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The incidence of bent dorsal fins in free-ranging cetaceans

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Abstract

Laterally bent dorsal fins are rarely observed in free-ranging populations of cetaceans, contrary to captivity, where most killer whale *Orcinus orca* adult males have laterally collapsed fins. This topic has been poorly explored, and data/information on its occurrence and possible causes are limited. The present study: (i) undertakes a review of the available information on bent dorsal fins in free-ranging cetaceans, and updates it with new records, (ii) reports on the proportion of bent fins in different study populations, and (iii) discusses possible causes. An empirical approach based on bibliographic research and compilation of 52 new records collected worldwide resulted in a total of 17 species of cetaceans displaying bent dorsal fins. The species with the highest number of records (64%) and from most locations was *O. orca*. On average, individuals with bent dorsal fins represent < 1% of their populations, with the exception of false killer whales *Pseudorca crassidens* and *O. orca*. While line injuries associated with fisheries interactions may be the main cause for *P. crassidens*, and the vulnerability to health issues caused by the evolutionary enlargement of the fin may be the cause for *O. orca* adult males, factors contributing to this abnormality for other species are still unclear. The occurrence of bent dorsals could be influenced by a set of variables rather than by a single factor but, irrespective of the cause, it is suggested that it does not directly affect the animals' survivorship. While still rare in nature, this incident is more common (at least 101 known cases) and widespread (geographically and in species diversity) than hypothesized, and is not confined only to animals in captive environments. Investigation into the occurrence of bent fins may be an interesting avenue of research.

Key words: anatomy; Cetacea; deformity; disfigurement; welfare.

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Introduction

The majority of species from the two most abundant vertebrate taxa inhabiting estuarine and marine systems, that is, fishes and cetaceans (whales, dolphins, and porpoises), have a dorsal fin. This fin is known to play an important role in the hydrodynamics of these animals (Fish, 1998; Lingham-Soliar, 2005) and in the case of cetaceans also has a thermoregulatory function (Rommel et al. 1993). By providing stability while swimming and allowing individuals to dissipate excess heat, this anatomical structure may contribute to increased success when hunting prey, escaping predators or controlling body temperature. In sexually dimorphic species such as the killer whale *Orcinus orca*, the large fin of adult males may be a secondary sexual characteristic shaped by sexual selection, for example, a way for females to assess the fitness of a male (Baird, 2002). Yet, to function optimally during swimming, a dorsal fin should be vertically straight, as it is in most healthy cetaceans in the wild (Kastelein et al. 2016).

Bending or collapsed dorsal fins are comparatively more common in cetaceans in captivity and particularly in *O. orca*, where most adult males and some females have collapsed dorsal fins (Parsons et al. 2012). Frequent fin bending in captivity could be the result of gravity acting on fins composed mainly of fibrous connective tissue, insufficient movement that affects the tissue structure, or breakdown of cartilage due to long exposure to warm air (Hoyt, 1992; Parsons et al. 2012). Conversely, bending dorsal fins are rarely observed in the wild. To our knowledge, apart from *O. orca*, for which several records exist (e.g. Visser, 1998; Bigg et al. 1987; Baird & Stacey, 1989; Matkin et al. 2008; Towers et al. 2012, 2015), bending dorsal fins in free-ranging cetaceans have been only documented anecdotally in four other species: the common bottlenose dolphin *Tursiops truncatus* (Wilson et al. 1997; Baird & Gorgone, 2005), the false killer whale *Pseudorca crassidens* (Baird & Gorgone, 2005), the white-beaked dolphin *Lagenorhynchus albirostris* (Higdon & Snow, 2008), and the dusky dolphin *Lagenorhynchus obscurus* (Kügler & Orbach, 2014).

The bending and collapse of the dorsal fin in free-ranging cetaceans was suggested to result from reduced nutrient intake and blubber thickness due to physical injury or illness, or from other causes directly linked to trauma, illness or malformation. Examples include longline entanglement for *P. crassidens* in Hawaii (Baird & Gorgone, 2005), a gunshot wound for *L. albirostris* in Newfoundland (Higdon & Snow, 2008), exposure to an oil spill for *O. orca* in Alaska (Matkin et al. 1999, 2008) and entanglement for *O. orca* in New Zealand (Visser, 1998). Pathology, trauma and malformation of the vertebral column (e.g. scoliosis) could also cause a dorsal fin to bend (Berghan & Visser, 2000). Nevertheless, even with increasing field research conducted on free-ranging cetaceans worldwide during the past 40 years and the ability to share scientific information (i.e. images), bending dorsal fins have rarely been reported. Furthermore, available data on proportions of such major dorsal fin abnormality within populations of cetaceans are scarce, and information on possible causes remains poorly reported.

The present study: (i) undertakes a review of the available information on bent dorsal fins in free-ranging cetaceans based on literature, and updates it with new records from around the world, (ii) reports on the proportion of bent fins in different study populations, and (iii) discusses the hypotheses that could explain these deformities and highlights the importance for future research on this topic.

Materials and methods

To review information on bent dorsal fins, data were compiled from a variety of sources including peer-reviewed and 'grey' literature (conference proceedings, book reviews, technical reports), as well as published (i.e. publically available and citable) photo-identification catalogues, and unpublished documents and theses. In addition, new records collected globally were added, including unpublished photographs and biological data collected by the co-authors during field studies. Specialists with relevant unpublished information were invited to join the present study. Additional data were obtained by posting a request on a global e-mail discussion list for marine mammals (MARMAM) on 6 July 2016.

For any record to be validated (including those based on personal communications), it had to include a good quality photograph of any bent fin, as well as date and location. Information on the individual animal included, whenever possible, data on its sex, age class (adult, subadult or juvenile), apparent health condition (good/normal or poor/ill), occurrence of physical injuries, and apparent spinal malformation. It was possible to determine sex in several ways: individuals regularly (i.e. over multiple encounters) accompanied by small calves were considered females; adult individuals from sexually dimorphic species could often be recognized as males (e.g. *O. orca*); based on photographs of the genital area; or based on genetic analyses of biopsy samples (e.g. for *P. crassidens* from Hawaii, see Martien et al. 2014). The age class was based on the comparison of the relative size of individuals using photographs featuring multiple individuals as well as on field observations. This study considered juveniles as individuals that were less than two-thirds the length of the adult individual that it was in close association with and had a lighter colour (in most species), and subadults as individuals smaller and less scarred than adults. These classes were attributed when first seen for individuals identified repeatedly. Neonates were excluded from the analysis as many do not have a naturally straight dorsal fin (Mead & Potter, 1990). Health condition was arbitrarily assessed by comparing the behaviour of each animal with that of the rest of the group. This was determined independently by each research party based on observational data. Additionally, the visual body condition of each animal, based on observational data and on photographs, was also used to support a poor health condition (e.g. emaciation). Physical injuries were defined as marks predominantly caused by fishing gear (lines or nets) or boat propellers (based on the presence of major linear dorsal fin mutilations), but also by intra- or inter-specific interactions (presence of non-linear body disfigurements) (Baird & Gorgone, 2005; Kiszka et al. 2008; Baird et al. 2015). Apparent

vertebral column malformations included anomalies in the vertebra structure such as lateral curvature (scoliosis), or increased convexity or anterior concavity in the curvature (kyphosis or lordosis, respectively) of the vertebral column, as reviewed in Berghan & Visser (2000).

Bent dorsal fins were defined as fins showing a curvilinear shape over any of the lateral sides and included several degrees of bending. All animals reviewed here were categorized according to three levels of intensity of bending, based on the insertion (breakdown point) between the fin tip and sagittal plane, as well as on the approximate angle, irrespective of the side. Categories included: (i) slightly bent – where only the top (last one-third of the fin) was bent or the fin was bent at no more than approximately 30° (Fig. 1A), (ii) moderately bent – where no more than two-thirds of the fin was bent or a portion of the fin was bent between approximately 30° and 60° (Fig. 1B), and (iii) severely bent – from two-thirds to the entire fin (i.e. collapsed at the base) was bent or a portion of the fin was bent more than 60°(Fig. 1C). In the present study, irregularly shaped and/or injured dorsal fins that were straight were not considered bent fins.

To examine the proportion of bent dorsal fins, data from study populations were collated. These included data from populations where animals featuring bent fins were observed, but also from other well-studied populations without bent fins. Only populations studied intensively over $\geq$ 4 years were included to minimize bias. Marked individuals included only distinctive adults and subadults, that is, those identified based on unique marks on the dorsal fin (e.g. nicks or notches, see Auger-Méthé & Whitehead, 2007; Kügler & Orbach, 2014; Urian et al. 2015) from good quality photos (based on focus, clarity and contrast of the image, following Alves et al. 2013).

Results and Discussion

Literature review and new records

This study provides the first review on bent dorsal fins in free-ranging cetaceans, and includes an empirical approach based on bibliographic research and compilation of new records collected worldwide. Previously, bent dorsal fins on cetaceans have only been reported for single species or in one specific area (Visser, 1998; Baird & Gorgone, 2005; Higdon & Snow, 2008), many of which lack detailed information and have not focused specifically on such abnormalities (e.g. Ford et al. 1994; Baird & Stacey, 1989; Wilson et al. 1997; Olson & Gerrodette, 2008; Kügler & Orbach, 2014; Towers et al. 2012, 2015; Bertulli et al. 2016). The present review adds 12 species to the list of free-ranging cetaceans displaying bent dorsal fins. This includes three species of baleen whales (mysticetes) and nine species of dolphins (odontocetes) (Table 1). For the new species added, multiple (between two and three) records from the same area are given for five species, and from different areas in four species. This review also provides information from new areas for three species in which bent and collapsed dorsal fins were already documented, namely *O. orca*, *T. truncatus*, and *L. albirostris* (Table 1). Finally, further information for *L. obscurus*, which was mentioned only briefly in Kügler & Orbach (2014), and for *P. crassidens* is provided (Supporting Information Table S1).

The bent fins described in the present study occurred over a wide geographic range including the Mediterranean Sea, Antarctic waters, Central, Western and Eastern Pacific, several regions of the North Atlantic, and the Indian Ocean. Of the cases of abnormalities described here (including new records and those in literature; n = 99), 23% were slightly bent, 31% moderately bent, and 46% severely bent (Table S1). The species with the highest number of records (64%) and from most locations was *O. orca* (Table 1). Overall, bent dorsal fins in free-ranging cetaceans are now recorded in 17 of 90 known species (Jefferson et al. 2015), and such abnormalities seem to occur worldwide. The literature review and the new records on free-ranging cetaceans with bent dorsal fins are summarized in Table 1, and additional information including photographs of the new records is presented in Supporting Information Fig. S1 and Table S1.

Comparing proportions of bent dorsal fins within populations

While bent dorsal fins are displayed worldwide in a relatively high number of free-ranging cetacean species, such

Fig. 1 Examples of the three levels of intensity of bending defined in this study (see Materials and methods), based on the insertion (breakdown point) between the fin tip and sagittal plane, as well as on the approximate angle, irrespective of the side: (A) slightly bent, (B) moderately bent, and (C) severely bent.

Table 1 Summary of the information on the known 101 free-ranging cetaceans with bent dorsal fins.

Species	No. of known individuals	Locations	Source
Balaenoptera brydei	2	Madeira (Portugal)	This study
B. borealis	1	Berkeley Sound (Falkland Islands)	This study
B. physalus	1	Long Island (USA)	This study
Delphinus delphis	4	Hauraki Gulf (New Zealand) and Madeira (Portugal)	This study
D. capensis	1	Algoa Bay (South Africa)	This study
Stenella coeruleoalba	5	Gulf of Corinth (Greece), and Strait of Gibraltar	This study
S. clymene	1	Gulf of Guinea (Gabon)	This study
Feresa attenuata	1	Hawaii (USA)	This study
Tursiops truncatus	4	Moray Firth (Scotland), Madeira (Portugal), Southern Evoikos Gulf (Greece) and Hawaii (USA)	Wilson et al. (1997) and this study
T. aduncus	2	Ponta do Ouro (Mozambique)	This study
Lagenorhynchus albirostris	2	Newfoundland (Canada) and Faxafloi Bay (Iceland)	Higdon & Snow (2008) and this study
L. obscurus	1	Kaikoura (New Zealand)	Kügler & Orbach (2014) and this study
Grampus griseus	2	Canaries (Spain) and Azores (Portugal)	This study
Globicephala macrorhynchus	2	Sea of Cortez (Mexico) and Madeira (Portugal)	This study
Phocoenoides dalli	1	British Columbia (Canada)	This study
Pseudorca crassidens	7	Hawaii (USA)	Baird & Gorgone (2005), Baird et al. (2015) and this study
Orcinus orca	64	New Zealand, Queensland (Australia), Eastern Tropical Pacific, California and Alaska (USA), British Columbia (Canada), Vesterålen (Norway), Iceland, Scotland, South Georgia (Antarctica), Sagres (Portugal) and Strait of Gibraltar	Bigg (1982), Bigg et al. (1987), Baird & Stacey (1989), Ford et al. (1994, 2000), Black et al. (1997), Visser (1998), Ford & Ellis (1999), Matkin et al. (1999), Ellis et al. (2007, 2008, 2011), Olson & Gerrodette (2008), Towers et al. (2012, 2015), Guerrero-Ruiz et al. (2005) and this study

deformities or disfigurements are still rare in nature. In general, these animals represent < 1% of their populations, with the exception of *P. crassidens* and *O. orca*, based on records from this study and the relevant literature (see Table 2). Our literature review shows that this anomaly is rarely reported. For example, Visser (1998) compared the proportion of abnormal fins in adult males of *O. orca* from New Zealand (23.3%) with that in the resident population from British Columbia (4.7%) and from Norway (0.6%). Baird & Gorgone (2005) found < 1% of disfigured fins (including fins that were missing or bent over) from several populations of odontocetes, consistent with the proportion presented here, although 3.5% of false killer whales from the main Hawaiian Islands population have such disfigurements. Guerrero-Ruiz et al. (2005) found that only four in > 1000 resident *O. orca* and two of > 300 transients from Alaska to Mexico had completely collapsed dorsal fins. Discrepancies in the proportion of abnormal fins (e.g. high values from New Zealand) could be explained by definitions given for bending between studies (i.e. to differences in how much of an angle is required in order to be classified as bent or unbent, or due to including other forms of malformation), making it difficult to compare species and areas. Despite such differences, the highest occurrence of bending was observed in apex predators *P. crassidens* and *O. orca* (Table 2). In the case of the former species, all known-sexed individuals with bent dorsal fins were adult females, whereas in the latter species this was mainly represented by adult males (91%; based on 58 adults of known sex).

Notwithstanding, most populations of cetaceans which have been photo-identified over long time scales (≥ 4 years) and include 100 or more animals, do not seem to include individuals with bent dorsal fins. For example, Baird & Gorgone (2005) reported seven delphinid species that did not show bending. In addition, there have been no reports of bent dorsal fins for *T. truncatus* in Mexican oceans (n = 4401 individuals identified; E. Morteo, pers. comm.) or off southwest Portugal (n = 493; S. Magalhães, unpubl. data). Although this comparison between populations is not comprehensive, these findings, along with those in

Table 2 Proportion of bent dorsal fins for well-studied populations (≥ 4 years) presented in this study (n = 14) and in the literature (n = 2). The number (no.) of marked individuals includes only distinctive adults or subadults based on marks in the dorsal fin and on good quality photos; note that Visser (1998) and Olson & Gerrodette (2008) can include other age classes and/or quality photos.

Species	Location	No. of marked individuals (no. with bent dorsal fins)	% with bent dorsal fins	Source
Delphinus delphis	Hauraki Gulf, New Zealand	2,083 (2)	0.10	K Hupman, CMRG - Massey University
Stenella coeruleoalba	Gulf of Corinth, Greece	415 (3)	0.72	G Bearzi, Dolphin Biology and Conservation
Feresa attenuata	Hawaii, USA	334 (1)	0.30	R Baird, Cascadia Research Collective
Tursiops truncatus	Madeira, Portugal	145 (1)	0.69	A Dinis, Oceanic Observatory of Madeira
T. truncatus	Hawaii, USA	708 (1)	0.14	R Baird, Cascadia Research Collective
T. aduncus	Ponta do Ouro, Mozambique	300 (2)	0.67	A Gullan, Dolphin Encountours Res. Center
Lagenorhynchus albirostris	Faxafloi Bay, Iceland	159 (1)	0.63	M Rasmussen & C Bertulli, Húsavík Res. Cent.
Globicephala macrorhynchus	Madeira, Portugal	537 (1)	0.18	F Alves, Oceanic Observatory of Madeira
Pseudorca crassidens	Hawaii, USA	179 (7)	3.91	R Baird, Cascadia Research Collective
Orcinus orca	Vesterålen, Norway	720 (5)	0.70	E Jourdain, Norwegian Orca Survey
O. orca	Snæfellsnes, Iceland	228 (2)	0.88	M Mrusczok, Orca Guardians
O. orca	Iceland	359 (7)	1.95	F Samarra, Marine & Freshwater Res. Institute
O. orca	British Columbia, Canada (Nort. resid. pop.)	528 (15)	2.84	J Towers & J Ford, Cetacean Res. Program
O. orca	British Columbia, Canada (Bigg's pop.)	643 (15)	2.33	J Towers & J Ford, Cetacean Res. Program
O. orca	Eastern tropical Pacific	195 (8)	4.10	Olson & Gerrodette, 2008;
O. orca	New Zealand	125 (7)[1]	5.60	Visser, 1998

[1]Visser (1998) reports that the seven animals with bent fins corresponds to 23% of the adult male population, but here we used her total number of catalogued individuals (n = 125).

Baird & Gorgone (2005), support the idea that bent dorsal fins are rare in nature.

Possible causes

This study indicates that 40% of deformed dorsal fins (based on 100 records) were observed on animals which also exhibited physical injuries. These were found on the dorsal fin (21%), at the base of the dorsal fin (9%) or on the vertebral column (10%; normally associated with scoliosis, see Berghan & Visser, 2000). Although physical injuries (e.g. resulting from boat strikes, entanglement in fishing gear, congenital malformations or infections) may cause dorsal fin bending (Berghan & Visser, 2000; Baird & Gorgone, 2005; Higdon & Snow, 2008; Baird et al. 2015), most (60%) of the records presented here were not associated with any injury or deformity (Table S1).

Slightly to severely bent dorsal fins (Fig. 1A-C) were observed in individuals of both sexes for the majority of species, with the exception of *O. orca*, where males have a higher prevalence (91%, as mentioned above), and *P. crassidens*, where females dominate (Table S1). Moreover, bending occurred on the right (52%), left (44%), and on both sides (i.e. either observed to the right or to the left in different occasions; 4%) of the dorsal fin (based on 97 records). Finally, this review showed that bent fins were observed predominantly in adults (94%), though one juvenile pygmy killer whale *Feresa attenuata* and two juvenile *O. orca* were repeatedly observed over the course of several years with a bent dorsal fin (Table S1).

Bent dorsal fins have been suggested to be caused by natural and/or anthropogenic sources. Exposure to stress, age or illness has been described as a potential factor causing a reduction in nutrient intake and/or blubber thickness, which can influence the bending and in some cases result in collapse of dorsal fins (Bigg, 1982; Matkin et al. 1999; Berghan & Visser, 2000; Baird & Gorgone, 2005; Higdon & Snow, 2008). The present study shows that the highest proportions of deformities (all proportions > 1%) were observed for *P. crassidens* in Hawaii and for *O. orca* in several regions (Table 2). The reasons causing such high proportions in the former species may be related to interactions with hook and line fisheries (Baird & Gorgone, 2005; Baird et al. 2015), as supported by dorsal fin disfigurement in other cetaceans caused by this type of fishery (e.g. Kiszka et al. 2008). In the case of *O. orca*, this may be due to the unique height of male dorsal fins (1–1.8 m) and the loss of fibrous connective tissue caused by age and starvation. Although there is no study that has systematically determined a loss of fibrous connective tissue, the

explanation is supported by the fact that this species is not proportionally abundant in comparison with other delphinids with lower proportions (e.g. *T. truncatus*, or short-beaked common dolphins *Delphinus delphis*) if we consider that these have been also the target of long-term photo-identification projects as well as of captivity (especially in the case of the *T. truncatus*, of which there are more animals in captivity than *O. orca*).

Only two animals were described as being in poor health, both with vertebral column malformations (Table S1). Additionally, bent fins occurred in individuals sighted only once, as well as in individuals sighted repeatedly (Table S1). The health of animals with bent fins could be further explored in studies covering well studied populations, as that would help to determine these animals' survivorship. Moreover, data on bent fins from necropsies using fresh dead animals could also help in assessing the health of these animals and inferring possible causes for this type of abnormality. Apart from those necropsies, it would be valuable for researchers to document and share information on individuals with bent dorsal fins or other striking physical abnormalities in general.

Overall, some of the factors contributing to bent dorsal fins in most free-ranging cetaceans are still unclear, and this physical abnormality could be influenced by a complex set of variables rather than by a single pattern or external condition, as well as varying by species. The present review showed that *P. crassidens* fins bent due to traumatic injuries and *O. orca* fins (in the case of adult males) bent possibly because the enlargement of the fin as a secondary sexual characteristic, making the fin more vulnerable to collapse due to other health issues (e.g. exposure to oil, nutritional stress). The scarce examples in other species are so infrequent as to not have clear identifiable causes. Nevertheless, apart from the possible factors contributing to bent dorsal fins, it is suggested that this bending does not directly affect the animals' survivorship and is not solely confined to animals in captivity. Recent advances in the care of captive animals showed that cetaceans have been occasionally described to show straightening over time from recovery from illness and improvements in an animal's body condition (Kastelein et al. 2016). Trying to understand the causes of bending in the wild is challenging and further research is needed.

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Conflict of interests

We have no competing interests.

Author contributions

F.A. conceived the study, compiled the data and drafted the manuscript. All authors collected data, critically reviewed the manuscript, and approved the version for publication.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Fig. S1. Photographs of the new records presented in this study.

Table S1. Detailed information on free-ranging cetaceans with bent dorsal fins, including new records (n = 52) and records from the literature.