Vol. 140: 103–108, 2020
https://doi.org/10.3354/dao03498

DISEASES OF AQUATIC ORGANISMS
Dis Aquat Org

Published online July 23

NOTE

Presenting vertebral deformities in bottlenose dolphin *Tursiops truncatus* calves from a protected population in northeast Scotland

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ABSTRACT: Photographs collected during a 23 yr photo-identification study in the Moray Firth were examined to assess the prevalence, type and severity of vertebral deformations present in bottlenose dolphin *Tursiops truncatus* calves. Fifteen cases of presenting spinal anomalies (scoliosis, kyphosis, lordosis and combinations thereof) of variable severity were identified in 7.4% of all known calves from the population. Thirteen of the 15 anomalies were either manifest from birth or acquired from an early age, as ascertained from longitudinal sightings histories of their mothers. Most afflicted calves died during early development or shortly after maternal separation. However, 3 survived to adulthood and persist in the population to date, in addition to 2 dependent infants whose fate remains to be established. At 15+ yr of age, the oldest surviving individual was remarkably one of the most severe cases identified, highlighting the ability of these delphinids for adaptation to such gross structural deformities. The aetiology of the observed conditions could be attributed to a range of causative factors that may have implications for the well-being and health of this North Sea coastal dolphin population, a topic which merits further investigation.

KEY WORDS: Vertebral column deformity · Scoliosis · Kyphosis · Lordosis · Bottlenose dolphin · *Tursiops truncatus*

1. INTRODUCTION

Deformities or deviations of the vertebral column may be either congenital or acquired. In most models studied, congenital deformities are highly associated with both spinal and extra-spinal defects, whereas acquired deformities may result from neurological disease, environmental contamination or may be idiopathic (Cowell et al. 1972, Giddens et al. 1984). In aquatic mammals, such as cetaceans, spinal deformations may further result from traumatic injury, with ship strikes (e.g. Wells & Scott 1997), fisheries interactions (Van Bressem et al. 2007), interspecific aggression or predation (Ross & Wilson 1996, Heithaus 2001) and agonistic behaviour from conspecifics (Watson et al. 2004, Robinson 2014) having all been implicated as causative factors.

In free-ranging delphinids, presenting deformities may be outwardly conspicuous in the form of scoliosis (abnormal deviation of the spine in a dorsal

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plane), kyphosis (increased convexity in the curvature of the spine), lordosis (increased concavity in the curvature of the spine when viewed from the side), kyphoscoliosis (backward and lateral curvature of the spine) or lordoscoliosis (lordosis complicated with scoliosis) (Berghan & Visser 2000), which are often present in varying combinations (Bertulli et al. 2015). The longevity of individuals exhibiting these anomalies is largely unknown (e.g. Wilson et al. 1997, Berghan & Visser 2000) but may invariably depend on the severity and attributed aetiology of conditions (Bertulli et al. 2015, Weir & Wang 2016).

Limited studies have been conducted to assess the prevalence of presenting deformities in free-ranging dolphin populations, but the high number of cases reported in younger animals within the general literature (e.g. Berghan & Visser 2000, Van Bressem et al. 2007, Bertulli et al. 2015, Weir & Wang 2016) may be significant for reproductive fitness, especially in smaller, closed populations with lower genetic exchange. In the following study, we examined a 23 yr photo-identification dataset from an isolated coastal bottlenose dolphin (*Tursiops truncatus*) population in northeast Scotland to assess the prevalence, type and severity of deformations in documented calves and to investigate the fate of these affected individuals, where known.

2. MATERIALS AND METHODS

Opportunistic data and photographs of bottlenose calves exhibiting vertebral anomalies were collected between 1997 to 2019 during a long-term, boat-based photo-identification study along the southern coastline of the outer Moray Firth (57° 41′ N, 2° 40′ W) using standard methodology (e.g. Robinson et al. 2017). Dedicated surveys were carried out approximately every 3 d between May and October, with the number of trips averaging from 50 to 80 per year. Presenting deformities in identified calves were categorised using terminology adopted by the International Committee on Veterinary Gross Anatomical Nomenclature (Bertulli et al. 2015). Field observations and photography were used to assess the type, severity, condition and ultimately the fate of affected individuals. Dependent calves were typically identified from co-observations of their known mothers from whom previous recaptures were used to estimate approximate birth dates. Following maternal separation, the affected youngsters were independently tracked based on their acquired markings. Dependent calves were assumed to have died if they were no longer present with their mothers prior to reaching 2 yr of age, as they would be unable to survive on their own. Gender was determined for several of the calves from photographs of their genital slits during surveys.

3. RESULTS

From a total of 203 calves catalogued by the Cetacean Research & Rescue Unit (CRRU) research team between 1997 and 2019, 15 cases of vertebral deformities, representing 7.4% of all known calves, were identified. Scoliosis, kyphosis and lordosis were

Table 1. Visible deformities observed in known bottlenose dolphin calves from long-term studies in the Moray Firth from 1997 to 2019. Dates given as d/mo/yr. CRRU: Cetacean Research & Rescue Unit. F: female; M: male; U: unknown sex

Ref.	CRRU ID	Birth year	Date first seen (with mother)	Date last seen	No. of sightings	Gender	Nature of deformity	Severity	Present from birth	Status (if known)
Tt_01	043	1992[b]	26/07/1997	02/09/1998	7	F	Kyphosis + lordosis	Moderate	No	Unknown (age 5+)
Tt_02	328	2002	28/09/2002	02/08/2005	14	U	Lordosis (tail stock)	Moderate	Yes	Deceased[d]
Tt_03	377	2005	23/07/2005	01/07/2017	41	F	Kyphoscoliosis + lordosis	Severe[c]	Yes	Alive (age 15+)
Tt_04	390	2006	17/08/2006	20/06/2009	28	U	Kyphosis + lordosis	Severe	Yes	Deceased[d]
Tt_05	417	2006	12/10/2006	16/10/2006	2	U	Kyphosis	Moderate	Yes	Unknown
Tt_06	430	2007	01/09/2007	04/09/2007	2	U	Scoliosis	Severe	Yes	Deceased[d]
Tt_07	484[a]	2009	05/08/2009	02/10/2012	48	U	Kyphosis	Severe	Yes	Deceased[d]
Tt_08	493	2009	14/09/2009	28/09/2009	2	M	Scoliosis	Severe[c]	No	Deceased[e]
Tt_09	631	2010	23/10/2010	02/06/2019	6	U	Kyphoscoliosis	Moderate	Yes	Alive (age (10+)
Tt_10	548	2012	09/10/2012	09/10/2012	1	U	Lordosis (tail stock)	Moderate	Yes	Deceased
Tt_11	579	2013	21/09/2013	21/07/2018	4	U	Kyphosis + lordosis	Moderate	Yes	Alive (age 7+)
Tt_12	599[a]	2015	22/07/2015	12/10/2016	21	F	Kyphoscoliosis	Severe[c]	No	Deceased
Tt_13	614	2016	28/07/2016	28/07/2016	1	U	Lordosis (tail stock)	Moderate	Yes	Deceased[e]
Tt_14	646	2017	30/09/2017	30/09/2017	1	U	Kyphosis	Moderate	Yes	Alive (age 2+)
Tt_15	688	2018	19/09/2018	03/10/2019	2	U	Kyphoscoliosis	Moderate	Yes	Alive (age 1+)

[a]Produced by the same mother (ID #067); [b]Wilson (1998); [c]most severe cases; [d]died after maternal separation; [e]infanticidal attack

observed in various combinations and degrees of severity and often occurred simultaneously in several individuals (Table 1, Fig. 1). In 13 of the 15 cases, the condition appeared to be present from birth (as ascertained from longitudinal sightings data) or acquired at an early age, but in 2 cases anomalies were acquired post-partum, during early calf development. For those animals photographically recaptured over several years, presenting deformities typically became more pronounced with age. In several of the most extreme cases, this was accompanied by visible loss of body condition and/or emaciation prior to subsequent demise. At least 3 calves (Tt_02, 06 and 07) appeared to have died after separating from their mothers, since they were never photographed again, although Tt_01 survived to at least 5 yr of age (as ascertained from photographic recaptures) (Table 1). Of the 5 individuals currently still alive in the popu-

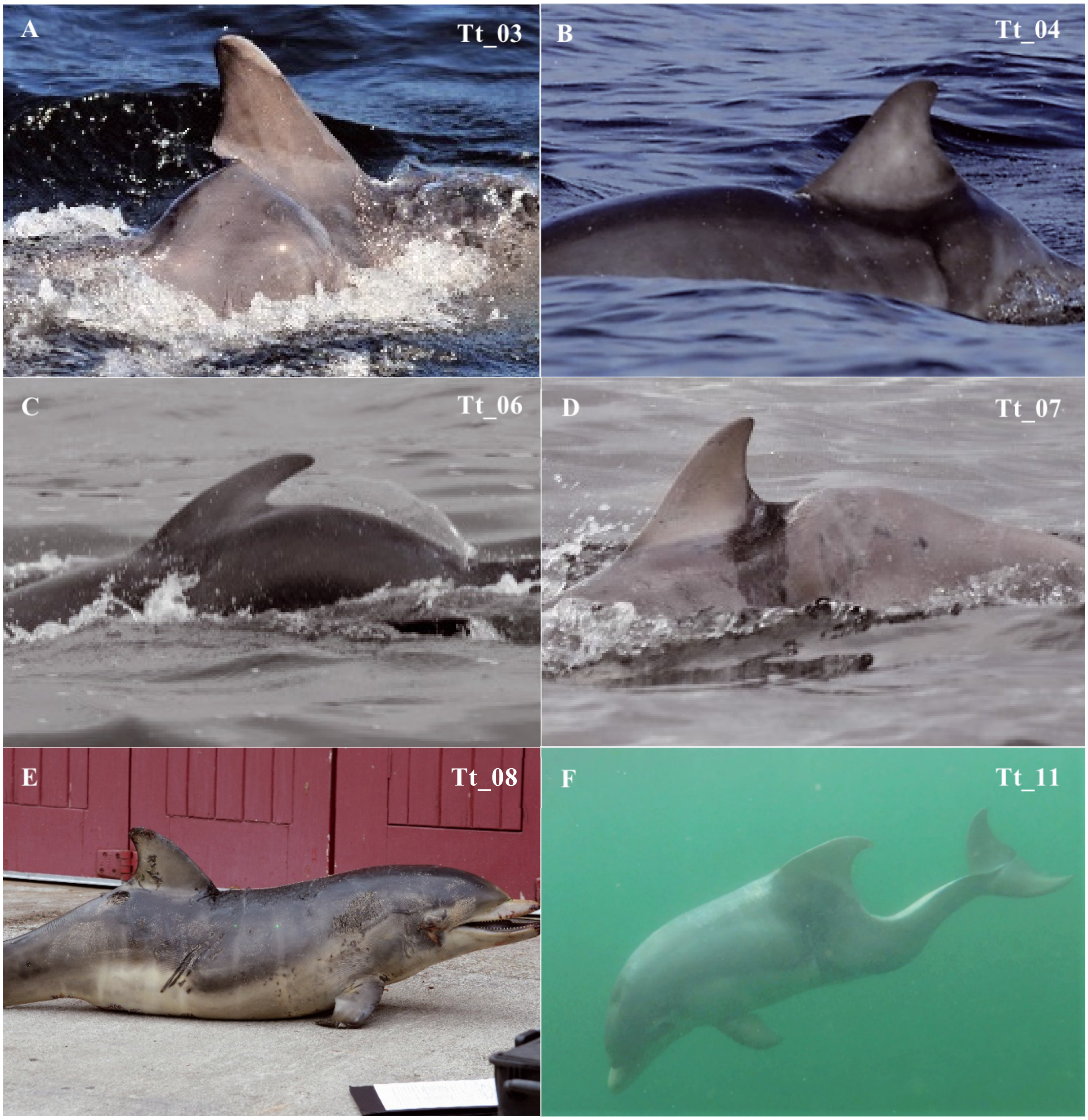

Fig. 1. Identified bottlenose dolphin calves from the Moray Firth exhibiting a range of conformational vertebral deformities: (A) kyphoscoliosis with lordosis, (B) kyphosis with lordosis, (C) scoliosis, (D) kyphosis, (E) lordoscoliosis, (F) kyphoscoliosis. Reference nos. of calves in upper right-hand corner. Photo credits: (A–D) Kevin Robinson; (E) Barbara Cheney, University of Aberdeen Lighthouse Field Station and (F) Theofilos Sidiropoulos (video still)

lation, 2 remained maternally dependent (Tt_14 and 15), and their fate is yet to be established, while 3 (Tt_03, 09 and 11) estimably survived to adulthood (Table 1).

Two of the identified calves (Tt_07 and 12) were produced by the same mother (female #067), but unlike its older sibling, Tt_12 displayed no sign of any deformation when first identified at approximately 3 d old (as established from sightings histories of its mother). However, when encountered during its second year, the spinal column was so grossly contorted (Fig. 1F) that the animal was unable to swim upright (shown in Video S1 at www.int-res.com/articles/suppl/d140p103_supp/). The compromised calf was no longer with its mother the following year and was presumed dead. The anomaly observed in Tt_08 was also acquired post-partum and was thought to have resulted from an infanticidal attack witnessed by the research team when the calf was just a few days old (Fig. 1 in Robinson 2014). The neonatal calf remarkably survived the attack, but subsequently stranded at 6 mo of age with a severe scoliosis (Fig. 1E) that was concluded to have been acquired from this attack (Robinson 2014). A similar fate was also projected for newborn calf Tt_13, which died within 1 d of its birth, as determined from sightings of the mother. Since only 4 calves were identifiable by sex, there was insufficient data to support if females were actually more often affected than males.

4. DISCUSSION

The vertebral deformities reported for bottlenose dolphin calves in the present investigation were consistent with those described in previous studies (e.g. Wilson et al. 1997, Berghan & Visser 2000, Berrow & O'Brien 2006, Bertulli et al. 2015, Weir & Wang 2016). Most calves were seen to exhibit their anomalies from birth, with defects arising during foetal development likely attributed to genetic or environmental factors (e.g. Erol et al. 2002). Of the 2 individuals acquiring anomalies post-partum, one (Tt_12) was possibly undetected at birth due to the initial subtlety of the presenting defect (B. Cheney pers. comm.), but the other (Tt_08) was inflicted during an attempted infanticide, which was witnessed first-hand (Robinson 2014). Intra-specific competition between males for female cohorts can be intense in the species (Connor et al. 2005), and attacks on young calves are thought to be commonplace in the study area (Patterson et al. 1998, Robinson 2014). Such behaviour is thought to have contributed, in part at least, to the number of scoliotic calves observed in this study. With just 195 animals (Cheney et al. 2013), however, genetic diversity in the study population is evidently low, and the 2 deformed offspring from the same mother may indicate a genetic component in explanation of the prevalence of cases. Furthermore, high levels of maternally transferred organic pollutants may also play a causative role in the aetiology of this condition in affected calves (e.g. Johnston & McCrea 1992, Jepson et al. 2016), with links having been established between perinatal PCB exposure and foetal development (Vafeiadi et al. 2014).

The survival rates of scoliotic calves in the Moray Firth may depend on a number of factors including, but not limited to, the age and maternal dependence of the afflicted calf, nature of the presenting anomaly (whether congenital or acquired), and the severity of the condition and any resulting complications (e.g. Wilson et al. 1997, DeLynn et al. 2011, Bertulli et al. 2015). Of the 8 calves raised to full term (3+ yr), 4 were lost shortly after maternal separation, of which 3 exhibited severe scoliotic conditions. Indeed, 5 of the 6 calves identified with 'severe' vertebral anomalies inevitably perished post-weaning, with sequential evidence of emaciation and subsequent decline in body condition being observed (K. Robinson pers. obs.). Since the main propulsive force in delphinids is generated by vertical oscillation of the caudal peduncle and flukes (Viglino et al. 2014), the severity of the observed calf deformities may impede their mobility — restricting their ability to capture prey, interact with other group members and even avoid predators — with subsequent implications for survivorship and reproductive success (e.g. Weir & Wang 2016). Younger animals are also evidently more vulnerable to boat collisions than adults owing to their lowered vigilance, lack of experience, slower swimming speeds and greater time spent at the surface (e.g. Stone & Yoshinaga 2000), although none of the cases identified in this study were attributed to this hazard. Remarkably, of the 3 calves that survived to adulthood, female Tt_03 exhibited the most severe case of scoliosis observed in the population (Fig. 1A), and yet she prevailed in spite of her condition, possibly benefitting from the support of other group members as established by studies in other group-living mammals (e.g. Clutton-Brock et al. 2000, Silk 2007). At 15+ yr of age, she is currently the oldest scoliotic individual surviving in this north coast dolphin population, although she has yet to produce a calf, and it remains to be seen whether she is capable of reproducing. Nevertheless, a former, severely deformed reproductive female from the Moray Firth population (Fig. 2j in Wilson et al.

1997) was seen to produce several healthy calves before her decline in 1998 at 18+ yr of age (N. Davison pers. comm., SAC 2000 [strandings report M319/98]). The fact that several individuals from the population have survived to adulthood (and even reproduced), in spite of the severity of their afflictions, highlights the ability of these delphinids for adaptation to such gross structural deformities.

Presenting anomalies in free-ranging delphinid populations are evidently biased towards acute cases (e.g. Wilson et al. 1997, Berghan & Visser 2000, Bertulli et al. 2015, Weir & Wang 2016, Alves et al. 2018), perhaps due to their relative ease in diagnosis, which may consequently result in an underestimation of the incidence of affected animals within study populations. This might be particularly relevant in the case of presenting lordosis as discussed by Weir & Wang (2016), as the condition can be difficult to detect in the lower tail stock and may have been more prevalent in Moray Firth calves than detected herein. In addition, congenital defects may also be difficult to identify at birth (Erol et al. 2002) (as in the subtle case of Tt_12), and some calves may not survive long enough for the symptoms to be recognised. Low genetic diversity in this North Sea population may also increase the likelihood of congenital anomalies (Parsons et al. 2002), which could conceivably contribute to the number of affected calves identified in this study. The bottlenose dolphins in northeast Scotland reside at the northern limit of their species' range and are presently of high conservation priority (Thompson et al. 2011). Indeed, reproductive success in this North Sea population is dependent on a low number of good breeders (Robinson et al. 2017), which are evidently important for the future viability of this population. Whether or not the number of calf anomalies detected in this study implies reduced fitness or has implications for the health of this population therefore merits further investigation. Thus, ongoing monitoring studies of the species in UK inshore waters will be essential for the adaptive design and future management of these coastally occurring delphinids.

Acknowledgements. All field work was carried out under licence from Scottish Natural Heritage. Thanks go to the numerous colleagues, interns, volunteers, supporters and funders who have made this long-term study possible. We thank the Born Free Foundation (formerly Care for the Wild International) for their long-standing support and our co-workers and collaborators from the University of Aberdeen, Scottish Marine Animal Strandings Scheme, University of St. Andrew's and Whale & Dolphin Conservation. Thanks also to the 3 anonymous referees for their valuable comments and input.

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Editorial responsibility: Michael Moore,
Woods Hole, Massachusetts, USA

Submitted: April 6, 2020; Accepted: June 9, 2020
Proofs received from author(s): July 17, 2020