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Reversible Bending of the Dorsal Fins of Harbor Porpoises (*Phocoena phocoena*) and a Striped Dolphin (*Stenella coeruleoalba*) in Captivity

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Abstract

The dorsal fin of odontocetes has, among other roles, hydrodynamic and thermoregulatory functions. In captivity, the dorsal fin sometimes bends laterally. Bending of the dorsal fin was described in 13 captive harbor porpoises and one captive striped dolphin. All had stranded and been given veterinary care in a small indoor treatment pool. After recovery, most of the animals were moved to a large outdoor floating pen for rehabilitation before being released at sea. The degree of bending of the dorsal fins was related to one, or several, of the following situations: (1) sickness, (2) recovery, (3) addition of pool-mates, (4) change in the direction of current in the pool, and (5) the move to the floating pen. In general, fins began to bend soon after stranding when the animals were ill, floating at the water surface and hardly moving in the small pool. Later in the recovery phase, when the animals could dive and had stereotypical swimming patterns, the fin bent even more. The fin often straightened when the social situation changed due to the introduction of pool-mates; the increase in social interactions usually led to irregular swimming patterns. When the direction of the current in the pool was changed, animals often changed their swimming direction. This often coincided with a change in the angles of their dorsal fins. When recovered, healthy animals were moved to the large floating pen to allow them to become fit enough for release. In the pen, their dorsal fins generally straightened. In order to avoid dorsal fin bending in captive cetaceans, we recommend that the direction of the current in pools should be changed often and that environments should be made as stimulating as possible. Bent dorsal fins of captive harbor porpoises can straighten to some degree. Rehabilitated stranded animals should spend some time in a large pool or pen, preferably with conspecific pool-mates, prior to being released.

Key Words: stereotypical behavior, captivity, social interactions, welfare, anatomy, odontocete, morphology

Introduction

In odontocetes that have a dorsal fin, the fin has a hydrodynamic function, preventing rotation of the body during high-speed swimming. The fin also increases agility, allowing animals to make short turns at high speed (Curren et al., 1994; Fish, 1998). The dorsal fin lacks a thick blubber layer (Kastelein et al., 1997d) but has arterio-venous systems that allow it to act as a heat exchanger (Scholander & Schevill, 1955; Sonne et al., 2011). It consists of two layers of skin with connective tissue in between. In the harbor porpoise (*Phocoena phocoena*), the ridge of the dorsal fin is covered with hard tubercles (bumps consisting of keratin; Andersen & Dziedzic, 1964; Kastelein et al., 1995, 1997b; Ginter et al., 2011). These may function to protect the skin on the dorsal side of the body from damage when the water surface is covered by thin ice; they also may play a tactile role in social interactions like the tubercles on the pectoral fins in Commerson's dolphins (*Cephalorhynchus commersonii*; Johnson & Moewe, 1999). Ginter et al. (2011) speculate that the tubercles may have a hydrodynamic function as well. For the dorsal fin to function optimally in its various roles, it should be straight as it is in most healthy odontocetes possessing a dorsal fin in the wild. Captive odontocetes sometimes develop bent dorsal fins.

Between 1991 and 2000, about 30 cetaceans that stranded alive on the Dutch, German, Belgian, and French coasts were given veterinary treatment in Harderwijk, the Netherlands; all those that recovered were released at sea. During the early 1990s, it became possible to treat unweaned juveniles due to the development of a formula on which they could be raised by tube feeding. Animals that stranded before weaning spent

longer in rehabilitation than animals that stranded as adults (Kastelein et al., 1997c). It was considered unwise to release hand-raised animals immediately after they had recovered their health and had been weaned onto a diet of thawed fish. Therefore, in 1995, a large outdoor floating pen was built in tidal seawater (in the Oosterschelde, a lagoon of the North Sea). This facility was used to prepare rehabilitated porpoises and dolphins for release at sea.

The dorsal fins of many of the stranded odontocetes bent during treatment in small indoor pools but were observed to straighten to some extent after the animals were transported to the outdoor pen for rehabilitation (Kastelein et al., 1997b). From 1993 to 2000, dorsal fin bending was documented photographically in order to gain insight into this phenomenon. In this descriptive study, we quantify dorsal fin bending in 13 harbor porpoises and one striped dolphin (*Stenella coeruleoalba*), and relate the degree of bending to the animals' health status, social situation, and housing situation. Specifically, we quantified responses in the degree of fin bending to the following: (1) sickness (often soon after stranding), (2) recovery, (3) addition of pool-mates, (4) change in the direction of current in the pool, and (5) move to a large floating sea pen.

Table 1. Details of the study animals and the time periods in which photographs of their dorsal fins were taken. The ID# includes an abbreviation of the species (Pp = harbor porpoise, Sc = striped dolphin). Columns show evidence from each animal for changes in the degree of bend in the dorsal fin occurring alongside (1) sickness, (2) recovery, (3) addition of pool-mates, (4) change in the direction of current in the pool, and (5) move to a large floating pen. "B" = increased bending; "S" = decreased bending (straightening); "N" (neutral) = little or no change in degree of bend; and "n/a" = not applicable/no evidence (e.g., for "Current change," that particular animal did not experience a current change). Examples of measurements of dorsal fin angles for the four animals indicated in the "Fig." column are shown as Figures 4 through 7. "Max." and "Min." columns show the maximum and minimum bend measured for each animal during the study period as degrees to left or right of vertical (not including the assumed vertical fin at the time of stranding). In all animals, some degree of straightening (recovery) took place during the study period, though in some it was followed by renewed bending.

ID#	Gender	Age during study (mo)	Time period (dd/mm/yyyy)	Sickness	Recovery	Pool-mates	Current change	Floating pen	Fig.	Max.	Min.
Pp 30	Male	11-52	22/07/1993 - 21/10/1997	B	B	N	n/a	S	--	45°	10°
Pp 36	Male	8-52	24/03/1994 - 21/10/1997	B	N	n/a	n/a	N	--	50°	27°
Pp 37	Female	33-39	27/03/1994 - 13/09/1995	B	N	n/a	n/a	S	--	40°	20°
Pp 47*	Male	7-36	19/01/1998 - 13/06/2000	B	N	N	n/a	n/a	--	35°	15°
Pp 48	Male	20-28	17/02/1998 - 26/10/1998	B	S	S	n/a	S	--	15°	2°
Pp 50	Male	14-25	22/08/1998 - 07/07/1999	B	S	S	S	N	4	20°	0°
Pp 51	Female	17-39	16/10/1998 - 03/08/2000	B	S	S	n/a	N	--	17°	0°
Pp 52*	Male	10-33	04/11/1998 - 26/10/2000	N	N	S	n/a	S	--	15°	0°
Pp 53	Female	20-28	02/02/1999 - 26/10/1999	B	S	S	n/a	S	5	30°	5°
Pp 55*ϰ	Male	27-35	06/04/1999 - 04/12/1999	B	n/a	S	n/a	n/a	--	32°	4°
Pp 57	Female	67-73†	04/12/1999 - 03/08/2000	B	B	S	n/a	S	--	27°	0°
Pp 60	Female	22-30	08/03/2000 - 08/11/2000	B	N	S	N	S	--	40°	2°
Pp 63	Male	120-132†	07/05/2000 - 08/11/2000	B	S	N	S§	S	6	40°	0°
Sc 01*	Female	36-60	08/12/1997 - 03/07/2000	B	N	N	n/a	S	7	40°	12°

* Not released during the study; all others were released.

ϰ Ill during the entire study period; died on 04/12/1999.

† Approximate age; accurate age determination not possible due to older age on arrival.

§ Dorsal fin straightened and then bent to the other side when the current was reversed.

Methods

Study Animals

The 13 harbor porpoises and one striped dolphin are described in Table 1 (see previous page). Ages were estimated from body length (Gaskin et al., 1984); all except the ages for harbor porpoises ID#057 and ID#063 were assumed to be accurate since the animals were young when they stranded. The age of the striped dolphin was estimated based on a length-to-age study on dolphins from the same population (Di-Méglio et al., 1996). Changes in social combinations were determined by the rehabilitation and release conditions of the animals.

Study Areas

The animals were kept indoors in two similar oval concrete medical treatment pools (8.6 m × 6.4 m; depth: 1.2 m) in Harderwijk, the Netherlands. The temperature of the clear chlorinated salt water (2.2 to 2.8% NaCl) was measured daily and varied between 14 and 21° C. The area was artificially lit, but daylight could also enter the pools (Figure 1a & b). A water current was present; in one of the pools, it was almost always counter-clockwise so that most animals swam clockwise against the current. By means of a 90° PVC elbow tube, the current could be reversed. The current in the second pool was always clockwise. These treatment pools were constructed to be small and shallow so that floating animals, and animals barely able to dive, could easily be handled (e.g., for tube-feeding formula, force-feeding fish, administering oral and injected medication, and treating wounds). The small volume of water in these pools also meant that water parameters such as temperature and salinity could be changed quickly and as often as necessary.

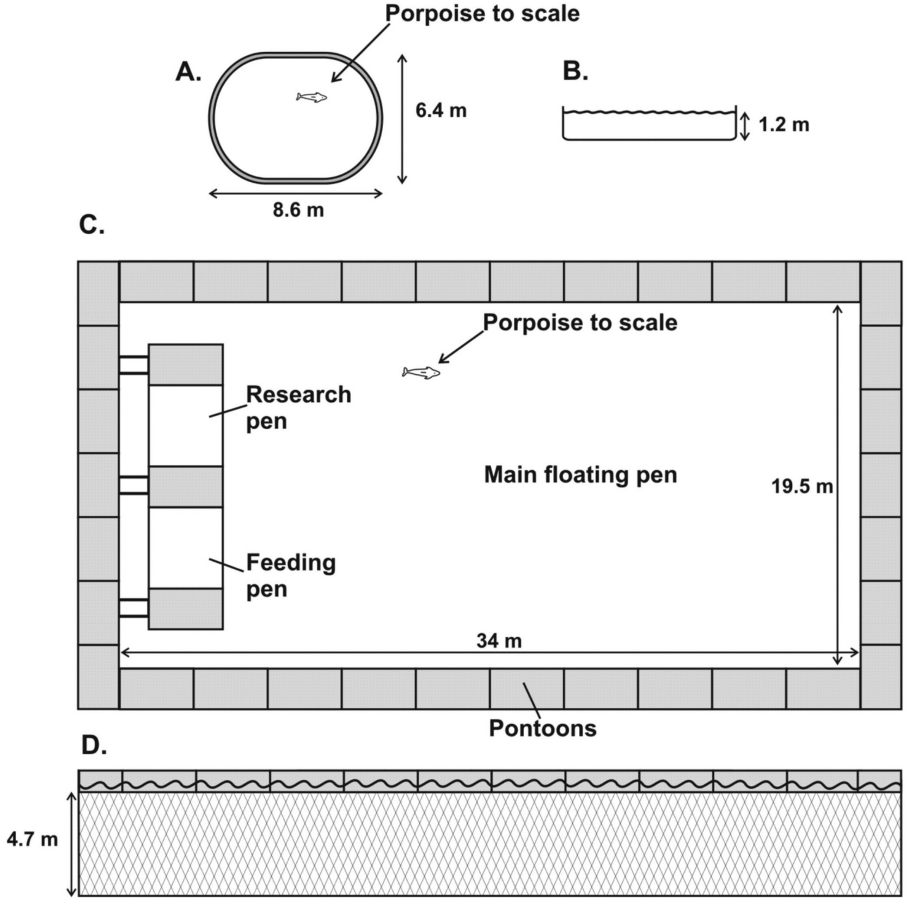

Figure 1. *The study areas:* (a) top view of the indoor pool, (b) side view of the indoor pool, (c) top view of the floating pen, and (d) side view of the floating pen. All drawings are to the same scale.

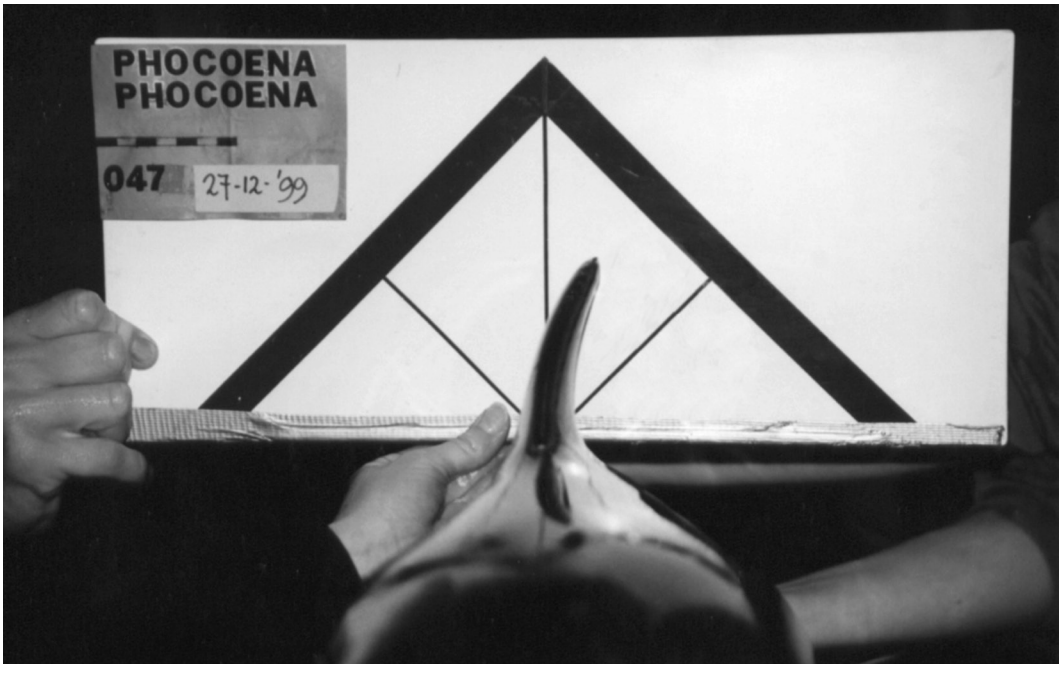

Figure 2. *An example of data collection:* Frontal view of the dorsal fin of male harbor porpoise (*Phocoena phocoena*) ID#047 with a dorsal fin angle of 104° (14° from vertical)

Healthy animals were moved to an outdoor floating sea pen (34 m × 19.5 m; 3.2 m deep at the sides and 4.7 m deep in the center; Figure 1c & d). The net pen was at Neeltje Jans, in the south of the Netherlands, in tidal seawater. The salinity in the pen was around 3%. The mean monthly water temperature over 5 y was 13 ± 2° C (SD) in May, 16 ± 1° C in June, 18 ± 2° C in July, 21 ± 2° C in August, 16 ± 1° C in September, and 13 ± 3° C in October (the months of the year when the floating pen was operational). There was a weak tidal current along the length of the pen, and the tidal difference was on average about 2.5 m. At low tide, the bottom of the pen just touched the sea floor.

Data Collection

Along with each animal's veterinary records, information was stored about its body weight (weekly recording), body length (weekly recording), girth in front of the dorsal fin (weekly recording), health condition (daily recording), temperature of the water in the pool it was kept in (daily recording), occasional changes in the direction of the current in the pool, and presence or absence of pool-mates. Each month, each animal's dorsal fin height (from the highest point of the dorsal fin to the dorsal surface, following the contour) and dorsal fin base length were measured and recorded.

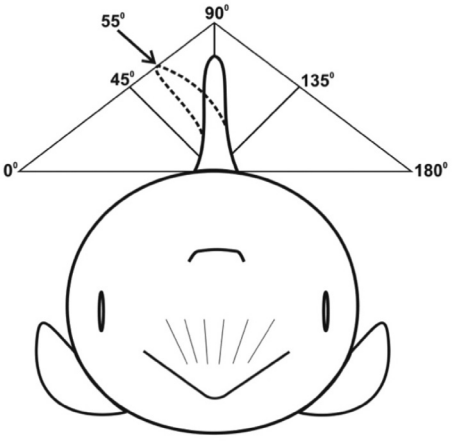

Figure 3. Depiction of how dorsal fin bending was quantified; the fin drawn with a dashed line is at an angle of 55° (35° from vertical).

The dorsal fin angle was recorded when the study animals were removed from the water for husbandry and veterinary procedures. Their dorsal fins were photographed (by using slides, color prints, and black and white prints). Behind the dorsal fin, a board showing the identification number of the animal, the date, a scale (in cm), and a quadrant scale was visible (Figure 2). Care

was taken to ensure that animals were lying in a straight line and that the sagittal plane was vertical when photographs were taken. The position of the animals' dorsal fins did not change when the animals were removed from the water; though often bent, they were not flexible.

From each available image, the angle of the fin tip relative to the sagittal plane was measured (Figure 3). Measuring from images rather than directly from the animals was considered to be more accurate and repeatable. A 90° angle indicated a straight dorsal fin; had fins ever been horizontal, they would have been represented by 180° (bent to the animal's left) or 0° (bent to the animal's right). For approximately 90% of the photographs, the animals were calm; and in those conditions, repeated measurements from photographs were within 5° of each other and of direct measurements of the fin angle. Fin angles were plotted in chronological order for each animal to examine changes in fin bending over time.

Results

Careful examination of chronological changes in dorsal fin angle for each animal (examples are shown in Figures 4-7) allowed us to summarize for each animal (Table 1) changes in the degree of fin bending corresponding with (1) sickness, (2) recovery, (3) addition of pool-mates, (4) change in the direction of current in the pool, and (5) the move to a large floating pen.

All harbor porpoises had straight dorsal fins when they stranded; however, during the initial weeks of rehabilitation, animals were usually quite sick, and the research and rescue team was so occupied with treatment that no photographs were taken. Within a week after arrival, the fins began to bend in 92% of cases (12 out of 13 porpoises, and also in the striped dolphin; Table 1 & Figures 4-7). The fin of the 13th porpoise (ID#052) remained within *ca*. 5° of vertical despite his illness.

The initial recovery period was associated with a straightening of the dorsal fin in five (42%) of the 12 harbor porpoises that recovered (Table 1 & Figures 4-6). In five porpoises (42%) and in the striped dolphin, recovery coincided with little or no change in the dorsal fin; and in two porpoises (17%), recovery coincided with increased bending.

The addition of pool-mates, experienced by 11 harbor porpoises and the striped dolphin, had mixed effects on the swimming patterns of animals in rehabilitation but coincided with straightening of dorsal fins in 73% of the porpoises ($n = 8$;

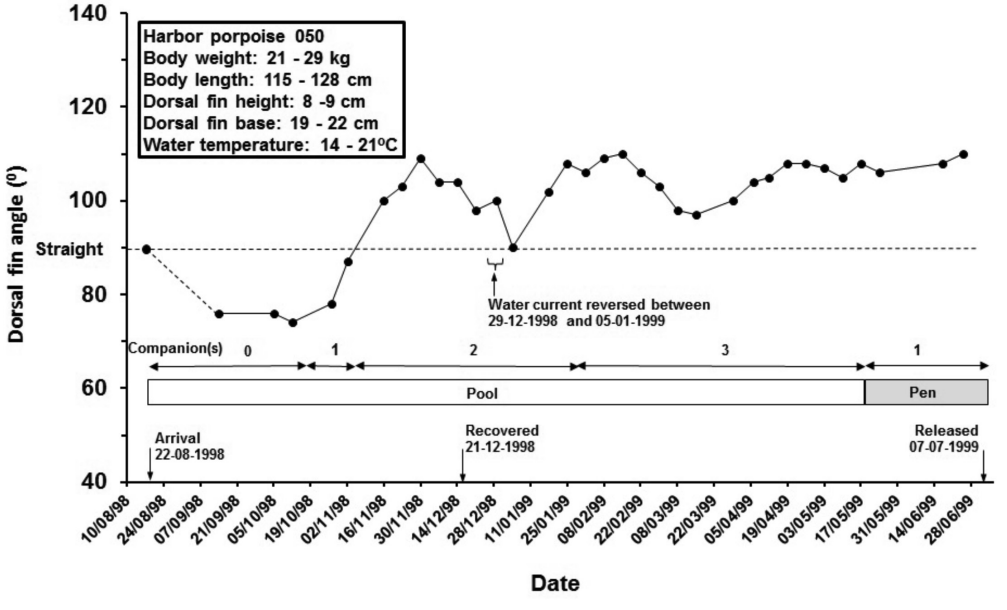

Figure 4. *Male harbor porpoise ID#050:* The dorsal fin of this porpoise bent to 73° when he was recovering alone in the treatment pool. His fin straightened when a pool-mate was introduced, but it bent towards the other side when a second pool-mate was added to the treatment pool. On 04/01/1999, his fin straightened temporarily when the water current in the treatment pool was reversed (between 29/12/1998 and 05/01/1999). It returned to its former angle soon after the water current was returned to its usual direction. His fin was at an angle of 110° when he was released at sea (dates are dd/mm/yyyy and dd-mm-yyyy).

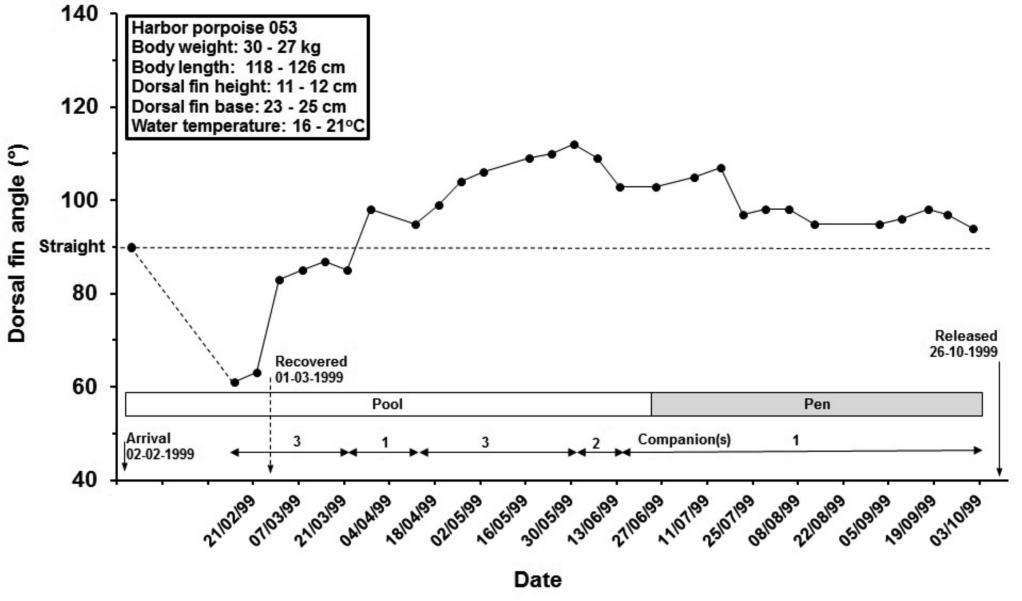

Figure 5. *Female harbor porpoise ID#053:* The dorsal fin of this porpoise bent to 60° during a few weeks of illness, but it quickly straightened when she recovered in the presence of three pool-mates. Her fin bent to the other side after two pool-mates were removed on 21/03/1999. When she was again kept with three pool-mates after 12/04/1999, she began to swim stereotypically, and her fin bent to around 110°. After the removal of a pool-mate on 31/05/1999, her fin started to straighten again. After her move to the floating pen, her dorsal fin straightened even further to around 95°. Her fin was at an angle of 94° when she was released at sea (dates are dd/mm/yyyy and dd-mm-yyyy).

Figures 4 & 5). In the remaining three porpoises and in the striped dolphin, the addition of pool-mates did not coincide with any change in the dorsal fin (Figures 6 & 7). Only three porpoises experienced a change in the current direction in the pool; and of these, two experienced subsequent straightening of the dorsal fin (Figures 4 & 6).

Eleven of the harbor porpoises and the striped dolphin were kept in the large floating pen. When they were moved to the pen, the dorsal fins of 73% of the 11 porpoises and that of the striped dolphin straightened (Figures 5-7). In 27% of the 11 porpoises (3 animals), there was no change (Figure 4), but the fin of one (ID#051) was already within 10° of vertical when he was moved to the floating pen.

Discussion

Sickness and Recovery

The dorsal fin of each stranded harbor porpoise and striped dolphin bent shortly after arrival; the animals were ill and usually floated motionless at the water surface. Their dorsal fins were above the water surface most of the time and, therefore, remained warmer than those of animals swimming normally. In general, the warmer a body tissue is, the more flexible it is. Once the recovering animals were healthy enough to begin diving, they initially usually avoided social interactions with pool-mates for several days (depending on the rate of recovery and the personality of the individuals), and they often swam stereotypic ovals or circles against the current in the treatment pool. During this period, the bent fins often bent more. The pool's water temperature was usually higher than water temperatures the animals would encounter in the wild. The elevated water temperature was maintained to reduce energy loss by thermoregulation in newly stranded animals, which were often emaciated (the higher temperature allowed ingested food to be used to increase body weight instead of for thermoregulation). The emaciated body condition led to looser than normal skin tensions around the base of the dorsal fin (see Figure 1, section 78, in Kastelein et al., 1997d). Thus, in addition to the higher tissue temperature, the dorsal fin probably bent more easily than that of an animal with normal body weight. The positive influence of improving health status (and associated improved swimming behavior) on the straightness of the dorsal fin was seen in several of the porpoises. Healthy porpoises show a more irregular swimming pattern so that water pressure on both sides of the dorsal fin is more equal.

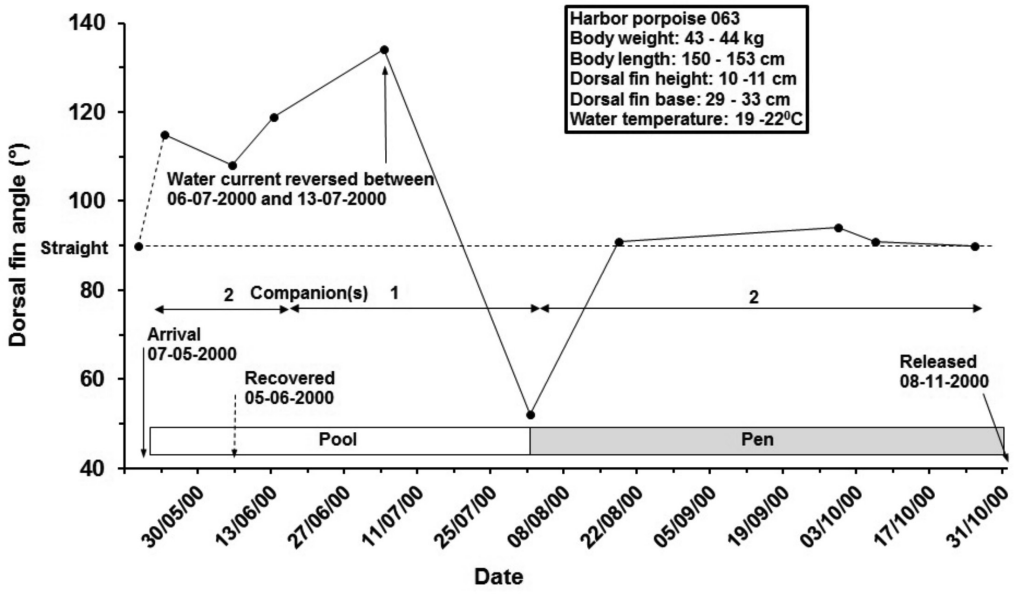

Figure 6. *Male harbor porpoise ID#063:* The dorsal fin of this porpoise bent to 118° during his initial period of illness. He had little social interaction with his pool-mates. His fin bent to the other side when the current in the treatment pool was reversed between 06/07/2000 and 13/07/2000, which led him to reverse his swimming direction. His fin straightened quickly when he was moved to the floating pen on 04/08/2000. His fin was at an angle of 90° when he was released at sea (dates are dd/mm/yyyy and dd-mm-yyyy).

Addition of Pool-Mates

The dorsal fins of some harbor porpoises changed when their social situation changed. The introduction of a pool-mate usually coincided with straightening of the fin. The presence of a pool-mate typically resulted in abandonment of stereotypical swimming in favor of a more erratic swimming pattern (see Kastelein et al., 1997a). Still, the dorsal fin did not always straighten due to the addition of a pool-mate. When a third animal was introduced into a pool or pen already containing a study animal and a second individual, the study animal's fin would bend more, stay the same, or straighten, depending on the social interactions between the newly arrived animal and the animals already in the pool. A third pool-mate could result in more interactions (and more irregular swimming) if the study animal formed a bond with the newcomer, or in fewer interactions (and more stereotypical swimming) if the other animals formed a bond that excluded the study animal. No obvious social interactions were observed between the striped dolphin and the porpoises with which she was kept.

Change in the Direction of Current and Move to a Floating Pen

The dorsal fins of some harbor porpoises and that of the striped dolphin straightened when they were moved from the treatment pool to the much larger floating pen. Even the dorsal fins of animals that were kept alone in the floating pen straightened. In general, in the small treatment pools, the animals swam against the current, which resulted in an oval swimming pattern. The animals increased their speed when passing through the straighter part of the pool (the length) and made a relatively sharp bend across the shorter part of the pool (the width). This generated pressure on the outside of the dorsal fin and may have caused it to bend. The observations in the present study suggest that the dorsal fins of healthy animals can be kept relatively straight if the direction of the current in their pool is changed regularly; however, not all animals reversed swimming direction when the direction of the current was changed (e.g., harbor porpoise ID#060 did not). In the floating pen, the animals could dive much deeper than in the treatment pool, and the absence of a circular current meant that the swimming pattern was irregular. In addition, the environment in the pen was dynamic; the pen moved up and down with the tides, and live fish, jellyfish, and crabs entered the pen. Birds sometimes landed in the pen, waves were generated by the wind, and rainfall occurred. During spring and autumn, the water temperature in the pen was lower than in the small indoor treatment pools; while in

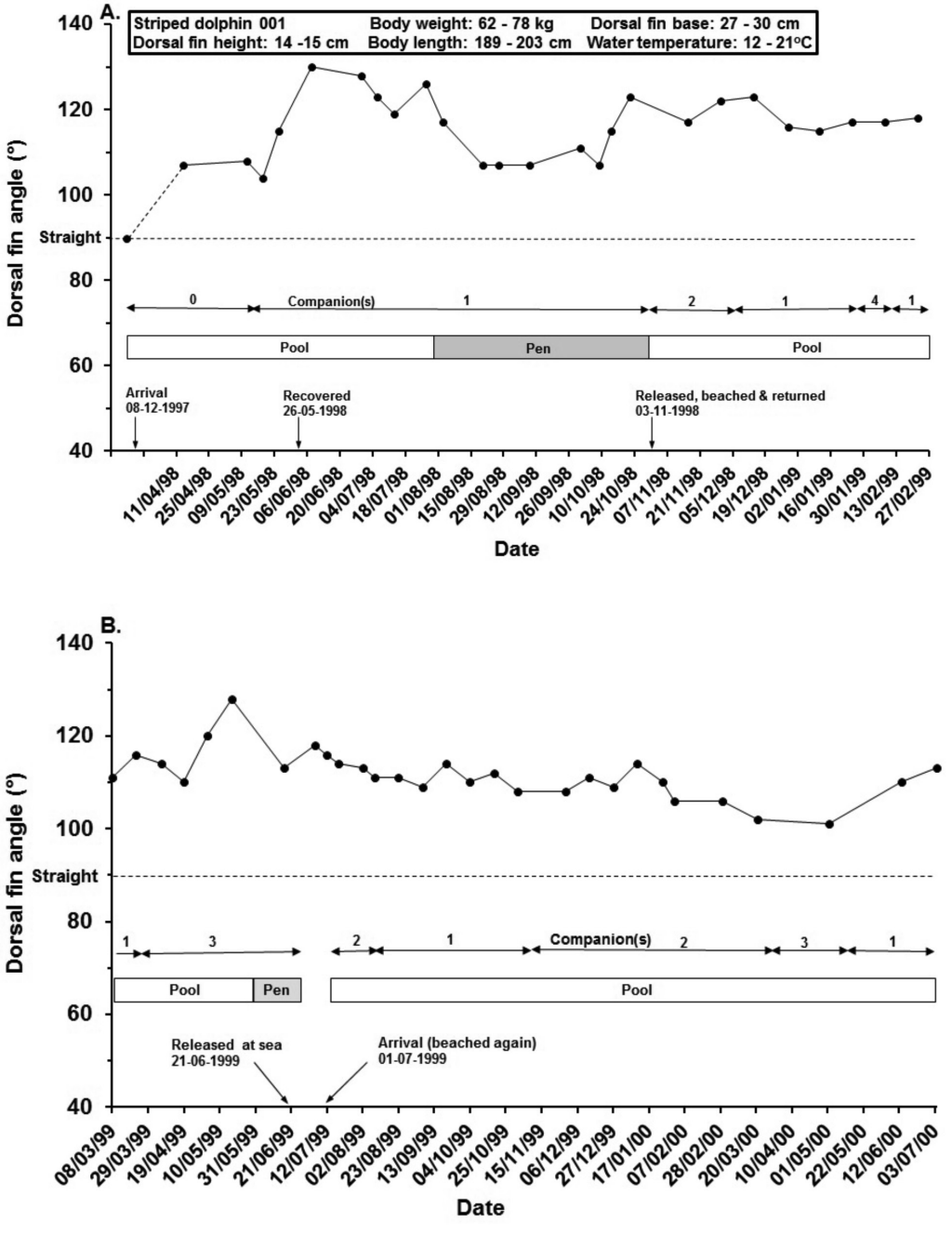

Figure 7. *Female striped dolphin ID#001:* Between her arrival and 14/04/1998, the dorsal fin of this striped dolphin bent to an angle of 114°. During recovery, when she began to swim more (but stereotypically), her fin bent to 130°, after which it straightened a little. When she was moved to the floating pen for the first time, her fin straightened greatly. On 03/11/1998, she was released at sea. She stranded again 4 h later and was brought back to the treatment pool where she had two pool-mates. When a fourth pool-mate was introduced on 22/03/1999, the striped dolphin's dorsal fin bent to 128°. After being moved to the floating pen for the second time, her dorsal fin straightened to 113°. On 21/06/1999, she was released for the second time. She stranded again after 10 d at sea and was moved back to the treatment pool. Thereafter, her fin remained at an angle of around 110°. All pool-mates were harbor porpoises, and no obvious social interactions were observed between the two species (dates are dd/mm/yyyy and dd-mm-yyyy).

the summer, the temperatures of both housing facilities were similar. Most body tissues become more pliable as the temperature increases, so it is possible that in the indoor treatment pools, with their relatively warm water in the winter period, the dorsal fins were more prone to bending than in the wild at sea between autumn and spring.

Conclusion

Unfortunately, it is not always possible to avoid dorsal fin bending, and sick, stranded animals may need to be treated in small pools. However, the present study shows that bent dorsal fins of captive harbor porpoises and striped dolphins can straighten partially or even completely. The factors related to this straightening are the recovery from sickness, the introduction of suitable pool-mates, the reversal of pool current direction, and the transfer to a large, stimulating floating pen full of marine life. Rehabilitated stranded animals should spend some time in a large outdoor pool or pen, preferably with conspecific pool-mates, prior to being released. This final stage of rehabilitation is important, not only to allow bent dorsal fins to straighten, but also to allow animals to improve their body condition and to become efficient predators of live fish, thus improving their chances of survival in the wild.

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