Preliminary analysis of the foraging strategy of seabirds on the basis of their behavior and physiological cost

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***Abstract*—Streaked shearwaters (*Calonectris leucomelas*) are pelagic seabirds that breed on isolated islands in East Asia. Sometimes, they fly long distances to search and forage for food over several hundred kilometers. During the chick-rearing period, efficient foraging is one of the most important tasks for parents because they have to obtain food not only for themselves but also for their chicks. To understand their foraging strategy of streaked shearwaters, their behavior and physiological cost should be quantified. In 2018, we attached GPS and acceleration loggers on breeding shearwaters (15 males and 11 females, including eight pairs) and collected blood samples from them at the deployment and recovery of the loggers. We confirmed that blood drawing from Streaked shearwaters did not have significant adverse effect on their foraging behaviors. We found oxidative and anti-oxidative markers via blood can be useful for assessing the physiological cost of their foraging behaviors. Our finding suggests that females were suffered from heavier stress than males, because females often conducted short trips and increased oxidative stress. To reveal how they perform foraging with minimal cost, we are going to analyze the relationship between foraging behavior and the associated physiological cost in detail.**

Keywords*—*streaked shearwaters, GPS, acceleration, oxidative stress, foraging strategy

I. INTRODUCTION

Streaked shearwaters (*Calonectris leucomelas*, Fig. 1) are pelagic seabirds that breed on isolated islands in East Asia. They can fly several hundred to thousand kilometers during a foraging trip by using a flight method called "dynamic-soaring" (Azuma, 1979).

On Awashima Island (38°28′ N, 139°14′ E, Niigata, Japan), the shearwaters lay one egg in July, and it hatches in mid-August. The chicks grow inside their nests until fledging in November. During the chick-rearing period, parents raise their chick by collaborating with each other whereas they conduct their foraging trips independently.

Since 2008, we have been recording the foraging movements of streaked shearwaters with loggers every year on Awashima Island. The foraging movements of shearwaters breeding on this Island shows sex-related differences during the chick-rearing period (Mastumoto *et al*. 2017). During the period, efficient foraging is one of the most important tasks for them because they have to feed prey not only to themselves but also to their chick. There may be many ways in which they can behave efficiently (i.e., foraging strategy). For example, they may use energy-saving flight (e.g., dynamic soaring; Philip 2018), mix short foraging trips with long ones suitable for their chick and themselves (Matsumoto et al. 2017), and/or eat only high-quality food items.

To understand their foraging strategy, accurate quantification of behavior and physiological cost is required. In this study, we recorded their large- and fine-scale behavior of streaked shearwaters by using GPS and acceleration data loggers and measured oxidative stress. We use these data to analyze the relationship between foraging behaviors and physiological cost and reveal the foraging strategy of the shearwaters such that they perform foraging trips with a minimum cost.

II. MATERIALS AND METHODS

A. Fieldwork

The fieldwork was performed on Awashima Island located in the Sea of Japan between mid-August and early October in 2018. We attached GPS and acceleration loggers (Axy-Trek, TechnoSmArt, Italy) on breeding streaked shearwaters to record their foraging behavior. The sampling interval was one fix per one minute for GPS and 25 Hz for acceleration. The loggers can record for about 12 days with this setting. After 7–10 days, we caught the birds, retrieved the loggers, and measured body metrics. When we attached and recovered the loggers, we collected blood samples. After the fieldwork, we measured oxidative and anti-oxidative markers in the blood samples by using FREE Carrio Duo (Diacron International, Italy).

B. Data analysis

We defined a foraging trip as the extended trip more than 3 km and 6 hour from Awashima Island.

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Using GPS, we could obtain extensive data of the foraging trip. We calculated total distance, maximum foraging range, and trip duration for each foraging trip. On the basis of the acceleration data, we classified the behaviors of the streaked shearwaters as takeoff, flapping, gliding, and landing. We calculated the energy consumption of each mode by using the Overall Dynamic Body Acceleration (i.e., a proxy for energy expenditure). We measured oxidative and anti-oxidative markers via blood samples and calculated oxidative stress as the index of the physiological costs during the foraging trips.

Using these data, we will unravel the relationship between foraging trip and physiological cost. In addition, we are going to examine whether the shearwaters help their partner and change their flight behavior according to total flight distances, homing timing, and accumulation of oxidative stress depending on the degree of the partner's fatigue.

We expect the following results:

1) Calculated energy consumption from acceleration (ODBA) and physiological cost quantified from oxidative stress may be correlated.
2) When we classify behaviors by acceleration, some specific behavior may accumulate oxidative stress.
3) Shearwaters may perform foraging with a minimum cost calculated using both acceleration and oxidative stress.
4) When their partner has a heavy load, they may help their partner.

III. Results

In the fieldwork conducted in 2018, we attached 66 loggers (36 males and 30 females) and collected blood samples from 26 birds (15 males and 11 females, including eight pairs during logger attachment; Table 1). In 2018, we collected both short- and long-trip data from the birds. We expect that different foraging trips such as short or long trips lead to different accumulation of physiological costs. A short trip is performed within a few days whereas a long trip is performed in about 10 days. We show examples of short and long total distance in Fig. 2.

We compared total flight distance of blood-sampled group and that of not-blood-sampled between males and females, respectively. There is no significance between total distance of blood-sampled group and that of not-blood-sampled group ($t = 0.93$, $p = 0.35$ and $t = 1.38$, $p = 0.17$ for male and female, respectively : Fig. 3).

We also compared oxidative stress at 1st blood drawing and 2nd blood drawing between males and females, respectively, using Wilcoxon signed-rank test. There was no significant difference in oxidative stress between 1st blood drawing and 2nd blood drawing males ($p = 0.49$), but there was significant difference in females($p < 0.05$) (Fig. 4). We found that only females increase oxidative stress during a week.

IV. Conclusion

We confirmed that blood drawing from Streaked shearwaters did not have significant adverse effect on their foraging behaviors. We found oxidative and anti-oxidative markers via blood can be useful for assessing the physiological cost of their foraging behaviors. Our finding suggests that females were suffered from heavier stress than males, because females often conducted short trips and increased oxidative stress.

We are going to classify their behaviors precisely by using ODBA and examine the relationship between foraging behaviors and the associated physiological cost.

Table. 1 : The number of samples

	Number of samples	
	Male	Female
Blood sampled [a]	15	11
Blood not sampled	21	19

[a] including 8 pairs

Fig. 1 : Streaked shearwater parents forage prey items during the daytime and bring food to their chick only at night. We captured them when they returned to their nest.

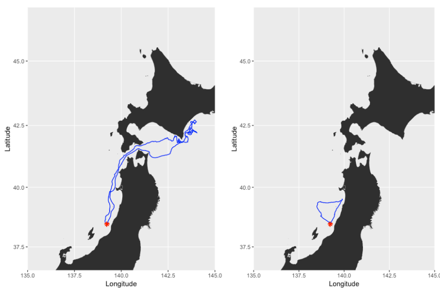

Fig. 2 : An example of GPS positions of streaked shearwaters recorded in 2018. GPS positions of streaked shearwaters (blue lines). The study colony is indicated with a red star. Right figure shows a short trip and left figure shows a long trip.

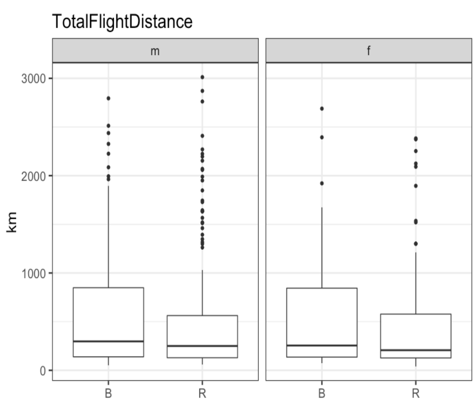

Fig. 3 : Total flight distance of the foraging trips of streaked shearwaters in 2018. We collected the trip data of females (m) and females (f). The number of trips is 47, 151, 74 and138 for blood-sampled males (m–B), not-blood-sampled males (m–R), blood-sampled females (f–B), and not- blood- sampled females (f–R), respectively.

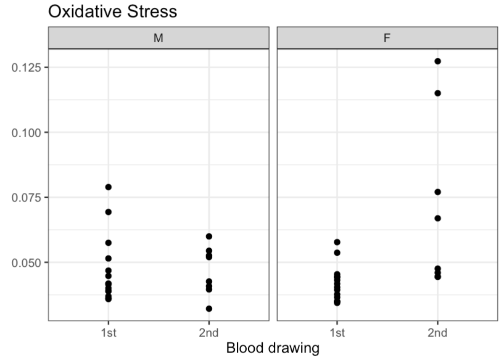

Fig. 4 : We collected blood samples when we attached (1st blood drawing) and recovered (2nd blood drawing) data loggers. Oxidative stress of males (M) are shown in the left figure and that of females (F) are shown in the right figure. Oxidative stress was calculated using the oxidative and anti-oxidative markers.

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