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Evidence of nighttime movement of finless porpoises through Kanmon Strait monitored using a stationary acoustic recording device

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ABSTRACT: From March 2005 to March 2006, the presence of the finless porpoise *Neophocaena phocaenoides* in the Kanmon Strait, Japan was monitored using a stationary acoustic event recording device. A stereo acoustic event recorder (A-tag) recorded biosonar signals as well as sound source directions, which can be used to count the number of echolocating porpoises within a distance of 126 m. During 75 days of effective observation, 37 porpoises were detected acoustically. On average, one individual was detected every two days. Most of the finless porpoises appeared at night, and no porpoises were observed from 12:00 to 18:00 hours. Shipping traffic observed using the same acoustic system showed trends opposite to that of finless porpoise during the daytime. The tidal current did not affect the presence of the animals (up to 5.2 knots). However, porpoises were suggested to swim along the current direction. Finless porpoises appeared to be isolated and used relatively long-range sonar during the observations, suggesting that the porpoises passed through the Kanmon Strait rather than searched for prey.

KEY WORDS: **biosonar, cetacean, dolphin, passive acoustics, ultrasonic.**

INTRODUCTION

Finless porpoises *Neophocaena phocaenoides* are known to distribute from Japan to the Persian Gulf, including some rivers in the Asian subcontinent.[1] In Japanese waters, a nationwide survey[2] as well as comparisons of skull morphology and mitochondrial DNA control region sequences[3,4] suggested five populations of finless porpoises. Finless porpoises may favor depths of less than 50 m,[5] which is consistent with the separation of the population by deep water areas.

However, further fragmentation or reduction of the populations of this species has been suggested recently.[6] For the sustainable management of wildlife, habitat fragmentation should be avoided. This causes genetic isolation of each fragmented group. Therefore, identification of independent groups is essential. Kasuya *et al.*[6] compared visual survey data of finless porpoises between the late 1970s and 1999–2000 in the Seto Inland Sea. They confirmed the disappearance of some habitat that was previously occupied by finless porpoises. The decline was statistically significant for 12 of 18 survey transects. An aerial survey of the Seto Inland Sea conducted in 2000 indicated a clumped distribution of finless porpoises.[7] Today, a major portion of the Inland Sea–Hibiki Nada population of this species (No. 3 of Fig. 1) possibly locate to the west end of the Seto Inland Sea and in the Sea of Japan. These areas are connected by the Kanmon Strait. Finless porpoises that reside on either side of Kanmon Strait seem to be the last strongholds of this population. It is necessary to monitor the movement between two areas to identify the unit of population for future conservation.

There are few reports of the movement of finless porpoises through the Kanmon Strait. Shirakihara *et al.*[8] reported stranded or by-catch finless porpoise at several sites on both sides of the strait, including inside the channel. Nakamura *et al.*[9] reported 48 strandings of finless porpoises in coastal waters of Yamaguchi and Fukuoka prefectures near the Kanmon Strait. Of these, eight and one individual were found dead and alive, respectively, in the strait during 1998–2002. Kaikyokan Whale Volunteers reported the stranding of finless porpoises within and on both sides of the strait,

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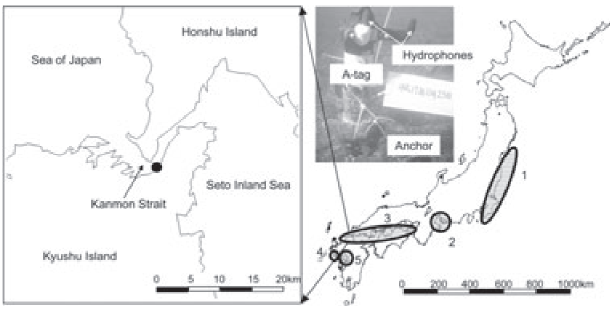

Fig. 1 Locations of five populations of finless porpoise in Japanese waters (Yoshida[4]): 1, Sendai Bay–Tokyo Bay; 2, Ise–Mikawa Bays; 3, Inland Sea–Hibiki Nada; 4, Omura Bay; and 5, Ariake Sound–Tachibana Bay. Location of stationary acoustic monitoring system within Kanmon Strait (●).

even recently.[10] According to this record, 10 finless porpoise were found dead and one Risso's dolphin was found alive inside the channel from May 2005 to July 2007.

However, the local movement pattern of finless porpoises through the Kanmon Strait is still unknown because of the low visibility of this species. The finless porpoise has no dorsal fin. Their behavior tends to be not energetic as that of dolphins.[1] Kanmon Strait is one of the most crowded international sea lanes in Japan. Shipping traffic creates waves that hinder the observation of watermarks caused by the respiration of porpoises. Shirakihara *et al.*[8] reported that the crews of ferry boats running across the pass had seen the porpoises. We addressed the questions of when and how frequently finless porpoises swim through the Kanmon Strait. We used an automatic acoustic monitoring system, which has previously been used in the detection of sonar signals of riverine finless porpoises.[11] Kanmon Strait is one of the ideal acoustical observation points for finless porpoises because of the narrow channel and low visibility of the target animal due to heavy shipping traffic.

The target animal observed acoustically in the present study is most likely the finless porpoise even though other odontocetes also produce high-frequency ultrasonic pulse signals,[12] as do finless porpoises. Other species such as bottlenose dolphin *Tursiops truncates* has been observed in the Kanmon Strait and adjacent waters, although rarely.[10] As described before, most of the stranding records inside the strait were finless porpoises.[9,10] According to local ship-based observation records,[10] finless porpoises were observed during every survey on both sides of the Kanmon Strait, but other species were rarely observed.

MATERIALS AND METHODS

The presence and swimming direction of finless porpoises in the Kanmon Strait, located in western Japan between the islands of Honshu and Kyushu, were monitored using a passive acoustic data logger referred to as A-tag (W20-ASII, Little Leonardo, Tokyo, Japan) during March 2005 to March 2006. The A-tag was tightly fixed to an iron anchor on the sea bottom at the Kyushu Island side of the narrowest stretch of the Kanmon Strait (33°54′ 57.5″N, 130°56′ 06.8″E) at a depth of 5 m (Fig. 1). It was deployed and recovered by divers.

The A-tag is an event recorder that measures the sound pressure level of ultrasonic pulses within the dynamic range of 136.1–160.7 dB peak-to-peak (p–p) (reference sound pressure, 1 μPa). The stereo hydrophones (MHP-140, Marine Micro Technology, Saitama, Japan) had a resonant frequency of 140 kHz, which is close to the dominant frequency of sonar signals of the finless porpoise.[13] The sound arrival time difference between two hydrophones located 10 cm apart allowed the identification of the sound source direction. The direction of the two hydrophones was fixed along the coastal line along the strait. The primary hydrophone was directed west and the secondary hydrophone was directed east. The lifetime of the A-tag was 4 weeks using two alkaline UM-1 battery cells in a pressure-resistant housing. To ensure data recovery, each deployment period was 2 weeks.

In the off-line analysis, double-stage filtering was used. In the first stage, lower level signals <143 dB p–p were eliminated. Because of intense ship noise and biological sounds such as snapping shrimp, a higher detection threshold was needed to improve the visibility of the sonar signals during the analysis. The high detection threshold level reduced the detection distance to as low as 8–126 m, assuming source levels ranging 163.7–185.6 dB p–p.[14]

In second-stage filtering, pulse trains that had regular interpulse intervals were extracted. The interpulse intervals of biological sonar sounds change gently, whereas those of noise created by waves, bubbles and snapping shrimp are irregular. Regularity was defined as successive interpulse intervals that change between 83 and 120%. The definition of regularity was more conservative than that used by Akamatsu *et al.*[15] for Yangtze finless porpoise. Very loud ship noises were still recorded even after double-stage filtering. These were used to count the number of ships passing close to the A-tag system.

The approach phase of pulse trains was examined. The approach phase is commonly observed during forging pursuit in the finless porpoise.[16]

Table 1 Periods of observation and number of acoustically detected animals in each period

Start	End	Days	No. porpoises (nighttime)	No. porpoises/day
17 Mar 2005	31 Mar 2005	14.0	10 (9)	0.71
23 Nov 2005	9 Dec 2005	16.1	11 (11)	0.68
5 Feb 2006	22 Feb 2006	17.0	5 (4)	0.29
22 Feb 2006	8 Mar 2006	14.0	1 (1)	0.07
8 Mar 2006	22 Mar 2006	14.1	10 (8)	0.71
	Total	75.2	37 (33)	0.49

A porpoise was detected once every two days on average.

During the approach phase, the interpulse interval decreases linearly to as low as a few milliseconds until the animal is close to the target. The number of approach phases detected is an indicator of prey pursuit behavior. Interpulse interval was used as the indicator of the sensing distance by echolocation in porpoises. The interpulse interval of sonar signals in dolphins proportionate to distance is sensed by echolocation.[17] Dolphins needs lag time to process each echo of the sonar signal.[18] Therefore, the distance sensed is estimated as the two-way sound-travel distance during the period of interpulse interval minus the lag time.

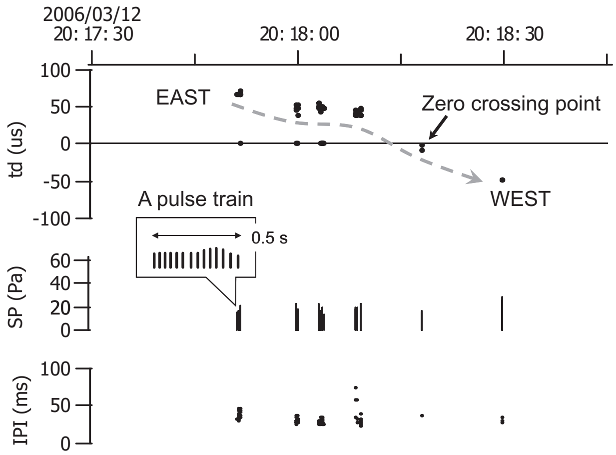

Fig. 2 Data indicating that a porpoise was swimming from east to west. Differences in arrival time of the sound at the stereo hydrophones (td) change from positive to negative, indicating that the sound source direction was moving from the Seto Inland Sea side to the Sea of Japan side of the strait, as indicated by the gray broken curve. Each pulse train shows smoothly changing sound pressure (SP) that had an interpulse interval (IPI) of approximately 30–40 ms. Some pulses had a completely zero time difference at the start of the recording, indicating that the received sound pressure was not strong enough to trigger the secondary hydrophone, even when the primary hydrophone received sound pressure greater than preset comparator level of the A-tag.

RESULTS

The A-tag was deployed in the Kanmon Strait for 75 days from March 2005 to March 2006 (Table 1). Many biosonar pulse trains were detected (Fig. 2). Biosonar signals could be identified by interpulse intervals of approximately 30–70 ms (lower inset of Fig. 2), which are typical of free-ranging finless porpoise.[13] Cetacean biosonar signals consist of several tens of pulses in a train (center magnified image of Fig. 2). The recorded noise was considered to come from passing cargo vessels and fishing boats (Fig. 3). It had randomly changing interpulse intervals and no distinctive train structure, making it easy to discriminate from biosonar signals.

The data on sound source direction allowed the enumeration of the number of animals. For example, a trace of changing time arrival differences corresponds to an individual that was swimming from east to west, i.e. from the Seto Inland Sea to the Sea of Japan (upper inset of Fig. 2). The detection time of the porpoise was defined as the point at which the time difference was nearly equal to zero, i.e. the zero crossing point. At that moment, the animal was positioned on one side of the data logger, perpendicular to the baseline of the two hydrophones. In the case of the detection of a single pulse train, the swimming direction could not be identified and the time of the sonar signal detection was used. To avoid the double counting of animals, short traces within 3 min of each other were considered to represent the same animal. Porpoises can swim 232 m in 3 min, assuming a swimming speed of 1.29 m/s,[19] which is outside the estimated detection range of the A-tag.

In total, 37 animals were detected during the effective observation period. Of these 37 animals, 16 produced multiple click trains near the A-tag, allowing the determination of swimming direction (Fig. 2, upper inset). The remaining 21 animals produced a single click train or multiple trains that

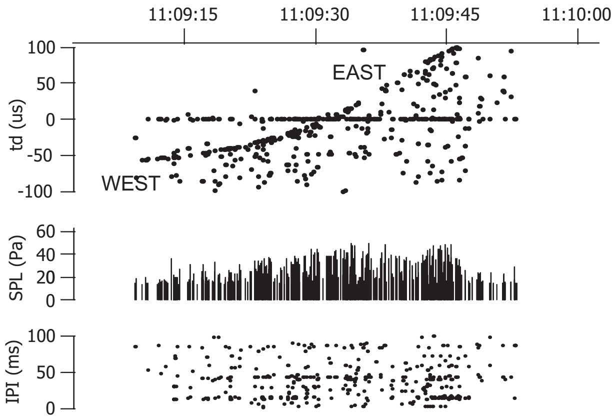

Fig. 3 Data indicating a ship passing from west to east, 14 March 2006. Various interpulse intervals occur within the sound, and no distinctive train sequence structure is observed. Continuous ship noise was created by bubbles around the rotating propellor. In some cases, the pulses had a completely zero time difference at the start of the recording, as shown in Figure 2.

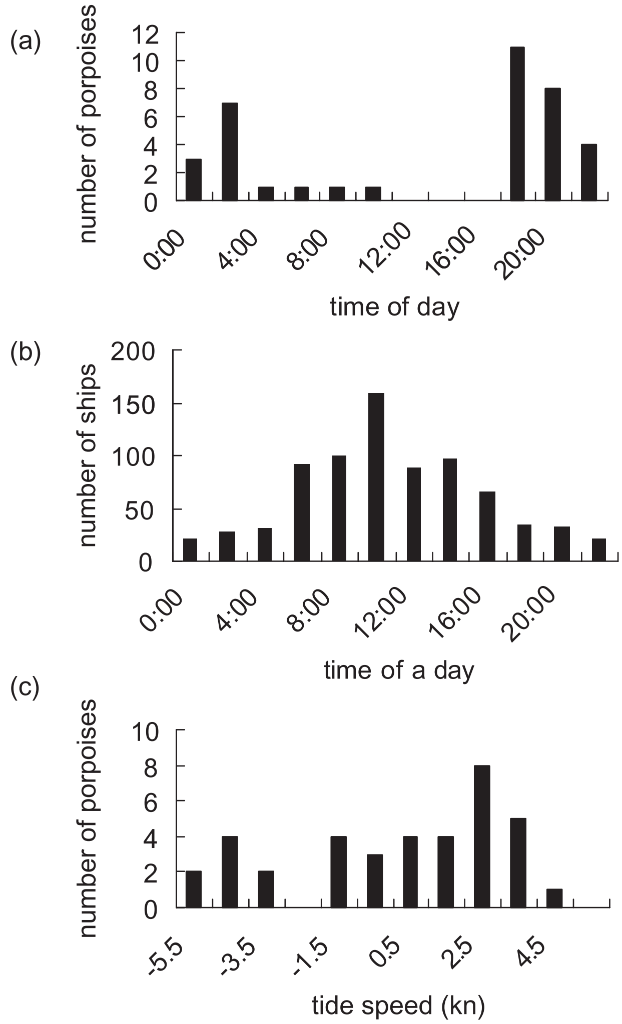

Fig. 4 The number of (a) finless porpoise detected and (b) ships recorded acoustically in each 2-h interval over the entire observation period, and (c) number of finless porpoise detected during various tidal current speeds. A positive current corresponds to a current direction from the Seto Inland Sea to the Sea of Japan.

had nearly constant time differences across the train sequence, which did not allow the acoustic determination of swimming direction.

Most of the porpoises were observed during the night and no porpoises were observed from 12:00 to 18:00 hours (Fig. 4a). Thirty-four of 37 finless porpoises were found in night. In contrast, shipping traffic during the 75 days, which was also recorded by the A-tag, was high during daytime hours (6:00–18:00 hours, Fig. 4b); it was highest at noon and lowest at midnight. Comparing between the tide table (2005 tide tables and 2006 tide tables, Japan and vicinities, Japan Coast Guard) and the presence of finless porpoises, the porpoises were recorded during tidal speeds up to 5.2 knots (2.68 m/s, Fig. 4c). They appeared in either a tidal direction to the west (positive) or east (negative). Acoustically detected swimming directions matched the current direction for 14 animals, but were opposite to the current direction for two animals. The swimming direction of animals significantly matched with the current direction ($P < 0.05$, binominal test).

The interpulse interval of the sonar signals ranged up to 90 ms (Fig. 5a), which is consistent with previous observations.[13,20] Three animals had interpulse intervals shorter than 5 ms, but no approach phase was observed. The duration of the sounding, which is defined as the period from the beginning to the end of a trace of time differences, was examined (Fig. 5b). It showed a bimodal distribution. Half (19) of the porpoises were used echolocation within 4 s during passing by the A-tag. Eighteen animals used echolocation for longer durations than 4 s, and 17 of them produced long-range sonar signals of more than 10 ms interpulse interval. Two of the 18 animals used an interpulse interval shorter than 10 ms with duration greater than 4 s. These animals could search over short distances and for long echolocation periods. The remaining animals searched over long distances or used sonar for short durations. To examine the isolation of each animal, the time differences between two successive detections are shown (Fig. 5c); 32 of 36 time differences were longer than 1 h apart. Short separations less than 10 min were 3.8–4.6 min apart.

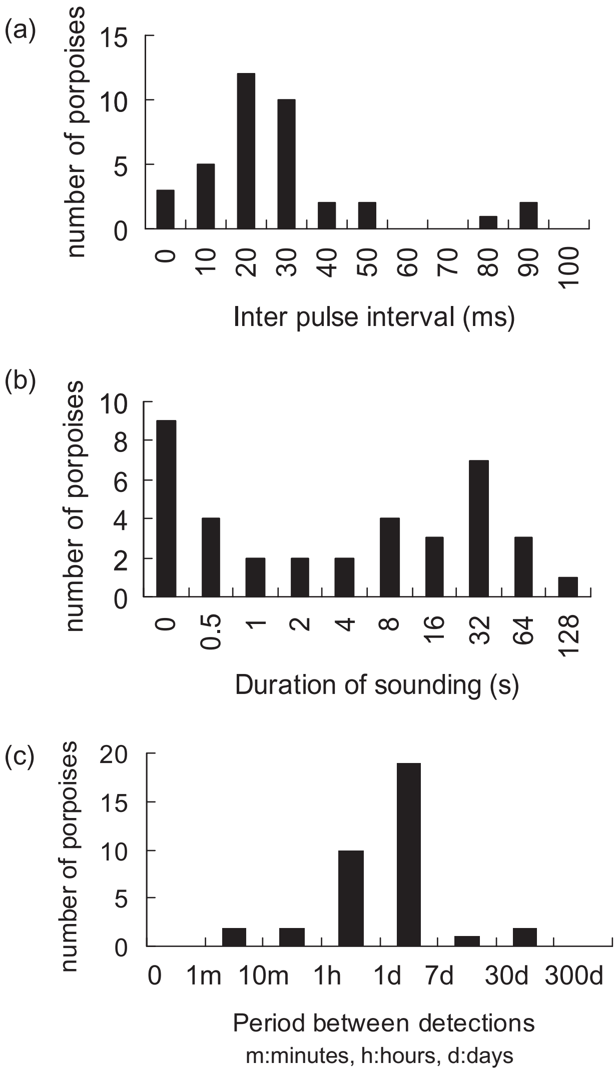

Fig. 5 Number of finless porpoises detected using sounding characteristics. (a) inter-pulse interval of the beginning of click trains, (b) duration between the detection of the first and last sounding. For a single train, duration is the period of a pulse train. For multiple trains, duration is the period between the beginning of the first train and the end of the last train, (c) time between two successive detections.

DISCUSSION

The stationary acoustic system successfully detected the presence of finless porpoises within the Kanmon Strait, where there have been very limited visual observations of the animal. Kanmon Strait is an international shipping lane. Heavy shipping traffic creates waves, even in calm weather, preventing the observation of the finless porpoise. Thus, stationary acoustic monitoring was powerful in identifying the animal's presence. Finless porpoise in the seminatural reserve at Shishou, Hubei, China, produce ultrasonic pulse-signal trains every 5.1 s on average,[16] and they swim no more than 20 m without producing sonar signals. Harbor porpoises, which belong to the same family as finless porpoises, also produce click trains every 12.3 s.[20] Porpoises do not swim more than several tens of meters without using sonar. Frequent sound production is essential for the high detection performance of passive acoustic monitoring. Porpoises are considered to be an appropriate species for passive acoustic monitoring because they avoid the major drawbacks of this methodology.

Most of the finless porpoises appeared at night, and no animal was detected in the afternoon before dusk (Fig. 4a). The diurnal pattern of presence was possibly driven by several factors. Shipping traffic is one candidate because it was high in the daytime and low at night (Fig. 4b). The presence of porpoises seemed to be negatively correlated with the number of ships near the observation system.

The effect of tidal current on movement was negative (Fig. 4c). Porpoises swam by the stationary observation system even up to 5.2 knots. The average and maximum swimming speeds of an adult finless porpoise are reported to be 1.29 and 3.74 m/s, respectively,[19] which correspond to 2.54 and 7.38 knots. Finless porpoises are physically able to swim against a current speed of 5.2 knots, which was the maximum current speed that occurred when a porpoises was detected. Finless porpoises may use the current to aid their movement from east to west or *vice versa* because 14 of 16 animals swam with the current. Due to the limited sample size, this hypothesis should be confirmed by using long-term monitoring data. Tidal level changes twice in a day. Therefore, it is not likely to assume the tidal current affected the nighttime presence of finless porpoises in the Kanmon Strait.

Prey species could also cause the diurnal presence of porpoises in the channel. Although we did not measure prey species simultaneously, the detected sonar behavior did not suggest the pursuit of prey. Sixty percent of the observed finless porpoises produced an interpulse interval of 20–40 ms (Fig. 5a), which indicates that the distance sensed was 11–26 m, assuming a 5-ms lag.[16] During the entire effective observation period, no approach phase was observed. All of the animals swam separately because successive observations were longer than 3 min apart. These animals appeared to be isolated and used relatively long-range sonar without focusing on a specific target. This suggests that most of these finless porpoises passed through the Kanmon Strait without capturing prey.

The acoustically detected sonar signals are considered to be from finless porpoises. In addition to the rare presence of other species in the study area, the observed group size of the present study was single individuals, which is consistent with the description of this species. Other species such as bottlenose dolphin and Risso's dolphin have group sizes that range from less than 20 to several hundred individuals.[1] The detection range of the A-tag was at most 126 m. This covered only 20% of the width of the channel. Regardless, these data suggest the frequent movement of this species through the strait. It is difficult to assume that other species frequently passed near the acoustic system without being observed. Thus, a very small portion of the present detection data might include other species, but most of the recordings are considered to be of finless porpoises.

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REFERENCES

1. Jefferson TA, Leatherwood S, Webber MA. *Marine Mammals of the World, United Nations Environment Programme*. Food and Agriculture Organization of the United Nations, London. 1993; 192–193.
2. Shirakihara K. A questionnaire survey on the distribution of the finless porpoise, (*Neophocaena phocaenoides*), in Japanese waters. *Mar. Mamm. Sci.* 1992; **8**: 160–164.
3. Yoshida H, Shirakihara K, Shirakihara M, Takemura A. Geographic variation in the skull morphology of the finless porpoise *Neophocaena phocaenoides* in Japanese waters. *Fish. Sci.* 1995; **61**: 555–558.
4. Yoshida H. Population structure of finless porpoises (*Neophocaena phocaenoides*) in coastal waters of Japan. *Raffles Bull. Zool.* 2002; **10** (Suppl.): 35–42.
5. Shirakihara M, Shirakihara K, Takemura A. Distribution and seasonal density of the finless porpoise *Neophocaena phocaenoides* in the coastal waters of western Kyushu, Japan. *Fish. Sci.* 1994; **60**: 41–46.
6. Kasuya T, Yamamoto Y, Iwatsuki T. Abundance decline in the finless porpoise population in the Inland Sea of Japan. *Raffles Bull. Zool.* 2002; **10** (Suppl.): 57–65.
7. Shirakihara K, Shirakihara M, Yamamoto Y. Distribution and abundance of finless porpoise in the Inland Sea of Japan. *Mar. Biol.* 2007; **150**: 1025–1032.
8. Shirakihara M. Shirakihara K, Takemura A. Records of the finless porpoise (*Neophocaena phocaenoides*) in the waters adjacent to Kanmon pass, Japan. *Mar. Mamm. Sci.* 1992; **8**: 82–85.
9. Nakamura K, Sakakibara S, Abel G, Tatsukawa T, Mizushima K, Wada M, Doi H, Kikuchi T. Notes on strandings and incidental catch of finless porpoise *Neophocaena phocaenoides* in coastal waters of Yamaguchi and Fukuoka prefecture, Western Japan. *Nihonkai Cetol. Res.* 2003; **13**: 13–18 (in Japanese).
10. Kaikyokan Whale Volunteer. *Stranding records (2005–2007).* Kujirabu letter, vol. 1–7. Shimonoseki Aquarium, Shimonoseki. 2007. (in Japanese).
11. Wang K, Wang D, Akamatsu T, Li S, Xiao J. A passive acoustical monitoring method applied to observation and group size estimation of finless porpoises. *J. Acoust. Soc. Am.* 2005; **118**: 1180–1185.
12. Richardson WJ, Greene CR Jr, Malme CI, Thomson DH. *Marine Mammals and Noise*. Academic Press, San Diego, CA. 1995.
13. Akamatsu T, Wang D, Nakamura K, Wang K. Echolocation range of captive and free-ranging baiji (*Lipotes vexillifer*), finless porpoise (*Neophocaena phocaenoides*) and bottlenose dolphin (*Tursiops truncatus*). *J. Acoust. Soc. Am.* 1998; **104**: 2511–2516.
14. Li S, Wang D, Wang K, Akamatsu T. Sonar gain control in echolocating finless porpoises (*Neophocaena phocaenoides*) in an open water. *J. Acoust. Soc. Am.* 2006; **120**: 1803–1806.
15. Akamatsu T, Wang D, Wang K, Wei Z. Comparison between visual and passive acoustic detection of finless porpoises in the Yangtze River, China. *J. Acoust. Soc. Am.* 2001; **109**: 1723–1727.
16. Akamatsu T, Wang D, Wang K, Naito Y. Biosonar behaviour of free-ranging porpoises. *Proc. R. Soc. Lond. B Biol. Sci.* 2005; **272**: 797–801.
17. Thomas JA, Turl CW. Echolocation characteristics and range detection threshold of a false killer whale (*Pseudorca crassidens*). In: Thomas JA, Kastelein RA (eds). *Sensory abilities of cetaceans: laboratory and field evidence.* Plenum Press, New York, NY. 1990; 321–334.
18. Au WWL. *The Sonar of Dolphins*. Springer-Verlag, New York, NY. 1993.
19. Akamatsu T, Wang D, Wang K, Wei Z, Zhao Q, Naito Y. Diving behavior of freshwater finless porpoises (*Neophocaena phocaenoides*) in an oxbow of the Yangtze River, China. *ICES J. Mar. Sci.* 2002; **59**: 438–443.
20. Akamatsu T, Teilmann J, Miller LA, Tougaard J, Dietz R, Wang D, Wang K, Siebert U, Naito Y. Comparison of echolocation behaviour between coastal and riverine porpoises. *Deep-Sea Res. II* 2007; **54**: 290–297.