産卵場付近におけるアカウミガメの回遊経路の推定

誌名	日本水産學會誌
ISSN	00215392
著者	内藤, 靖彦 坂本, 亘 内田, 至
巻/号	56巻2号
掲載ページ	p. 255-262
発行年月	1990年2月

Nippon Suisan Gakkaishi 56(2), 255–262 (1990)

Estimation of Migration Route of the Loggerhead Turtle *Caretta caretta* around the Nesting Ground*1

Yasuhiko Naito,*2 Wataru Sakamoto,*3 Itaru Uchida,*4
Kazuo Kureha,*5 and Tomoyuki Ebisawa*3

(Received October 4, 1989)

The adult loggerhead turtles *Caretta caretta* use the sandy beaches of Japanese Islands as their nesting place. A female went to sea after her first spawning and 20 days later she returned again to the same beach to make a second spawning. Her migration route during this interval was estimated using time series water temperature data directly obtained from the female *C. caretta* by TTR, and oceanographic survey data. She was thought to arrive at the Kuroshio zone at first and to be drifting for several days in the current. After drifting, she would begin to swim toward the nesting beach, seemingly selecting the direction to arrive at the nesting ground. Therefore any random swimming motion could not be found on her estimated swimming trajectories.

The migration pattern of fish has been summarized by H. Jones[1] in the form of a simple triangular diagram. With regard to the seasonal travelling of fish, there are three main grounds used in the migration circuit, *i.e.* feeding, spawning and nursery. This triangular model should be applicable to the migration of other marine animals as well, such as turtles and mammals. The animals migrate repeatedly between the same grounds, and pursue the same course throughout their whole life stage. However, very little is known about the mechanism to travel such long distances in the open sea on the migration between feeding ground and spawning ground. Furthermore there is no data about the swimming behavior, for instance, swimming behavior on feeding, performances in the currents or in the frontal zone neighboring different water masses and the relationship between individual daily rhythmic activity and environmental fluctuation. Knowledge about these fundamental questions concerning swimming behavior could give us some important clues in the research of the navigation or orientation of marine organisms.

The present study was carried out to research into the swimming behavior around the spawning ground of the female loggerhead turtle *Caretta caretta*. Although the main part of the behavior of *C. Caretta* is not well known, one knows that adult turtles utilize sandy beach along the Japan Islands, mainly within the area surrounding 24° to 36°N latitudes,[2] as nesting place. The spawning season begins in May and continues for four months. An adult female lands on the sandy beach to spawn and leaves just after her first spawning. About 15 days later she returns again to the same beach to make a second spawn. This pattern of intermittent spawning on the beach is repeated three times or more during one season.[3] There are several reports on the behavior of the spawning female turtles during the period they are landed on the sandy beach,[4,5] but there is no data on how they spend their intervals while at sea in the spawning season. We tried to measure the swimming speed, water temperature along the course of the swimming route, temperature in stomach and diving depth and frequency during the spawning interval.

Method

A continuous record of water temperature, temperature in the stomach, swimming distance and diving depth were measured by the TTR (Time-

*1 Study on the behavior of loggerhead turtle *Caretta caretta* during inter-nesting periods-I.

*2 National Institute of Polar Research, Kaga, Itabashi, Tokyo 173, Japan (内藤靖彦：国立極地研究所).
*3 Department of Fisheries, Faculty of Agriculture, Kyoto University, Kyoto 606, Japan (坂本　亘，海老沢智幸：京都大学農学部水産学教室).
*4 Nagoya Prot Office, Irifune, Minato, Nagoya 455, Japan (内田　至：名古屋港管理組合).
*5 Himeji City Aquarium, Tegarayama, Himeji 670, Japan (呉羽和男：姫路市立水族館).

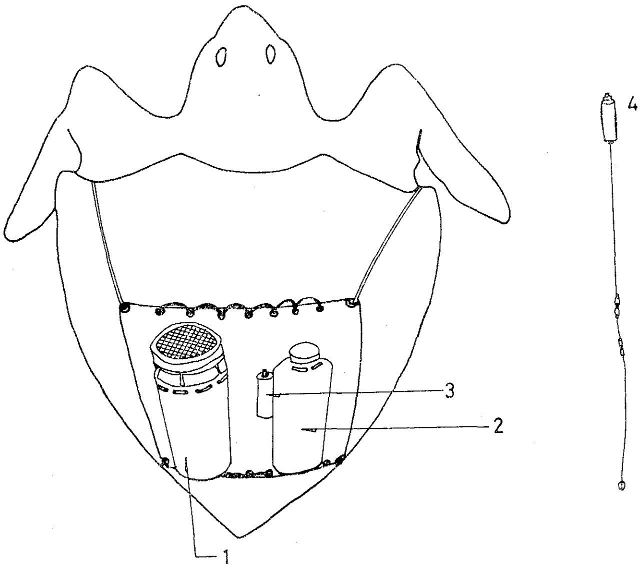

Fig. 1. Apparatus attached to the back of a female loggerhead turtle *C. caretta*; 1: time swimming distance recorder (TSDR), 2: time depth recorder (TDR), 3: time temperature recorder (TTR), 4: time temperature recorder to measure the temperature in the stomach.

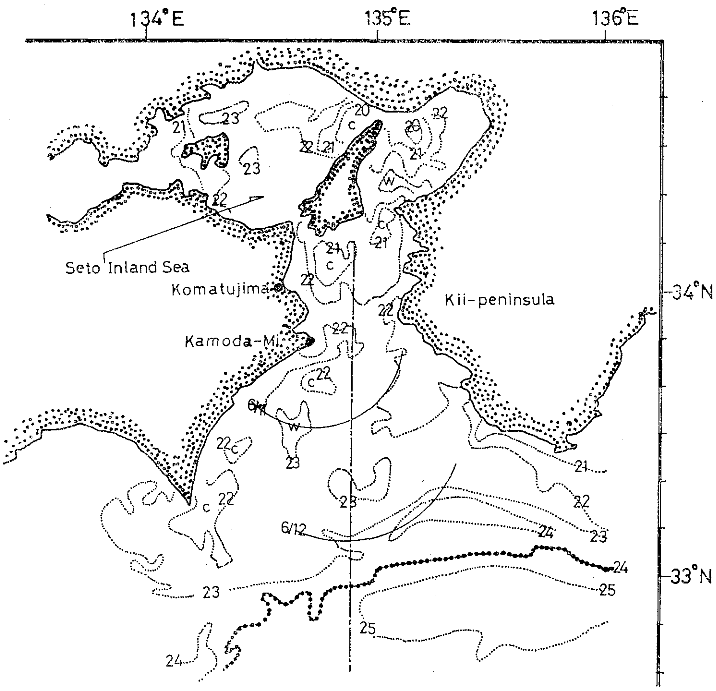

Fig. 2. Location of experiment. Dotted lines are iso-therms based on the NOAA-10 infra-red image on June 13. Thin half circles are the estimated travelling to arrive at northern boundary of the Kuroshio current before June 12. The broken line is the routine oceanographic survey line of the Wakayama Prefectural Fisheries Station.

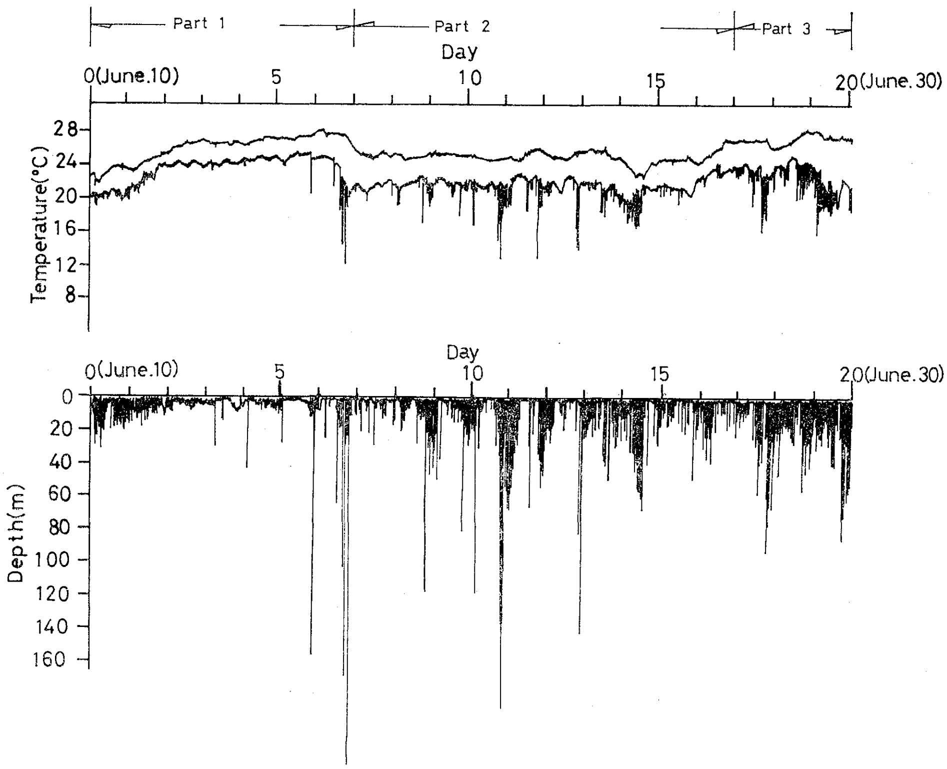

Fig. 3. Results of the TDR (lower), stomach temperature (upper) and water temperature (middle) indicated as a function of time (day).

Temperature Recorder), TSDR (Time-Swimming Distance Recorder) and TDR (Time-Depth Recorder). These instruments are designed to record temperature, swimming distance, and diving depth continuously on pressure sensitive paper for about 130 days. The TTR is 18 mm wide by 84 mm long, the TSDR is 76 mm wide by 202 mm long and TDR is 76 mm wide by 160 mm long. Total additional mass weighs 1.3 kg in water. The instrumental design, size of each apparatus, its accuracy and total research system are reported by Naito *et al.*[6] These apparatuses were attached to the back of a female loggerhead turtle as shown in Fig. 1 when she finished the first spawning at the Kamoda coast (Gamoda coast), Tokushima Prefecture on June 10, 1988. The female loggerhead turtle is a good subject for obtaining records since she can carry apparatuses without significant impediment to her swimming. The location of the experiment is shown in Fig. 2. The apparatuses were packed into a small pockets on the vinyl leather sheet (35 cm×40 cm) to fit them securely on the carapace and this sheet was tied with a string along the carapace (see Fig. 1). She landed at 02: 27 on the 10th and spawned 107 eggs. Her standard carapace length was 89.4 cm. She left the beach at 03: 55 carrying the apparatuses on her back. They were recovered on June 30 when she landed on the same beach again to begin her second spawning. We were watching out for her return on the same beach, and easily distinguished this female turtle landing. The recovered pressure sensitive papers were enlarged, digitized in one min time series and recorded on floppy disk for use in computer analyses. The TTRs were calibrated before deployment and after recovery.

With regard to the time series of water temperature recorded on the TTR, it was also referred to the oceanographic survey data on the same season measured by the Wakayama Prefectural Fisheries Station and surface water temperature data arranged by the Gyogyou Jouhou Service Center. Our research areas are included in the information network zone of the Gyogyou Jouhou Service Center, where the surface water temperature is shown in a form of iso-thermal lines presented in three day intervals. The water temperature data recorded by the TTR directly from the turtle allow to establish a detailed outline of the migration route taken between the first and second spawning. As this paper focuses on the migration routes, the research is based predominantly on the water temperature data. The remaining data obtained, such as stomach temperature or diving frequency are not relevant in this research, and will be discussed in the next reports.

Result

The water temperature, fluctuation in stomach temperature and vertical swimming pattern are shown in Fig. 3 as a function of time. The stomach temperature was seen to be 2 or 3°C higher than that of the environment. The lowest water temperature was 12.0°C. The time series of water temperature seemed to be divided into three distinct periods, the first period having a high water temperature, the next lower and the final period again showing higher temperature.

Part 1: The first period was begun after her depature from the beach and ended on June 16. The water temperature dropped below 21°C at first, two days later it gradually went up from 21° to 24°C. The highest temperature was recorded to be 25.5°C on the 15th. At 16: 00 on the 16th, temperature suddenly dropped below 21°C from 24°C and the pattern shifted to Part 2.

Part 2: The second period continued for about 10 days, during from the 17th to the 26th. The water temperature was lower throughout this period and the lowest temperature, 12.0°C, was recorded on the 16th. This indicates the deep diving behavior of *C. caretta*. In Fig. 4, the isotherm of 14°C extends below 230 m at 33°N latitude. She had the capacity to dive more than 230 m (see Figs. 3 and 4). As she dived vertically many times throughout this duration, frequent temperature fluctuations were found in the time series data. On the 26th, the temperature again went up to around 23°C.

Part 3: The final period, from the 27th to the 30th, was spent swimming around the spawning ground. The TTR records fluctuated as much as those during the earlier period, but the mean surface water temperature was higher than before. This pattern continued until she landed again on the Kamoda coast (Gamoda coast).

Surface temperature distribution is shown in Fig. 2, based on the data from the NOAA-10 infra-red image. To know the temperature distribution below the surface layer, the vertical cross sectional temperature distribution is shown

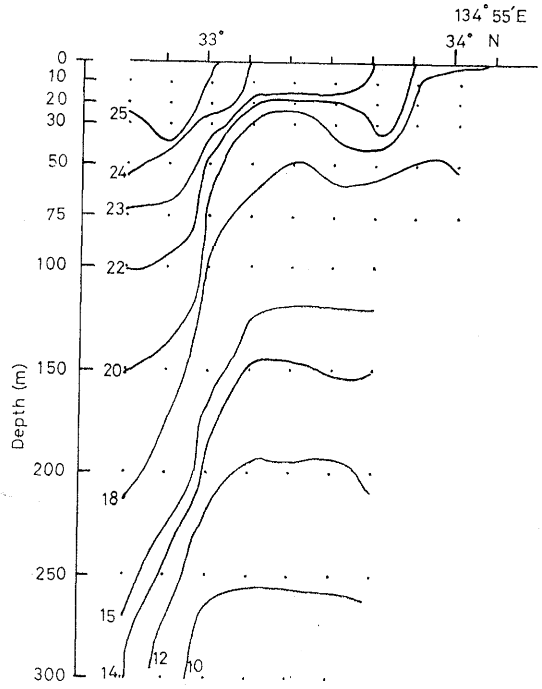

Fig. 4. Vertical water temperature distribution pattern along the routine oceanographic survey line on June 23.

in Fig. 4 along the broken line in Fig. 2, which was surveyed by the Wakayama Prefectural Fisheries Station on June 23. The surface water temperatures along the coastal area and the northern inner part were seen to be 2°C lower than those of the off shore side. The iso-therms could be drawn by 21°C to 22°C lines in almost all the area of the northern inner part of the Seto Inland Sea, whereas in the southern off shore area, isotherms were higher than 22°C. The boundary zone between the Kuroshio and the neighbouring waters seemed to be marked by the 24°C isotherm around 33°N. The iso-therm of 24°C attained about 50 m depth near 33°N latitude (Fig. 4).

Estimation of Swimming Route

Figure 5 shows the iso-thermal distribution of the surface layer around the survey area. From Figs. 2, 3, 4 and 5, we took special notice of the surface water temperature since the *C. caretta* was swimming near the surface layer during most of her time spent at sea (see Fig. 3). Therefore, by comparing the TTR record and the oceanographic survey data we were able to estimate rough-

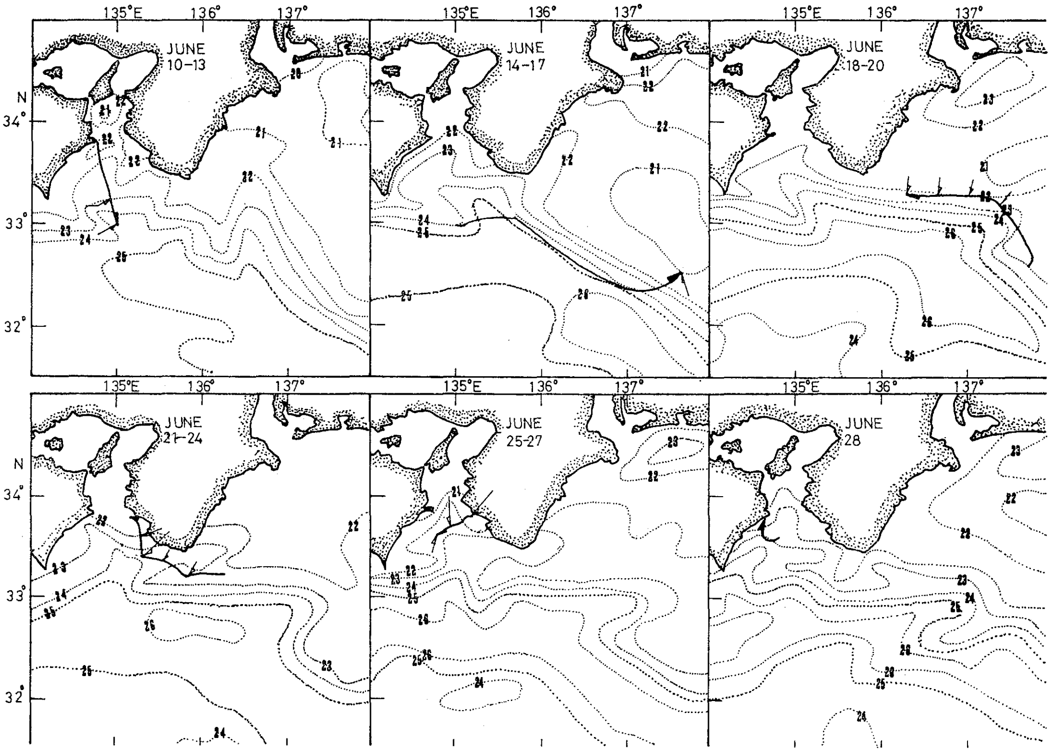

Fig. 5. Estimated migration route (solid line) and surface water temperature pattern (dotted line) arranged by the Gyogyou Jouhou Service Center in three day intervals.

ly her swimming route. There routes were considered possible; 1) She stayed the whole period in the area neighboring the sandy beach and did not travel very far. 2) She travelled to the northern inner part of the Seto Inland Sea. 3) She travelled to the southern part and migrated quite far during the time spent at sea. The first route was considered most unlikely. If she had stayed in the same area throughout the interval, the TTR data would not have fluctuated so widely as between 20°C and 26°C. Next, the second route was also rejected as the surface water temperature of the inner part of the Seto Inland Sea did not exceed 23°C as shown in Fig. 2. If she had migrated to the northern part, the temperature on the TTR would have stayed lower than 23°C during most of the duration.

We therefore focused on the southern route. The time series temperature data are overlaid the iso-therms in Fig. 2. Undoubtedly she arrived at a 24°C temperature zone on the 12th, the maximum probable travelling distance could be drawn in concentric circles for each day contering on the nesting beach. The southeastern course was though to be the shortest probable route to arrive at northern boundary zone of the Kuroshio (the Japan current) before the 12th, where surface water temperature was higher than 24°C. In Fig. 5, estimated routes are shown by solid lines at three day intervals conferring with the iso-thermal distribution based on the announcement described above. In the period from the 12th to the 16th, she was carried by the current of the Kuroshio. During this period, no diving behavior was found (see Fig. 3), but there were horizontal shifts. This made her long distance travelling without any swimming effort. From the data of the TTR, we found that she suddenly encountered the cool water mass of the 21°C iso-therm on the 16th. The maximum diving depth, 233 m, was recorded when she passed through the boundary zone between warm and cool waters on the same day. The similar cool water mass of the 21°C iso-therm could be found off the southern part of the Kii-peninsula (Fig. 5, second panel). She spent 5 days, from the 17th to the 21st, in cooler water mass with a temperature lower than 22°C. On the 21st, the temperature went up to 23°C, but it dropped again to below 21°C on the 24th (Fig. 3). From the comparison

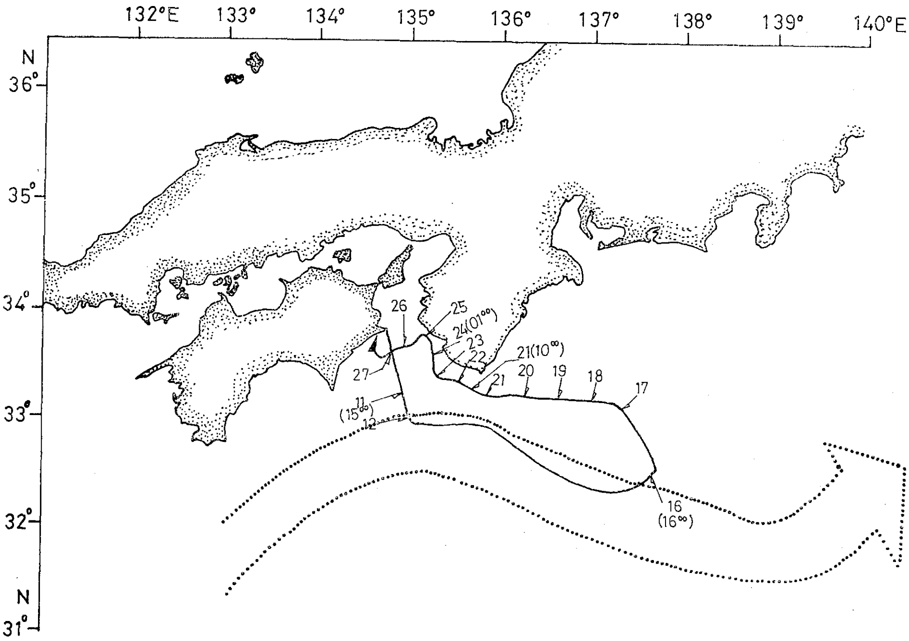

Fig. 6. Estimated migration route throughout the spawning interval, indicating the day or significant hour when she encountered the frontal zone, the dotted line is an outline of direction of the Kuroshio during the same period.

Table 1. Comparison between estimated daily travelling distance and recorded distance on the TSDR, and remarkable clues used for estimation, ⇑ : rise, ⇓ : drop, ⇔: fluctuate

Day No. (date)	Estimated km (mile)	Recorded km (mile)	Remarkable clue
1 (6.10)	35.0 (18.9)	25.4 (13.7)	03: 55 release, 21°C
2 (6.11)	68.3 (36.9)	25.8 (13.9)	15: 00 21°C ⇑ 22°C
3 (6.12)	80.0 (43.2)	2.6 (1.4)	00: 00 22°C ⇑ 24°C
4 (6.13)	80.0 (43.2)	0.6 (0.4)	24°C
5 (6.14)	80.0 (43.2)	0.4 (0.3)	14: 00 24°C ⇑ 25°C
6 (6.15)	80.0 (43.2)	0.4 (0.3)	14: 00 25.5°C ⇑
7 (6.16)	63.5 (34.3)	15.1 (8.2)	16: 00 Front (25.5°C ⇓ 21°C)
8 (6.17)	39.4 (21.3)	23.7 (12.8)	21°C⇔22°C
9 (6.18)	35.0 (18.9)	24.5 (13.3)	21°C⇔22°C
10 (6.19)	39.0 (21.1)	24.9 (13.5)	21°C⇔22°C
11 (6.20)	39.0 (21.1)	30.1 (16.2)	21: 00 Front (22°C ⇑ 23°C)
12 (6.21)	39.0 (21.1)	31.4 (17.0)	03: 00 23°C, 10: 00 22°C ⇓
13 (6.22)	31.1 (16.8)	26.3 (14.2)	22°C⇔23°C
14 (6.23)	23.3 (12.6)	16.3 (8.8)	22°C⇔23°C
15 (6.24)	21.5 (11.6)	14.5 (7.8)	0.1: 00 Front (21°C ⇓)
16 (6.25)	21.5 (11.6)	12.3 (6.7)	13: 00 Front (23°C ⇑)
17 (6.26)	15.6 (8.4)	11.8 (6.4)	17: 00, 24°C ⇑
18 (6.27)	8.2 (4.4)	8.2 (4.4)	24°C⇔25°C

between the TTR data and the iso-thermal distribution pattern, we found that she changed swimming course from a southeastern to a northwestern direction on the 17th, and began to swim toward the nesting beach after the 17th, she was thought to arrive at the southern coastal area of the Kii-peninsula on the 24th, since the temperature below 22°C that she experienced on the 24th could be found along the southern part of the Kii-peninsula (see Fig. 5). The temperature on the TTR again went up to around 23°C on the 25th and on the 26th it went higher than 24°C. The route was therefore thought to be going in a southern direction, and crossing the Kii-channel as can be seen in the last two panels of Fig. 5. Total estimated route is summarized in Fig. 6. In the same figure, the outline of the Kuroshio direction is shown based on the information from the Maritime Safety Agency (No. 13, 1988).

As the swimming distance was directly measured by the TSDR throughout whole inter-nesting periods, we compared these estimated daily travelling distance with the record of the TSDR in Table 1. Daily estimated distance was always longer than recorded data, it was especially clear when she was drifting in the Kuroshio. The TSDR had a tendency to record lower value when an individual begun to oblique diving or swimming along with the current. In the same table, remarkable clues to use estimation were cited. They were useful to compare with the spatial surface temperature distributions since the frontal zones in the iso-therms coinsided with temperature fluctuation on the TTR.

Discussion

Previously a hypothetical idea was presented by Koch *et al.*[7] to explain the long distance navigation of the green turtle *Chelonia mydas*. They evaluated the possibility that orientation was based on the detection of some chemical substance originating from the nesting ground. However the verification is impossible sufficiently in the open sea because animals' olfactory sensitivity though to be far higher than that of any artificial analytical technique. Their hypothesis was based on the detection of a concentration gradient of chemical substance. However their hypothesis seems to be unlikely because the turtles would have to move randomly for long distances under turbulent oceanic conditions to detect the horizon--tal concentration gradient by means of the olfactory organ. The area where the animals have to swim at random increases in proportion to the distance from the source in the nesting ground if the concentration gradient is due to the homogeneous turbulent diffusion process.[8,9] When migrating long distances, saving energy is an urgent problem for the animals. Thus it seems unlikely that they would waste energy by moving at random during the migration, even if only for a relatively short distance. The same comment was made by Carr[10] in the navigation of the green turtle.

What is remarkable in the movement of *C. caretta*, therefore, is that she is being transported on the Kuroshio. She was thought to go southeast after her first spawning and we could not detect any random swimming motion until she arrived at the 24°C water zone on the 12th. She seemed to go directly to the Kuroshio zone as if she already know the position or flow direction of the current. Was it necessary for her to encounter the Kuroshio zone? If this is habitual behavior after her first spawning, two merits would be brought from the transportation in a warm water layer. One is that she could recover from spawning stress by drifting without any active swimming motion during the transportation in the Kuroshio, another is thought to be a physiological necessity to mature the eggs in a warm water layer, preparing for the next spawning. In June, in the area around the Kii-peninsula, there was no warmer water zone except the inner part of the Kuroshio. The relationship between her energy conservation and response motion to fluctuation of environment will be presented in the next report.

Acknowledgement

We would like to express our gratitude for the research staff of the Himeji City Aquarium for the kind assistance. We would like to thank Dr. Toshio Sakamoto, researcher of the Wakayama Prefectural Fisheries Station and Mr. Hideo Tameishi, researcher of Gyogyou Jouhou Service Center for supplying the informations on water temperature. The research was supported by the National Institute of Polar Research and was partly supported by a Grant-in-Aid Co-Operative Research (A), the Ministry of Education, Science and Culture of Japan (62304022).

References

1) H. Jones: in "Fisheries mathematics" (ed. by J. H. Steel), Academic Press, London, 1977. 145–170.
2) I. Uchida and M. Nishiwaki: in "Biology and conservation of sea turtles" (ed. by K. A. Bjorndal), Smithonian Inst. Press, Washington D. C., 1982, pp. 317–319.
3) I. Uchida: *Saishu to Shiiku*, **43**, 472–476, (1981).
4) H. R. Bustard and P. K. Tognetti: *Science*, **163**, 939–941 (1969).
5) H. Hirth: *Amer. Zool.*, **20**, 507–523, (1980).
6) Y. Naito, I. Uchida, Y. Ohyama, and K. Kureha:

Antarct. Rec. (in manuscript).
7) A. L. Koch, A. Carr, and D. W. Ehrenfeld: *J. Theoret. Biol.*, **22**, 163–179 (1969).
8) A. Okubo: *J. Oceanogr. Soc. Japan*, **22**, 1–6 (1966).
9) H. Kawai: *J. Oceanogr. Soc. Japan*, **42**, 30–38 (1986).
10) A. Carr: *Sci. Amer.*, **212**, 79–86 (1965).

Nippon Suisan Gakkaishi : Formerly *Bull. Japan. Soc. Sci. Fish.*