Mammalian Biology
https://doi.org/10.1007/s42991-022-00300-z

ORIGINAL ARTICLE

Prevalence and spatio-temporal variation of epidermal conditions, deformities and injuries in common bottlenose dolphins (*Tursiops truncatus*) in Welsh waters

Anastasios Stylos[1] · Eleni Akritopoulou[1,4] · Chiara G. Bertulli[2] · Katrin Lohrengel[2] · Niall McGinty[3] · Dimitrios K. Moutopoulos[5] · Peter G. H. Evans[1,2]

Received: 26 March 2021 / Accepted: 4 August 2022

Abstract

Epidermal conditions, traumatic marks, deformities, and unusual body pigmentation were visually assessed on common bottlenose dolphins (*Tursiops truncatus*) using photo-identification and sightings data collected between 2007 and 2018 in Welsh waters. The goals of this study were to describe and categorize external body conditions, in particular, analyse the influence of age, sex, and distribution patterns on the mark prevalence, and assess the temporal and spatial patterns of lesions over time. During 222 boat-based trips, 287 individual dolphins were identified and almost all (99.3%) had skin marks, with individuals carrying between 1 and 12 different types. Linear, conspecific tooth-rake, dark fringe and abraded fin tip were the most prevalent mark types. The investigation of the influence of age, sex, and distribution patterns on skin lesion prevalence showed that adults had significantly higher prevalence compared to calves ($t_{75}=3.6$, $p=0.001$, $\mu_A=3.9$, $\mu_{C+J}=2.6$), males compared to females ($t_{64}=2.3$, $p=0.03$, $\mu_F=4.4$, $\mu_M=5.6$), whilst "transients" had a significantly higher number of different marks ($t_{31}=3.3$, $p=0.001$, "residents" = 3.6; "transients" = 5.9) compared to "residents" within the study area. Eighteen mark types were re-sighted over time. Despite a number of limitations which need to be taken into account, the minimum skin mark prevalence estimates produced in this study provide insights into the health status of common bottlenose dolphins and key evidence on local antagonistic, anthropogenic, infectious and parasitic pressures informing the conservation of this species in Welsh waters.

Keywords Deformity · Epidemiology · Injuries · Photo-identification · Skin lesion · Tattoo skin disease · *Tursiops truncatus*

Introduction

Marine contaminants and boat traffic are becoming more prevalent in marine ecosystems (Johnston and Roberts 2009; Tournadre 2014). While increased boat traffic may lead to animal injuries or even fatality (Moore et al. 2013; Schoeman et al. 2020), anthropogenic contaminants threaten the health of aquatic organisms (Wilson et al. 1999; Sanino et al.

Handling editors: Stephen C.Y. Chan and Leszek Karczmarski.

This article is a contribution to the special issue on "Individual Identification and Photographic Techniques in Mammalian Ecological and Behavioural Research – Part 2: Field Studies and Applications" — Editors: Leszek Karczmarski, Stephen C.Y. Chan, Scott Y.S. Chui and Elissa Z. Cameron.

✉ Anastasios Stylos
tasosstyl94@gmail.com

✉ Chiara G. Bertulli
chiara.bertulli@gmail.com

[1] School of Ocean Sciences, Bangor University, Menai Bridge, UK

[2] Sea Watch Foundation, Ewyn y Don, Bull Bay, Amlwch LL68 9SD, Isle of Anglesey, UK

[3] Department of Oceanography, Dalhousie University, Halifax, NS, Canada

[4] Marine Mammal Monitoring Unit, Department of Ichthyology and Aquatic Environment, School of Agricultural Sciences, University of Thessaly, Volos, Greece

[5] Animal Production, Fisheries and Aquaculture, University of Patras, 30 200 Mesolonghi, Greece

Published online: 15 November 2022

2014; Fossi and Panti 2018). Climate change can also alter environmental water parameters ultimately causing severe skin conditions in dolphins worldwide (Duignan et al. 2020). Estimating the impact of contaminants and vessel presence on complex marine ecosystems as a whole is challenging. However, by evaluating the impact of these two pressures on cetaceans, we may in turn get an insight into the overall health of the marine ecosystem. Common bottlenose dolphins (*Tursiops truncatus*; hereafter as bottlenose dolphins) are long-lived apex predators that can concentrate large amounts of contaminants and are regarded as good indicators of the health of the whole marine ecosystem (Wells et al. 2004; Fossi and Panti 2018; Powell et al. 2018). Therefore, effective long-term monitoring of these animals is essential for a variety of stakeholders, including fisheries and public health institutions (Sanino et al. 2014; Hupman et al. 2017).

Skin lesions are a useful visual manifestation of the health of cetaceans and the marine ecosystem they occupy (Murdoch et al. 2008; Van Bressem et al. 2003, 2008, 2009; Mouton and Botha 2012; Chan and Karczmarski 2019). Cutaneous diseases may be of bacterial, fungal, viral and environmental origin (Van Bressem et al. 2008; Bearzi et al. 2009; Bertulli et al. 2012; Kautek et al. 2019; Duignan et al. 2020). Injuries and scars can be caused by vessel collisions and entanglement (Moore et al. 2013; Basran et al. 2019). Other factors including increased intra/interspecific interactions, reduced salinity, ultraviolet radiation, and temperature fluctuations are also known to contribute to the prevalence and spread of skin conditions (Wilson et al. 1999; Martinez-Levasseur et al. 2010; Hupman et al. 2017). However, in many cases the etiology of skin conditions are still unknown (Van Bressem et al. 2015).

Studies focusing on visually assessing cutaneous disorders, traumata and malformations in bottlenose dolphins have used photo-identification images and classified skin conditions according to their gross characteristics (Thompson and Hammond 1992; Maldini et al. 2010; Burdett Hart et al. 2012; Toms et al. 2020), and by the etiological agents (Bradford et al. 2009; Van Bressem et al. 2009; Burdett Hart et al. 2010). Skin marks have been documented on the body of Welsh bottlenose dolphins via photo-ID methods (Baines et al. 2002; Pesante et al. 2008) since 1989 but systematically reported from 2001 (Feingold and Evans 2014). The first attempt to categorize body marks in Cardigan Bay bottlenose dolphin populations was made by Magileviciute (2006) who described six, found that 61% of individuals carried one or more, and concluded that dark-fringed spots (DFS) were the most prevalent marks. Later, Akritopoulou (2014) analysed bottlenose dolphin data (2007–2014), described fifteen marks, and found that 72.8% of individuals carried more than one mark, some persisting over time, and that white lesions were the most prevalent type.

Cardigan Bay is the largest embayment in the United Kingdom and is home to 150–300 bottlenose dolphins (Pesante et al. 2008; Feingold and Evans 2014; Lohrengel et al. 2017), with sightings consisting of "residents", "occasional visitors", and "transients" (Feingold and Evans 2012). In this study images of epidermal conditions, traumatic marks, deformities, and unusual body pigmentation on bottlenose dolphins are collected from around Wales, UK, and the three aims: (1) to provide the first long-term (2007–2018) photographic skin lesion assessment of bottlenose dolphins within Cardigan Bay (2), to analyse the influence of age, sex, and distribution patterns on mark prevalence, and (3) to study the temporal and spatial patterns of skin conditions on these dolphins.

Materials and methods

Study area and population

Located on the west coast of Wales, Cardigan Bay covers around 5,000 km^2, running from the Llŷn Peninsula in the north to St. David's Head in the south (Evans 1995; Fig. 1). The region is largely rural with a low human population density. Cardigan Bay is a shallow embayment (max depth 60 m) with depths gradually reducing from southwest to northeast and is characterised by very gentle slopes, with four main estuaries (Glaslyn, Mawddach, Dyfi, Teifi) and other smaller rivers bringing freshwater into the bay (Evans 1995). It is a large open bay, exposed to strong winds (Evans 1995) limiting the opportunities to conduct systematic surveys unless the sea is in an optimal state (Beaufort scale <3). Cardigan Bay hosts the largest coastal population of bottlenose dolphins in the UK (Pesante et al. 2008; Feingold and Evans 2014; Lohrengel et al. 2017), which are regular visitors to coastal areas from Aberaeron to Cardigan, as well as the Sarns (Sarn Badrig, Sarn y Bwch, and Sarn Cynfelin), south coast of the Llŷn Peninsula, and Tremadog Bay in the northeast. As a result, two Special Areas of Conservation were established under the EU Habitats and Species Directive (Council Directive 92/43/EEC): Cardigan Bay SAC, an area of 958.65 km^2, and Pen Llŷn a'r Sarnau SAC an area of 1460.35 km^2, for both of which the species is a qualifying feature under Annex II (CCW 2005; CCC 2008; Fig. 1).

Data collection

Since 2001, two types of boat surveys have been conducted in Cardigan Bay between March and October, focusing on coastal waters (up to ten km from land) but on occasions reaching the outermost limits of the bay: (1) dedicated line transect (LT), and (2) dedicated non-line transect (NLT) surveys. Surveys were weather dependant, conducted

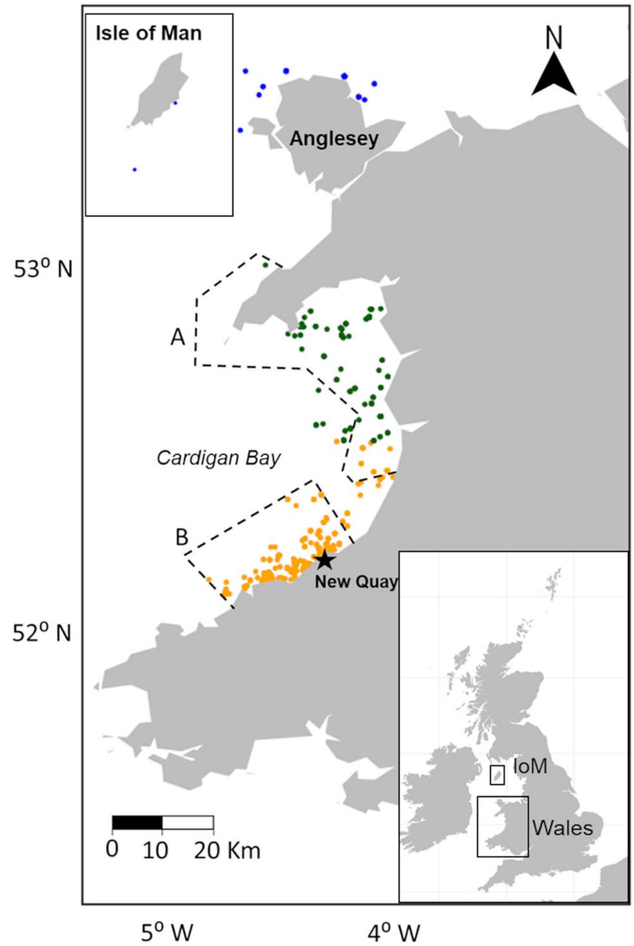

Fig. 1 Bottom right inset: map of the United Kingdom showing the location of the study area in Wales and the Isle of Man (IoM). Main chart: a map of the common bottlenose dolphin sightings recorded in Pen Llŷn a'r Sarnau SAC (**A**), Cardigan Bay SAC (**B**) and around the Isle of Man. Green dots indicate dolphins sighted in southern Cardigan Bay (SCB), yellow dots dolphin sighted in northern Cardigan Bay (NCB) and blue dots, dolphin sighted in the northern Irish Sea (NIS). Sightings were collected between 2007 and 2018

in Beaufort sea state 0–3, visibility > 1.5 km, and no precipitation. NLT surveys were mainly conducted to obtain additional data through photo-ID when weather conditions or vessel availability did not allow whole-day surveys. From 2008, NLT surveys were also carried out opportunistically at any time of year (but mainly between November and April) off the north coast of Anglesey in North Wales. Opportunistic bottlenose dolphin photos were also provided by members of Manx Whale and Dolphin Watch conducting fieldwork from the Isle of Man.

Photo-identification

A photo-ID session was initiated when dolphins were encountered and did not react negatively to the presence of the survey vessel. Once dolphins were sighted, the boat approached them slowly, generally on a parallel course to start photo-ID typically 20–50 m away from the animals. Photo-ID images were usually taken with a Canon EOS DSLR camera equipped with 75–300 mm lens. Photography was conducted under licence from Natural Resources Wales, using protocols laid out in the photo-ID licence, to minimise potential disturbance. Behaviours such as deliberate avoidance, continuous tail slaps and prolonged dives were considered signs of disturbance, and encounters were aborted if animals repeatedly showed them. A photo-ID encounter lasted a maximum of 40 min, ending earlier if both sides of each dolphin's body had been photographed well. In most cases, full photographic coverage of every individual was not possible.

Data analyses

Photographic analyses

Photographs obtained in the field were matched against the Sea Watch Foundation photo-ID catalogue currently holding images of around 400 bottlenose dolphin individuals. The matching process was undertaken by eye with matches always confirmed by a second experienced person. Each individual dolphin in the catalogue was given a unique reference code number which was related to the extent and position of any marks. Those individuals with no nicks or notches but secondary markings such as scars, deformities or pigmentation patterns, were catalogued on the left or right side.

Images selected for skin lesion analysis followed a quality grading system comprising six stages ($Q = 1$–6; Gowans and Whitehead 2001) based on the distance, focus, clarity, and body area showing. Images of $Q = 5$ and $Q = 6$ were close-up, well-focused shots of high quality, providing a good representation of a body part or the whole body. Only photos graded $Q \geq 5$ were used for the analysis to avoid possible mistakes in the detection and subsequent evaluation of body marks (e.g. Elwen et al. 2009; Rosso et al. 2011; Bertulli et al. 2016b). Images taken between 2001 and 2006 were excluded to ensure comparability since the great majority of those were taken with analogue cameras.

Age, maturity, and sex determination

Age and gender of individuals were estimated according to physical characteristics, body pigmentation and association with conspecifics (e.g. Smolker et al. 1992; Feingold and Evans 2012; Bertulli et al. 2016a). Confirmation of gender was made only when the genital area was observed during aerial behaviours. However, individuals closely accompanied by a calf on more than one occasion were classified as adult females (e.g. Bearzi et al. 2009; Feingold and Evans 2012; Van Bressem et al. 2013), and individuals with large and heavily marked bodies were considered potential males if they were mature and had been observed for several years without accompanying calves.

Home range and geographical areas

The study area was divided into three sectors: (a) southern Cardigan Bay (SCB: < 52.5° N), (b) northern Cardigan Bay (NCB: 52.5°–53° N), and (c) northern Irish Sea (NIS; > 53° N) which includes Anglesey and the Isle of Man (Fig. 1). Individuals recorded only in SCB were classified as "residents" and the rest as "transients".

Assessment and classification of conditions

Images of high quality were screened for cutaneous conditions, traumatic and parasitic marks, deformities, and atypical body pigmentation patterns. The measurements (size and width) of each mark as well as the distance between tooth rakes were calculated using dorsal fin height measurements available in the literature (e.g. Rowe and Dawson 2008) and ImageJ software (http://rsb.info.nih.gov/ij; e.g. Fearnbach et al. 2011). Measurements of bottlenose dolphin dorsal fin heights are not available in the UK so those from New Zealand were used as an alternative, even though the species is known to be smaller in size in NZ compared to populations in the UK. Mark types were categorized using terms previously applied to bottlenose dolphins and other cetacean species (see Table A1). For those skin marks that had not been described in the literature, a new terminology was proposed.

Of the total 30 mark types identified and described based on appearance, colour, relative size and, shape, 13 used terms previously utilised for bottlenose dolphins, 15 were found in the literature when describing skin marks on other cetacean species, whilst 2 new terms were created (Table A1). All mark types were grouped in the results within the following five categories (adapted from Kautek et al. 2019): (I) cutaneous disorders (from "tattoo-skin disease" to "small white dot" in Table A1 and Figs. 2 and 3), (II) traumatic injuries/lesions (from "back indentation", to "scar" in Table A1 and Fig. 4), (III) masses (including "mass"), (IV) deformities (including "vertebral column deformation" and "amputation"), and (V) Emaciation (including "emaciation" in Table A1 and Fig. 5). The etiology of these marks was searched in the literature and validated in eleven cases (37%) and labelled as unknown or possible in the remaining nineteen (Table A1). "Lamprey bite" and sea lamprey "skidding" (Pike 1951; Bertulli et al. 2012; Miočić-Stošić et al. 2020) were marks probably attributable to lampreys (although no lampreys were observed attached) and associated with skidding marks which were only considered when the point of attachment was visible and present, along with dental parallel incisions. "Anthropogenic" scars included at least two of the following pieces of evidence: a deep cut in the caudal base of the dorsal fin trailing edge (Bertulli et al. 2012; Kügler and Orbach 2014; Herr et al. 2020), a cut on the leading edge of the dorsal fin (Kiszka et al. 2008; Kügler and Orbach 2014), non-linear severed dorsal fin (Agler et al. 1990; Kügler and Orbach 2014; Luksenburg 2014), amputation (Moore et al. 2013), fresh wounds (Bertulli et al. 2012; Dwyer et al. 2014), incisions along the ridge cranial or caudal to the dorsal fin (Visser 1999; Parsons and Jefferson 2000; Bertulli et al. 2016b; Herr et al. 2020), linear impressions (Moore et al. 2013; Robbins and Mattila 2004). "Antagonistic" scars include dental parallel incisions (faint, clearly visible or new e.g. Figure 1 in Scott et al. 2005) resembling those of killer whales with inter-dental marks measuring 25.6–35.1 mm (George et al. 1994; Ross and Wilson 1996; Barnett et al. 2009), Risso's dolphin (15.28–17.67 mm; Ross and Wilson 1996) and long-finned pilot whale (25–40 mm; Lockyer and Morris 1985). Among the newly described marks, there were "light grey rounded lesion" and rounded marks surrounded by a light grey thick halo similar to what is observed in halo nevus ("halo mark" in Table A1; Wayte and Elwig 1968).

Statistical analyses

There was considerable variation in the number of photographs available for each individual, with 153 of them being photographed only once and six photographed over 10 times. These numbers do not represent the number of times that individuals were re-sighted over the years but simply the number of images used showing the same side of the body where marks were placed and graded $Q5$–$Q6$. Amongst those photographed several times, there were also considerable differences in the interval between the first and last photographs, ranging from 1 to 2587 days. The fact that some comparisons involved repeats of the same individual whilst other individuals were recorded only once could bias results unless accounted for in analyses. To overcome issues with pseudo-replication and sampling frequencies, we first counted the presence or absence of a mark per individual a single time throughout a calendar year if photographed more than once. We further filtered the data to represent the presence or absence of a mark at any time rather than at a specific time, providing a presence or absence per individual rather than per individual and day. The total number of mark types was summed for each individual and compared between three different pairwise groups (age: calf + juvenile–adult; sex: male–female; dispersal: ranging–non-ranging) using a two-sample t test (Banda 2018). The total number of mark types between each of the three pairwise groups was compared using a t test for

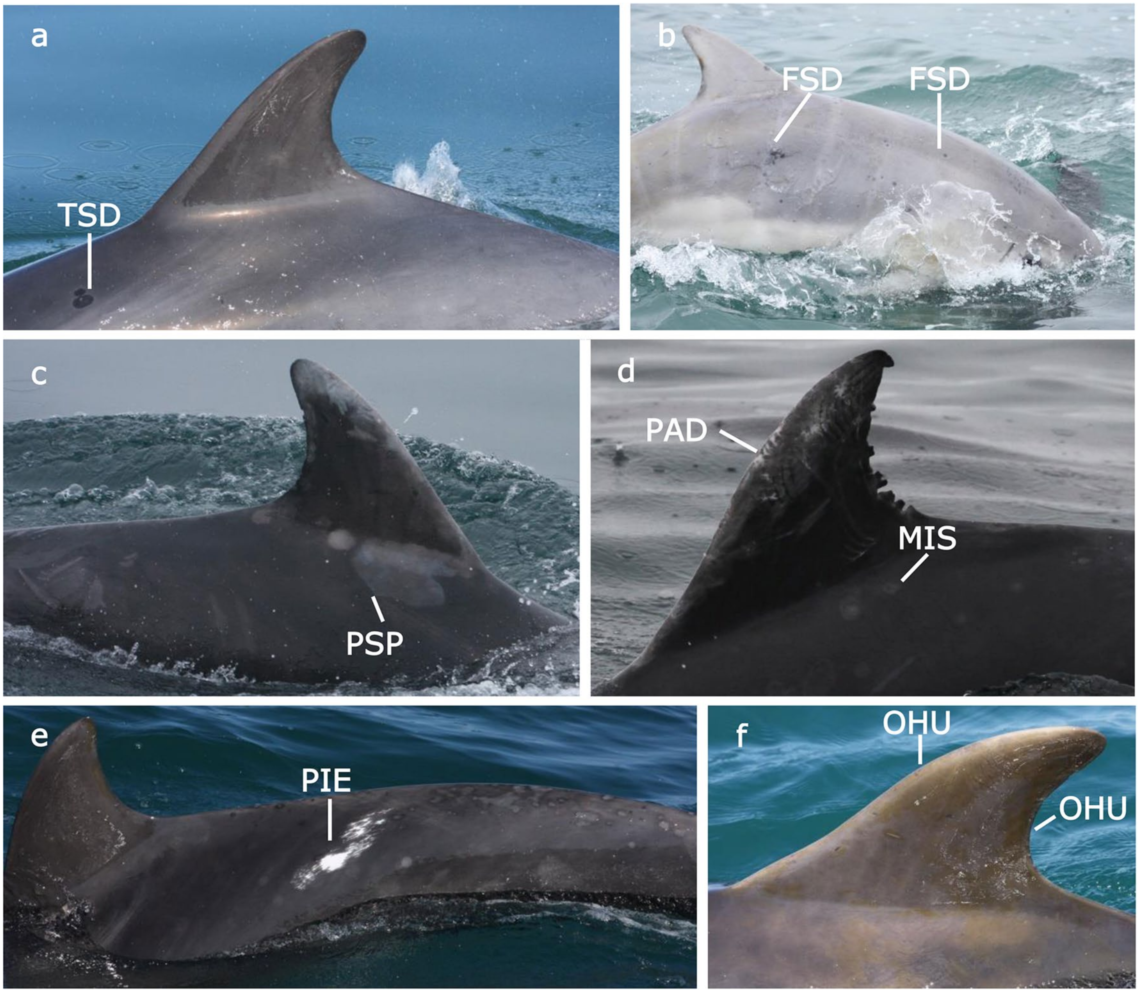

Fig. 2 Examples of cutaneous disorders in common bottlenose dolphins photographed between 2008 and 2018 in Welsh waters: **a** tattoo skin lesion (TSD), 066-10L, September 2012; **b** dark focal skin disease (dark FSD), U42, July 2013; **c** pale skin patch (PSP), 186-05S, May 2012; **d** pale dermatitis (PAD) and miscellaneous (MIS), 045-04W, August 2018; **e** piebaldism (PIE), 113-06R, July 2013; **f** orange hue (OHU), 164-90S, May 2013. Photo credits: Sea Watch Foundation

unpaired samples with unequal variances. We also compared the expected ratios of the most prevalent mark types between each of the three pairwise groups using a Chi-square test.

To compare the strength of association between the different marks and the prevalence of skin marks between years we chose to focus on those that were found most often. We restricted our sample size to include only those marks that were found in at least 20 individuals, which resulted in a total of 13 marks used for analysis (Table 1).

To determine the strength of the relationship between two mark types, an association coefficient (AC) was calculated as outlined by Maldini et al. (2010). A binary distance classifier was used to find the AC for each of the 13 mark types using the formula;

$$\mathrm{AC} = \frac{2J}{A+B}, \tag{1}$$

where J indicates the number of times both marks are present on each individual, and A and B indicate the overall frequency each mark has been identified in a population. An AC < 0.3 is considered a weak association between mark types (Maldini et al. 2010).

We used generalised additive mixed models (GAMM; Zuur et al. 2009) to analyse the detection probability of the 13 most prevalent mark types over time. The mark data are binary (presence or absence of a particular mark type) and as such we used a binomial distribution with a log link function. The GAMM model expression is of the form;

$$X_{ij} \sim B\left(\pi_{ij}, 1\right) \tag{2}$$

$$\mathrm{logit}\left(\pi_{ij}\right) = \alpha + s\left(\mathrm{Year}_{ij}\right) + \mathrm{Season}_{ij} + a_i + \varepsilon_{ij}, \tag{3}$$

Fig. 3 Examples of cutaneous disorders in common bottlenose dolphins photographed between 2008 and 2018 in Welsh waters: **a** nodule (NOD) and blister (BLI), 203-90S, May 2018; **b** dark fringe (DFR); **c** white fringe (WFR), 117-08L, July 2013; **d** halo mark (HMA) and light grey rounded mark (LGR), 117-08L, August 2012; **e** dark spot (DSP); **f** hyper-pigmented irregular patch (HIP) and miscellaneous rounded (MRO), U104 September 2012; **g** small white dot (SWD), 072-01S, September 2012. Photo credits: Sea Watch Foundation

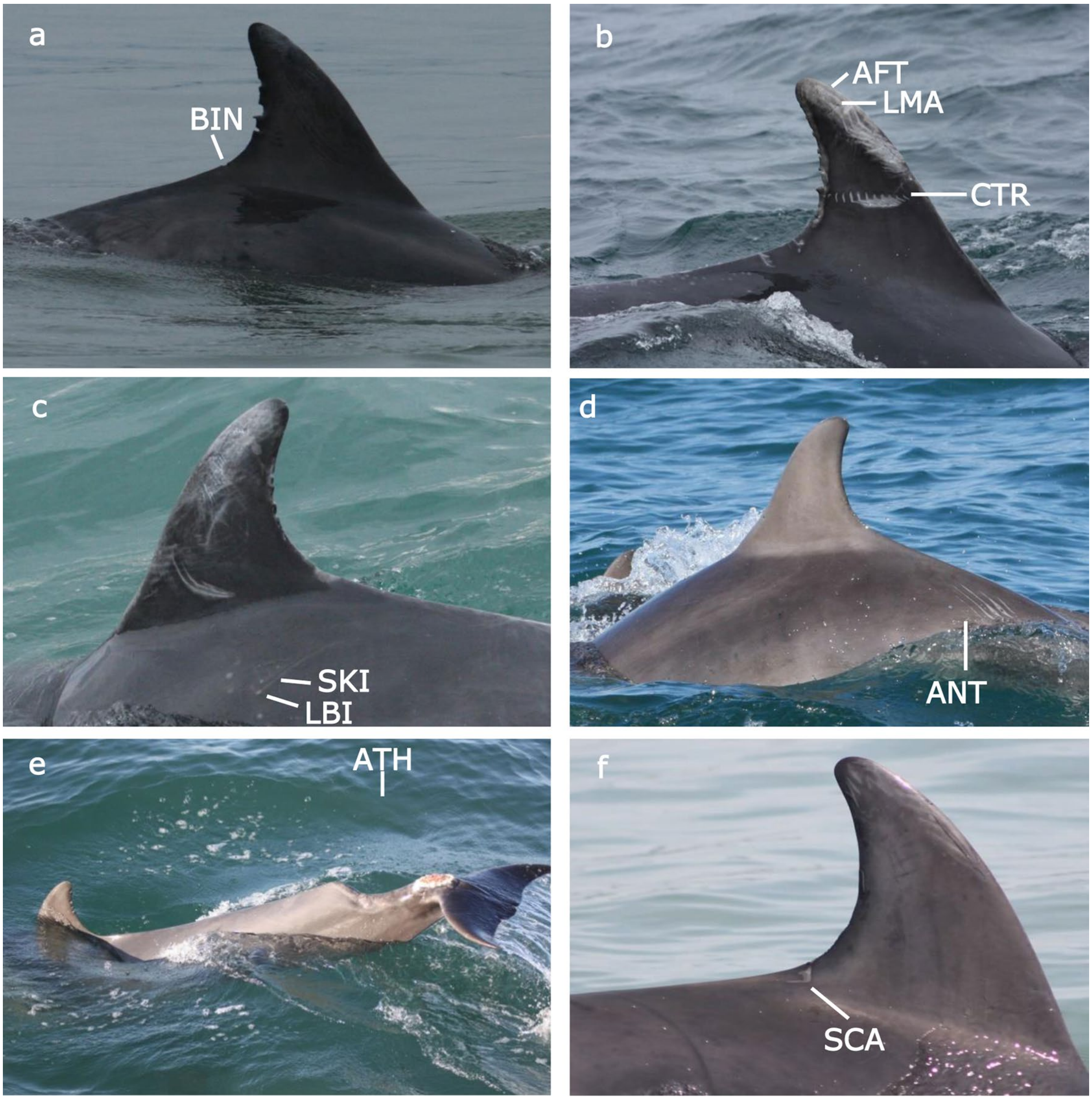

Fig. 4 Examples of traumatic injuries and lesions in common bottlenose dolphins photographed between 2007 and 2018 in Welsh waters: **a** back indentation (BIN), 158-05W, March 2012; **b** abraded fin tip (AFT), linear (LMA) and conspecific tooth-rake mark (CTR), 062-06W, August 2012; **c** lamprey bite (LBI) and associated skidding (SKI) mark, 086-06W, September 2015; **d** antagonistic (ANT), U73, June 2013; **e** anthropogenic (ATH), 035-03W, January 2012; **f** scar (SCA), U25, July 2016. Photo credits: Sea Watch Foundation

where X_{ij} is the presence/absence of a mark type in the jth observation for the dolphin i. The logit function π contains an intercept α and a smoothing function for year, $s(\text{Year}_{ij})$. The smoothing term is fitted using thin plate regression splines and the amount of smoothing is estimated using cross-validation (Wood 2006). The maximum number of splines k is set to 3 to prevent overfitting. The categorical factor Season_{ij} was also fitted and a random effect a_i was added due to the fact that each photographic record is not independent and that some dolphins were photographed multiple times throughout the duration of the study. An error term ε specifies the unexplained variance contained in any of the fixed or random effect terms.

Results

Sampling effort

A total of 651 $Q \geq 5$ digital photographs of bottlenose dolphins collected during 222 trips between 2007 and 2018 were analysed. The total effort amounted to 865 h

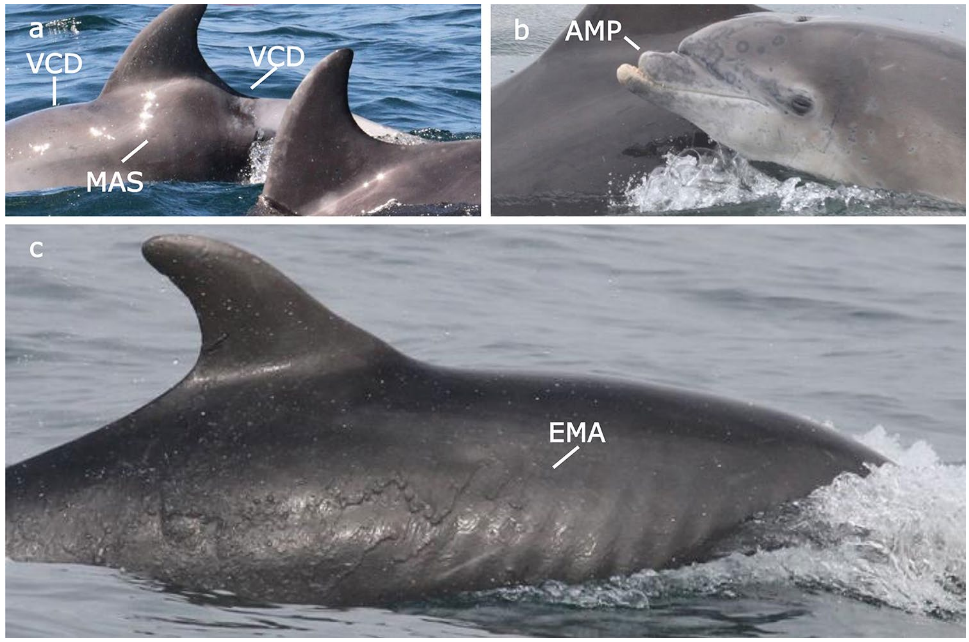

Fig. 5 Examples of deformities and masses in common bottlenose dolphins photographed between 2008 and 2016 in Welsh waters: **a** mass (MAS) and vertebral column deformity (VCD), U23, June 2013; **b** amputation (AMP), 259-15S calf, June 2018; **c** emaciation (EMA), 164-90S, September 2013. Photo credits: Sea Watch Foundation

and 11,482 km for the 11 years of surveys. Photographs were collected in the summer (June–August, 51%), spring (March–May, 24%), autumn (September–November, 24%) and winter (December–February, 1%).

Sex, age and home range

Of the 287 bottlenose dolphins photo-identified from the 651 images selected for the analysis, 45 were males, 13 females, and 212 were of uncertain sex, plus 8 possible females, and 9 possible males. There were 221 adults, 4 juveniles, 43 calves, 11 possible adults and 1 possible calf. A total of 7 individuals were photographed in more than one age class. Most images of bottlenose dolphins were taken in SCB ($n=182$), followed by NCB ($n=61$) and finally the northern Irish Sea (NIS; $n=15$; Fig. 1). There were a total of 29 "transient" individuals that were photographed in at least two areas between 2007 and 2018.

Assessment and classification of conditions

Almost all photo-identified dolphins carried skin conditions (99.3%), with individuals carrying between one to twelve different mark types. The most prevalent mark types across all categories were linear (80%, $n=231$), conspecifics tooth-rake (76%, $n=218$), dark fringe (33%, $n=95$) and abraded fin tip (21%, $n=60$; Table 1). Sixty percent ($n=18$) of cutaneous disorder marks (tattoo skin disease, focal skin disease, pale skin patch, orange hue, pale dermatitis, piebaldism, halo mark, light grey rounded, dark fringe, miscellaneous rounded, dark spot, hyperpigmented irregular patch) and traumatic injuries and lesions (abraded fin tip, anthropogenic, conspecific tooth-rake, linear, lamprey bite and skidding) were re-sighted on the same individual over time.

Cutaneous disorders

Seventeen types of cutaneous disorders were recorded in Welsh bottlenose dolphins (Table A1 and Figs. 2, 3), with the top three most prevalent conditions being dark fringe (33%, $n=95$), miscellaneous rounded (18%, $n=52$) and focal skin disease (FSD; 18%, $n=51$; Table 1). Two types of atypical body colouration were recorded: piebaldism and pale dermatitis (Fig. 2d, e). Acute ulcerated pale dermatitis was recorded two times on the leading edge of the dorsal fin of two adults (Fig. 2d). Individuals "215-08W" and "U1-R" had nodules associated with conspecific tooth-rake marks. Among the marks detected on multiple occasions within and between seasons, two medium-sized tattoo-skin lesions (TSD) lasting for 4 years (2012–2016) were carried by individual "140-12L" before showing signs of regression in 2016. Light focal skin disease (FSD) marks lasted from 1 month in dolphin "U8", and up to 5 months in dolphin "003-07R". Within the same season, the persistence of dark FSD marks varied from 9 days (dolphin "U3 069-01Scalf") to 3 months (dolphin "U15 117-08Lcalf"). Between seasons, these lesions persisted from 1 to 3 years among three dolphins ("195-07S", "212-08S", and "U66 FSD 133-03Scalf") re-sighted during the study. Pale skin patches (PSP) in two individuals were re-sighted between seasons, and lasted from 1 month (dolphin "074-03W—Bond") up to 3 years (dolphin "096-90W—Graham").

Table 1 Occurrence of each body condition found on individual common bottlenose dolphins (Tursiops truncatus) between 2007 and 2018 in Welsh waters for sex (F—female, M—male, P.F.—possible female, P.M.—possible male, unknown), maturity (A—adult, C—calf, J—juvenile, P.A.—possible adult, P.C.—possible calf) and geographical area (South Cardigan Bay—SCB, North Cardigan Bay—NCB and North Irish Sea—NIS

Mark type	F	M	P.F.	P.M.	U	A	C	J	P.A.	P.C.	SCB	NCB	NIS	Total	%
Linear (LMA)	40	14	4	6	167	184	32	5	9	1	160	58	13	231	80.5
Conspecific tooth-rake (CTR)	38	15	6	8	151	188	18	3	9	0	152	50	16	218	76.0
Dark fringe (DFR)	20	6	2	6	61	83	10	1	1	0	64	29	2	95	33.1
Abraded fin tip (AFT)	3	13	0	9	35	60	0	0	0	0	32	20	8	60	21.0
Focal skin disease (FSD)	10	1	0	0	40	30	17	2	2	0	38	12	1	51	18.1
Miscellaneous rounded (MRO)	23	2	1	1	25	48	2	1	1	0	37	12	3	52	17.7
Halo mark (HMA)	10	5	1	4	28	45	2	1	0	0	32	14	2	48	16.7
Orange hue (OHU)	14	2	0	1	26	28	13	1	1	0	31	8	4	43	15.0
Piebaldism (PIE)	17	2	1	0	16	34	0	2	0	0	26	10	0	36	12.5
Pale skin patch (PSP)	3	5	0	3	22	32	1	0	0	0	25	6	2	33	11.5
Light grey rounded lesion (LGR)	5	3	1	1	21	24	5	0	2	0	24	7	0	31	10.8
Anthropogenic (ATH)	3	4	1	4	18	27	1	1	1	0	18	9	3	30	10.5
Hyperpigmented irregular patch (HIP)	0	1	0	0	19	12	8	0	0	0	14	6	0	20	7.0
Antagonistic (ANT)	4	0	0	0	13	12	3	2	0	0	12	5	0	17	6.0
Dark spot (DSP)	4	0	0	0	13	14	0	2	1	0	14	2	1	17	6.0
Nodule (NOD)	8	3	0	0	6	17	0	0	0	0	9	6	2	17	6.0
Pale dermatitis (PAD)	1	1	0	7	8	15	1	0	1	0	11	5	1	17	6.0
Miscellaneous (MIS)	2	1	1	0	9	12	1	0	0	0	12	0	1	13	4.5
Scar (SCA)	3	1	0	1	7	11	1	0	0	0	7	4	1	12	4.2
Small white dot (SWD)	1	0	1	0	9	9	0	1	1	0	6	5	0	11	3.8
Lamprey bite (LBI)	4	3	0	0	2	9	0	0	0	0	8	1	0	9	3.1
Skidding (SKI)	5	3	1	0	0	9	0	0	0	0	8	1	0	9	3.1
White fringe (WFR)	2	0	0	0	7	6	0	2	1	0	5	3	1	9	3.1
Tattoo skin disease (TSD)	5	0	0	0	3	6	1	0	1	0	5	2	1	8	2.8
Back indentation (BIN)	0	1	0	0	4	5	0	0	0	0	3	1	1	5	1.7
Vertebral column deformation (VCD)	0	0	0	0	3	1	2	0	0	0	3	0	0	3	1.1
Blister (BLI)	2	0	0	0	0	2	0	0	0	0	1	1	0	2	0.7
Emaciation (EMA)	1	0	0	0	1	2	0	0	0	0	2	0	0	2	0.7
Mass (MAS)	0	0	0	0	2	0	2	0	0	0	2	0	0	2	0.7
Amputation (AMP)	0	0	0	0	1	0	1	0	0	0	0	1	0	1	0.4
Total number of individuals	45	13	8	9	212	221 (3)	43 (3)	4 (1)	11	1	182 (23)	61 (6)	15	287	

Also shown is the total number of individuals within each categorical group. The numbers in parentheses specify the individuals found in more than one category

A literature search resulted in no other mark similar to the "halo marks" (Fig. 3d) described here. They could be an intermediate stage of other marks which are known under another name or be something that has not been described before. Light grey rounded lesions (Fig. 3d) could be confused with healing tattoos (Blacklaws et al. 2013) but in this study, there is no evidence of "tattoo remains" in them.

Traumatic injuries/lesions

Nine types of traumatic injuries and lesions were recorded in Welsh bottlenose dolphins (Table A1 and Fig. 4), with linear (Fig. 4b) (80%, $n = 231$) conspecific tooth-rake (76%, $n = 218$), and abraded fin tip (21%, $n = 60$; Table 1) being the most prevalent mark types. Traumatic marks also include parasitic bites believed to be attributable to lampreys (Fig. 4c).

The anthropogenic injuries included deep cuts at the base and on the leading edge of the dorsal fin, a cut of the dorsal fin, amputation of part of the posterior peduncle, fresh wounds, incisions along the ridge cranial or caudal to the dorsal fin, and linear impressions (Fig. 4e). One adult female ("035-03W") had a missing part from the posterior peduncle with a deep penetrating wound exposing the blubber and skin near the intersection of the peduncle with the tail flukes, a mark of anthropogenic origin which lasted for at least 8 years.

Antagonistic scars (Fig. 4d) included tooth-rakes possibly inflicted by killer whales, Risso's dolphin and/or long-finned pilot whales. To our knowledge, it is possible that some other authors have included "scars" (Fig. 4f) in their "miscellaneous" mark categories (Auger-Méthé and Whitehead 2007; Maldini et al. 2010).

Deformities and masses

Masses and two conditions ascribed as deformities were recorded in Welsh bottlenose dolphins (Table A1 and Fig. 5). One calf showed a mild dorsal convexity caudal to the fin indicating kyphosis, and the other a marked kyphotic hump anterior to the fin, and lordosis and kyphosis caudal to the fin (Fig. 5a). A third bottlenose dolphin calf was observed with a partly missing upper beak (Fig. 5b), linear marks of unknown origin, and highly probable poxviral tattoo lesions.

Emaciation

Emaciation was recorded in June 2009 and in September 2013 each time on one single occasion (Fig. 5c). Both individuals also carried linear marks on the dorsal fin and on the flank where the rib impressions showed.

Statistical analyses

Adults had a significantly higher number of different mark types compared to calves and juveniles ($t_{75} = 3.6$, $p = 0.001$, $\mu_A = 3.9$, $\mu_{C+J} = 2.6$; Fig. 6), while males had a higher number of different mark types compared to females ($t_{64} = 2.3$, $p = 0.03$, $\mu_F = 4.4$, $\mu_M = 5.6$; Fig. 6). Considering "residents" vs. "transients", transient individuals were found to have a higher number of different mark types than resident individuals ($t_{31} = 3.3$, $p = 0.001$, "residents" = 3.6; "transients" = 5.9). There was a significant difference in the ratio of the thirteen most prevalent mark types between males and females ($\chi^2 = 21.1$, $df = 12$, $p < 0.001$; Table 2). Deviations between the two groups were due to the increase in abraded fin tip and decreases in dark fringe and FSD in males. Significant differences were also found between adults and juvenile and calves ($\chi^2 = 44.8$, $df = 12$, $p < 0.001$; Table 2). The deviations were due to a decrease in the expected mark ratios for almost all mark types in juveniles and calves, in particular the absence of abraded fin tip. In contrast, there were no significant differences in the ratio of mark types between resident and transient individuals ($\chi^2 = 5.4$, $df = 12$, $p = 0.2$; Table 2).

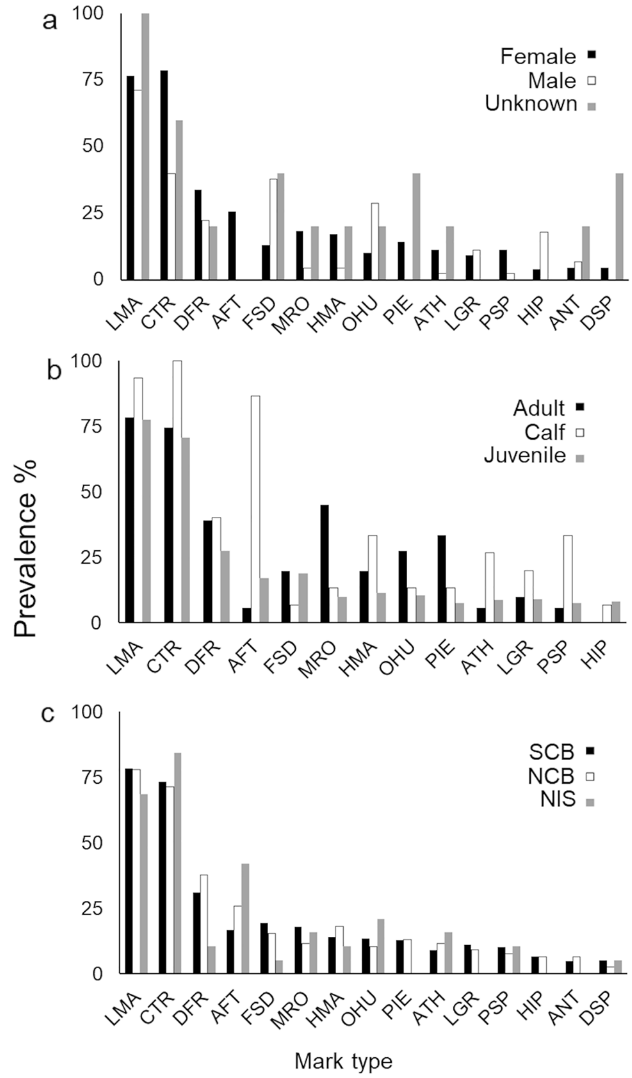

Fig. 6 The prevalence of each skin type, expressed as a percentage of the total number of dolphins reporting that skin type for **a** sex (female, male and unknown), **b** maturity (adult, calf and juvenile), and **c** geographical area (South Cardigan Bay—SCB, North Cardigan Bay—NCB and North Irish Sea—NIS)

The following eleven mark pairs showed strong associations: conspecific tooth-rake marks were associated with linear (AC = 0.8), dark fringes (AC = 0.5), and abraded fin tips (AC = 0.4). Linear marks were also associated with dark fringe (AC = 0.5), abraded fin tip (AC = 0.3) and miscellaneous rounded (AC = 0.3). Additionally, dark fringe was associated with abraded fin tips (AC = 0.3) and halo marks (AC = 0.4). Abraded fin tips were also associated with anthropogenic (AC = 0.4) and PSP (AC = 0.3). Finally, miscellaneous rounded marks were marginally associated with piebaldism (AC = 0.3).

Table 2 The frequency of the 13 most prevalent skin marks and the results of the Chi-squared test (χ^2) and associated probability *p* (significant results indicated in bold) between each pair group; sex (male and female), age (adult and calf + juvenile) and range (resident and transient). Also shown are the average total number of mark types per individual and the 95% confidence interval (95% CI) for each category

	Sex		Age		Range	
Mark type	**Female**	**Male**	**Adult**	**Calf + Juv**	**Resident**	**Transient**
Linear	40	14	184	37	206	25
Conspecific tooth-rake	38	15	188	21	189	29
Dark fringe	20	6	83	11	79	16
Abraded fin tip	3	13	60	0	50	10
Focal skin disease	10	1	30	19	46	5
Miscellaneous rounded	23	2	48	3	39	13
Halo mark	10	5	45	3	38	10
Orange hue	14	2	28	14	35	8
Piebaldism	17	2	34	2	28	8
Anthropogenic	3	4	27	1	26	7
Light grey rounded lesion	5	3	24	5	26	5
Pale skin patch	3	5	32	2	25	5
Hyperpigmented irregular patch	0	1	12	8	19	1
χ^2	**21.1**		**44.8**		5.4	
p-value	**< 0.001**		**< 0.001**		0.2	
Total number of lesions per individual	4.4	5.6	3.9	2.6	3.6	5.9
95% CI	3.7–5.1	4.9–6.3	3.6–4.2	2.2–3.2	3.4–3.8	5.6–6.2

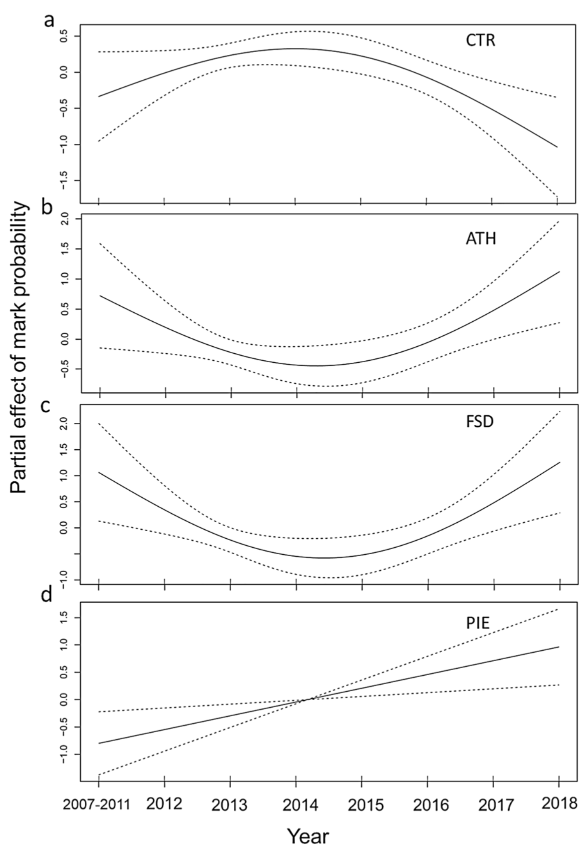

Fig. 7 The GAMM smoothing function of Year for skin mark probability for **a** conspecific tooth-rake—CTR, **b** focal skin disease—FSD, **c** anthropogenic—ATH, and **d** piebaldism—PIE. The solid line indicates the mean linear trend of detection probability and the dashed lines represent the 95% confidence intervals

The GAMM analysis showed that 4 of the 13 most prevalent marks (conspecific tooth-rake, FSD, anthropogenic and piebaldism) showed a significant change in the detection probability across the time series (Fig. 7 and Table 3). Both FSD and anthropogenic (Fig. 7b, c; Table 3) marks showed a decline in detection probability from 2007–2011 to 2014 and 2015 before increasing again in 2017 and 2018. Otherwise, there has been a steady linear increase in piebaldism since 2007–2011 (Fig. 7d and Table 3).

Discussion

The present 11-year study (2007–2018) is the first long-term study conducted in Welsh waters to identify and describe epidermal conditions of antagonistic, anthropogenic, parasitic fish and infectious origin in local bottlenose dolphins. Estimates representing minimum skin lesion prevalence proposed in this study show that, in Welsh waters, bottlenose dolphins have an overall high prevalence of visible external conditions, similarly to other dolphin populations of this species in England (100%; Wilson et al. 1999), Scotland (98.5%; Wilson et al. 1999), New Zealand (94.1–100%; Wilson et al. 1999; Rowe et al. 2010), Portugal (91.6%; Wilson et al. 1999), and USA (90%, Maldini et al. 2010; 96%, Fazioli and Mintzer 2020). Results from this study are particularly relevant to shed light on the pressures affecting bottlenose dolphins in Welsh waters and to help assess the health and conservation status of this local cetacean population.

Table 3 The parameters of the GAMM for each of the 13 most dominant mark types modeled in this study (please consult Table A1 for a description of each mark type)

	LMA	CTR	DFR	AFT	FSD	MRO	PIE	HMA	OHU	ATH	LGR	PSP	HIP
Intercept (SE)	0.5 (0.2)	0.7 (0.2)	− 1.7 (0.3)	− 1.5 (0.15)	− 2.5 (1.1)	− 2.1 (0.2)	− 2.3 (0.2)	− 2.2 (0.2)	− 2.3 (0.2)	− 2.5 (0.2)	− 2.7 (0.2)	− 2.7 (0.2)	− 3.1 (0.2)
t	2.4*	3.0***	6.4***	9.2***	2.4*	12.9***	12.9***	13.1***	13.1***	11.9***	12.9***	12.7 ***	12.5 ***
Season (autumn)													
Spring (SE)	0.6 (0.3)	0.6 (0.3)	0.7 (0.4)	–	–	–	–	–	–	–	–	–	–
t Spring	1.8*	1.9*	1.9*	–	–	–	–	–	–	–	–	–	–
Summer (SE)	0.6 (0.3)	0.2 (0.3)	1.1 (0.3)	–	–	–	–	–	–	–	–	–	–
t Summer	2.1	0.5	3.2***	–	–	–	–	–	–	–	–	–	–
Winter (SE)	− 0.7 (1.6)	− 0.9 (1.6)	− 1.7 (1.5)	–	–	–	–	–	–	–	–	–	–
t Winter	0.4	0.6	1.1	–	–	–	–	–	–	–	–	–	–
Smoother													
Year	1.8	1.9	1	1	1.9	1	1	1.6	1	1.9	1.7	1	1
F	1.4^{NS}	5.9**	2.8^{NS}	0.68^{NS}	5.1**	0.1^{NS}	7.6***	0.6^{NS}	1.2^{NS}	6.0**	0.6^{NS}	2.9^{NS}	0.15^{NS}

Shown here are the parameter estimate, standard error (SE) and the *t* value for the intercept and seasons. Also shown are the estimated degrees of freedom (edf) for the yearly smoother and associated *F* value. The significance of *t* and *F* values are indicated by NS (not significant). A dash (–) indicates parameters that were not selected in the final model

*($p<0.05$), **($p<0.01$) and ***($p<0.001$)

Cutaneous disorders

The overall prevalence of tattoo-skin marks was 2.8% which is low compared to many other dolphin studies (e.g. Van Bressem and Van Waerebeek 1996; Van Bressem et al. 2003; Maldini et al. 2010; Powell et al. 2018). The TSD lesions in bottlenose dolphins from Wales were mostly observed on adults (75%), in contrast to other studies (Van Bressem et al. 2003, 2009; Powell et al. 2018; Toms et al. 2020) where older age classes of immature were the ones showing higher prevalence (Van Bressem et al. 2003, 2009; Powell et al. 2018). Caused by poxvirus infections, tattoo lesions have been reported among cetaceans around the UK (Baker 1992; Blacklaws et al. 2013; Barnett et al. 2015) and described as possible health indicators amongst whales, dolphins and porpoises worldwide (Van Bressem et al. 2009).

FSD is a condition of unknown origin, and it is encouraging to know that its occurrence appears to have decreased over time, especially whilst the causative agent has yet to be determined. We suggest that "hypo-pigmented" lesions described in common dolphins (*Delphinus* sp.) from New Zealand (Hupman et al. 2017), "spotted" marks found in bottlenose dolphins from three sites around the NW Atlantic (Burdett Hart et al. 2012), and "small white dot" marks in long-finned pilot whales (*Globicephala melas*) from Nova Scotia, Canada (Fig. 1h in Auger-Méthé and Whitehead 2007) resemble our FSD.

PSP represents a skin condition of unknown etiology, first identified in Peale's and Chilean dolphins by Sanino et al. (2014), and then later described in bottlenose dolphins in Pensacola Bay, Florida ("white freckles"; Toms et al. 2020) and in other cetacean species (Bertulli et al. 2012; Auger-Méthé et al. 2010). PSP patches lasted between 2 days and 2 months on Peale's and Chilean dolphins in Chile (Sanino et al. 2014) and their persistence was suggested to strongly vary according to the location of the patches which are undetected depending on the angle used to photograph the patches and the available light conditions.

Present cases of acute and healed pale dermatitis are similar to those described by Van Bressem et al. (2015) and in a bottlenose dolphin off the Strait of Gibraltar (Fig. 32b in Herr et al. 2020). These marks are of unknown origin but were described as "a suspected primary infectious or super-infected skin condition" (Van Bressem et al. 2015).

Piebaldism in this study was consistent with reported cases in bottlenose dolphins (Kautek et al. 2019; Savenko 2020), common dolphins, sperm whales (Herr et al. 2020), and Atlantic spotted dolphins (Lodi and Borobia 2013) reported outside of the UK. A case of a blue whale (*Balaenoptera musculus*) off the Galician coast with a condition described as vitiligo or piebaldness (Methion and Díaz Lopez 2019) is also reminiscent of cases described in this study. The etiology of this condition is unknown but the lack of melanin in parts of the skin could be a problem with increased UV radiation in the atmosphere (Martinez-Levasseur et al. 2010; Polanowski et al. 2012). A steady increase in cases of piebaldism over the years and the reduced protective pigmentation amongst Welsh bottlenose dolphins do not seem to limit the activities of these top predators. However, problems such as reduced heat absorption and UV radiation-induced skin damage (Fertl and Rosel 2008) which can affect piebald animals should prompt regular monitoring of this condition.

The orange hue observed in this study is a diatomaceous algae thought to be the cause of the orange film observed on the skin of bottlenose dolphins from California (Bearzi et al. 2009; Maldini et al. 2010). This alga seems to be more prevalent in sea surface temperatures (SST) of 13 degrees Celsius or below (Nemoto et al. 1980). This is in accordance with existing records of SST in Wales of 11.4 degrees (Wilson et al. 1999).

Among the cutaneous disorder marks which were re-sighted over time, white and black irregular patches, similar in appearance to our "hyperpigmented irregular patch", were found to have high loss and gain rates (Gomez-Salazar et al. 2011; Bertulli et al. 2016b) making them unsuitable for long-term photo-identification studies.

Traumatic injuries/lesions

Linear marks of unknown origin were carried by 80% of the dolphins, which is similar to results from other dolphin studies (e.g. Bertulli et al. 2016b; Mariani et al. 2016; Leone et al. 2019). With a low loss rate and high severity, these marks were reliable features for mark-recapture studies shown to last at least 5 years in a recent study on white-beaked dolphins (Bertulli et al. 2016b).

Parasitic bite and skidding marks were likely caused by lamprey's teeth while moving on the skin of bottlenose dolphins. However, lampreys were not seen on any *T. truncatus* during this study. Rounded bites and associated teeth marks found on dead common dolphins and harbour porpoises (*Phocoena phocoena*) in British waters were described as possible lamprey bites although no teeth marks were visible (Baker 1992). River (*Lampetra fluviatilis*) and sea lampreys (*Petromizon marinus*) are uncommon but widespread in Welsh river estuaries with the latter also occurring in shallow inshore waters of Wales (Kay and Dipper 2009). Both species are listed as features of Cardigan Bay SAC and Pen Llyn a'r Sarnau SAC, with the Teifi Estuary being one of the most important sites for the two species in the UK (CCC 2008). The temporal stability of lamprey bite marks was found to last less than 1 year on killer whales (Samarra et al. 2012) and also to be short-lasting in bottlenose dolphins (Miočić-Stošić et al. 2020).

To our knowledge, this study is the first one providing evidence of Welsh bottlenose dolphins with antagonistic scars in the form of inter-dental rakes with spacing similar to that of killer whales, Risso's dolphins and long-finned pilot whale (Lockyer and Morris 1985; George et al. 1994; Ross and Wilson 1996; Barnett et al. 2009). The Sea Watch Sightings Database contains records in Welsh waters (Sea Watch Foundation, unpublished data) of 14 sightings of killer whales, one of long-finned pilot whale, and > 500 of Risso's dolphins collected between 2000–2021. Antagonistic interactions between bottlenose dolphins, Risso's dolphins and pilot whales have been recorded in two stranded specimens from the southwest of England (Barnett et al. 2009). Bottlenose dolphins have been reported displaying aggressive behaviours towards other odontocetes in UK waters, in some cases, killing them (notably harbour porpoise; Ross and Wilson 1996; Feingold and Evans 2014) but also other dolphin species (summarised in Barnett et al. 2009). Five of the seventeen individuals with antagonistic scars were immatures (3 calves, 2 juveniles) which supports the hypothesis suggested by Patterson et al. (1998) that some attacks may be targeting individuals of similar length to calves as practised occasionally in bottlenose dolphin infanticide attacks. On the other hand, bottlenose dolphins have been directly observed attacking adult porpoises and other explanations for the attacks are interactions over shared prey species or protective behaviour towards young and sick or injured group members (Ross and Wilson 1996; Feingold and Evans 2014; Boys 2015).

Lesions of anthropogenic origin included nicks or notches on the leading and trailing edge or a deep cut at the base of the dorsal fin, fresh wounds, back indentations and incisions on the ridge cranial to the dorsal fin, and linear marks indicating rope, chain or fishing gear entanglement marks. The prevalence of these marks was relatively high (10%) with a significant peak between 2007–2011 then declining but increasing again in the most recent years. The initial decline of marks of anthropogenic origin indicates that local regulations minimising the disturbance of boat traffic on bottlenose dolphins may have been successful. However, the increase in recreational activities in recent years indicates that renewed testing of existing guidelines used by local boaters may be necessary to minimise disturbance to bottlenose dolphins in the southern part of Cardigan Bay where 64% of cases occurred. A decline in the abundance of bottlenose dolphins in Cardigan Bay has been recorded since 2009, possibly linked to a disturbance from the increasing number of recreational craft in the region (Lohrengel et al. 2017; Vergara-Peña 2020). Bottlenose dolphins are known to be vulnerable to injuries particularly during the calving season which coincides with high boat traffic involving speed craft from July through September (Pesante et al. 2008; Pierpoint et al. 2009; Feingold and Evans 2014; Vergara-Peña 2020). Harbour porpoises have also been seen in Cardigan Bay with injury marks caused by boat propellers, (Kirkwood et al. 1997).

Deformities and masses

Masses were observed in bottlenose, Atlantic spotted and rough-toothed dolphins from La Gomera, Canary Islands (Kautek et al. 2019). "Humps", "swelling" and "lumps" have been used to describe consistent marks to masses described in this study in bottlenose dolphins from the Strait of Gibraltar (Herr et al. 2020) and Scotland (Wilson et al. 1997), respectively. The origin of these marks remains unclear since it cannot at present be ascertained from photographs.

Cases of vertebral column deformities and associated masses in bottlenose dolphins (calves, juveniles, adults) in the UK waters have been reported in the Moray Firth (Thompson and Hammond 1992; Wilson et al. 1997; Haskins and Robinson 2007; Robinson 2013), and causes included either congenital or trauma-induced (summarized in Robinson 2013). Long-term photographic studies combined with post-mortem examinations will shed light on the causes of these marks and the longevity of bottlenose dolphins carrying them in the wild.

It was unknown whether the recorded case of a shortened upper part of the rostrum in a calf was congenital (Van Bressem et al. 2007) or from an injury (Moore et al. 2013) but without further photographic material and pre- and post-information on the individual life history, it is not possible to be sure about its origin.

Emaciation

The cause of the emaciation recorded in 2009 and 2013 is unknown but overall prey availability in Cardigan Bay is thought to be highest between April and August and lower outside of these months (Feingold and Evans 2014). This serious condition that can lead to death among dolphins (McFee and Lipscomb 2009; Schick et al. 2020) might also indicate a lack of food or general food shortage as described in bottlenose dolphins from La Gomera, Spain (Kautek et al. 2019) and orcas from Vancouver, Canada (Wasser et al. 2017). Further investigation into stranding cases could provide a better picture accompanied by information on fish abundance, diversity and availability, water quality and productivity, and fishing pressure within the present study area which might also help explain the occurrence of malnourished dolphins.

Association coefficients

The association between tooth-rakes, abraded fin tips and dark fringes in conspecifics could be explained by the fact that the continuous tooth-rakes by adults create white areas on the dorsal fin (Wilson et al. 1997). The scratched area could also be a gateway for infections some of which may debilitate the dolphin's immune system favouring the spread of viruses like those causing dark fringe marks. Considering the association between anthropogenic and PSP marks, we cannot exclude that human-related activities could have caused these marks as hypothesised by Sanino et al. (2014) who linked salmon farming activities and the release of chemicals in the water to the occurrence of skin lesions like PSP. Miscellaneous rounded, halo and linear marks are all of unknown origin so it is difficult to discuss further their association with other marks (e.g. Maldini et al. 2010).

Potential biases and limitations

There is a large body of evidence documenting the use of visual assessments to study the occurrence of epidermal conditions (e.g. Wilson et al. 1997; Van Bressem et al. 2003; Hupman et al. 2017), injuries and anomalous body pigmentation in cetacean species (*e.g.* Gomez-Salazar et al. 2011; Van Bressem et al. 2015; Kautek et al. 2019). However, these visually assessed marks carry limitations which need to be taken into account. In this study, a bias in the analysis of skin lesion prevalence was introduced by the lower coverage of both opportunistic and dedicated boat surveys in Pen Llŷn a'r Sarnau SAC and waters further north compared with Cardigan Bay SAC. This applies particularly considering that the ranges of individual bottlenose dolphins extend beyond Cardigan Bay to include much of the Irish Sea (Feingold and Evans 2012, 2014; Lohrengel et al. 2017). Therefore, skin lesion prevalence and the influence of age, sex, and distribution patterns as well as temporal and spatial patterns of skin lesions may be biased depending upon the overall extent of movements of those individuals that have been photo-identified. There is also uneven seasonal coverage with most effort within Cardigan Bay occurring in summer whereas in North Wales sightings are mainly between October and April when part of the Cardigan Bay population moves out into the wider Irish Sea (Feingold and Evans 2012, 2014; Lohrengel et al. 2017).

Other sources of bias which may affect the results obtained are linked to reduced sample sizes when images graded as $< Q5$ were excluded from the analyses. In this study, the majority of individuals were of unknown or uncertain age and gender and so had to be excluded from particular analyses thus limiting our ability to fully examine the effect of these two parameters on the occurrence and stability of cutaneous disorders in Welsh bottlenose dolphins. Individual animals may also differ by age or gender in the probability of being photographed well if they show more responsive movement than others. During photo-ID surveys, we attempt to correct for this potential bias and photograph the entire group, but this may not always be successful. Similarly, since photo-ID tends to target dorsal fins for individual recognition, other parts of the body may not be so well represented which could bias the assessment of skin lesion prevalence, with body parts such as flippers, tails and belly areas being less often photographed.

We suggest combining the use of photographic assessments conducted in the UK such as this study (see also Magileviciute 2006; Aktritopoulou 2014) and the study of the other major coastal bottlenose dolphin population in East Scotland (Thompson and Hammond 1992; Wilson et al 1997), with local long-term stranding data (Coombs Ellen et al. 2019) and previous studies on the epidemiology and toxicology of skin conditions (Baker 1992; Kirkwood et al. 1997; Law et al. 1995, 2012; Wilson et al. 1999) for a definitive etiological diagnosis.

Conclusions

Deformities, injuries and epidermal conditions among bottlenose dolphins occurring in Welsh waters affect the majority of individuals, represented by marks of antagonistic, anthropogenic, infectious and parasitic origin. The prevalence of marks varied among individuals, sex and age classes, and the results show that transients have a higher number of different mark types than residents. More than half of the skin marks described in this study were re-sighted over time, but further investigation into their gain and loss rates is needed to identify those marks that are most stable for use in population estimates. We recommend using photos of live or recently dead-stranded bottlenose dolphins of known age and gender in Welsh waters and elsewhere in the Irish Sea, to support findings from field studies, and where feasible, to investigate the etiology of some of the observed skin conditions. For conservation and management of bottlenose dolphins in Wales, attention should be given to monitoring the dynamics including any sudden changes in the prevalence of relevant cases (emaciation, anthropogenic trauma, viral marks, piebaldism) and any unexpected appearance of previously unreported types of lesions (e.g. antagonistic). Analysis of water quality and environmental variables (e.g. sea surface temperature, salinity and ultraviolet radiation) should be related to the prevalence and severity of bottlenose dolphin skin marks to determine factors triggering and favouring the spread of cutaneous conditions of animals in this region.

Appendix

See Table A1.

Table A1 Skin mark types found in Welsh common bottlenose dolphins

Category	Mark type	Description	Colour	Body location	Estimated size	Etiologic agent	N_T	References	Species
Cutaneous disorders	Tattoo-skin lesion (TSD)	"Irregular, stippled skin lesions" (Van Bressem et al. 2009)	Dark grey, grey	Back, flank, peduncle	Vary	Poxvirus	8	Geraci et al. (1979), Van Bressem and Van Waerebeek (1996), Van Bressem et al. (2009), Bertulli et al. (2012), Sanino et al. (2014)	Worldwide distribution including CBD
	Focal skin disease (FSD)	"Numerous small or medium-sized round or oval skin lesions that may present "pinholes" in their core and may fuse, occurring on all parts of the visible body" (Sanino et al. 2014)	Light or dark grey	Back, dorsal fin, flank, peduncle	≤1 cm	Unknown	51	Sanino et al. (2014), Hupman et al. (2017), Kautek et al. (2019)	ASD, CBD, CDO, CHD, PDO, PIW
	Pale skin patch (PSP)	"Areas of opaque to translucent skin, variable shapes and rounded, distinctive borders" (Sanino et al. 2014)	Opaque grey	At the base, on and in upper back near the fin	Vary	Unknown	33	Sanino et al. (2014), Bertulli et al. (2016a), Kautek et al. (2019)	CHD, PDO, WBD
	Pale dermatitis (PAD)	"Irregular, slightly raised skin sores, either ulcerated or with a smooth velvety aspect". Dermis visible in "acute" cases with elevated broken skin patches; scars visible once skin healed" (Van Bressem et al. 2015)	Light grey, off-white	Dorsal fin	Vary	"Suspected primary infectious or super-infected skin condition" (Van Bressem et al. 2015)	17	Wilson et al. (1997), Van Bressem et al. (2015), Herr et al. (2020)	CBD, FKW, GDO, PIW
	Miscellaneous (MIS)	Marks not included in any of the cutaneous disorder categories	Vary in colour	Back, flank, dorsal fin, peduncle	Vary	Unknown	13	Auger-Méthé and Whitehead (2007), Auger-Méthé et al. (2010), Bertulli et al. (2018b)	MIW, NAR, PIW, WBD
	Piebaldism (PIE)	"Irregular white flecks of blotches superposed on the normal pattern" (Van Waerebeek 1993)	White, off-white	Dorsal fin, peduncle	Vary	Genetic mutation	36	Van Waerebeek (1993), Fertl and Rosel (2008), Lodi and Borobia, (2013), Herr et al. (2020), Savenko (2020)	ASD, AFS, CBD, CDO, DDO, SPW
	Orange hue (OHU)	"Orange or rusty-coloured films over the skin either uniformly covering the body or found in dense but small patches on dorsal fin and/or body" (Maldini et al. 2010)	Orange, rust	Back, dorsal fin, base dorsal fin, flank	Vary	Diatomaceous algae	43	Bearzi et al. (2009), Sears et al. (1990), Wilson et al. (1997), Feinholz and Atkinson (2000), Maldini et al. (2010), Durban and Pitman (2011), Burdett Hart et al. (2012), Jefferson et al. (2015), Bertulli et al. (2016a), Hupman et al. (2017), Toms et al. (2020)	BWH, CBD, CBW, DAP, KIW, WBD

Table A1 (continued)

Category	Mark type	Description	Colour	Body location	Estimated size	Etiologic agent	N_T	References	Species
	Nodule (NOD)	"Skin elevations are single or numerous" (Bertulli et al. 2012)	Skin, light grey	Back, dorsal fin	Punctiform or 1–2 cm	Unknown	17	Bertulli et al. (2012), Van Bressem et al. (2012, 2014)	MIW, CBD, IDO, IBD, WBD
	Blister (BLI)	"Blister-like vesicles, some craterous" (Hamilton and Marx 2005)	Skin	Back, peduncle	≤1 cm	Unknown	2	Hamilton and Marx (2005), Martinez-Levasseur et al. (2010), Barlow et al. (2019)	BWH, MIW, FIW, NRW, SPW
	Dark fringe (DFR)	"Pale areas of skin surrounded by a dark halo and were most often circular" (Wilson et al. 1997)	Light grey core, dark grey contour	Dorsal fin, flank, peduncle	≤2 cm (width)	Poxvirus	95	Wilson et al. (1997), Burdett Hart et al. (2012), Hupman et al. (2017), Herr et al. (2020), Taylor et al. (2020)	CBD, CDO
	White fringe (WFR)	"Halos surrounding small circles of normal-coloured or black skin" (Wilson et al. 1997)	Dark grey core, light grey contour	Flank	≤1 cm	Poxvirus	9	Wilson et al. (1997), Mariani et al. (2016), Hupman et al. (2017)	CBD, CDO, RDO
	Halo mark (HMA)	Rounded mark with thick halo around it and encircled by a circular thin contour	Light grey core, skin-coloured halo, dark contour	Dorsal fin, flank, peduncle	≤3 cm	Unknown	48	This paper	CBD
	Light grey rounded lesion (LGR)	Multiple rounded marks	Light grey	Back, peduncle	Vary	Unknown	31	This paper	CBD
	Dark spot (DSP)	Singular circular mark	Dark grey	Dorsal fin, back, flank, peduncle	< 1 cm	Unknown	17	Wilson et al. (1997), Toms et al. (2020)	CBD
	Hyperpigmented irregular patch (HIP)	"Hyper-pigmented, large, clumped lesions" (Hupman et al. 2017)	Dark grey	Dorsal fin, back, flank, peduncle	Vary	Unknown	20	Gomez-Salazar et al. (2011), Hupman et al. (2017); Toms et al. (2020)	CBD, CDO, PRD
	Miscellaneous rounded (MRO)	"Rounded mark of miscellaneous origin" (Maldini et al. 2010)	Light grey	Dorsal fin, flank, peduncle	≤3 cm	Unknown	52	Maldini et al. (2010), Gomez-Salazar et al. (2011), Mariani et al. (2016)	CBD, PRD, RDO
	Small white dot (SWD)	Singular circular mark	Off white	Back, dorsal fin, flank	< 1 cm	Unknown	11	Gowans and Whitehead (2001), Auger-Méthé and Whitehead (2007), Gomez-Salazar et al. (2011), Mariani et al. (2016)	NBW, PRD, PW, RDO
Traumatic injuries/ lesions	Back indentation (BIN)	"Semicircular indentation" (Bertulli et al. 2016b)	Skin	Caudal to the dorsal fin along the ridge	≤2 cm (width)	Unknown	5	Agler et al. (1990), Gowans and Whitehead (2001), Rosso et al. (2011), Bertulli et al. (2016b)	CBW, MIW, FIW, NBW, WBD

Table A1 (continued)

Category	Mark type	Description	Colour	Body location	Estimated size	Etiologic agent	N_T	References	Species
	Abraded fin tip (AFT)	"White areas composed of a mass of criss-crossed scratch marks and tooth-rakes" (Wilson et al. 1997)	Off white	Dorsal fin	Vary	Tooth-rakes	60	Wilson et al. (1997), Bearzi et al. (2009), Herr et al. (2020)	CBD
	Linear (LMA)	Single or pair of parallel linear marks	Light, dark grey	Dorsal fin, flank, back, peduncle	Vary	Unknown	231	Agler et al. (1990), Gowans and Whitehead (2001), Rosso et al. (2011), Bertulli et al. (2012)	FIW, MIW, NBW, WBD
	Conspecific tooth-rake (CTR)	Three or more parallel linear marks produced by conspecifics	Skin, dark grey	Dorsal fin, flank, peduncle	10.97–- 12.32 mm	*Tursiops truncatus*	218	Scott et al. (2005), Ross and Wilson (1996), Lee et al. (2019)	CBD
	Lamprey bite (LBI)	"Circular area in which the epidermis is completely abraded by the teeth of the sucking disc. There is a hole in the centre caused by the rasping tongue" (Pike 1951)	Grey, light grey	Back, dorsal fin, flank, peduncle	≤3 cm	*Petromyzon marinus*	9	Pike (1951), Agler et al. (1990), Bertulli et al. (2012), Miočić-Stošić et al. (2020)	CBD, KIW, FIW, MIW
	Skidding (SKI)	"A long streak of parallel lines in the epidermis, terminating at one end or both in the oval-shaped scar" (Pike 1951)	Light grey	Back, dorsal fin, flank, peduncle	<3 m long	*Petromyzon marinus*	9	Pike (1951), Bertulli et al. (2012), Miočić-Stošić et al. (2020)	CBD, KIW, MIW
	Antagonistic (ANT)	Marks of antagonistic origin e.g. orca, Risso's and pilot whale tooth-rakes	Light, dark grey	Back, dorsal fin, peduncle	KW: 25.6–35.1 mm; RD: 15.28–17.67 mm; PW: 25–40 mm	Predators and other cetacean species	17	Lockyer and Morris (1985), George et al. (1994), Ross and Wilson (1996), Gowans and Whitehead (2001), Barnett et al. (2009), Rosso et al. (2011), Bertulli et al. (2012), Bertulli et al. (2016b)	CBD, CBW, MW, NBW, WBD
	Anthropogenic (ATH)	Marks of anthropogenic origin e.g. rope, propeller scars	Light, dark grey	Back, flank, peduncle, dorsal fin	Vary	Human-caused	30	Agler et al. (1990), Visser (1999), Parsons and Jefferson (2000), Robbins and Mattila (2004), Kiszka et al. (2008), Bertulli et al. (2012), Moore et al. (2013), Dwyer et al. (2014), Kügler and Orbach (2014), Luksenburg (2014), Bertulli et al. (2016b), Herr et al. (2020)	ASD, CBD, FKW FIW, HUW, IHD, IBD, KIW, MIW, WBD
	Scar (SCA)	"Unidentified scar" (Hupman et al. 2017)	Grey, dark grey	Back, dorsal fin	Vary	Unknown	12	Hupman et al. (2017)	CDO
Masses	Mass (MAS)	"Abnormal tissue growths" (Kautek et al. 2019)	Skin	Base of dorsal fin	As wide as the dorsal fin	Congenital or trauma-induced	2	Seol et al. (2006), Eldin Eissa and Abu-Seida (2015), Kautek et al. (2019)	ASD, CBD, RTD, ASD

Table A1 (continued)

Category	Mark type	Description	Colour	Body location	Estimated size	Etiologic agent	N_T	References	Species
Deformities	Vertebral column deformation (VCD)	Malformation of the vertebral column e.g. kyphosis, lordosis or scoliosis	Skin	Back	Vary	Congenital or trauma-induced	3	Wilson et al. (1997), Berghan and Visser (2000), Van Bressem et al. (2006), DeLynn et al. (2011), Weir and Wang (2016), Herr et al. 2020	AHD, CBD, CDO, KIW, IHD, WBD
	Amputation (AMP)	Missing portions of a body part e.g. upper beak	Skin	Beak	Vary	Congenital or trauma-induced	1	Wells et al. (2004), Bertulli et al. (2016a, b), Van Waerebeek et al. (2017), Moore et al. (2013), Luksenburg. (2014)	ASD, CBD, FKW, HPO, HUW, MIW, WBD
Emaciation	Emaciation (EMA)	"Loss of body mass with visible ribs" (Kautek et al. 2019)	Skin	Flank	Vary	Unknown	2	Ridgway and Fenner (1982), Joblon et al. (2014), Kautek et al. (2019)	CBD, CDO, PIW

AHD = Atlantic humpback dolphin; ASD = Atlantic spotted dolphin; AFS = Atlantic fur seal; BWH = blue whale; CBD = common bottlenose dolphin; CDO = common dolphin; CHD = Chilean dolphin; DDO = dusky dolphin; DAP = Dall's porpoise; GDO = Guiana dolphin; FKW = False killer whale; FIW = fin whale; KIW = killer whale; IBD = Indo-Pacific bottlenose dolphin; IHD = Indo-Pacific humpback dolphin; HPO = harbour porpoise; HUW = humpback whale; MIW = minke whale; NAR = narwhal; NRW = Northern right whale; IDO = Irrawaddy dolphin; PDO = Peale's dolphin; PRD = Pink River dolphin; PIW = pilot whales; RDO = Risso's dolphin; SPW = sperm whale; WBD = white-beaked dolphin. Etiologic agent reports if that skin condition has been "validated" or "suspected" in the literature. N_T shows the total number of common bottlenose dolphins in this study carrying that mark type

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s42991-022-00300-z.

Acknowledgements We thank all the Sea Watch Foundation interns and volunteers, and previous staff, who assisted in the collection of sightings and photo-ID data, and to Natural Resources Wales (previously Countryside Council for Wales) for funding many of the surveys since 2001. Thanks go also to New Quay Dolphin Spotting Boat trips for providing space on their vessels as platforms to collect data; and to Megan Pew for helping with the earlier drafts of the introduction. Immense gratitude goes to Marie-Francoise Van Bressem and Koen Van Waerebeek for helping in the evaluation of lesions with their veterinary and epidemiological expertise. Thanks go to Jacopo di Clemente, Dagmar Fertl, and David J. Janiger for making several papers available. We also greatly thank Marie-Francoise Van Bressem, the editors Stephen Chan and Leszek Karczmarski, and an anonymous reviewer for their constructive comments, many suggestions, and helpful advice.

Author contributions Conceived and designed the experiments: AS, CGB, EA, DM, PE. Performed the experiments: AS, CGB, NMcG. Analyzed the data: AS, CGB, NMcG. Contributed reagents/materials/analysis tools: DM, KL. Wrote the paper: AS, CBG, EA, NMcG, PE.

Declarations

Conflict of interest On behalf of all the authors, the corresponding author states that there is no conflict of interest.

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