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Forage-diving behaviour of adult Japanese female loggerhead turtles (*Caretta caretta*) inferred from Argos location data

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Adult female loggerhead sea turtles (*Caretta caretta*) nesting in Japan use different feeding habitats as a function of body size. The Argos location data of two females inhabiting either oceanic or neritic habitats were analysed to infer their foraging and diving behaviour. There were no significant differences in the number of transmissions received per satellite pass, the number of locations per day, and the frequency of location-accuracy classes between oceanic and neritic females, implying that there was little difference in the time these two turtles stayed at the sea surface. Two possible forage-diving behaviours are suggested for these turtles: (1) both dive duration and depth were not different between the two feeding habitats; or (2) although dive duration was not different between feeding habitats, dive depth was different.

Satellite tracking using the Argos system has frequently been used to examine movements of marine air-breathing animals. This system locates the animals based on signals sent from transmitters attached to their bodies when they breathe at the surface. Before animals dive longer, they must stay longer at the surface to gain more oxygen (Kramer, 1988). The longer the animals stay at the surface, the greater the numbers of transmissions received per satellite pass and of locations that are fixed, and those calculated locations should be more accurate (Plotkin, 1998; Hays et al., 1999). Based on these characteristics of Argos location data, we inferred foraging and diving behaviour of adult female loggerhead sea turtles (*Caretta caretta*) nesting in Japan which use different feeding habitats as a function of body size (Hatase et al., 2002).

Argos location data of two female loggerheads (Nos. 9903 and 9904) out of five females in Hatase et al. (2002) were used. Turtle 9903 inhabited the oceanic Pacific and was considered to feed on macroplankton, while Turtle 9904 inhabited the neritic East China Sea and was considered to feed on benthic invertebrates (Figure 1). The two females landed on beaches to nest at Minabe (33°46′N 135°18′E), Wakayama prefecture, Japan, on 28 and 29 July 1999, respectively. The straight carapace length, straight carapace width, and body mass for Turtle 9903 were 812 mm, 625 mm, and 64.0 kg, and those for Turtle 9904 were 812 mm, 663 mm, and 85.5 kg. Satellite transmitters (ST-18, Telonics Inc.) were attached on the carapace of the females. Transmitters had a pulse repetition frequency of 60 seconds. The duty cycle of the transmitter was set to be 8 hours on/16 hours off to save the battery life. The transmitter for Turtle 9903 was switched on at 0310 JST (Japan Standard Time), while that for Turtle 9904 at 2150 JST. Therefore, the location data from both turtles were obtained at night/early morning.

The Argos system classified the locations of the females into seven classes of decreasing accuracy: $<$150 m, 350 m, 1 km for the first three (3, 2, 1, respectively), with no limits of accuracy for the remaining four (0, A, B, Z). Locations with Classes 3–A were used to reconstruct the migratory route. Judging from adjacent locations, obviously erroneous locations were omitted from analysis. When more than one location was obtained within a particular day, the location with the most accurate class was adopted for the route reconstruction. The location data throughout the tracking period (87 locations during 145 days) were used for Turtle 9903, whereas those on and after 17 October 1999 (51 locations during 92 days), which were obtained from areas of 100–150 m depths in the East China Sea, were used for Turtle 9904 (Figure 1). We regarded those periods as their main foraging periods. The numbers of transmissions received per satellite pass for the oceanic and neritic females ranged from 2 to 9 and from 1 to 6, respectively, and the modal number was 2 for both females. Although the mean ($\pm$SD) number of transmissions received per satellite pass for the oceanic female (3.10 $\pm$1.53) was higher than that for the neritic female (2.61 $\pm$0.87), the difference was not significant (Mann–Whitney *U*-test, P=0.10). The numbers of locations per day for the oceanic and neritic females ranged from 0 to 4 and from 0 to 3, respectively, and the modal number was 0 for both females. Their mean ($\pm$SD) numbers of locations per day were 0.60 $\pm$0.95 and 0.55 $\pm$0.80, respectively, and the difference was not significant (Mann–Whitney *U*-test, P=0.92). Class B was the most dominant location accuracy for both females. Although higher location-accuracy classes were obtained more for the oceanic female, the frequencies of the classes were not significantly different between the two females (exact test, P=0.25).

The lack of significant differences in the location data between oceanic and neritic females implies that there was little difference in the time that these two females stayed at the sea surface in their foraging areas. Because dive duration is proportional to surface duration (Kramer, 1988), there also may not have been a difference in dive duration between them. Dive depth is positively related to dive duration in several diving animals (e.g. Le Bouef et al., 1988). Thus, the dive depth of the oceanic female may have been similar to that of the neritic female. Alternatively, the dive depth of the oceanic female may not be positively related to dive duration, as has been found in the Marbled Murrelet,

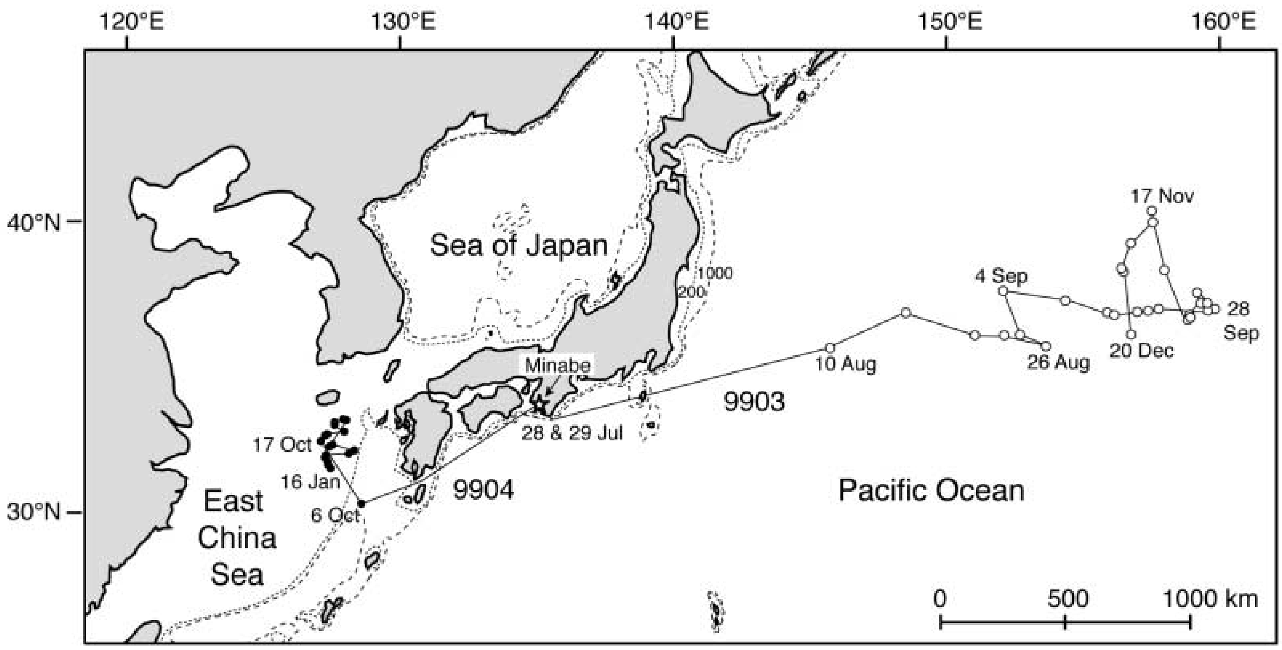

Figure 1. *Caretta caretta*. Post-nesting migratory routes of two adult female loggerhead turtles (Turtles 9903 and 9904) released from Minabe (star symbol), Japan, on 28 and 29 July 1999 (modified from Hatase et al., 2002). Broken lines indicate isobaths in metres.

Brachyramphus marmoratus (Jodice & Collopy, 1999). With this assumption, although the dive depth of the oceanic female may have been shallower than that of the neritic one, the dive duration of the oceanic one may have been similar to that of the neritic one. This diving behaviour of the oceanic female may have been related to the macroplankton distribution throughout the water column and so its dive depth could have changed according to the macroplankton distribution. In contrast, the neritic female foraged on benthic invertebrates at a fixed bottom depth.

Another reason for the lack of significant differences in location data between oceanic and neritic females may be that the data of both females were obtained at night/early morning, when turtles may be inactive from resting compared with in the middle of the day (Godley et al., 2003). Since sea-surface temperatures at oceanic locations (mean ±SD: 23.8 ±3.5°C) were significantly higher (t-test, $P<0.0001$) than those at neritic ones (21.2 ±1.9°C), this also could have caused the lack of significant differences in the location data as a result of metabolic differences. The oceanic female may have stayed longer at the surface to gain more oxygen because of the higher ambient temperatures. The inferences in this study must be verified in future studies by using new devices such as satellite relayed data loggers that can record multiple types of data such as dive depth, duration, profiles, and temperature, etc. (e.g. Hays et al., 2004).

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