

論文内容の要旨

論文題目

Diving behaviour of loggerhead turtles, *Caretta caretta*, migrating to the northern Pacific coast of Japan

(日本の北部太平洋沿岸域に來遊するアカウミガメ (*Caretta caretta*) の潜水行動に関する研究)

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Five out seven extant species of sea turtles are listed as either critically endangered or endangered in the IUCN Red List of Threatened Species in 2009. Threats potentially affecting the sea turtle populations exist both on the land (e.g. degradations in nesting beaches) and in the ocean (e.g. by-catch, pollution etc.). An extensive number of sea turtle studies have been conducted around the nesting beaches where mature females land to nest, accumulating information of nesting females and hatchlings. However, there is only limited information for other life stages of sea turtles, such as males and pre-mature turtles. Therefore, understanding biology of sea turtles is essential part for proper conservation of these endangered animals.

Sanriku, the northern Pacific coast of Japan, is known as one of the most nutrient-rich fishing grounds in the Japan. Although it is located far beyond north from the northern limit of nesting grounds of sea turtles, some turtles were often sighted by local fisherman during summer. Therefore, it is suggested that Sanriku coastal area provide seasonal habitat for sea turtles.

In the present study, firstly, 1) the demographic survey was conducted at Sanriku coastal area, the northern Pacific coast of Japan, and the occurrence of sea turtles

were reported. Secondly, to reveal underwater activities of loggerhead turtles in the study site, 2) three-dimensional movements were reconstructed by using multi-sensor data loggers. Then, 3) orientation behaviours during directional travel and 4) mid-water foraging behaviours were discussed.

1. Demographics of sea turtles at the northern Pacific coast of Japan

During 2005 and 2009, bycatch incidents within the range of approximately 40 km radius from the International Coastal Research Center, Ocean Research Institute, The University of Tokyo (39°21.05N, 141°54'05E) were reported. During the study periods, a total of 120 loggerhead turtles (*Caretta caretta*) and 39 green turtles (*Chelonia mydas*) were incidentally captured in the set net. Bycatch incidents were reported in the periods between June through October for loggerhead turtles, and between July through October for green turtles, suggesting the turtles seasonally migrate to the study site. The size of loggerhead turtles collected ranged from 49.5 to 88.4 cm in SCL (mean \pm s.d. = 70.4 \pm 6.4 cm, $N = 120$), which was relatively smaller than the size of adult females nesting in Japan. Therefore, it is assumed that loggerhead turtles migrating to the study site are either immature or mature turtles. On the other hand, the size of green turtles ranged from 40.7 to 85.6 cm (mean \pm s.d. = 48.6 \pm 10.9 cm, $N = 39$) in SCL, which was considerably smaller than nesting turtles, suggesting that green turtles in the study site are immature. In addition, there was a conspicuous extension in tail was observed in 4 loggerhead turtles (i.e. SCL > 70 cm, TL > 30 cm), of which were indicative of males. Therefore, it is suggested that Sanriku coastal water, the northern Pacific coast of Japan, provided seasonal habitats for immature and mature loggerhead turtles, including males, and immature green turtles.

2. Estimation of 3-D movements

Uses of animal-borne recorders are often useful to study underwater activities of marine animals. Diving behaviours of sea turtles have been studied 2-dimensionally (i.e. time and depth). However, as turtles live in the 3-dimensional world, reconstruction of 3-D movements is required to understand their underwater activities, such as orientation and foraging behaviours. In the present study, 3-D movements were estimated for the first time for sea turtles by integrating locomotion vectors (i.e. dead-reckoning), which were computed from data obtained by a multi-sensor data logger (i.e. swim speed, depth, tri-axis geomagnetisms and tri-axis accelerations). The resulting 3-D movements successfully showed fine-scale underwater movements, which could not be detected in the traditional 2-D dive profiles. However, unrealistic fluctuations associated with strokes

were observed in time-series heading data computed from tri-axis geomagnetisms and accelerations. It was suspected that such fluctuations in heading associated with stroking were artifacts derived from frequency-based filters, which were widely used in analysis of acceleration data. Although the fluctuations in heading were observed from all turtles, the effects of such fluctuations in 3-D paths were obscured at the scales of metres. In addition, as dead-reckoning could not include effect of drift by external forces, such as ocean current, the resulting 3-D movements represent how turtles moves in the water, but not the true ground position. Take account of all these precautions inherent to data analysis, a total of 213.7 hours of 3-D movements of 12 loggerhead turtles were estimated ready for the further analysis.

3. Orientation behaviours during directional travel

A total of 118 hours of 3-D movements from 8 turtles over 9 deployments were analysed to examine temporal changes during directional travel. Turtles maintained straight-line courses (straightness index ≥ 0.95) during 41 % of the total duration (i.e. 'travelling periods'). During travelling periods, turtle swam continuously, maintaining unidirectional heading throughout dives (mean directionality $r \pm \text{s.d.} = 0.99 \pm 0.44$, $N = 2216$) whereas remarkable changes in heading were occasionally observed at the surface (mean directionality $r \pm \text{s.d.} = 0.94 \pm 0.13$, $N = 691$). Despite highly directional movements during dives, travel direction tended to shift by the end of dives lasting tens of minutes. Such deflections in travel directions seemed to be compensated during the subsequent surfacing periods because changes in travel direction arising during dives were negatively related to that arising during subsequent surfacing periods. Hence, remarkable changes in heading at the surface could be interpreted as direction-searching behaviour. The results suggested that turtles undertaking directional travel were more dependent on directional information available at the surface although further studies are required to determine the particular source(s) of information used by the turtles.

4. Mid-water foraging behaviour

To describe foraging behaviours of free-ranging turtles, a total of 197.5 hours of 3-D movements of 12 turtles over 13 deployments were analysed. In some deployments, animal-borne video cameras ('Cittercam') were used to record the prey items. From a total of 23.8 hours of video data, a total of 71 foraging events were identified. In 67 out of 71 events, turtles fed on gelatinous prey while they were actively swimming either in the mid-water or near the sea surface. Only one turtle performed 3 benthic foraging events. By examining video and 3-D data together, it was found that

most of mid-water foraging events shared a common feature having a certain period of deceleration (range of deceleration duration = 3 – 66 sec). Based on this characteristic, potential mid-water foraging events (i.e. 'presumptive events') were extracted from 3-D data. As a result, a total of 323 presumptive foraging events were extracted and the detection rate of events related to mid-water foraging was 72.3 %. By combining the true and the presumptive events, the rate of mid-water foraging events was estimated as 2.0 times h^{-1} . Although loggerhead turtles are generally considered as benthic feeder according to digestive tract analysis, the result suggested that the previous study underestimate the importance of easily digestible gelatinous prey in the diet of loggerhead turtle. In addition, in some events, turtles changed its direction toward the prey 5.2 ± 5.2 m (mean \pm s.d.) before reaching to the prey. However, such turning point tended not to exist in night-time events, suggesting that turtles used visual cue as the primary source of information in prey finding.

5. Summary and future perspective

The present study showed that some loggerhead and green turtles periodically migrate to Sanriku coastal water, the northern Pacific coast of Japan, where no nesting ground exists in proximity. The occurrences of turtles were restricted to the period between early summer to autumn, suggesting that the study site provide seasonal habitat for immature and mature loggerhead turtles, and immature green turtles. Some mid-water foraging events were confirmed when underwater activities of sea turtles at the study site were examined by using 3-D and video loggers. As being famous for its fertility, it is suggested that the Sanriku coastal water potentially provided important summer foraging grounds for turtles. In addition, by examining 3-D movements, the present study showed the turtles had ability to maintain unidirectional heading while directional travelling although turtles were more dependent on the directional cues available at the surface. Furthermore, the possibility that turtle use visual cues while feeding on gelatinous prey in the mid-water was presented.

These findings about basic biology of sea turtles would be important as a first step to understand their strategies to maximise survival in the oceanic environment. In addition, information about the distribution and underwater activities of sea turtles at the northern edge of their habitat would provide important knowledge required for proper conservation of sea turtles.