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REVIEW

Database documentation of marine mammal stranding and mortality: current status review and future prospects

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ABSTRACT: Databases are systematic tools to archive and manage information related to marine mammal stranding and mortality events. Stranding response networks, governmental authorities and non-governmental organizations have established regional or national stranding networks and have developed unique standard stranding response and necropsy protocols to document and track stranded marine mammal demographics, signalment and health data. The objectives of this study were to (1) describe and review the current status of marine mammal stranding and mortality databases worldwide, including the year established, types of database and their goals; and (2) summarize the geographic range included in the database, the number of cases recorded, accessibility, filter and display methods. Peer-reviewed literature was searched, focussing on published databases of live and dead marine mammal strandings and mortality and information released from stranding response organizations (i.e. online updates, journal articles and annual stranding reports). Databases that were not published in the primary literature or recognized by government agencies were excluded. Based on these criteria, 10 marine mammal stranding and mortality databases were identified, and strandings and necropsy data found in these databases were evaluated. We discuss the results, limitations and future prospects of database development. Future prospects include the development and application of virtopsy, a new necropsy investigation tool. A centralized web-accessed database of all available postmortem multimedia from stranded marine mammals may eventually support marine conservation and policy decisions, which will allow the use of marine animals as sentinels of ecosystem health, working towards a 'One Ocean–One Health' ideal.

KEY WORDS: Cetacean · Monitoring system · Inventory · Stranding network · Stranding response programme

INTRODUCTION

A stranding is an event when an individual or group of marine mammals washes ashore dead or live strands on a beach or in shallow water, unable to return to the water without assistance (Geraci & Lounsbury 2005). Each stranding and mortality event is a valuable scientific opportunity to gain knowledge and understanding regarding both individuals and populations (Perrin & Geraci 2002). Even a decomposing carcass on a beach may still provide important information regarding an individual's life

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history, genetics, predators, contaminants and feeding ecology through necropsy. Strandings occur worldwide, and when the expertise and resources are available, interventions with live strandings and necropsies of euthanized or dead animals provide information to biologists, veterinarians and resource managers through the use of statistics and in-depth analysis of parameters, such as seasonal distribution, life history, population health, contaminant levels and prevalence of disease.

A stranding and mortality database conceptually works as (1) an information repository, like a spreadsheet recording large volumes of stranding and necropsy parameters; (2) a tool that displays data in tables and forms as defined by structured query language in relational database management systems; and (3) a search tool for trend analysis or particular questions of interest. Stranding and mortality databases are no longer limited to a desktop/standalone database physical format and are mostly developed into an online system, which can be web-accessed any time. To perform a systematic analysis of stranded marine mammal data, a well-managed and well-presented system is indispensable.

The purposes of a multimedia platform are to (1) standardize data entry of marine mammal health findings across species and within geographic regions; (2) combine diverse data sources, including stranding response, entanglement response, live capture-release or research investigations; (3) allow the analysis of health and disease trends to support the public and resource managers in recognizing potential public health hazards; and (4) enable quick communication of health data, combined with environmental data and additional disease information from terrestrial wildlife (Simeone et al. 2015). Ocean health may be declining as indicated by increases in the reporting of mortality and morbidity in marine mammals worldwide (Gulland & Hall 2007, Bossart 2011). The recognition of the ocean's importance and the inextricable links between the health of people and the health of animals and ecosystems has led to the 'One Ocean–One Health' research paradigm (Schwacke et al. 2013).

Despite some literature regarding individual stranding and mortality databases worldwide, to date, we lack a thorough review of the currently available marine mammal stranding and mortality databases. There is a need to integrate currently available marine mammal stranding datasets in order to understand larger trends and how these datasets have been stored in databases. This article is divided into 2 sections. The first section is a systematic review and summary of existing databases relating to the storage of records for both live and dead strandings. The second section is a discussion on results, limitations and future prospects of database development.

REVIEW OF EXISTING MARINE MAMMAL STRANDING AND MORTALITY DATABASES

Several public databases including Google Scholar, PubMed, Medline, ResearchGate, Academia and ScienceDirect were queried for terms related to the documentation system (i.e. database, inventory, repository, platform, monitoring and data exchange system), as well as necropsy findings of both live and dead marine mammal strandings (i.e. marine mammal/cetacean/pinniped strandings, mortalities, unusual mortality events, diseases, illnesses, pathologies and health data). Marine mammals, including all cetaceans, pinnipeds, sirenians, sea otters and polar bears, were included. English printed peer-reviewed journal articles, proceedings and official reports from conferences, workshops, symposia and authorized institutions and governments that developed databases related to marine mammal strandings and mortality were selected. Databases that were not published in the primary literature or recognized by government agencies were excluded, due to difficulty with verification and limited credibility. Only strandings and necropsy data recorded in identified databases were evaluated.

In principle, stranding and mortality databases can be categorized into 2 types. One is the custom-designed relational database (Type 1), solely designed to be managed by information technology personnel for the collection, categorization and illustration of marine mammal data. The other type of database is the use of existing software packages with specific customization to cluster marine mammal data (Type 2). Various biological recording software packages were commercially available, which offered standards-based means for compilation and collation of biological recordings.

The content review for each independent database is divided into 2 parts. First, an overview of the database is provided, based on the written description from published reports, journals, leaflets and the official websites. Data collected included the name of the database, year of establishment, type of database and the organization responsible for database operation. Second, the databases are described based on their geographic range for stranding response, accessibility, filter and display method. Additional infor-

mation regarding the total number of datasets and data collection period is summarized in Table 1. A summary of goals of the listed databases is provided in Table 2.

Table 1. Summary of the current status of marine mammal stranding and mortality databases. Type 1 databases are custom-designed; Type 2 databases use existing commercial packages. MMHMAP: Marine Mammal Health Monitoring and Analysis Platform; MMC: Marine Mammal Center; NOAA: National Oceanic and Atmospheric Administration; SMASS: Scottish Marine Animal Stranding Scheme; WSI: Whale Stranding Indonesia; ANMMD: Australian National Marine Mammal Database; AMMC: Australian Marine Mammal Centre; MMSDB: Marine Mammals Stranding DataBase; DFO: Fisheries and Oceans Canada; MRCSD: Maritimes Region Cetacean Sightings Database; BIO: Bedford Institute of Oceanography; CSIP: Cetacean Strandings Investigation Programme; MCSD: Moroccan Coast Strandings Database; PMMSD: Philippines Marine Mammal Stranding Network Database

Database	Database-response organization(s)	Type of database	Type of dataset	Open access?	Responding coastal region	Total no. of datasets; data collection period (reference)
MMHMAP Pilot	MMC & NOAA	1	Marine mammal health and disease	Yes	NOAA West Coast Marine Mammal Stranding Network	4483; 1961–2013 (http://axiomdatascience.com/maps/ioos/mbon/#map?lg=a4b0bec0-b9be-11e3-835f-00219bfe5678)
SMASS	Scottish government	1	Marine animal strandings	Yes	Coast of Scotland	4123; 2005–2015 (www.strandings.org/cgi-bin/map.pl)
WSI Database	WSI	2	Marine mammal strandings	Yes	Indonesia	330; 1987–2017 (www.whalestrandingindonesia.com/stranding-database.html)
ANMMD	AMMC	1	Marine mammal health and disease	Yes	Australia	15922; 1885–2017 (https://data.marinemammals.gov.au/nmmdb)
MMSDB	National Museum of Nature and Science	1	Marine mammal strandings	Yes	Sea of Japan	8574; 1970–2014 (www.kahaku.go.jp/english/research/db/zoology/marmam/drift/)
DFO MRCSD	DFO & BIO	1	Opportunistic cetacean sightings	Yes	Scotian Shelf, Gulf of Maine, Bay of Fundy and areas of eastern Canada	39268; 1966–2014 (www.iobis.org/explore/#/dataset/2832)
CSIP web-accessed database	UK government	1	Cetacean strandings and necropsies	No	Coast of the UK	9894; 1990–2012 (Deaville & Jepson 2012)
MCSD	Team of Masski & De Stephanis	1	Marine mammal strandings	No	Coast of Morocco	205; 1980–2009 (Masski & De Stephanis 2015)
StrandNet	Queensland (Australia) government	2	Marine mammal strandings and necropsies	No	Queensland waters	290; 2008–2011 (Meager et al. 2012)
PMMSD	PMMSD	1	Marine mammal strandings	No	Coast of the Philippines	713; 1998–2017 (Aragones et al. 2017)

RESULTS

We reviewed 6 publicly accessible and 4 non-publicly accessible databases for marine mammal strandings (Table 1). The listed databases had a more intense geographic coverage in well-developed regions compared to underdeveloped regions. A higher degree of cooperation between the stranding networks also contributed to a larger geographic coverage of data collection. In most of the well-developed regions and countries, stranding response organizations and networks have been developed over 3 to 4 decades with a general aim to obtain information, which facilitates further diagnostics and research and contributes to ecological understanding of a local stranding event. This distinct aim was also presented as a goal for most of the databases.

Marine Mammal Health Monitoring and Analysis Platform (MMHMAP) pilot

The US MMHMAP was a 3 yr pilot project developed by the National Oceanic and Atmospheric Administration's (NOAA) National Marine Fisheries Service (NMFS), Marine Mammal Commission (MMC), The Marine Mammal Center (MMC) and the National Marine Mammal Foundation (NMMF). Many additional groups have collaborated on the project, including the Integrated Ocean Observing System (IOOS) and the National Wildlife Health

Table 2. Summary of the goals of the investigated marine mammal stranding and mortality databases. MMHMAP: Marine Mammal Health Monitoring and Analysis Platform; SMASS: Scottish Marine Animal Stranding Scheme; ANMMD: Australian National Marine Mammal Database; DFO: Fisheries and Oceans Canada; MRCSD: Maritimes Region Cetacean Sightings Database; CSIP: Cetacean Strandings Investigation Programme; MCSD: Moroccan Coast Strandings Database; PMMSD: Philippines Marine Mammal Stranding Network Databases

Database	Goals of database
MMHMAP Pilot	(1) Develop a marine mammal health monitoring and analysis platform with consistent and standardized fields and terminology by collaborating with potential data providers (2) Promote collaborations and ensure the availability of marine mammal health data to researchers, scientists, managers and the public (3) Correlate marine mammal health trends with biological, chemical and physical environmental parameters
SMASS	(1) Provide a systematic and coordinated approach to the surveillance of Scotland's marine species (2) Collate, analyse and report data of all stranded cetaceans, seals, marine turtles and basking sharks on the Scottish coastline (3) Perform investigation of stranded marine animals that can yield solid information on the health and ecology of these species and highlight possible conservation issues they may face
ANMMD	(1) Provide a summary of the biology of marine mammals to the Australian public (2) Assist data-driven management and conservation planning (3) Collate, protect and archive marine mammal health and disease data (4) Support with cetacean sighting, entanglements, ship strikes and strandings (5) Promote the collaboration, analysis and reporting among ocean researchers and marine experts in Australia
DFO MRCSD	(1) Import sightings records from different sources including whale watchers, researchers, fishermen and the at-sea observer programme (2) Accommodate information on large marine animals such as sea turtles and basking sharks (3) Evaluate the impact of human interaction (4) Study the migration, distributions and feeding habits of cetaceans
CSIP web-accessed database	(1) Collate, analyse and report data for all cetacean strandings around the coast of the UK (2) Examine the cause of death in stranded cetaceans, including by-catch and physical trauma (3) Perform surveillance on the incidence of disease in stranded cetaceans and identify any substantial new threats to their conservation status (4) Preserve a national cetacean tissue collection
MCSD	(1) Describe 16 species stranding along the Moroccan coast (2) Examine the relative importance and potential distribution of cetaceans (3) Study their possible interactions with human activities (4) Improve the collaboration between Moroccan institutions and raise awareness in the Moroccan public of environmental issues
StrandNet	(1) Summarize all records of sick, injured, dying and dead marine cetaceans, pinnipeds, dugongs and turtles in the coastal area of Queensland, Australia (2) Assess causes of injury and death, especially from anthropogenic effects, to different species (3) Indicate the overall trends in number, species composition and distribution of strandings, including other species of marine animals such as sharks, rays and seabirds
PMMSD	(1) Collate all data on stranding events nationwide (2) Examine the species composition, temporal variation (i.e. frequency of stranding per year and seasonality), spatial variation (i.e. frequency of stranding per region and province), proportions of live or dead specimens and the stranding hotspots for different aspects of marine mammal strandings in the Philippines

Center (NWHC), as well as a variety of non-governmental organizations (NGOs), academics and state agencies (MMC & NOAA Fisheries 2015). This custom-designed relational database is operated by the IOOS and can be accessed via the IOOS portal (http://axiomdatascience.com/maps/ioos/mbon/#map?lg=a4b0bec0-b9be-11e3-835f-00219bfe5678).

Prior to developing a national MMHMAP database, a pilot project was created to integrate data from the California stranding network organizations (Simeone et al. 2014). Cases of dead strandings were inserted into MMHMAP, and each was assigned into a health category. Health categories were then assigned based on their reported cause of death (COD), including infectious disease, biotoxin, trauma, neoplasia, malnutrition, other or unknown (Table 2). Development is currently underway to expand the MMHMAP nationally.

Scottish Marine Animal Stranding Scheme (SMASS)

SMASS is a custom-designed relational database that has been operating since 1992. This project is funded by the Scottish and UK governments, which jointly contribute to the Cetacean Strandings Investigation Programme (CSIP). Numerous institutions have also contributed, such as the Moredun Foundation, National Museums Scotland, University of Chester and Animal and Plant Health Agency. Postmortem findings and cause of death are classified into 1 of 15 categories, such as generalized debilitation, infectious disease, physical trauma and starvation/hypothermia. By using the spatial map of strandings (www.strandings.org/cgi-bin/map.pl), the stranding location of a case filtered by date, species and COD is clearly illustrated on Google Earth. Limited requested data (2000 cases) can be displayed at a time. With the use of SMASS, a density plot can be calculated and visualized from areas of high stranding reports in Scotland.

Whale Stranding Indonesia (WSI) database

WSI is the first online stranding database in Indonesia, operating since 2013 (Mustika et al. 2016). Any cetacean and sirenian strandings in Indonesia are recorded by WSI. This online database does not belong to an NGO or governmental authority but is administered collaboratively with the Indonesian government. The mission of WSI is to compile, analyse and present marine mammal stranding events in Indonesia in a systematic and user-friendly manner. Currently, WSI is managed and maintained by Cetacean Sirenian Indonesia (Cetasi) and uses a commercial existing package, Knack, for storage of the marine mammal stranding data in Indonesia (www.whalestrandingindonesia.com/stranding-database.html). WSI uses simple tables, charts and maps to represent the details and locations of the disclosed stranding data.

Australian National Marine Mammal Database (ANMMD)

ANMMD is a custom-designed relational database developed by the Australian Marine Mammal Centre (AMMC) in 2010 (original name: Western Australian Whale and Cetacean Sightings database). Strandings found in 7 states including New South Wales, Victoria, Queensland, Northern Territory, South Australian, Tasmania and Western Australia, are reported to ANMMD. The majority of stranding and necropsy information is provided by AMMC, International Whaling Commission (IWC) and Department of Primary Industries, Parks, Water and Environment (DPIPWE). The public can access this database via the ANMMD portal (https://data.marinemammals.gov.au/nmmdb). With grids, maps and tables, the spatial location, the top 6 species and their corresponding necropsy information are clearly displayed. Such an integrated, multi-disciplinary, cross-jurisdictional research framework allows high quality science to support management and policy making by the Australian government and marine-user stakeholder groups.

Marine Mammals Stranding DataBase (MMSDB)

MMSDB, a custom-designed database, was established by the National Museum of Nature and Science, Tokyo, Japan (www.kahaku.go.jp/index.php), and jointly compiled with the Institute of Cetacean Research (ICR) and the Shimonoseki Academy of Marine Science (SAMS). It is used to document the distribution, population structure and movements of over 60 species of marine mammals from the coasts of Japanese waters. This online database (www.kahaku.go.jp/english/research/db/zoology/marmam/drift/) summarizes necropsy findings based on biotic information (e.g. species, sex, identification number and body length) and discovery data (e.g. date found,

prefecture, geographical region and spatial information), and displays the information in tabular form instead of a mapping system. In addition to basic animal data, health assays are also included in the datasets, such as analyses of morphometrics, bloodwork, histology and tissue contaminant levels.

Fisheries and Oceans Canada (DFO) Maritimes Region Cetacean Sightings Database (MRCSD)

DFO MRCSD is a national database to collect opportunistic sighting data on large marine animals, especially for species at risk in Canadian coastal regions. Opportunistic sightings represent marine mammal incidents reported by any observer to a responsible body (i.e. DFO or marine mammal response network). Multiple marine mammal response networks operate throughout Atlantic Canada. Stranded cetacean data in the Maritimes from 1990–2009 have been integrated (Hooker et al. 1997, Nemiroff et al. 2010). Diverse stranding networks contribute to this national database (Harris 2015). MRCSD is a custom-designed database operating in the Ocean Biogeographic Information System (OBIS) Canada, and is managed by DFO and the Bedford Institute of Oceanography (BIO). The design and structure of this database are consistent with other DFO databases and the University of Rhode Island (USA) whale sightings database.

Opportunistic sightings of over 50 species have been recorded in the MRCSD (www.iobis.org/explore/#/dataset/2832). The vast majority originate from the Scotian Shelf, Gulf of Maine, Bay of Fundy and other areas along the east coast of Canada. The Whale Sighting Database contains data from opportunistic sightings of live animals reported by the public and whale watching companies, and observer reports from commercial fishing, as well as records of strandings, floating carcasses and fishing gear interactions (Themelis et al. 2016). This open database displays the collected data in OBIS maps, tables and charts. This mapping system allows the visualization of the density of reports, while histograms enable understanding of entire trends in opportunistic sighting data.

Cetacean Strandings Investigation Programme (CSIP) web-accessed database

Funded by the UK government, the CSIP web-accessed database was established in 2008 and fully integrates data on both stranding and necropsy information in the UK (http://ukstrandings.org/). Operating since 1990, CSIP has been responsible for coordinating data on stranding and death investigation of all cetaceans, marine turtles and basking sharks in UK waters. This custom-designed project is currently under the management of the Institute of Zoology, Zoological Society of London (ZSL). All information on stranding and mortality events are summarized and included in the CSIP annual report (http://ukstrandings.org/csip-reports/).

To better integrate the data collected in adjacent waters, CSIP has also contributed to the UK's programme of research in the North Sea and the Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS) regions. A small project under ASCOBANS is to create a centralized web-accessed database in Europe. This web-accessed database was proposed at the 19th ASCOBANS Advisory Committee Meeting held in 2012. Deaville & Jepson (2012) noted near unanimous approval for the concept of a centralized web-accessed database, which will be used to integrate and collaborate on the collected data provided by 9 countries (Belgium, Denmark, France, Spain, Germany, Ireland, Netherlands, Portugal and UK) with 9 stranding networks (Marine Animals Research and Intervention Network, Miljøministeriet Naturstyrelsen, Pelagis Observatory, Coordinadora para o Estudio dos Mamíferos Mariños, Schleswig-Holstein regional network, Irish Whale and Dolphin Group, Naturalis, Portuguese Wildlife Society and CSIP). It is anticipated that at least 41 380 cetacean stranding cases, in which over 7000 animals were necropsied, will be included in the database. It is believed this centralized database will act as a centralized repository for selected data from strandings and necropsy by national stranding networks, and serve as a successful analytic tool in ASCOBANS regions.

Moroccan Coast Strandings Database (MCSD)

MCSD was constructed by Masski & De Stephanis (2015), with collaboration by the Institut National De Recherche Halieutique (INRH) and Department of Fisheries, National Fisheries Board, Morocco (DFNFB). The MCSD collated cetacean stranding data along the Moroccan coast. This non-publicly accessible database presents stranding datasets using maps, circular charts and geographic distribution to assist data analysis and statistics. The establishment of this ob-

servation network has collated robust data and allowed structured monitoring of cetacean stranding and population densities in Morocco.

StrandNet

StrandNet is a commercial package of the Oracle database managed by the Department of Environment and Heritage Protection and Queensland government, Australia, since 2012. It collaborates with the Department of National Parks, Recreation, Sport and Racing, the Great Barrier Marine Park Authority and the Department of Agriculture, Fisheries and Forestry. All necropsy and stranding reports since 1999 have been imported into StrandNet (https://www.derm.qld.gov.au/strandnet/application/public/security/logon.xhtml). This internal online database is not open to the public. Information on stranding and mortality events has been integrated and included in marine wildlife stranding annual reports (https://www.ehp.qld.gov.au/wildlife/caring-for-wildlife/strandnet-reports.html). StrandNet displays data using tables and maps of geographical distribution, allowing systematic analysis of species composition and distribution.

Philippines Marine Mammal Stranding Network (PMMSN) database

PMMSN responds to stranding and unusual mortality events in the coastal regions of the Philippines. In 2008, a 12 yr database (PMMSND) covering the period 1998 to 2009 was created, recording a total of 178 stranding events comprising 163 single and 10 mass stranding events (Aragones et al. 2010). Currently, this custom-designed database is operated and maintained by the University of the Philippines, which is located in Quezon Province. Various partner institutions contribute to PMMSND, including the Department of Agriculture, Republic of the Philippines, Wildlife In Need and Ocean Adventure.

This non-publicly accessible database records stranding events and summarizes necropsy data from stranded marine mammals in Philippine waters. Geographical distribution is recorded using hot spots on maps and in tables, allowing analysis of strandings. By changing the map filter, an analysis of stranding data can be presented in terms of trends in seasonality, stranding distribution and stranding density. Recognition of the top 5 regions and species composition can also be demonstrated. Collating stranding data on a national level is remarkable, and has enhanced and developed response capabilities for strandings and the related rehabilitation programme for live stranded marine mammals.

DISCUSSION

Diverse databases for the documentation and management of marine mammal stranding and mortality events have been established and continue to be developed and advanced. Although a standardized method for the documentation of postmortem information, data entry and data retrieval (i.e. the parameters of preliminary data and necropsied data) is still lacking, various stranding networks are progressively working together, sharing their datasets and establishing collaborative work between regional experts. These repository systems are anticipated to continuously improve, with better and more systematic data displays (i.e. online mapping interfaces), which can be used in conjunction with statistical analysis for meta-analyses of marine mammal health trends and stranding locations, and most importantly, creating links between human health and the health of marine mammals and ecosystems.

Over the past 3 decades, databases have been developed in regions of marine mammal strandings worldwide to advance the interests and needs of NGOs, research scientists and government agencies. Eight of the 10 databases evaluated herein are custom-designed. This approach is believed to guarantee the simplicity and expandability and reduce errors in data import and export, such as the MMHMAP pilot. A custom-designed system is usually more user friendly, since the design of functions and the ways to store and interpret data are not limited by the framework of the existing commercial system. The development cost for a new database and the maintenance charge vary, depending on the functionality, efficiency, stability and size of the custom-designed system. The remaining 2 evaluated databases made use of existing software packages with specific customization to cluster marine mammal data. These software packages ensure the standardized collection of death records and smooth integration of records into larger databases. Examples of commercial packages are Marine Recorder (exeGesIS Spatial Data Management), Jeppesen PRIMAR ECDIS Service (Jeppesen Marine) and Knack (EvenlyOdd). Both database types enable structured documentation and development of an online mapping interface for the display of marine mammal data.

We found some potential limitations in the course of preparing this review. The most critical one is database accessibility. Although published papers and reports related to stranding records are available, access to raw data for review would ensure the authenticity and update of this review. A second consideration is the extent of data sharing or openness. Most organizations reserve their right to revoke or restrict the public's access to proprietary data. Here we assumed that stranding and health data were made available under the listed databases. Many of these databases involve multiple collaborators, which may hamper data sharing. A third limitation is the status of the database. It is important to note (1) that the databases are operational; (2) types of data recorded in the database; (3) when a database started operating and how far back the recorded data go; (4) the date of the last update and display of updated cases; (5) the quality of the data (i.e. quality assurance and quality control regarding data uploading and verification of information). For example, the MMHMAP pilot has 4483 marine mammal cases from 1961 to 2013, and was operating as of 2015. However, cases have not been updated for public access since 2013 (Table 1). This delay can impede contemporaneous or real-time assessment of marine mammal stranding data.

In the past few decades, NOAA has acted as an excellent role model and collaborator between different stranding networks across the boundaries of countries to obtain the prospective data, and has used retrospective information from its own database for extensive studies on threatened marine mammal species, such as southern right whales *Eubalaena australis* in South America (Uhart et al. 2008, Figueiredo et al. 2017, Torres et al. 2017), Irrawaddy dolphins *Orcaella brevirostris* in South and Southeast Asia (Jackson-Ricketts et al. 2016, Peter et al. 2016), beluga whales *Delphinapterus leucas* (Hobbs et al. 2015, Bettridge et al. 2016) and bowhead whales *Balaena mysticetus* in the Arctic (Mocklin et al. 2015, Stafford et al. 2017). Another highlighted NOAA programme is the National Marine Laboratory's Polar Ecosystems Program, which conducts studies and monitoring on pinnipeds, such ringed seals *Phoca hispida* and their endangered sub-species, Ladoga ringed seals *P. hispida ladogensis* and Saimaa ringed seals *P. hispida saimensis* in the Arctic, sub-Arctic and Antarctic marine ecosystems (Quakenbush et al. 2011, NMFS 2012, 2014, 2016).

Studies on the demography, ecology, health and acoustic assessments of these threatened marine mammal species are essential to learn about populations and distributions, and to determine appropriate conservation and policy making strategies. Collaboration and integration between stranding networks are urged, not only across regional boundaries, but also across multiple disciplines, agencies, institutions and even international boundaries, allowing unification of retrospective information. This will allow measurement of marine mammal health trends and contribute a centralized web-accessed database. Such a complete ecosystem indicator may eventually support the conservation and policy decision for all oceans, leading to a 'One Ocean–One Health' paradigm using marine animals as sentinels of potential emerging hazards.

FUTURE PROSPECTS

Veterinary clinical and diagnostic sciences have experienced revolutionary changes in different fields (Thrall 2013, Miller & Fowler 2014). Apart from the recording of marine mammal health and conventional necropsy data, a variety of ancillary diagnostic examinations and their datasets have become an option to integrate with the existing databases, for example, photo identification of marine mammals, 3-dimensional photogrammetric analysis and advanced imaging on live, euthanized and freshly dead (code 2) animals. Conventional X-ray technology has been used on dead cetaceans (Brook 1994, Butti et al. 2007), and more advanced imaging modalities such as computed tomography (CT) and magnetic resonance imaging (MRI) have been increasingly used postmortem.

Virtopsy, using postmortem CT and postmortem MRI, provides a virtual alternative to the conventional autopsy for death investigations (Thali et al. 2003, Dirnhofer et al. 2006). It increases the accuracy in diagnosis of the COD in human adults (Roberts et al. 2012), and contributes findings that are not readily obtained during conventional autopsy (Thali et al. 2003). Kot et al. (2016) applied virtopsy to 160 stranded cetaceans in the waters of Hong Kong, Bohai Sea and the Yangtze River, augmenting conventional necropsy protocols. These volumetric image datasets provide invaluable initial or supplementary information of the COD in the stranded marine animals prior to a conventional necropsy. With the advantages of being observer-independent, non-subjective, non-invasive, digitally storable and transferable, thereby facilitating a second opinion, virtopsy has become a valuable alternative technique to provide new insights of findings in stranded carcasses. For example, atlanto-

occipital dissociation was among the recognizable findings commonly observed in virtopsy of the stranded cetaceans in Hong Kong and adjacent waters, which could be difficult to recognize via necropsy (Kot et al. 2016).

Virtopsy-driven databases could serve to (1) assist individual projects and diagnostic procedures for stranded marine mammals through non-invasive imaging; (2) enable analysis, comparison and re-evaluation of large numbers of deceased cases using both virtopsy and necropsy data through the access of personal computers and mobile applications; (3) allow further education of stranding response personnel and pathologists by providing initial or additional information, which is a virtual alternative to the conventional necropsy; (4) enhance the efficiency of communication among stranding response personnel, researchers and marine experts via telemedical distance conferencing; (5) facilitate further investigation of stranding and mortality trends in corresponding coastal regions; and (6) support a wide range of researchers with topics ranging from *in vivo* diagnostics and taxonomy and distribution, to global warming and climate change for stranding rehabilitation and conservation.

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