Full paper

SATELLITE TRACKING OF COASTAL BRYDE'S WHALES *BALAENOPTERA EDENI* ALONG THE SOUTHWEST COAST OF JAPAN

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Abstract

To examine the movements of Bryde's whales, *Balaenoptera edeni*, in coastal waters off Japan, satellite tagging was conducted off Kochi, the southwest coast of Tosa Bay from 2004 to 2008, and off Nomaike, on the southwest coast of the Satsuma Peninsula in 2005. Using an air gun, an Argos satellite tag was attached on the animal from a whale watching boat. A total of 20 shots were taken at 17 individuals, and tags were successfully attached to 11. Geographical locations from the Argos Satellite were obtained from seven animals. The maximum tracking period was 30 days in Tosa Bay, and 40 days off Nomaike. Most individuals stayed in the same waters for at least several weeks in the summer season (July to August). However, one individual moved from Tosa Bay to the Kii Peninsula, and one from Nomaike to the Goto Islands in the East China Sea. No animals moved to the offshore waters across the Kuroshio Current. This result supports the current classification of the stock of coastal Bryde's whales (the East China Sea Stock). Further technical improvements are necessary to increase the tagging success rates and extend the tracking period to investigate movements and distributional ranges of Bryde's whales in the coastal waters off Japan.

Key words Coastal Bryde's Whale, Satellite Tracking, Movement.

Introduction

Bryde's whales *Balaenoptera edeni* are distributed worldwide in warm temperate oceans between around 40° N to 40° S (Omura, 1959). Currently, at least two genetically distinct forms are recognized (Kato and Perrin, 2009, 2017): coastal Bryde's whales (*B.e.edeni*) and offshore Bryde's whales (*B.e.brydei*). Coastal Bryde's whales are distributed in coastal waters around southwest Japan and have been utilized in commercial whale watching activities by the local fishermen in southwestern Tosa Bay, Kochi prefecture since 1989, and in Nomaike, on the southwest coast of the Satsuma Peninsula, Kagoshima prefecture since around 1996 (Morioka, 2000). Offshore Bryde's whales are distributed broadly in offshore waters from the equator to around 40° N in the western North Pacific.

To elucidate the status and stock structure of the coastal Bryde's whales around Kochi and Kagoshima, several studies have been carried out using line transect shipboard sighting surveys, as well as photo-identification studies, and genetic analyses. The results of these surveys and studies indicated that Bryde's whales off Kochi and Kagoshima are an isolated coastal population isolated from the offshore Bryde's whales, separated by the Kuroshio Current (Kato *et al*., 1996; Kishiro *et al*., 1997; Yoshida and Kato, 1999; Kato and Kishiro, 1999). Bryde's whales off Kochi are sighted within 15 nautical miles from the southwest coast of Tosa Bay year round and have apparent seasonal changes

in density with a peak in the summer season (Kishiro *et al*., 1997). Bryde's whales near Kagoshima are sighted in the regional waters between Koshiki Island and off Nomaike, and are also frequently sighted during the summer season (Kato and Kishiro, 1999). However questions concerning the seasonal movements and distributional range of Bryde's whales remain.

The satellite telemetry technique is one efficient way to investigate the migration of marine mammals, and recent development in tagging techniques have increased the opportunity to investigate animal movements (Mate *et al*., 2007; Heide-Jørgensen *et al*., 2001). To examine individual movements and distributional ranges of Bryde's whales in the coastal waters off Japan, this study applied this technique to track tagged Bryde's whales off Kochi and Kagoshima.

An earlier version of the present paper was consisting of the author's doctoral thesis submitted to Tokyo University of Marine Science and Technology.

Materials and Methods

Study area and shipboard surveys

The two study areas off Nomaike, Kagoshima (a) and off Kochi (b) are shown in Figure 1. Both

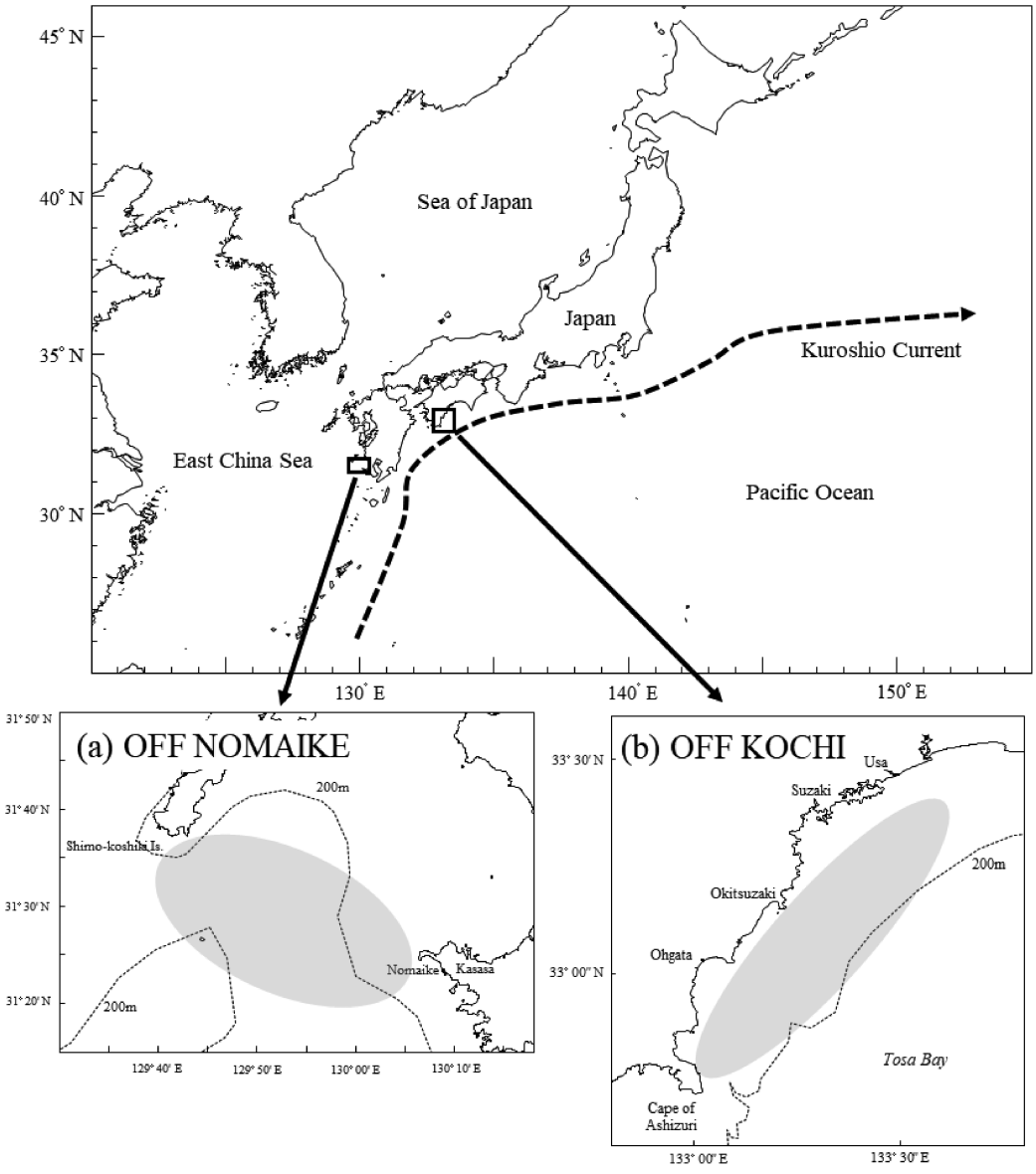

Fig. 1. Geographic map of the study area and the main whale watching grounds (shaded area) for Bryde's whales off the southwest coast of Japan.

areas are known as commercial whale watching areas for Bryde's whales.

Shipboard surveys were carried out using local whale watching boats (5 to 12 GT) off Kochi from 2000 to 2015 and off Nomaike from 2001 to 2005. Each survey lasted 3 to 14 days in the summer season (July to August), which was thought to be the peak migration of the whales in both areas (Kato and Kishiro, 1999). During a survey, 2 to 5 boats were used simultaneously, with 1 to 3 researchers on board each vessel. The vessel GPS locations, sea surface temperature, and sea weather conditions were recorded every 15 minutes during the cruises. Using 7×50 binoculars and the naked eye, searching was carried out non-randomly. Search area and route of individual vessels was determined daily based on the weather conditions and sighting information from commercial vessels. When a whale was sighted, the vessels approached to confirm species identification, record the GPS position, determine group size and behaviors, and take photographs for individual identification.

Tagging device and tracking methods

As a part of the shipboard surveys, satellite tagging was attempted in the waters off Kochi from 2004 to 2008, and off Nomaike in 2005. As per agreement with local whale watching operators, the number of whales to be tagged was pre-determined to be 2–3 animals per year in the respective waters.

A Spot-5 implantable tag with a two-month battery life (Wildlife Computers, USA) was used as the Argos transmitter. A 40 mm air gun (Miroku Machinery Co. Ltd, Japan) was used for tagging (Fig. 2), with the filling pressure set to 110 kgf/cm^2. The forecastle deck was used as the tagging platform. The tagging dart used in this study consisted of a dart with a 3-bladed tip, an Argos transmitter, and retrievable float (Fig. 3). The float was connected to the dart by a water-soluble string. When the dart hit the

Fig. 2. Air gun used for attachment of the satellite tags from 2004 to 2008.

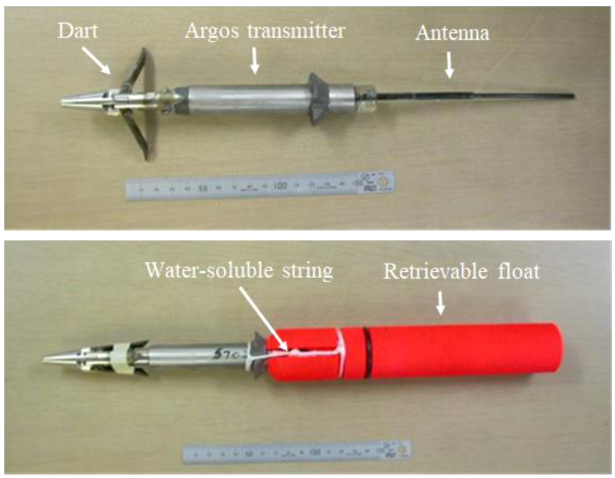

Fig. 3. The satellite tag used for Bryde's whales from 2004 to 2008. Upper photograph indicates Argos transmitter with a dart. Lower photograph indicates the tag with a retrievable float.

whale, it was embedded through the blubber into the muscle, the string dissolved, the float detached, and the antenna of the transmitter was exposed on the body surface. When the target was missed, the dart floated on the sea surface and was then retrieved by a hand net. The dart was coated with povidone iodine to reduce physical damage and potential infection caused by tagging. The tracking data from tagged animals were obtained from the Argos satellite.

Animal tagging was carried out following the basic guidelines of the 3R principle for animal experiments in Japan issued by the Ministry of Agriculture, Forestry and Fisheries.

Results

Tagging results

A total of 20 tagging attempts were carried out, and 11 tags were successfully attached on 11 whales. In Tosa Bay (off Kochi), a total of 12 shots were made at 12 individuals from 2004 to 2008. Among them, 10 darts hit their target, and nine transmitters were successfully attached. For successful tagging, the chase time ranged from 5 to 23 minutes (mean: 14.7 minutes), and shooting distance ranged from 5 to 6 m (mean: 5.3 m). When the darts missed the target, the chase time ranged from 6 to 62 minutes (mean: 33.0 minutes), and shooting distance ranged from 5 to 10 m (mean: 7.6 m).

Off Nomaike, a total of eight shots were taken at five individuals in 2005, and two individuals were successfully tagged. For successful tagging, chase time ranged from 6 to 11 minutes (mean: 8.5 minutes), and shooting distance was 7 m. When the darts missed, chase time ranged from 3 to 79 minutes (mean: 33.5 minutes), and shooting distance ranged from 7 to 10 m (mean: 8.2 m) (Table 1).

Table 1. Results of the tagging for Bryde's whales in Tosa Bay and off Nomaike from 2004 to 2008.

Area	Whale ID	Shooting Date	Shooting Time	Argos ID	School size	Sea state*	Time for chasing (minutes)	Shooting distance (m)	Verdicts	Transmitter attached
Tosa Bay	–	18 Jul. 2004	12:31	49483	1	3	31	10	Hit	Lost
	#1	20 Jul. 2004	14:38	49482	1	3	17	6	Hit	Fix
	#2	16 Jul. 2005	14:40	57022	2	2	5	5	Hit	Fix
	#3	16 Jul. 2005	14:56	57023	2	2	16	5	Hit	Fix
	–	20 Jul. 2005	16:02	–	2	2	6	8	Ricochet	Retrive
	#4	20 Jul. 2005	16:20	57021	2	2	10	6	Hit	Fix
	#5	24 Jul. 2006	13:54	64634	1	3	18	5	Hit	Fix
	#6	24 Jul. 2006	15:57	64635	1	2	23	5	Hit	Fix
	#7	25 Aug. 2006	12:05	64636	2	2	14	5	Hit	Fix
	–	11 Aug. 2007	12:40	–	1	3	62	5	Miss	Retrive
	#8	11 Aug. 2007	16:21	64637	1	2	21	5	Hit	Fix
	#9	31 Aug. 2008	15:18	64639	1	3	8	6	Hit	Fix
Off Nomaike	–	10 Aug. 2005	9:26	–	1	2	5	7	Miss	Retrive
	–	10 Aug. 2005	11:17	–	same ind.	2	56	7	Miss	Retrive
	–	10 Aug. 2005	13:56	–	1	2	5	10	Miss	Retrive
	#10	11 Aug. 2005	12:29	57026	1	1	11	7	Hit	Fix
	–	13 Aug. 2005	10:28	–	2	2	3	9	Miss	Retrive
	–	13 Aug. 2005	11:18	–	same ind.	2	53	9	Miss	Retrive
	–	13 Aug. 2005	11:44	–	same ind.	3	79	7	Miss	Retrive
	#11	13 Aug. 2005	12:53	57025	1	3	6	7	Hit	Fix

* Beaufort scale

Fig. 4. Example of the tag attachment on a Bryde's whale. The tag was attached on 20 July 2004 in Tosa Bay (whale #1), and photographed on 23 July 2004.

Tags were attached on either side of the body anterior to the dorsal fin (Fig. 4). All targeted whales swam quickly during chasing, and no behavioral change was observed during or after the tagging operation.

Transmission received by the Argos Satellite

Table 2 summarizes the results of tag transmissions received by the Argos Satellite. Although 11 tags were successfully deployed, only ten tags transmitted signals that were received by the satellite, and no signal was obtained from one tag (whale #3). For the ten active tags, the time period between tag attachment and final reception of the signals lasted from 1 to 40 days, and the number of transmission signals ranged from 2 to 191 (Fig. 5). From this signal data, geographic locations were obtained 17 times from five animals in Tosa Bay, and 19 times from two animals off Nomaike. The accuracy for these locations was classified and recorded as class 0 (one time), class A (14 times), and class B (21 times) by the Argos data collection and location system. According to the accuracy from a past calibration study (class 0: ≥1 km; class A: ≤46 km; class B: ≤73 km (Baba et al., 1997)), the accuracy of this study ranged from 1 km to 73 km.

Table 2. The number of transmission signals received, and locations estimated by the Argos satellite from Bryde's whales tagged in Tosa Bay and off Nomaike from 2004 to 2008.

Area	Whale ID	Tagging date	Argos ID	Reception period (days)	No. of signals received	Tracking period (days)	No. of locations estimated	Accuracy class		
								0	A	B
Tosa Bay	#1	20 Jul. 2004	49482	4	10	4	4	0	2	2
	#2	16 Jul. 2005	57022	34	81	30	1	0	1	0
	#3	16 Jul. 2005	57023	0	0	–	–	–	–	–
	#4	20 Jul. 2005	57021	5	37	0	0	–	–	–
	#5	24 Jul. 2006	64634	4	17	4	3	0	3	0
	#6	24 Jul. 2006	64635	7	2	0	0	–	–	–
	#7	25 Aug. 2006	64636	1	6	0	0	–	–	–
	#8	11 Aug. 2007	64637	15	41	13	5	1	2	2
	#9	31 Aug. 2008	64639	2	20	2	4	0	2	2
Off Nomaike	#10	11 Aug. 2005	57026	4	10	2	1	0	0	1
	#11	13 Aug. 2005	57025	40	191	40	18	0	4	14

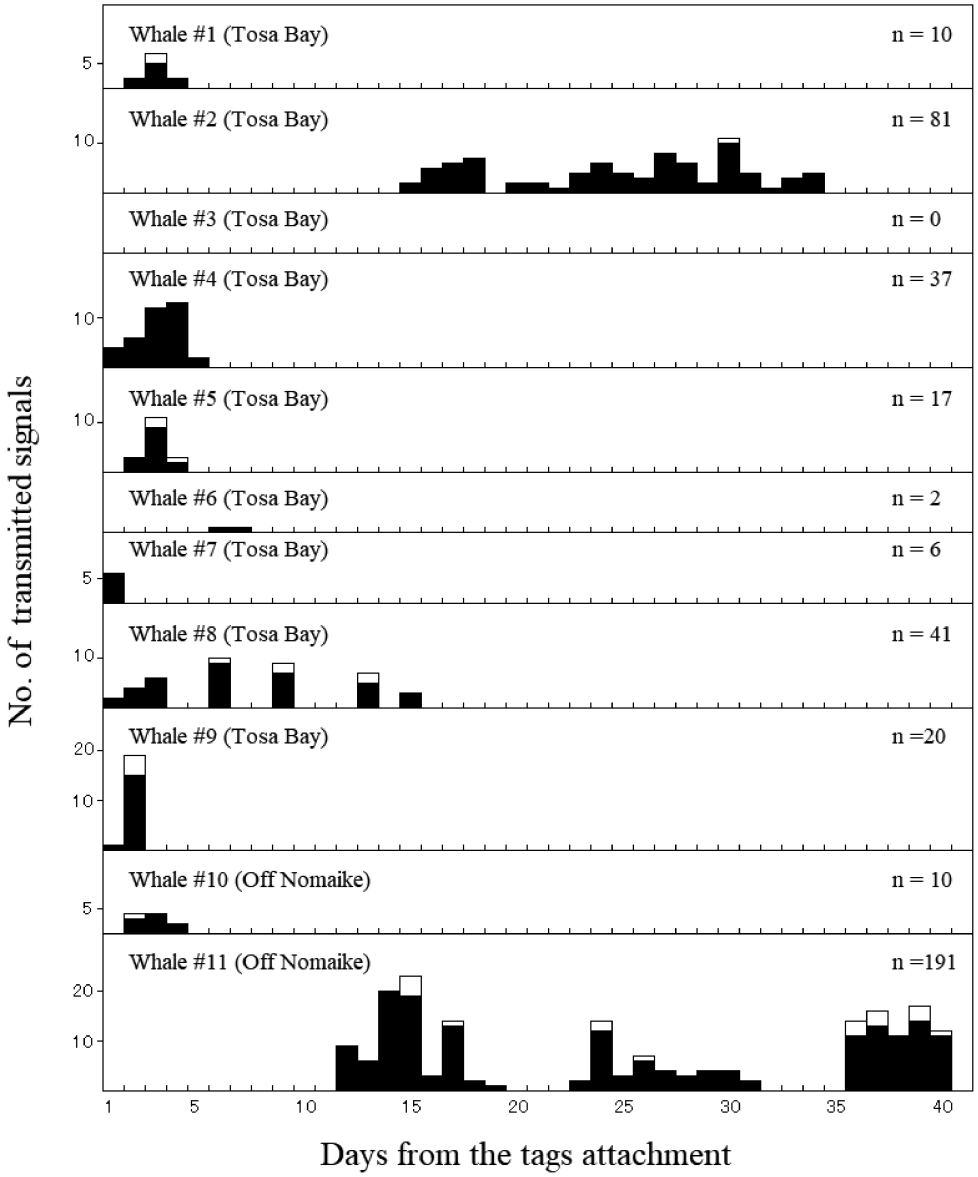

Fig. 5. Frequency distribution of the transmitted signals received by the Argos satellite, with days from tag attachment on Bryde's whales. Open bar: Location was determined; closed bar: Only reception.

Geographical movements of tagged animals

Four out of five animals tagged in Tosa Bay (whale #1, #2, #5, and #9: Fig. 6 a-d) stayed in the Bay throughout the transmission period (2 to 30 days). One animal tagged in the Bay on 11 August 2007 (whale #8) moved out of the Bay, moving eastward and reaching the east coast of the Kii Peninsula (off Owase) on 19 August, nine days after tagging. It then turned westward and returned to the Bay by 23 August (Fig. 6 e).

Off Nomaike, two individuals were tracked (Fig. 7 a-b). One individual (whale #10) was located near the tagging site the next day; however, no location could be determined after that, even though transmitted signals were sporadically received until two days later. Another individual (whale #11) was tracked for 40 days after tagging. After staying near the tagging site for 15 days (13 to 27 August), #11 moved to the Goto Islands then returned to near the tagging site (29 August), and stayed in this vicinity until transmitting signals were lost on 21 September.

Re-sightings of tagged animals

One tagged individual (whale #1) was re-sighted during the transmitting period (Fig. 6 a). The loca-

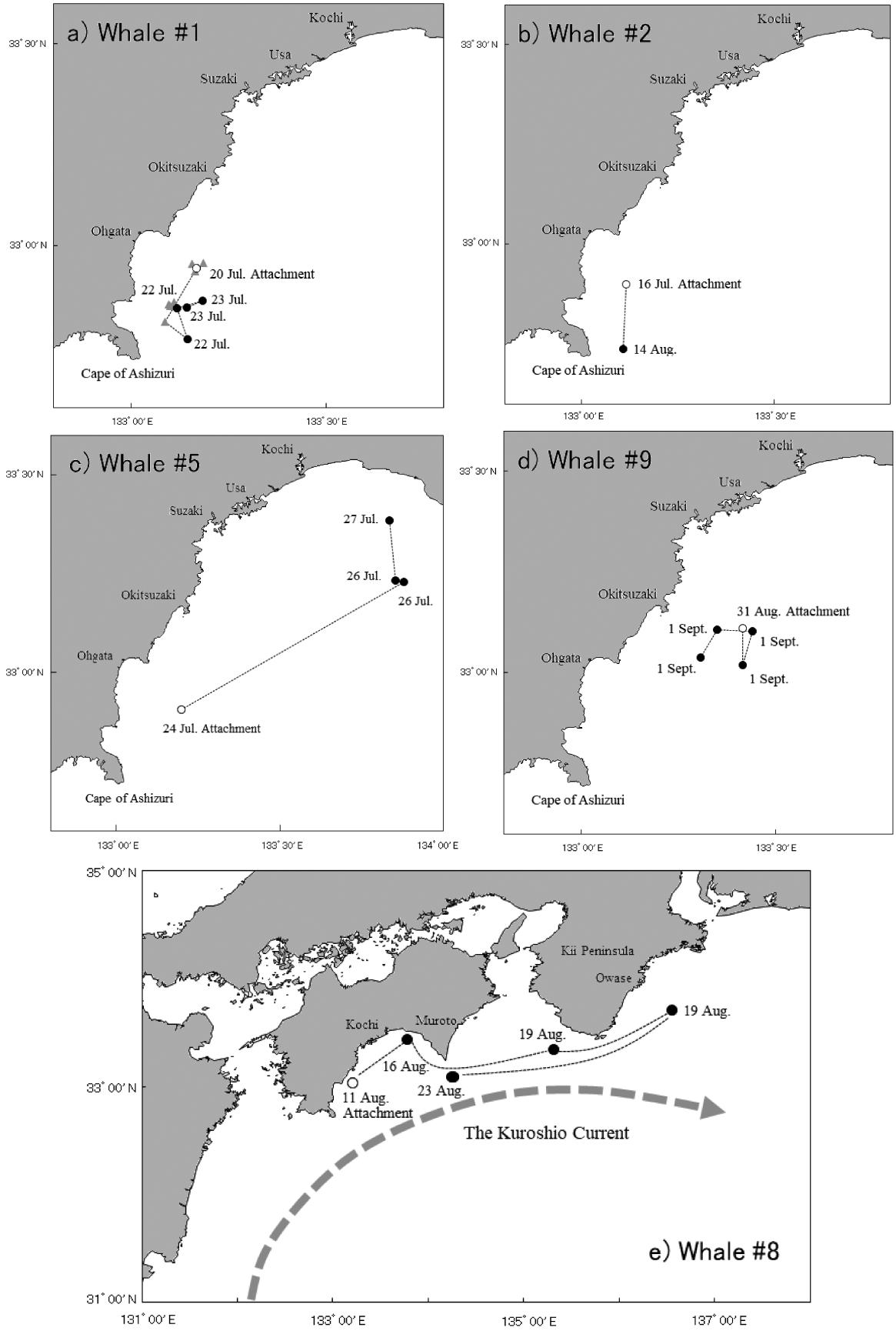

Fig. 6. Satellite-based movements of five Bryde's whales tagged in Tosa Bay in 2004 (whale #1), 2005 (whale #2), 2006 (whale #5), 2007 (whale #8), and 2008 (whale #9). Open circles: Positions at tag attachment; closed circle: Positions determined by the Argos satellite; grey triangle: re-sighting positions during the transmitting period.

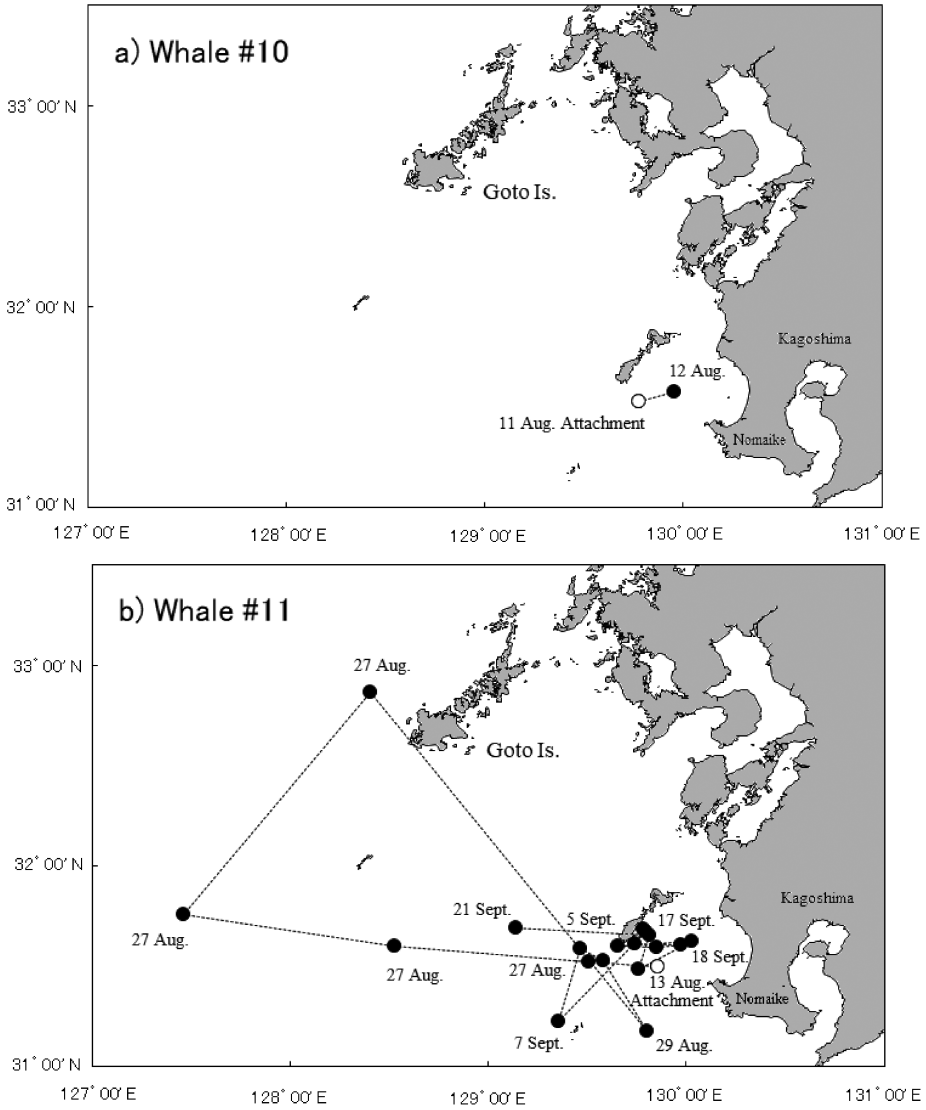

Fig. 7. Satellite-based movements of two Bryde's whales tagged in the waters off Nomaike in 2005 (whale #10 and #11). Open circles: Positions at tag attachment; closed circle: Positions estimated by the Argos satellite.

tions determined by transmitted signals (accuracy class A and B) coincided well with actual sighted positions of the whale.

Two tagged individuals in Tosa Bay were re-sighted years later. Whale #2 was tagged on 16 July 2005, and was re-sighted on 6 August 2007 and again on 23 and 27 July 2008 in the Bay. Whale #4 was tagged on 20 July 2005, and re-sighted on 22 August 2006 and 6 August 2007 in the Bay. These re-sightings were determined by Photo-ID (Fig. 8), and it was noted that the tags had fallen off. Tagging scars on the body had healed similarly to old cookie-cutter shark bites (Fig. 8). Animals did not show any behavioral changes. No problems were observed by approaching the whales in the whale watching boat, and one (whale #4) remained calm during a 70-minute observation. Whale #2 associated with another individual, and both animals remained calm during observations. These instances suggested that tagging impacts were not severe or lasting in these animals.

Discussion

The trials and results reported in the present study are the first attempt at the satellite tracking of Bryde's whales in the coastal waters off Japan. Although the number of transmitted signals was small

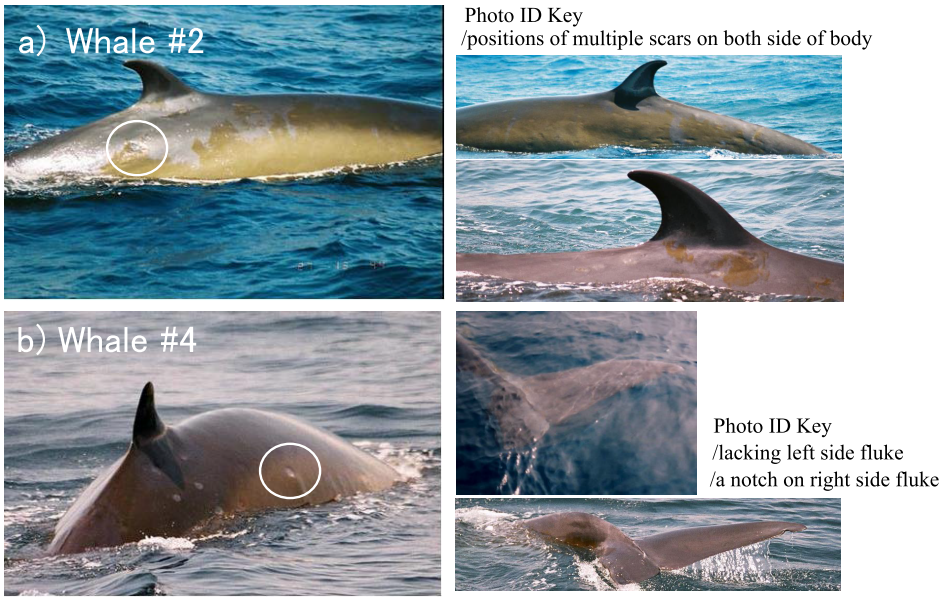

Fig. 8. Re-sightings of two tagged Bryde's whales in Tosa Bay, with photo ID keys to identify the animals. White circles indicate the tagging site of the whales. a) whale #2: Tagged on 16 July 2005, and re-sighted on 27 July 2008; b) whale #4: Tagged on 20 July 2005, and re-sighted on 22 August 2006.

and the tracking period was short, the results suggested that the Bryde's whales in the coastal waters did not move long distances, and possibly stayed in Tosa Bay and off Nomaike for at least several weeks during the summer season (Figs. 6 and 7). East-west movements of one animal from Tosa Bay to the Kii Peninsula indicated that whales could move beyond the Bay, and their distributional range possibly expands around the Kii Peninsula along the Pacific coastline. Movements of one animal off Nomaike to the Goto Islands indicated that the distributional range is possibly wider than the regional waters off Nomaike in the East China Sea. Both results revealed that the whales stayed in the same general location, with occasional movements to a wider area than the regional waters of Tosa Bay and Nomaike.

In the western part of the North Pacific, the Scientific Committee of the International Whaling Commission (IWC) sets two management stocks for the Bryde's whales: the western North Pacific stock and the East China Sea Stock (International Whaling Commission, 1997). The western North Pacific stock corresponds to the offshore Bryde's whales distributed in a broad area from the equator to around 40° N and west of 160° W in the North Pacific. The East China Sea Stock corresponds to whales distributed in the East China Sea. Based on previous studies, the Bryde's whales off Kochi (in Tosa Bay) have been treated as an extension of the East China Sea stock, and their range is thought to expand to at least off Kochi in Tosa Bay (Kato *et al*., 1996; Kishiro *et al*., 1997; Yoshida and Kato, 1999; Kato and Kishiro, 1999). However, the tracking results from this study (whale #8) imply that the northern limit of their range might expand beyond Tosa Bay, with possible migrations along the coast to the Kii Peninsula. If so, it would be necessary to re-consider their range to improve management of the East China Sea stock.

Based on the sighting distributions, Kato and Kishiro (1999) suggest that the warm Kuroshio Current acts as a physical barrier between the two stocks. No whales tagged in this study crossed the Kuroshio Current towards the offshore waters in the western North Pacific region. Although the sample size was small, this result may support the IWC stock classification and suggestion for the Kuroshio as the barrier between the two stocks.

In this study, transmitted signals from the tags and resultant estimated locations were sporadic, and poor reception by the satellite decreased the accuracy of the estimations. One possible reason might

be mechanical trouble with the tag caused by the physical shock of deployment or striking the whale body. Another reason might be the location of tag attachment on the body. In this study, the tags were mainly attached near the base of the dorsal fin. However, the base of the dorsal fin emerges just before long dives, and is not as frequently exposed compared to anterior parts of the body (around the blowhole). To estimate accurate locations, the satellite needs at least three successive transmitted signals while passing over the animal. The low frequency of tag exposure caused inadequate signal reception. If the tag could be attached more anteriorly, the transmission frequency might increase enough to improve uplink to the satellite.

To elucidate the movements of the whales after the summer season, a longer tracking period is desired; unfortunately, the maximum tracking period was 30 days in Tosa bay, and 40 days off Nomaike. It is presumed that tags fell off of individuals after the last signal transmission. To extend the longevity of the tags, further technical improvements to the dart, such as a modification of the shape and number of blades, introduction of a flexible mechanism in the anchor blades, and using adapted materials to prevent biological reactions will be needed. To control the pressure and depth of dart penetration, use of other shooting gear such as the Norwegian LK-Arts system (e.g. Heide-Jorgensen et al., 2001; Olsen et al., 2009) that can easily control the filling pressure may also be useful.

Increasing the tagging success rate and extension of the tracking period are desirable for future studies, and further improvements to the darts and shooting gear as mentioned above will be needed. It is important to continue to monitor whale movements and to build a larger dataset including a greater number of individuals. The accumulated data obtained could bring further insight into the movements and distributional ranges of Bryde's whales around Japan. In addition, if possible, simultaneous biopsy sampling and genetic analyses would be valuable for further elucidation and confirmation of stock structure.

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