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REVIEW

Defining a common language to assess external deformities in free-ranging cetaceans

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ABSTRACT

1. Wild animals are increasingly exposed to human-induced threats in the ocean realm. Cetacean species, as predators and biomonitoring models, are subjected to a variety of stressors that may result in poor health, injuries, and persistent marks. These malformations can easily be documented by photography or video and can be used to infer about the animals' health, especially if combined with long-term photographic identification. However, the value of such information for monitoring is vastly increased if a standardised language is used. We provide a broad definition of deformity, as a general concept for conditions or abnormal features in cetacean species, and categorise externally detected deformities in free-ranging individuals.
2. We define six categories and 58 sub-categories of deformities in cetaceans: anatomical malformations (11 sub-categories), skin lesions (29), anomalous pigmentation (4), injuries due to physical impacts (14), emaciation, and epibionts.
3. Categorisation was based on peer-reviewed literature published between 2000 and 2021 ($n = 253$ studies), comprising 80 of the 101 extant species, documented in studies conducted across 50 countries; reviewed literature included papers from 86 scientific journals, with three journals contributing 100 out of the 253 documents.
4. Overall, and for both Odontoceti and Mysticeti, physical impact was the most reported category; injuries due to physical impacts were documented in 74% of the 253 studies we reviewed. This may be related to the common exposure of cetaceans to intense human marine traffic and fishing activities.
5. Especially with the growing use of open science, a consistent and common language is fundamental for data comparison and to support cetacean research, management and conservation efficiently. We suggest that researchers adopt these definitions and categories when describing abnormalities observed in free-living cetaceans.

INTRODUCTION

Marine ecosystems are increasingly exposed to human activities, resulting in wild animals being highly impacted by multiple stressors. Many species classed as marine megafauna, specifically cetaceans, are long-lived predators that are particularly susceptible to bioaccumulation and biomagnification processes (Kershaw & Hall 2019). This makes them appropriate sentinel species and biomonitoring models of marine ecosystem health (Fossi et al. 2020, Nelms et al. 2021). Cetacean populations are exposed to chemical and noise pollution, overfishing, vessel collision, and pressures from tourism (Moore et al. 2021, Alves et al. 2022). The derived impacts of these stressors can produce visible external alterations on the body surface of the animals. Seawater pollution can lead to abnormal skin conditions (e.g. Chan & Karczmarski 2019, Taylor et al. 2021), thus, these can be a good indicator of water quality. Malnutrition, and ensuing emaciation, can be brought on by stress, prey depletion, and/or illnesses (e.g. Groch et al. 2018, Huggins et al. 2020, Raverty et al. 2020). Physical deformities may be indicative of interactions with fisheries or vessel collisions and have been used to assess the severity of these threats (e.g. Hill et al. 2017, Leone et al. 2019, Greenfield et al. 2020, Feyrer et al. 2021). Additionally, some physical indicators of impact, such as scars or wounds, can result from inter- or intraspecific interactions, allowing for insights into marine ecology, from the species to the ecosystem level (e.g. Ajó et al. 2018, Feunteun et al. 2018, López et al. 2018, Puig-Lozano et al. 2020, Castelblanco-Martínez et al. 2021, Corsi et al. 2021, Ham et al. 2021).

Given that external conditions offer such crucial hints about the health, threats, and ecology of cetaceans (and consequently, of marine ecosystems), it is relevant to assess their prevalence in cetacean populations – a process that can easily be combined with photographic identification (photo-ID). Photo-ID is an important, non-invasive, and cost-effective technique, frequently applied to assess the abundance, demography, residency, and migratory patterns of wild animals. In cetaceans, researchers rely on natural marks on the dorsal fin to identify the individuals (e.g. Dinis et al. 2017, Morteo et al. 2017, Alves et al. 2018a, 2019, Bonneville et al. 2021). Even though the use of these features has proven successful, often, these are not permanent marks, changing or disappearing with time (Rosso et al. 2011, Alessi et al. 2014, Mariani et al. 2016). Externally detected conditions offer additional and important clues for the identification of free-ranging individuals, particularly when there are persistent marks (e.g. due to amputation, anomalous pigmentation, or deep scars; Urbán-Ramirez et al. 2004, Nascimento et al. 2008, Bradford et al. 2011, Gil et al. 2019).

Monitoring externally detected conditions can serve multiple applications in support of cetacean conservation and management. To that end, it is vital to standardise the documentation of these features to facilitate cross-species and cross-temporal comparisons. Our main goal is to provide: a broad definition of cetacean conditions or abnormal features, here generally conceptualised as deformities; a categorisation of externally detected deformities in free-ranging individuals; and a framework on how and what should ideally be documented to facilitate comparative studies and other research. In addition, we analyse the geographic and taxonomic coverage of the assembled literature.

METHODS

Constructing a state-of-the-art baseline

To enable an inclusive definition and categorisation of external deformities in wild cetaceans, we compiled a state-of-the-art baseline consisting of a list and summary of scientific papers published between 2000 and 2021 (Appendix S1). The review undertaken was systematic, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA; McIvor et al. 2022). First, we searched Google Scholar for peer-reviewed literature (i.e. restricted to scientific papers, and excluding grey literature such as theses, reports, or conference communications), published between 2000 and 2021, using the following words: 'cetacean(s) / marine mammal(s) / dolphin(s) / whale(s)' plus 'deformity(ies) / malformation(s) / lesion(s) / anomaly(ies) / disease(s) / injury(ies) / disfigurement(s) / mark(s) / scar(s)'. The scientific papers retrieved in the first 10 pages of the search engine (i.e. the most relevant results) were checked. Then, we screened the titles and abstracts of the papers, selecting those reporting on deformities that could be detected externally (i.e. excluding those only reporting on deformities uniquely detected through necropsies). When screening the full papers to compile the relevant information, others were excluded under the same criteria. When the papers presented external and internal conditions, sources were maintained, but only externally detected deformities were compiled.

Categorising and defining deformities

For the definition and categorisation of deformities, the state-of-the-art baseline was used and carefully revised. The deformity concept used here includes any condition or abnormality described in a cetacean species; therefore, it was applied in this context. The concept included knowledge gathered during the literature review, used the expertise of the authors, and was in line with Segen's Medical Dictionary (2011; https://medical-dictionary.thefreedictionary.com/deformity). Although the definition of deformity can apply to the whole range of deformities (i.e. including internal), only those detected externally were categorised. Records that described malformations purely based on histopathological findings or on the appearance of internal tissues were not taken into account for the categorisation. We collected the deformity records found in the papers, both as primary or secondary sources, but considering only those records that were the main topic of the manuscript (i.e. those that were properly reported in the paper, excluding those only referred for introduction/discussion purposes). During this revision process, we occasionally used keywords to facilitate our search and prevent us from missing information (i.e. 'emac' for emaciation or derived words).

The categorisation was made following a two-step hierarchy: defining general categories of deformities, followed by classification into sub-categories. General categories were set upon an overview of the literature in the state-of-the-art baseline (Appendix S1), and the scientific papers were organised according to the general categories they reported on. We examined the geographical and species diversity representativeness of the general categories to determine if we could guarantee an inclusive categorisation. For the species classification into Odontoceti and Mysticeti, we used the World Register of Marine Species (WoRMS 2022). To assess geographical coverage, for each research paper, we defined the country (or countries) where the work was conducted, taking into account the description of the study area provided in the article (detailed under Appendix S1). Often, this process consisted of registering the country-associated coast with the area sampled at sea. More than one country may have been attributed to a single research paper provided the study presented deformities in several areas. Studies with a global coverage were not included in this analysis. For each general category, sub-categories were established upon rigorous analysis of the state-of-the-art baseline, considering the external appearance of the deformities. The process consisted of gathering existing definitions and producing a final consensus definition (Appendix S2). To provide an illustrative image of the deformities, for each sub-category, one or two figures were selected from the state-of-the-art baseline and are referenced in Box 1, prioritising: higher definition and colour photographs that are representative of the sub-category, deformities recorded in live animals, images from research papers targeting that specific sub-category, and more recent publications.

RESULTS

Definition and categorisation of deformities

A deformity was defined as a condition, congenital or acquired during the individual's life, irrespective of the source, in which all or part of the body differs from the shape, colour, or appearance that is naturally expected/typical/characteristic of the species. Six categories and 58 sub-categories were established: anatomical malformations (with 11 sub-categories), skin lesions (29), anomalous pigmentation (4), injury due to physical impact (14), emaciation, and epibionts (Box 1, Appendices S1 and S2). A photography of an example of a sub-category for each of the six categories is provided under Fig. 1.

For a standard process in reporting externally detected deformities in wild cetaceans, Box 1 is provided as a tool to identify categories and sub-categories. Definitions can be adapted, and new categories and sub-categories can be created when deemed necessary. After identifying the category and sub-category of the deformity, as much detail as possible should be noted by researchers; relevant information to report is detailed in a framework with suggested guidelines for reporting (Fig. 2).

Analysis of the state-of-the-art baseline

A total of 253 publications were compiled in the state-of-the-art baseline, of which 47 included the category of anatomical malformation, 103 skin lesions, 12 anomalous pigmentation, 186 physical impact, 55 emaciation, and 44 epibionts (papers reporting on more than one category were accounted more than once). Injuries due to physical impacts were presented in 74% of the papers, while only 5% reported anomalous pigmentation (Fig. 3a). In total, the studies documented deformities in 80 species (out of the 101 extant species), including toothed cetaceans (67 out of 82 Odontoceti species) and baleen whales (13 out of 19 Mysticeti species; as of data reported for 2021, WoRMS 2022). The category physical impact was the most described across all species, with approximately 80% representativeness for Odontoceti and 68% for Mysticeti. The categories emaciation and epibionts were described in a lower percentage of Odontocetes (23% and 17%, respectively; Fig. 3b). Only clear records describing a specific category for a species were considered. Scientific papers reporting on several categories for different species were not always explicit about which category was present in each species and so were not compiled for the literature analysis on species' representativeness.

The state-of-the-art baseline included case reports in study areas from 50 countries (26% of the 195 countries in the world; Worldometers 2022), providing global coverage for

Box 1. Categorisation of externally detected deformities in wild cetaceans. General categories and sub-categories are defined considering the established state-of-the-art baseline (Appendices S1 and S2). Sub-categories in alphabetical order. References to illustrative figures for each deformity are provided (name of the figures are in conformity with those provided by the paper).

DEFORMITY: A condition, congenital or acquired during the individual's life, irrespective of the source, in which all or part of the body differs from the shape, colour, or appearance that is naturally expected/typical/characteristic of the species

CATEGORIES OF EXTERNALLY DETECTED DEFORMITIES IN CETACEANS

ANATOMICAL MALFORMATION

Deviation from the normal formation of a body part's shape and/or structure, with various degrees of severity.

Blowhole anomaly	Abnormal configuration of the blowhole, including the occurrence of an additional functional blowhole Relvas et al. 2020 – fig. 2
Body depression	Sunken area that affects a substantial part of the body, forming a concavity Martinez & Stockin 2013 – fig. 2b; Bertulli et al. 2015 – fig. 3c
Body protrusion	Localised prominent mass or swelling of any size, occurring on any part of the body, including tumour-like masses (neoplasia), swollen tissues, and osteomyelitis or spondylitis-like masses (fusion of the bones or infection of the bones, respectively) Kautek et al. 2019 – fig. 5a–c; Herr et al. 2020 – fig. 4
Conjoined twinning	Physical union of twin individuals on, at least, an anatomical zone of the body, including cases of equally conjoined parts (symmetrical twins); or unequally conjoined parts, with one incomplete individual attached to and completely dependent on, an individual that is mostly or completely normal (asymmetrical twins) Kompanje et al. 2017 – fig. 1; Tamburin et al. 2017 – fig. 2
Deformed dorsal fin	Deformation of the dorsal fin, including twisting and bending Alves et al. 2018b – fig. 1; Stack et al. 2019 – fig. 2
Lordoscoliosis	Lordosis complicated with scoliosis, resulting in ventral and lateral curvature Robinson et al. 2020 – fig. 1e.
Lordosis	Ventral curvature of the vertebral column, viewed from the side as an anterior concavity Ambert et al. 2017 – fig. 2a; Weir & Wang 2016 – fig. 1f,g
Kyphoscoliosis	Kyphosis complicated with scoliosis, resulting in dorsal and lateral curvature Robinson et al. 2020 – fig. 1f.
Kyphosis	Dorsal curvature of the vertebral column, resulting in a hump, viewed from the side as an increased convexity Ambert et al. 2017 – fig. 2b; Robinson et al. 2020 – fig. 1d
Rostrum deformities	Deviation from the normal formation of the rostrum, with deformities assuming varying configurations Wang et al. 2016 – fig. 2; Dinis et al. 2017 – fig. 1
Scoliosis	Lateral curvature of the vertebral column, with deviation on the dorsal plane to the right or left side Robinson et al. 2020 – fig. 1c; Weir & Wang 2016 – fig. 1j–m

SKIN LESION

Cutaneous lesion, not caused by mechanical trauma, observed on the body surface of the individual, that alters the aspect of the skin surface.

Dark area	Area of a darker colouration, with variable shape and dimension. Colouration can vary from dark grey to black. Smooth surface, flat or slightly depressed, with sharp or indistinct edges. Localised or multiple hyper-pigmented areas across the body. Taylor et al. 2021 – fig. 2. Black lesions; Toms et al. 2020 – table 1.Hyper-pigmentation: Black Amorphous.
Dark-fringed spots	Dark halo of black or dark grey colour, surrounding small circles of pale skin. Borders may be flat or slightly raised. Localised or multiple widespread lesions Taylor et al. 2021 – fig. 2. Dark-fringed lesions; Toms et al. 2020 – table 1.Potentially Pathogenic: Dark Fringe
Dark linear lesion	Linear lesion, not identified as a scar, of darker colour. The lines are occasionally interconnected in an intricate reticulated pattern, with sharp or indistinct borders Sanino et al. 2014 – fig. 17
Dark mark	Small to medium-sized oval or irregular mark, of dark grey to black colour. Flat surface or slightly depressed. Circumscribed marks, occurring as single or multiple lesions across the body Bertulli et al. 2016 – fig. 3b,m; Toms et al. 2020 – table 1. Hyper-pigmentation: Dark Spots.
Dark speckles	Numerous small to medium-sized dark dots scattered across the body, with a round to oval shape, and flat surface. Speckling appearance. The severity of the lesion may vary from mild to severe, depending on the extent of the body area affected Bertulli et al. 2012 – fig. 2a; Hupman et al. 2017 – table 1. Hyper-pigmented. Left image.
Dermatitis	Wide range of gross appearances of the skin with smooth or slightly raised surfaces, that include one or a combination of other categories of skin lesion, namely those related to hyper- and hypo-pigmentation, vesicular, nodular, and ulcerative lesions. Van Bressem et al. 2015 – fig. 5; Herr et al. 2020 – fig. 32b

Box 1. Continued (Skin Lesion Category)

Expansive annular lesion	Ring-shaped lesion, with concentric rings of alternated hyper- and hypopigmented bands. Localised or multiple widespread lesions Bertulli et al. 2012 – fig. 5; Van Bressem et al. 2015 – fig. 6
Hole	Visible, but small, depression or sunken tissue, circular shape. Hupman et al. 2017 – table 1. Depressed and sunken. Norman et al. 2018 – fig. 4d
Hyperplasic lesion	Irregular to circular raised epidermis, of normal skin colour or slightly lighter. Variable in size but focal, with a smooth surface. Single or multiple lesions across the body Bertulli et al. 2016 – fig. 1M'wl'; Hupman et al. 2017 – table 1. Raised and proliferative
Light area	Area of a lighter colour, of variable shape and dimensions. Colour can vary between light grey, cream, or white, occasionally with pink or yellow highlights. Appearance can be velvety, skin colour, from opaque to translucent. Flat surface or slightly raised, with sharp or indistinct edges. Localised or widespread discoloured areas over the body Barlow et al. 2019 – table 1. Blaze; Taylor et al. 2021 – fig. 2. Pale lesions
Light fringed spot	Light halo of white or cream colour, surrounding small circles of black or normal-coloured skin. Borders may be flat or slightly raised. Localised or multiple widespread lesions Gonzalvo et al. 2015 – fig. 2b; Toms et al. 2020 – table 1. Potentially Pathogenic: White Fringe
Light linear lesion	Linear lesion, not identified as a scar, with a lighter colour, and often with a raised appearance. Localised or multiple widespread lesions Riggin & Maldini 2010 – fig. 1l
Light mark	Small to medium-sized mark of lighter colour with circular, oval, or irregular shape. Colour can vary between light grey, cream, and white. Flat surface or slightly raised. Circumscribed marks, occurring as single or multiple widespread lesions Hamilton & Marx 2005 – fig. 3. Red arrows; Bertulli et al. 2016 – fig. 1e'wm'
Light outline	Light bands surrounding the edge of a particular feature (e.g. lesion, lips, blowhole, callosity). Colour can vary from greyish to white, with opaque to translucent aspect Hamilton & Marx 2005 – fig. 3. White arrows
Light speckles	Numerous small to medium-sized light dots scattered across the body, round to oval shape, and flat surface. Speckling appearance. The severity of the lesion may vary from mild to severe, depending on the extent of the body area affected Sanino et al. 2014 – fig. 12; Gonzalvo et al. 2015 – fig. 3
Linear skin marks	Superficial, but depressed, dorsoventral lines, generally parallel and variable in length, width, and depth. Located laterally, may occur on both sides of the body but not trespassing on the dorsal surface, and may connect at the abdomen region Titcomb et al. 2020 – fig. 1
Lobomycosis-like lesion	Proliferation of nodules, plaque-like, and/or verrucous features, often raised and ulcerated. Lesion with variable extent, characterised by greyish, or whitish to slightly pink pigmentation. Localised or widespread across the body Bessesen et al. 2014 – figs 2–4; Ramos et al. 2018 – figs 3, 4, and 6
Lunar lesion	Irregular shape, often extensive, with a mixture of black, grey, blue-grey, and white skin. Borders are distinct and the surface is both raised and pitted, with an appearance of corroded aluminium Maldini et al. 2010 – fig. 1.III. Polygons; Toms et al. 2020 – table 1. Hyper-pigmentation: Lunar
Orange-like lesion	Irregular shape, colour varying from yellowish, orange, rusty, green, to brown. Lesion can be small, cover the skin continuously over a larger area, or occur in small patches. Thickened rough or smooth velvety surface. Hupman et al. 2017 – table 1.Yellow/orange discolouration; Kautek et al. 2019 – fig. 3d
Necrosis	Necrotic tissue of yellowish colour, and erythematous areas. Size and shape are variable, and single or multiple necrotic areas may occur. Bossley & Woolfall 2014 – fig. 3; Riggin & Maldini 2010 – fig. 5
Nodules	Circular cutaneous elevations of the skin, with grey or normal skin colour. Size may vary but always smaller than a mass/swelling protrusion. Occasionally with a necrotised centre. Single lesion or multiple nodules, localised or scattered across the body Van Bressem et al. 2014 – figs 2 and 3; Chan & Karczmarski 2019 – fig. 1c
Snake-like light lesion	Light line with a sinuous shape that varies in length and resembles a moving snake. Mariani et al. 2016 – fig. 2d
Spotted dark patch	Clustered small to medium-sized dark spots, with a round to oval shape, resulting in a patch of darker colouration, but with singular spots distinguishable Hupman et al. 2017 – table 1. Hyper-pigmented.Right image

(Continues)

Box 1. Continued (Skin Lesion Category)

Spotted light patch	Clustered small to medium-sized light spots, round to oval shape, that result in a cauliflower appearance. The singular spots are distinguishable Toms et al. 2020 – table 1. Potentially Pathogenic: Spotted; Feyrer et al. 2021 – fig. 5b
Starburst lesion	Light-coloured mark, with a central origin and tendrils extending outwards from the centre Barlow et al. 2019 – table 1. Starburst
Tattoo-like lesion	Ring or irregular shape of variable size, and colour varying between grey, black, whitish, and/or yellowish. Often with hyper- or hypopigmented outlines. Surface can be flat, slightly raised, or depressed. Characteristic punctiform stippled pattern, resembling a tattoo. Localised or multiple widespread lesions, that may form clusters, and occasionally fuse into larger lesions. Cocumelli et al. 2018 – fig. 1; Powell et al. 2018 – fig. 1
Ulcer	Open sore caused by a break in the superficial epithelium, with poor or no healing process. Exposure of the hypodermal stratum (i.e. blubber) or the subcutaneous fibrous tissue. Colour varies between whitish, pinkish, or reddish. Inflammation may be raised, with different degrees of severity. Size and shape are variable, and single or multiple ulcers may occur Chan & Karczmarski 2019 – fig. 1d; Herr et al. 2020 – fig. 19
Vesicular lesion	Skin blister-like, air- or fluid-filled, elevation. May occur as a single lesion, or in multiple lesions, often aggregated. Colour varies from whitish to dark grey. Occasionally, craterous-type vesicles develop and are characterised by raised edges with a protruded centre Hamilton & Marx 2005 – fig. 4; Barlow et al. 2019 – table 2. Blisters
White freckles	Numerous, small, white dots spread across the body. Circular in shape with distinct edges, occasionally raised from the skin, with the appearance of white freckled bumps Toms et al. 2020 – table 1. Hypo-pigmentation: White Freckles

ANOMALOUS PIGMENTATION

Abnormal colour variation, due to an excess or deficit in the production of melanin. The colour variation encompasses a wide continuum from hypo- to hyper-pigmented, affecting the entire body or a large part of it.

Albinism	Complete absence of pigmentation over the whole body, that presents a white, whitish, or yellowish white colour. The pigmentless eyes are red or pink Stockin & Visser 2005 – fig. 3
Leucism	Total or partial hypo-pigmentation over most of the body, characterised by a white, whitish, or yellowish white colour. The eyes and, in some cases, the body extremities maintain normal pigmentation Cardoso et al. 2019 – fig. 6; Gil et al. 2019 – fig. 2
Melanism	Total or localised hyper-pigmentation, characterised by patches or the entire body being dark or black Visser et al. 2004 – fig. 1b
Piebaldism	Localised hypo-pigmentation resulting in irregular patches of white to light-grey colour. The ratio of lighter to normal colouration may vary between individuals Lodi & Borobia 2013 – fig. 1; Herr et al. 2020 – fig. 33

PHYSICAL IMPACT

Any abnormality in the gross appearance of body tissue, caused by an external physical impact.

Bruising	Colour change of the external cutaneous tissues, frequently with associated swelling, corresponding to internal hematomas Dwyer et al. 2014 – fig. 1a
Cookiecutter mark	Crater-like, scooped-out, wound or depressed scar, of circular to oval shape. When fresh, a red to pink colour may occur Feunteun et al. 2018 – fig. 2; Grace et al. 2018 – fig. 1
Cut	Cut-like lesion resulting in the loss of tissue; including incisions, indentations, and lacerations, of various shapes and degrees of severity Slooten et al. 2013 – fig. 4a,d; Hill et al. 2017 – fig. 2a,b
Fin amputation	Significant loss of tissue, with partial or complete mutilation of a fin. Wang et al. 2017 – fig. 3.Bottom right; Herr et al. 2020 – fig. 15b,c
Linear scrape	Line, narrow to wide, but always longer than wider, generally superficial. Colour can vary between black, grey, cream, and white. Lesion can be one, two, or more parallel linear marks. Includes tooth rake marks, often infected, and with brownish colour in the surrounding tissue Capella et al. 2018 – fig. 2; Maieski et al. 2020 – figs 2 and 3
Scar	Deformation of the epidermis resulting from the healing of a wound. Irregular, indented, or swelled surface. Often depigmentation occurs, with varying colours, from white to dark grey, but in advanced stages of scarring. The skin can be of normal body colour. Variable in shape and size Basran et al. 2019 – fig. 4; Herr et al. 2020 – fig. 6

Box 1. Continued (Physical impact category)

Scratch patch	Area with a high density of superficial scratches or abraded cutaneous tissue Herr et al. 2020 – fig. 32b
Sea lamprey mark	Circular mark with texture, raised edges, and dentition pattern. The lesion is pale to grey, often outlined with a dark colour Nichols & Tscherter 2011 – fig. 2; Miočić-Stošić et al. 2020 – figs 3 and 5
Shark-bite mark	Semi-circular fresh wound or healed scar, with a curved or triangular outline. Crescent-shaped and jagged pattern, often with punctiform tooth marks Smith et al. 2018 – fig. 3; Castelblanco-Martínez et al. 2021 – fig. 2a–c
Skidding mark	Parallel sliding scratches of paler colour, associated with sea lamprey marks. Herr et al. 2020 – fig. 5b; Miočić-Stošić et al. 2020 – figs 5'c' and 6
Squid mark	Circular to oval thick halo surrounding a dark or white disk Mariani et al. 2016 – fig. 2a'smb'
Notch	Missing tissue along the outline of the fins. Notches may be shallow or deep and vary in size. Shape may be triangular, rectangular, circular, semi-circular, jagged, or indented. Scarring may occur at the edges of the lesion Orbach et al. 2015 – fig. 3; Bamford & Robinson 2016 – fig. 1
Protruding tissue	Triangular or square piece of tissue protruding, often associated with a cut or notch Bertulli et al. 2016 – fig. 2d'pp'.
Wound	Fresh damage to the epidermis, with exposure of blubber, muscle, and/or viscera. Variable shape, dimension, and depth, often with associated haemorrhage, bruising, and/or swelling Harnish et al. 2019 – fig. 1; Herr et al. 2020 – fig. 17

EMACIATION

Unnatural thinning, taking into account the species and the age class of the individual, characterised by muscular and adipose tissue atrophy. The degree of thinness may vary between individuals, from mildly thin to severely emaciated. Emaciated individuals may present one or several of the following visually detected characteristics: post-nuchal fat pad softening, sunken cervical region, concavity along the epaxial profile, and visible bony prominences (ribs, scapula, vertebral transverse and dorsal apophyses)

Kautek et al. 2019 – fig. 5d; Herr et al. 2020 – fig. 2

EPIBIONTS

Organism(s) encountered on the body surface, with a commensal or parasitic relationship, often causing visible skin lesions or leading to physical impact deformities. Persistence and area of infection may vary between epibiont species and host individuals

List of taxa:

Conchoderma sp. Elorriaga-Verplancken et al. 2015 – fig. 3
Coronulidae. Bradford et al. 2011 – figs 1–4; Herr et al. 2020 – figs 27 and 28
Cyamidae. Rolland et al. 2016 – fig. 1b; Groch et al. 2018 – fig. 2b
Echeneidae. Kautek et al. 2019 – fig. 3c
Ophichthidae. No figure was found in the references
Pennellidae. Vecchione & Aznar 2014 – fig. 3; Herr et al. 2020 – fig. 25
Petromyzontidae. Miočić-Stošić et al. 2020 – fig. 1; Nichols & Tscherter 2011 – fig. 1

all categories (Fig. 4). The physical impact category was reported in studies conducted in 47 countries. The European and American continents were the most well-represented, with an evident underrepresentation of Africa and Asia. Three countries had over 30 papers reporting externally detected deformities in wild cetaceans: 130 in the USA, 62 in Canada, and 34 in Australia. The literature included papers from 86 scientific journals, but three journals between them contributed 100 out of the 253 documents (*Marine Mammal Science* with 40; *Aquatic Mammals* with 33; and *Diseases of Aquatic Organisms* with 27; Fig. 3, Appendix S1).

DISCUSSION

Based on a comprehensive analysis, we created a well-sustained definition of deformity and a standardised and updated categorisation of externally detected deformities in free-ranging cetaceans. In addition, we provided a framework with guidelines for reporting deformities. These tools can support cetacean monitoring in health assessments and photo-ID, further providing relevant information to studies on distribution, habitat, diet, genetics, behaviour, migration, and overall conservation.

Cetacean health assessments are fundamental in determining population viability and conservation status, and in inferring the status of marine ecosystems (Taylor et al. 2021). Population viability is usually investigated through changes in abundance that may take a long time to reflect the effects of stressors in long-lived and slow-breeding species such as cetaceans. Moreover, due to spatiotemporal gaps in monitoring effort, these estimates are often extrapolations with low precision (CetAMBICion 2022),

Fig. 1. Photographic records of each of the defined categories of externally detected deformities in cetaceans (representation of a sub-category as an example).

that only permit the detection of substantial changes, mostly over time scales larger than those at which the legislative drivers operate. Considering the increasing rate of change in marine ecosystems (Bryndum-Buchholz et al. 2019), direct health assessments can be vital for the detection of impacts and threats, and for earlier application of mitigation measures. Currently, the majority of cetacean health assessments derive from data on captive or stranded animals and are, therefore, unrepresentative of wild populations (Joly et al. 2009). At sea, researchers collecting health data from live cetaceans often resort to invasive techniques, which are not suitable for more susceptible or elusive species (Alves et al. 2020). However, new technologies and sampling methods are already being used to evaluate the health status of cetaceans (e.g. Bierlich et al. 2022). Monitoring of deformities can be employed alongside non-invasive techniques and integrated into existing monitoring programmes and photo-ID studies. An extensive body of literature reporting on deformities, usually ones that are easily detected, supports the potential to use such data to inform on health status and pressures (e.g. Van Bressem et al. 2007): anatomical malformations and physical impacts may indicate interaction with vessels (e.g. Barcenas-De la Cruz et al. 2018, Stack et al. 2019); skin lesions may evidence disease and/or water pollution (e.g. Reif et al. 2009, Taylor et al. 2021); anomalous pigmentation can indicate congenital conditions leading to individuals being more susceptible to environmental stressors (e.g. Alves et al. 2017, Gil et al. 2019); emaciation is indicative of malnutrition (e.g. Pettis et al. 2017); epibionts may indicate immunosuppressed individuals that are more susceptible to parasites (e.g. Vecchione & Aznar 2014).

External deformities identified during photo-ID can be used to complement other identification clues. Photo-ID techniques solely based on fin nicks, scars, and pigmentation patterns can be insufficient or may significantly limit the number of catalogued individuals or matches (Alessi et al. 2014), especially for poorly marked species (Hupman et al. 2017, 2018). Permanent marks, such as anatomical malformations, anomalous pigmentation, or physical impacts causing severe damage (e.g. cuts, fin amputation)

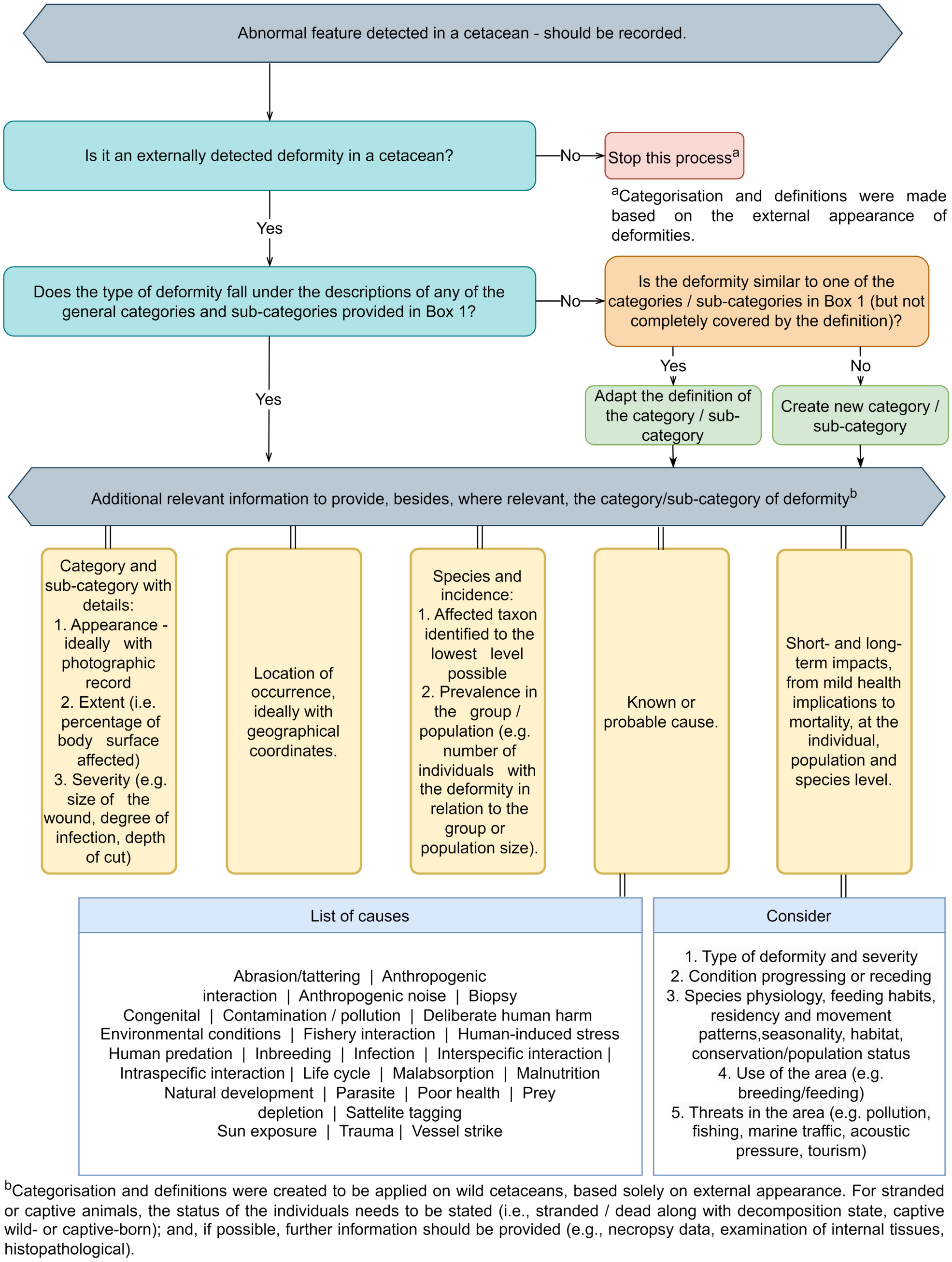

Fig. 2. Suggested process and guidelines to record and communicate externally detected deformities in wild cetaceans. The list of potential causes was created and standardised from the state-of-the-art baseline (Appendix S1).

should, therefore, be included in standard photo-ID procedures as identification tools. Previous studies have used these features to recognise individuals and track their life histories, providing information about residency (Gil et al. 2019), movements (Urbán-Ramirez et al. 2004), and habitat use (Bradford et al. 2011).

The literature we reviewed was not geographically homogeneous: some areas have higher numbers of scientific papers reporting deformities. This is unlikely to reflect the frequency of deformities globally but is rather a combination of heterogeneous research effort across the globe and spatial bias of the systematic review. In fact, only three scientific journals (out of 86) published 100 of the 253 papers we included. It is likely that there was an underrepresentation or a bias of regional journals retrieved by the search engine, and that some regions have greater

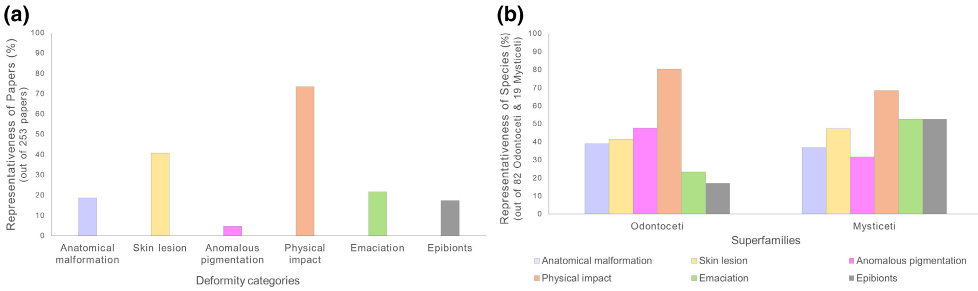

Fig. 3. Representation of the number of scientific papers in the state-of-the-art baseline for each deformity category (a) and representativeness of the number of species out of the total described species (b) considered for categorising externally detected deformities in wild cetaceans. Paper representation is described as the number of papers considered for each general category, in relation to the total number in the state-of-the-art baseline (n=253). Species representativeness corresponds to the percentage of species reported with externally detected deformities, in relation to the total number described for each taxon (82 species of Odontoceti and 19 species of Mysticeti, as of 2021, according to WoRMS 2022), by general category. Scientific papers that report on more than one category and one species are represented more than once in both a and b. See 'Methods' for paper selection procedures. The graphs were generated based on the information compiled in Appendix S1.

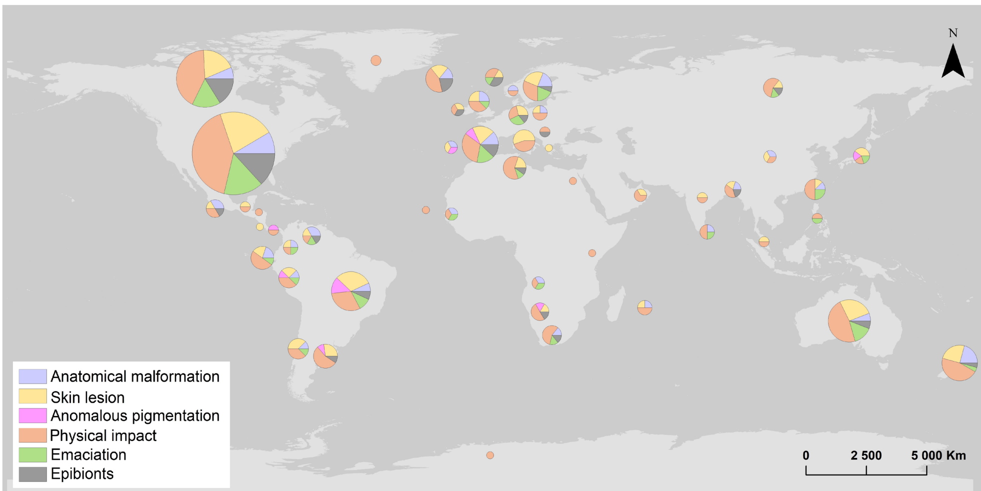

Fig. 4. Global distribution of research studies reporting on externally detected deformities in wild cetaceans, from 2000 to 2021, by general categories. The size of each pie chart is proportional to the total number of papers from research studies in each country. Scientific papers that report on more than one category and for more than one country are compiled in more than one pie chart and pie chart category. The countries considered correspond to the study areas of the papers (see methodology; description of study area detailed under Appendix S1).

documentation of deformity cases in anecdotal records or grey literature (not included in this review). We are, therefore, aware that relevant literature may have been missed. Nevertheless, the present systematic review aimed at providing comprehensive coverage of deformities, across categories and species, which was achieved.

Deformity categorisation resulted in six general categories and 58 sub-categories, classified based on the development of consensus definitions (across the compiled literature). While the cause of some deformities is clear (e.g. bites from the cookiecutter shark *Isistius* sp.), this is not always the case for others (e.g. cuts, wounds). Therefore, the categorisation was made based on the external appearance of the features, regardless of the cause. Additionally, though we attempted to generate specific sub-categories for each feature, some of the sub-categories present a variety of appearances, and it was not possible to specify further. In some of these cases, the deformity can include a combination of other sub-categories (e.g. lobomycosis-like lesion, dermatitis, wound). Also, a sub-category type of deformity can be the consequence of another (e.g. scars deriving from wounds), and some sub-categories are often correlated (e.g. vesicular and starburst lesions are associated, Barlow et al. 2019; skin lesions can be infested with cyamids, Lehnert et al. 2021). In general, individuals in poor health are more susceptible to epibionts and more likely to contract additional diseases or get injured (Vecchione & Aznar 2014, Herr et al. 2020, Olaya-Ponzone et al. 2020). This also relates to the severity of the deformities and their impacts at the individual, population, and species levels. The consequences of a deformity might range from harmless to fatal (e.g. intraspecific linear scrapes resulting from tooth rakes may be harmless; deep open wounds impede survival and may be fatal). Therefore, it is important to report adequately on the type of deformity, location of occurrence, species, prevalence, possible cause(s), and likely short-term and long-term impacts.

Of the six categories of deformities we defined, injury due to physical impact was the most reported category for both Odontoceti and Mysticeti; it was also reported by studies in most of the countries (covered by the literature we reviewed). This probably relates to the fact that this category encompasses naturally occurring and highly prevalent marks used for photo-ID (scars, notches, and linear scrapes; e.g. Dinis et al. 2018, Alves et al. 2019, Bonneville et al. 2021). Also, the category includes features frequently linked to vessel collision and interaction with fisheries: wounds, cuts, fin amputations, scars, scrapes, and bruising – human pressures to which cetaceans are increasingly being exposed, and a target research topic for many authors (e.g. Douglas et al. 2008, Wang et al. 2016, Félix et al. 2018). Moreover, the physical impact category includes features related to intra- and interspecific interactions, between cetaceans and with other marine species (cookiecutter shark, other sharks, sea lamprey *Petromyzon marinus*). These marks are often investigated for ecological purposes, such as in behavioural studies (e.g. Pitman et al. 2001, Corsi et al. 2021), or as indicators of the occurrence of certain species in the area (e.g. Moore et al. 2003, Wcisel et al. 2010). A high number of papers have reported on skin lesions, making this a very promising category to infer on cetacean health status (e.g. lesions can be indicative of diseases and water quality). Most of the skin lesion sub-categories are easily detected on the body surface of cetaceans (e.g. Toms et al. 2020, Taylor et al. 2021). On the contrary, emaciation, a good indicator of body condition (and of malnutrition, possibly disease, and/or prey depletion), is usually detected at sea only in an advanced state (i.e. bony prominences). Most records of emaciation derive from stranded animals that allow for closer observation and measurements (e.g. Ewing et al. 2020, Herr et al. 2020, Huggins et al. 2020).

Anatomical malformations, anomalous pigmentation, and epibionts were the categories with the fewest papers. The presence of epibionts is likely to be underestimated because it is difficult to detect epibionts on the body surface of free-ranging cetaceans. As for anatomical malformations and anomalous pigmentation, many of these are congenital abnormalities with a low prevalence in cetacean populations (Berghan & Visser 2000, Abreu et al. 2013). A review highlighted a knowledge gap on anomalous pigmentation – only 14 cases of leucism in dolphins were described from 1929 to 2019 (reference not retrieved by the systematic review process – Hauser-Davis et al. 2020). Knowledge gaps are likely to exist for other deformities as well. Furthermore, some anatomical malformations may impede individuals' survival, thus making them unlikely to be encountered (Berghan & Visser 2000, Dinis et al. 2017, Kompanje et al. 2017).

Assessing and reporting cetacean deformities through a common language is proposed as a valuable non-invasive monitoring methodology. In this way, a clear and consistent terminology for cetacean deformities can easily be implemented alongside, and in support of, photo-ID studies, and the knowledge gained can provide crucial indicators of populations and ecosystem health. Establishing a standard framework is essential for comparing data among studies and for providing efficient support for cetacean management and conservation efforts.

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DATA AVAILABILITY STATEMENT

All the data used in this study are available under supporting information (Appendices S1 and S2).

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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. State-of-the-art baseline on externally detected cetacean deformities, consisting of a list and summary of scientific papers published between 2000 and 2021 and used in the review of deformities in cetaceans.

Appendix S2. Categorisation and definition of deformities in cetaceans.