	Uterine adenocarcinoma, *Anisakis simplex*, *Pseudoterranova* sp., *Braunina cordiformis*, *Corynosoma australe*, poxvirus	1	Sánchez et al. (2002)

operations have improved in recent decades, implementing practices that have resulted in a 97% reduction in dolphin mortality (Hamer et al. 2008), and some studies report that mortalities are low despite interactions (Escalle et al. 2015). However, bycatch rates are still a concern as highlighted by more recent studies (Mangel et al. 2010, Roussouw et al. 2022, Tomo & Kemper 2022), and even with legal protection implemented, cetacean takes can still occur (Van Waerebeek & Reyes 1994).

In our study, 45% of entanglements were lacking documentation of the type of gear involved, likely because of variation in study design and aims. However, Tulloch et al. (2020) reported that one quarter of entanglement records lack this specific information, solidifying the need for improved reporting. The most common bycatch type reported in this study was shark nets/bather protection nets; however, bycatch type is dependent on geographic jurisdiction. Gillnets accounted for 20% of reported bycaught animals and was reported across a larger geographic scope compared to shark nets. Gillnet fisheries have previously been reported as the most significant fishery responsible for the bycatch of marine mammals (Read et al. 2006). It was reported by a mark–recapture study of bycaught dolphins that the incidence of entanglement cases washing ashore is only 7.6% (Prado et al. 2013), indicating a likely underestimation of bycatch from commercial fishing operations. Accurate documentation of bycatch rates also remains a challenge, particularly in countries where a stranding network or monitoring scheme has not been established (Reeves 2003). Studies focused on bycatch rates build estimates in fractions of time, when rates often depend on fishing effort, seasonal variation in cetacean abundance, geographic location (e.g. coastal vs. oceanic), and fishery/equipment type (Fruet et al. 2012, Thompson et al. 2013). Many studies also rely on skipper logbooks where there are uncertainties in the rate at which an entanglement is reported (Hamer et al. 2008, Escalle et al. 2015, Slooten & Dawson 2020).

The high numbers of anthropogenic-induced mortality events documented in this study raise concerning conservation issues, with fatal interactions recognised to be unsustainable in some populations (Monteiro-Neto et al. 2000, Kinas 2002, Negri et al. 2012, Mintzer et al. 2013). In the NH, unprecedented bycatch rates have resulted in extinction of *Lipotes vexillifer* (the baiji) in China and near extinction of *Phocoena sinus* (the vaquita) in North and Central America (Read 2008, Taylor et al. 2017). In New Zealand, *Cephalorhynchus hectori* is classified as endangered, with fisheries interactions causing continued population declines (Reeves 2003, Slooten & Dawson 2020). Low genetic diversity has been detected in *Sousa plumbea* from South Africa (Lampert et al. 2021) and *Tursiops truncatus* from South America (Fruet et al. 2014), and it is attributed to high fisheries related mortalities. With a changing climate, increasing anthropogenic pressures on marine ecosystems and emerging infectious diseases, it is important to protect vulnerable species such as marine mammals from unnecessary deaths due to entanglements.

Diseases that often presented with co-morbidities were known global threats to Odontocete health and included CeMV, brucellosis, and toxoplasmosis. These infectious diseases have been reported to present with concurrent infections such as parasitosis, bacterial infection, and fungal colonisation, supporting the role in immune suppression and decreased resistance to opportunistic pathogens (Stephens et al. 2014, Kemper et al. 2016, Bossart et al. 2019). Aetiological agents have also been reported in bycaught and free-living individuals or detected as latent/asymptomatic infections (Van Bressem et al. 2001b, Tachibana et al. 2006, Buckle et al. 2017). Fatal dissemination and disease can be seasonal (McFee et al. 2020) or more likely to occur in individuals with challenged immune systems (e.g. females prior to calving, concurrent disease, extreme weather events) (Kemper et al. 2016, van de Velde et al. 2016, Roberts et al. 2020). This suggests that infectious diseases may be easily overlooked in routine health assessments, and we may be underestimating pathogen distribution, prevalence, and health impacts (Davison et al. 2011). Known consequences include large-scale mortality events (Domingo et al. 1992, Kemper et al. 2016, Cunha et al. 2021), neonatal mortality (Jardine & Dubey 2002, Colegrove et al. 2016), immune suppression, interference with normal biological requirements such as foraging (Lahvis et al. 1995, Díaz-Delgado et al. 2019a, b, Costa-Silva et al. 2023), and disease spill-over to other species (McDonald et al. 2006, Ahmadpour et al. 2022). Testing for infectious diseases remains challenging (Guzmán-Verri et al. 2012, van de Velde et al. 2016) and costly, and multiple disease presentations can occur (Roe et al. 2013, Attademo et al. 2018, Sánchez-Sarmiento et al. 2019). This reduces the chance of targeted testing being performed and data may be non-representative; therefore, the extent of infectious disease prevalence, adverse health effects, and factors contributing to small Odontoceti health is likely poorly understood.

There are limited studies assessing the effects of anthropogenic contaminants on small Odontoceti health in the SH. Accumulation of POPs and heavy metals have increasing evidence of their adverse health outcomes in marine mammals, much of which is described in the NH. Some contaminants have known toxic effects such as endocrine disruption, immune modulation, neurotoxicity, and reproductive failure (Ross et al. 1996, Kannan et al. 2000, Desforges et al. 2016, Davis et al. 2021, Williams et al. 2021). High levels of polychlorinated bisphenols

(PCBs) have been associated with immune suppression in *Tursiops truncatus* (Lahvis et al. 1995), reduced testicular size in *Phocoena phocoena* (harbour porpoise) (Williams et al. 2021), immune toxicity in *Phoca vitulina* (harbour seal) (de Swart et al. 1994), and urogenital cancer in *Zalophus californianus* (California sea lions) (Gulland et al. 2020). In the SH, Weijs et al. (2020) described associations between contaminant profile and CeMV status. Although sample sizes were too small to draw definitive conclusions, CeMV victims were influenced by contaminant concentrations differently when compared to CeMV carriers. In pinnipeds, associations between multiple variables (e.g. haematological values and trace elements concentrations) have been investigated, suggesting the influence of non-essential trace elements on red blood cell parameters (Taylor et al. 2022). Other studies have utilised a retrospective approach using long-term data to assess for pathological changes associated with high levels of contaminants (Lavery et al. 2009, Kemper et al. 2014, Tomo et al. 2018), though case numbers are small. By performing thorough pathological investigations (including neuropathological investigations) and quantitative toxicant analysis for a range of anthropogenic pollutants, improved understanding of adverse health outcomes from contaminant exposure may be developed in the SH.

Morbidity and mortality events can have a primary triggering insult. Some studies detected associations between disease outbreaks and external factors such as extreme weather events (Fury & Reif 2012, Kemper et al. 2016, Duignan et al. 2020). Poxviruses, which often remain latent, reactivate during periods of stress and new cases have been reported following flood events (Fury & Reif 2012). Cetaceans are considered more susceptible to mycotic disease in environmental conditions such as warm temperatures, humidity, and high rainfall (Moreno et al. 2008). Heatwaves and subsequent loss of benthic marine environment have been associated with reduced reproductive success in coastal dolphins (Wild et al. 2019, Mann et al. 2021). Heatwaves can also trigger toxic algal blooms. In the NH, algal toxins have been associated with mortality in marine mammals (Bossart et al. 1998, Gulland & Hall 2007, Buckmaster et al. 2014, Fernández et al. 2022). Brevetoxicosis has been associated with a mortality event of *Trichechus manatus latirostris* (the Florida manatee) (Bossart et al. 1998) and *Steno bredanensis* in the Canary Islands (Fernández et al. 2022). Chronic domoic acid exposure has been linked to hippocampal atrophy and epilepsy in *Zalophus californianus* (Buckmaster et al. 2014). Another algal toxin, β-*N*-methylamino-L-alanine (BMAA), is suggested to interact with mercury, causing neurodegenerative lesions in dolphins (Davis et al. 2019, 2021). This highlights the possibility of contaminants interacting, creating additional effects not yet currently described (Cáceres-Saez et al. 2019). No reports of algal toxicity were definitively identified in this review; however, Bengtson Nash et al. (2017) suggested that mass strandings coincide with periods of higher ocean productivity and subsequent increased likelihood of domoic acid toxicity. Additionally, a large mass stranding of baleen whales in Chile was likely attributed to a harmful algal bloom (Häussermann et al. 2017). Investigating the roles of natural or anthropogenic toxins in marine mammal mortality events is often limited due to insufficient funding, lack of experienced personnel, or constraints regarding laboratory testing and specific assays.

This study focused on the causes of morbidity and mortality in small Odontoceti of the SH, but recognises cetacean mortality reports in the NH are of equal importance. A similar review has not been performed in the NH, making comparisons difficult; however, key differences identified from this review are summarised. Apart from differences in environmental threats that have not been reported in the SH (e.g. ice entrapment) (Westdal et al. 2017), there is a lack of understanding in the role of biotoxins and anthropogenic pollutant toxicity in stranding or disease circumstance, when compared to the NH where most of the associations have been reported. No reports of algal toxicosis or toxicity from POPs, and limited cases reporting negative associations with heavy metals, highlights the need for further exploration into the significance of these threats to Odontoceti health. Additionally, there appears to be an underrepresentation of natural causes of mortality in the SH (e.g. neonatal death, starvation/emaciation, predation). This is possibly due to a focus on stranded or bycaught specimens in the literature examined, limiting the chance of such circumstances being reported. However, in the NH, increased neonatal death has been attributed to infectious disease (Colegrove et al. 2016) and climate change is a known threat to marine mammal populations (Lettrich et al. 2023), the latter potentially influencing susceptibility to infectious disease. In the SH, cetacean strandings have increased in the last decades without a known cause (Alvarado-Rybak et al. 2020b), highlighting the need for more detailed investigations.

Assessing the significance of an individual stressor on marine mammal populations remains a challenge due to high numbers of variables and the complexity of marine environments. Stressors can have cumulative impacts, resulting in extreme difficulty when exploring cause–effect relationships (New et al. 2020, Keen et al. 2021). This highlights the importance of a holistic approach to mortality events, examining individual, population, and environmental factors. As climate change and anthropogenic interference continues to increase in their effects, key indicator species such as marine mammals will likely suffer severe consequences in survival and recruitment. Species biology, pathological findings, contaminant burden, anthropogenic stressors, and environmental conditions need to all be considered when investigating cetacean health. Long-term cetacean stranding surveillance and archival of data, such as that observed in South Australia (Kemper et al. 2005, 2008, 2014, 2016, 2019, Tomo et al. 2010, 2018, Segawa & Kemper 2015, Adamczak et al. 2018, Tomo & Kemper 2022), provide an example of how population health can be monitored overtime. This information is crucial to enforce more sustainable change to human practices and provide the best opportunity for marine species conservation and management.

Recommendations for future research in small Odontoceti health

The cumulative effects of multiple stressors in the marine environment must be considered during morbidity and mortality investigations (Pulkkinen et al. 2020, Murray et al. 2021). Multiple variables (e.g. climatic events, environment condition, geographic location, anthropogenic influence, and infectious disease) may play a role in the epidemiology of mortality events. What manifests as the 'cause of death' may be the result of predisposing factors (e.g. starvation, senescence, injury, extreme weather events, infectious disease) reducing an individual's physical fitness. Studies targeting adverse health outcomes from anthropogenic pollutant and biotoxin exposure would be useful to improve knowledge within this area, including detailed neuropathological examinations (López-Berenguer et al. 2020, Sacchini et al. 2022). Continuous, robust pathological surveillance programmes implemented over a wider distribution and the uptake of new genomic technologies would be useful to increase our understanding of small Odontoceti health and disease in the SH, particularly in data-deficient areas such as Africa and Southeast Asia. We propose the establishment of a platform that enables the real-time capture and dissemination of stranding events, pathological findings, histological parameters, results from infectious disease testing, and haematological/biochemical profiles. This platform could be an extension of data already collected through the International Whaling Commission (IWC) reporting and simulate a platform such as Wildlife Health Incident Reporting (Wildlife Health Australia) where a quarterly publication is produced. This platform should include information from the NH to ensure that the spread of significant threats, such as H5N1 (Puryear et al. 2023), are monitored over time. This platform would serve as a timely alert system for researchers, conservationists, and decision makers.

Limitations

The limitation of this review relates to the search strategy applied. A broad approach covering a diverse range of topics was used, resulting in many eligible articles and extensive data collection. Focusing the research questions would have assisted in this process and removed any bias caused by varying study aims and sample collection techniques. The terminology used in our search may have also resulted in omissions, particularly involving ecological associated stranding events. Not having a date range applied to our search could have also introduced a potential bias to mortality events, as commercial fishing operations in some areas have implemented modifications to reduce bycatch. It is also important to mention the likelihood of data overlap. Many studies use long-term data to assess stranding patterns overtime (Kemper et al. 2005, Van Bressem et al. 2006, 2007, Tomo & Kemper 2022), and some studies use the same data to target different diseases (Van Bressem et al. 1993, 1994, 2000).

CONCLUSION

This review underscores critical issues such as: 1) the challenge of identifying cause of mortality in many cases, highlighting the urgent need for enhanced marine mammal stranding response programmes and investigations in the SH, and 2) the significant impact of human activities, such as entanglements in fishing gear and protection nets, on small cetacean mortality. Urgent conservation and management efforts are needed, especially given the changing climate, and growing human pressures on marine ecosystems. Additionally, there is a notable lack of research on the toxicological effects of persistent organic pollutants, trace elements, and biotoxins in small Odontoceti of the SH, despite evidence from NH studies. In response, we call for a holistic approach: improved surveillance of cetacean strandings, comprehensive pathological examinations, increased infectious disease testing, toxicant analysis, and a real-time data-sharing platform to enhance our understanding and response to stranding events. Despite study limitations, this review provides a valuable starting point for safeguarding these vulnerable marine species.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available in the supplementary material of this article.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article at the publisher's website.

Appendix S1. This appendix contains a comprehensive list of articles reviewed, detailing the region/s where studies were conducted, the species included, and the extracted sample size. Primary, secondary, or observed causes of morbidity and mortality are also included.