



# Time-lapse camera photographs reveal arrival and breeding timing of short-tailed albatrosses *Phoebastria albatrus*

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**ABSTRACT:** Monitoring the ecology of seabirds breeding on remote islands is often challenging. However, time-lapse cameras have enabled the surveillance of inaccessible sites. We examined arrival/departure movements and breeding timing of the endangered short-tailed albatross *Phoebastria albatrus* with time-lapse cameras on Torishima, a remote and uninhabited island in the northwestern Pacific, from November 2016 to June 2017. The photographic images revealed that the first arrival of the albatrosses on the island was on 7 October 2016, and the number of birds reached a peak of 506 on 5 November. The white pairs arrived and began incubating approximately 1 wk earlier than the white/brownish pairs. From the end of January, the number of birds repeatedly increased and decreased within a short period of time. The birds' movement out of the breeding colony often occurred synchronously with a rapid decline in the mean daily air pressure. Adult birds began to leave the colony in April. The number of chicks reached up to 200 at the beginning of May, but they all left the colony before 1 June. The processing of the photographic images taken during the incubation and early guard periods revealed that hatching failed in approximately 10% of the pairs. The validity of information collected by time-lapse cameras was confirmed by comparing it with the results of previous field studies. This study will contribute to the collection of essential information for monitoring and conserving seabirds breeding on remote islands where successive or frequent fieldwork is difficult.

**KEY WORDS:** Short-tailed albatross · Time-lapse camera · Remote islands · Breeding timing · Shift changeover · Hatching rate · Image processing

## 1. INTRODUCTION

Seabirds are not only one of the most numerous and visible components of marine ecosystems, but are also important indicators of ecosystem health (Piatt et al. 2007). However, there is a lack of baseline information on the ecology of some species, especially seabirds breeding on remote islands, which are difficult to study because of the limited accessibility (De Pascalis et al. 2018). Many seabirds are long-lived with delayed maturity and low reproduction. Such traits often contribute to their endangered sta-

tus once a population declines (Hasegawa 2020). To design and manage conservation plans for stabilizing and restoring seabird populations and their habitats, baseline information, such as distribution, colony size, breeding timing, breeding success, and foraging behaviors, is essential (Southwell & Emmerson 2015, Hinke et al. 2018). To overcome the difficulties in collecting baseline information, time-lapse photography has recently been used to study seabirds breeding on remote islands (e.g. Piatt et al. 1990, Lorentzen et al. 2010, Huffeldt & Merkel 2013, Merkel et al. 2016, Southwell & Emmerson 2015, De Pascalis

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et al. 2018, Hinke et al. 2018). In these studies, hatching, fledging, breeding success, foraging trip durations, and nest behaviors were examined using time-lapse cameras installed near the nests or the colonies of the targeted seabirds.

We installed time-lapse cameras to monitor the breeding colony of the short-tailed albatross *Phoebastria albatrus* on Torishima, southern Japan, in the northwestern Pacific. The short-tailed albatross is an endangered species categorized as Vulnerable (VU) in the IUCN Red List (IUCN 2021). It is widely distributed in the North Pacific during the non-breeding season (Howell 2012), but only breeds on Torishima, Senkaku, and a few other small islands in the northwestern Pacific (Onley & Scofield 2007, Howell 2012, Hasegawa 2020).

Short-tailed albatrosses were abundant until the middle of the 19th century, when the total number of the population was believed to be over 1 million. However, from the end of the 19th century, excess hunting on Torishima, the major breeding site, to collect feathers for duvets, caused a rapid population decline, and the species was considered extinct in 1949 (Austin 1949, Fujisawa 1967). However, a few pairs were rediscovered breeding in Tsubamezaki, on the southern edge of Torishima, in 1951 (Yamamoto 1954). Consequently, the species was designated as a special national natural monument of Japan in 1961 (Fujisawa 1967). Due to conservation efforts over decades by Hiroshi Hasegawa of Toho University, the Ministry of the Environment of Japan (MOE), and the Yamashina Institute for Ornithology, a few new breeding sites have been established, and the total number of the population has recovered to more than 5000 (Yamashina Institute for Ornithology 2019, Hasegawa 2020).

However, the largest colony, Tsubamezaki, on Torishima, has been threatened by scoria debris flows that often occur due to heavy rains and typhoons. The flows sometimes spread over the colony, burying and killing the chicks (Hasegawa 2020). Furthermore, although Torishima is the primary breeding site for short-tailed albatross, the whole island is an active volcano, posing a threat of population collapse from new eruptions (Tanakadate 1940, Ito et al. 2012, Yamashina Institute for Ornithology 2018a).

The colony size, number of breeding and non-breeding birds, breeding success, and return rates of the albatrosses have been revealed by field observations and leg ringing for over 40 yr (Yamashina Institute for Ornithology 2018b, Hasegawa 2020). However, studies throughout one whole breeding season have never been conducted because of the difficul-

ties of access and long-term stay on the island. More baseline information is required to improve conservation and management plans. In this study, using time-lapse cameras, we examined the detailed movements to and from the colony and the breeding timing of the albatrosses through careful investigations of photographic images. Here, we report the change in bird abundance during the breeding season, arrival date and the start of incubation, incubation shifts, and estimated number of breeding pairs of the albatrosses in the colony. We also analyzed the effect of the weather on the number of albatrosses staying in or departing from the colony. Considering the baseline information on the breeding ecology and the accuracy of data obtained by the time-lapse cameras, we discuss the use and potential of time-lapse cameras for future research.

## 2. MATERIALS AND METHODS

### 2.1. Study area and data collection

The study site is Tsubamezaki, which hosts the largest colony of short-tailed albatrosses on Torishima. Torishima is located at 30° 29' 02" N, 140° 18' 11" E in the northwestern Pacific (Fig. 1). It is a volcanic island with a diameter of 2.5 km and is mainly covered with scoria and old lava composed of basalt and andesite (Honda et al. 1954). The peak of the present central volcano, Ioyama, is 394 m above sea level.

Vegetation occurs mainly on the gentle slope of the western side of the island. The dominant plant species are *Boehmeria biloba*, *Chrysanthemum pacificum*, *Miscanthus condensatus*, *Elaeagnus umbellata* var. *rotundifolia*, and *Morus kagayamae*. There is no water on the surface except after heavy rains. No reptiles or amphibians have been recorded, but black rats *Rattus rattus* are distributed widely on the island.

A weather station was established by the Japan Meteorological Agency (JMA) near the western edge of Torishima in 1947 (JMA Torishima Club 1967). However, it was closed due to warnings of the eruption of 1965 (JMA Torishima Club 1967). The island has been uninhabited for over 50 yr, except for a few visiting research teams investigating short-tailed albatrosses during the breeding season.

The Tsubamezaki colony sits on a steep scoria slope facing the ocean at the southern end of Torishima. Most surfaces are covered with scoria during the breeding season, while several are covered with dead herbaceous plants (*Imperata cylindrica*). Approximately 61 %

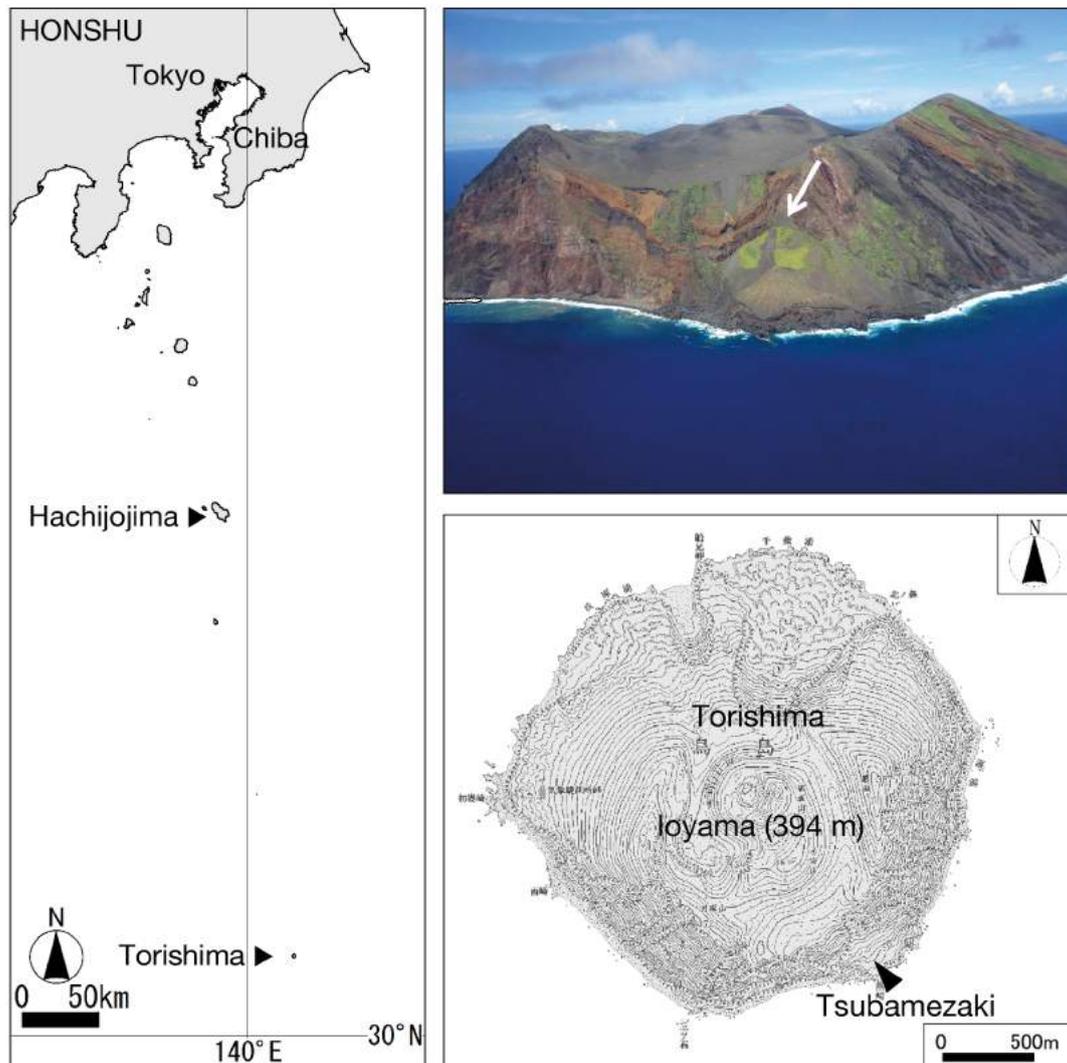


Fig. 1. Location of Torishima (left), a major breeding site of short-tailed albatrosses, and Tsubamezaki (right image and map; arrows), the largest short-tailed albatross colony on Torishima

of short-tailed albatrosses on Torishima breed there (Hasegawa 2017a). Black-footed albatrosses *Phoebastria nigripes* also breed around this colony.

## 2.2. Short-tailed albatross

The body length of the short-tailed albatross is 80–90 cm, and the wingspan is 220–240 cm (Howell 2012). The adults have whitish plumage, while immature individuals have dark brown plumage (Howell 2012). Seven plumage stages have been provisionally distinguished for the albatross. Stages 1 and 2 are shades of brown, while stage 3 shows brown only on the upper side of the body. White plumage starts to dominate from stage 4 when the birds are

considered to be older than 7 yr (Howell 2012). Approximately half of the albatrosses start breeding at the age of 7 (Hasegawa 2020), while approximately 25% and 80% start breeding at the ages of 6 and 9, respectively (Hasegawa 2020). The whitest plumage of stages 6 and 7 appears around the age of 10 (Hasegawa 2020). Sex identification from their appearance is difficult. Pairs are formed after a series of displays in the colony. Males return to the colony and establish territories a few days before females arrive in October (Hasegawa 2020). Soon after the partners meet, females lay eggs and the incubation period starts. Females incubate for the first day or for the first few days, and then males take over (Hasegawa 2020). Incubation shifts between the parents usually occur from October to December until the

eggs hatch. Parent birds take turns to forage for their chicks for approximately 4 mo. Most parent birds leave the colony in May for the Aleutians, where they spend the non-breeding season. The short-tailed albatross is monogamous, and the pairing lasts for the birds' lifetime (Hasegawa 2020). Among sexually mature birds in the colony of Torishima, approximately 20% do not breed (non-breeding birds) due to re-pairing or other reasons (Hasegawa 2017a).

### 2.3. Equipment

The time-lapse cameras Ltl Acorn 6210 and Ltl Acorn Ltl-6210MC (with an SD card of 8 to 16 GB) were used. The picture size was set as 5 Mp = 2560 × 1920 pixels. The time-lapse mode was set at an interval of 1 h. Each camera was placed in a rugged metal 'security lock box' as protection from strong winds bearing scoria sands or dust, which often caused serious damage to the equipment (Fig. 2). We placed 2 cameras on a cliff ledge from which the colony could be observed. Data were downloaded once or twice every year, mainly in October and February, when we visited the island.

### 2.4. Change in numbers during the breeding season

We counted the number of short-tailed albatrosses on photographic images taken approximately 1–2 h before sunset when the number of birds reached the daily maximum. One hundred days of data or 100 photographic images taken from October 2016 to June 2017, i.e. data for every 2 to 3 d on average,



Fig. 2. Time-lapse camera (Ltl Acorn 6210) in metal housing, installed at Tsubamezaki on Torishima

were used for analysis. These data included images of breeding and non-breeding birds. Chicks were also counted when they grew sufficiently large for detection. Counting was conducted manually in the laboratory. As the angle of the view of the photographs was not wide enough to cover the entire Tsubamezaki colony, we counted birds on the west side of the colony separated by a trace of debris flows (Fig. 3); 70.1% of the colony or 376 pairs were included in this part of the colony, with approximately 20 pairs hidden by the cliff in front in 2016 (Hasegawa 2017a). The target colony had a length of 80 m and a width of 50 m, and the cameras were set approximately 140 m from the colony center.

### 2.5. Arrival date and start of incubation

We focused on 22 breeding pairs close to the cameras on the upper slope of the Tsubamezaki colony to see the movements of birds in detail (Fig. 3). We checked all the photographic images taken every hour from sunrise to sunset from October 2016 to January 2017. The total number of images was over 1400. The cameras were approximately 50–80 m apart from the pairs. Fourteen of the 22 pairs were white pairs, while the other 8 each consisted of one white and one brownish bird. We recorded the dates of arrival at the colony and the start of incubation for the above 22 pairs. We assumed that incubation started when one parent bird stayed at the nest throughout the day without absence. Eggs were not detectable in the images.



Fig. 3. The Tsubamezaki colony of short-tailed albatrosses. The white 'dots' are individual albatrosses, most of which indicate nest locations. The colony is divided in two by the debris flow running from right to left in the central part of the photograph. The upper part is the west side and the lower part the east side

## 2.6. Incubation shift changeovers

For the 8 white/brownish pairs among the above 22 pairs, incubation shift changeovers were accurately detected by plumage color (e.g. a white bird was replaced by a brown bird when incubation occurred). We recorded dates of shift changeovers, and then we calculated the mean incubation shift length of one parent, excluding the first and last very short incubation periods of one or a few days. We also calculated the total incubation period. The end of the incubation period was when eggs hatched. We assumed that eggs hatched on the day when parents suddenly began to practice frequent shift changeovers. Incubation shifts of the other 14 white pairs were not detectable because there was no difference in appearance between the males and females.

## 2.7. Estimating numbers of breeding pairs by processing photographic images

The photographic images showed both the breeding and non-breeding birds in the colony, indicating no differences in appearance. During the incubation period from November until the end of December, the breeding birds constantly remained at their nests to incubate the eggs. Similarly, during the first 2 wk of the guard period at the beginning of January, the parent birds also constantly remained at their nests to protect the very young chicks. We sampled 7 d of photographic images evenly from the incubation period and the first 2 wk of the guard period. We processed them, marking the birds as dots on each image, and overlaid the images in each of these 2 periods so that the dots overlapped if the birds remained in the same place (see Fig. 8). The photographic images used for processing were those taken approximately 1–2 h before sunset, when the number of birds reached the daily maximum. Processing was conducted using Spatial Information System (SIS) version 6.2, a Geographic Information System (GIS) software. We assumed that the overlapped bird images, where birds sat at the same location on each image, represented the nests and counted the number of cases to which this applied. We compared these numbers during the 2 periods, the incubation period and the guard period. We considered that the difference in number was due to the eggs that did not hatch. With this difference, we calculated the hatching rate, noting that there was a possibility of overestimation because pairs that failed very early would not be counted as incubating pairs.

## 2.8. Effect of weather on numbers of short-tailed albatrosses

As an index of weather conditions, we considered the mean daily air pressure and the mean daily wind speed, by which the flying and foraging behaviors of the albatrosses would be greatly influenced. We measured the air pressure and wind speed using a Vaisala Weather Transmitter WXT520 on Torishima every hour from 2016 to 2017. We also obtained weather data at the seashore of Chiba Prefecture, where the albatrosses forage, from archival data published by the Japan Meteorological Agency (Kiyota & Minami 2008; see Fig. 1 for the location). We studied the relationship between the number of albatrosses in the colony and the weather conditions, focusing on the guard period in February when the albatrosses frequently left the colony for foraging.

## 2.9. Statistical analyses

Differences in arrival and incubation timing between the white and the white/brownish pairs were analyzed for the 22 breeding pairs in the Tsubamezaki colony using Mann-Whitney *U*-test. To observe the effect of weather conditions on the numbers of short-tailed albatrosses in the colony, we conducted correlation analysis and linear regression with data on the mean daily air pressure, mean daily wind speed, and numbers of short-tailed albatrosses in the colony of Tsubamezaki. We also analyzed the similarity in weather conditions of the breeding site of Torishima and the foraging area of Chiba Prefecture by showing the correlation in mean daily air pressure between the 2 areas in February. All data analyses were conducted using Microsoft Excel for Microsoft 365 MSO (16.0.13901.20516).

## 3. RESULTS

### 3.1. Change in numbers during the breeding season

From the photographic images taken by the time-lapse cameras, the first arrival of short-tailed albatrosses was detected in the late afternoon on 7 October 2016. The number of birds increased rapidly from a few days after the first arrival (Fig. 4). Arrivals continued for approximately 1 mo, during which approximately 20 birds arrived each day on average. The number of birds peaked at 506 indi-

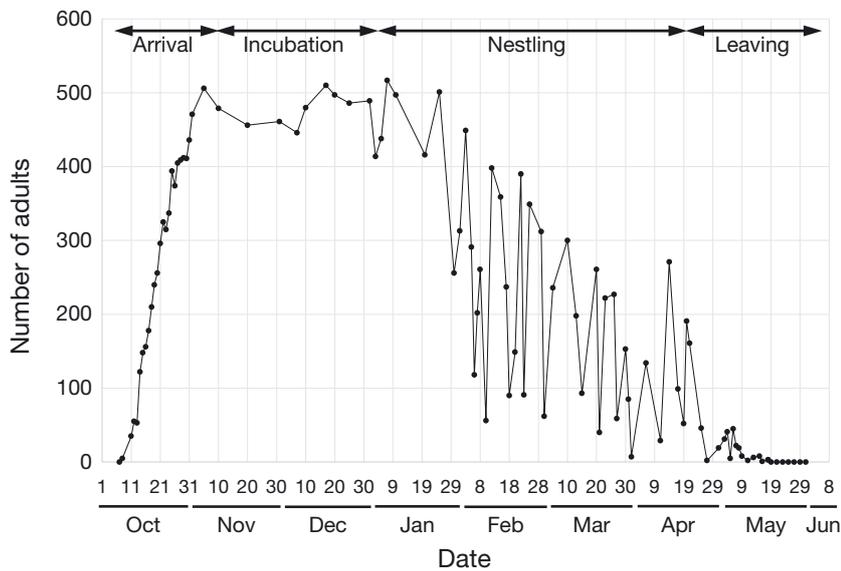


Fig. 4. Seasonal changes in the number of adult short-tailed albatrosses recorded by time-lapse cameras on the west side of the Tsubamezaki colony from October 2016 to June 2017

viduals on 5 November. The number of birds remained stable until early January. Then, numbers of birds repeatedly increased and decreased over short periods of time. Sometimes, more than 300 birds disappeared and returned within a few days. The total number of birds slowly decreased thereafter, and in May, most of them left the colony. There were approximately 200 chicks at the beginning of May. Their numbers declined rapidly in late May, and all left the colony before 1 June (Fig. 5). There was approximately a 1-mo gap between the departing times of parents and chicks.

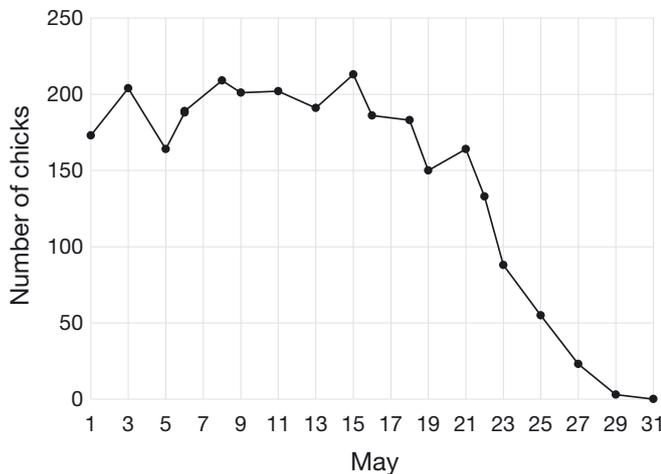


Fig. 5. Number of short-tailed albatross chicks on the west side of the Tsubamezaki colony in May 2017

### 3.2. Arrival date and start of incubation

The white pairs arrived at the colony from 13 October, while the white/brownish pairs began to land from 18 October (Fig. 6). Among the white/brownish pairs, the white bird always appeared before the young brownish one. As males return to the colony a few days earlier than females, the white bird was assumed to be male and the brownish one female. On average, the white pairs arrived approximately 1 wk earlier than the white/brownish pairs. Similarly, the white pairs began incubation at the end of October, while the white/brownish pairs started incubating approximately 1 wk later in early November.

### 3.3. Incubation shift changeovers

The albatross parents took turns to remain on the nest during the incubation period (Fig. 7). The mean ( $\pm$ SD) incubation length of one parent was  $11.8 \pm 4.4$  d with a range of 2–25 d, and the mean total incubation period was  $65.2 \pm 6.0$  d with a range of 60–69 d. After hatching, one or both parents stayed at their nest until the middle of January. From the end of January, the parents were often absent from their nest simultaneously. Thus, a chick could be left alone for as long as 5 d, 3 times within 1 mo.

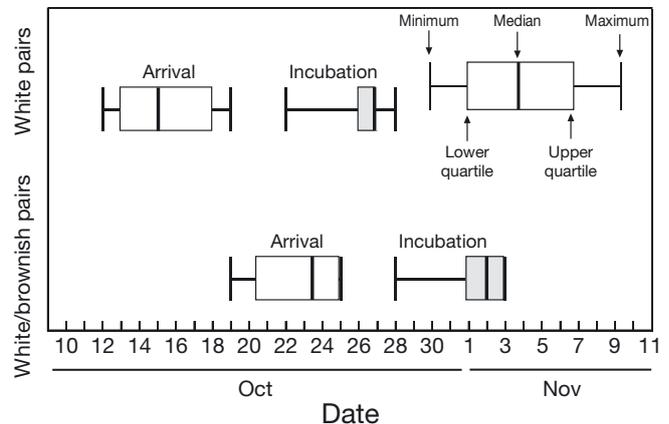


Fig. 6. Arrival date and first date of incubation in the white pairs and white/brownish pairs of short-tailed albatrosses in the Tsubamezaki colony in 2016. Arrival: Mann-Whitney  $U = 3.5$ ,  $p < 0.01$ ; incubation:  $U = 4$ ,  $p < 0.05$

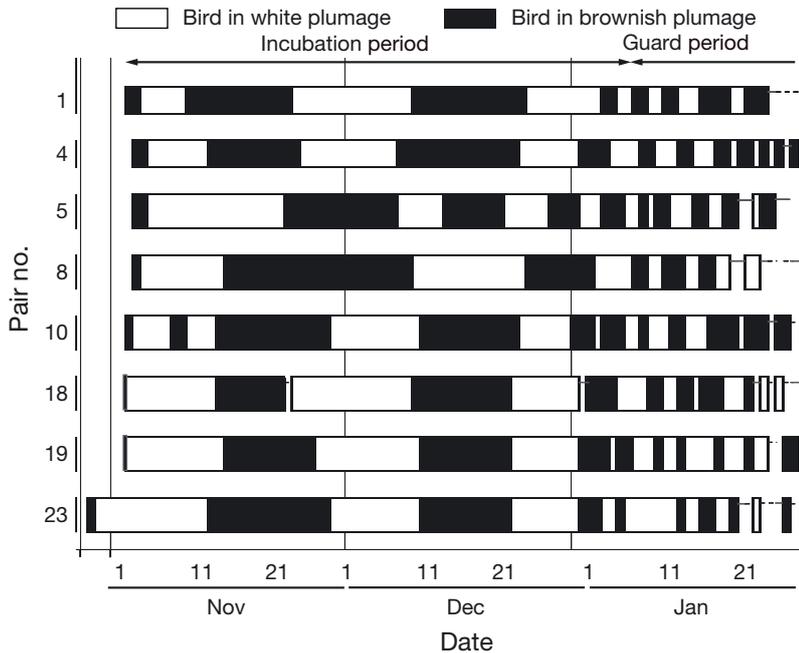


Fig. 7. Incubation shifts for individuals of pairs of short-tailed albatrosses in the Tsubamezaki colony during the incubation and guard periods. Each white and black segment represents a single incubation shift length



Fig. 8. Images used for processing and overlaying of photos taken during the incubation period (top) and the first 2 wk of the guard period (bottom). Yellow and green dots represent the overlapped bird images, indicating the nest locations

### 3.4. Estimating numbers of breeding pairs by processing photographic images

We detected 348 nesting locations from the overlapped photographic images during the incubation period, while we counted 313 during the 2 wk after hatching (Fig. 8). Thirty-five pairs had left their nest before the guard period; i.e. 35 pairs had failed to hatch their eggs. Thus, the hatching rate was 89.9%.

### 3.5. Effect of weather on numbers of short-tailed albatrosses

Rapid changes in the number of synchronized movements were found throughout the guard period. More than 300 birds left the colony on a single day (Fig. 4). We observed that these synchronized movements often occurred when the mean daily air pressure displayed a rapid decline and the mean daily wind speed was high (Fig. 9). Air pressure ( $x$ ) and wind speed ( $y$ ) were strongly negatively correlated ( $y = -0.26x + 266.5$ ,  $r = -0.6650$ ,  $p = 0.007$ ). The mean daily air pressure ( $x$ ) and the number of albatrosses in the colony ( $y$ ) were positively correlated ( $y = -15.09x - 14922$ ,  $r = -0.6850$ ,  $p = 0.005$ ; Fig. 10). On 23 February, when approximately 300 birds moved out of the colony, for example, the mean daily air pressure dropped by 11 hPa within one day, and the mean daily wind speed was over  $11 \text{ m s}^{-1}$ . According to the weather data in February 2017, air pressure in Chiba Prefecture ( $x$ ) and Torishima ( $y$ ) were positively correlated ( $y = 0.59x + 406.3$ ,  $r = -0.84$ ,  $p = 0.0001$ ), suggesting that the low air pressure zone was widely distributed from Torishima to Chiba Prefecture.

## 4. DISCUSSION

### 4.1. Breeding timing detected from photographic images

The change in the number of birds in the colony enabled us to monitor the detailed breeding timing of short-tailed albatrosses. The increase in number from October to November represented the arrival period at Torishima. The stability in numbers from November

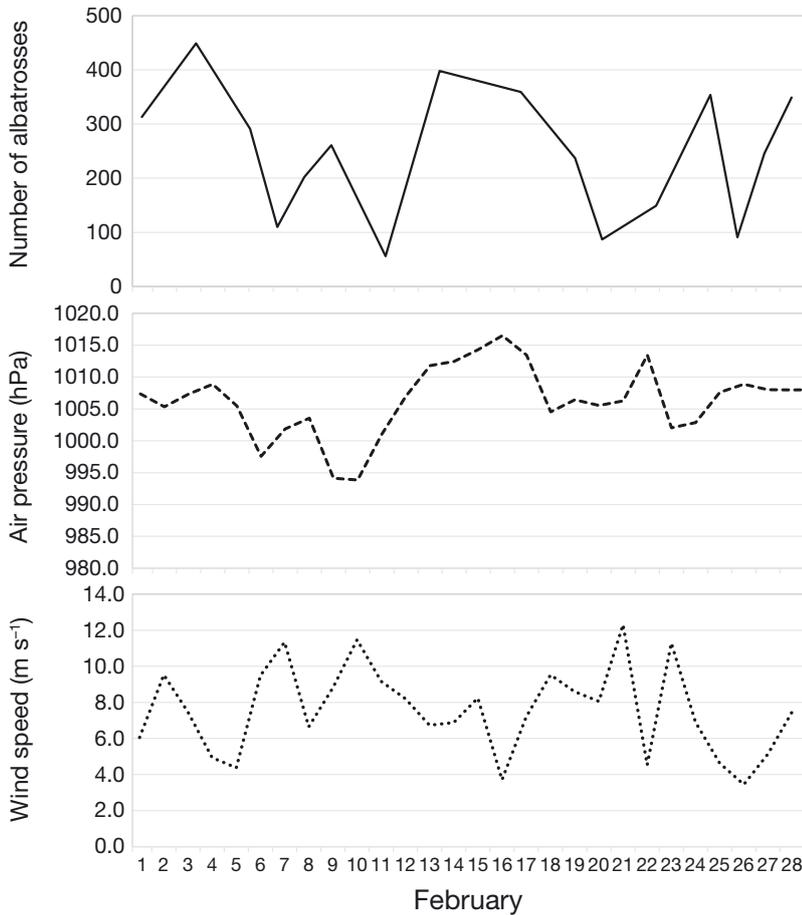


Fig. 9. Number of short-tailed albatrosses in the colony (top), air pressure (middle), and wind speed (bottom) in February 2017

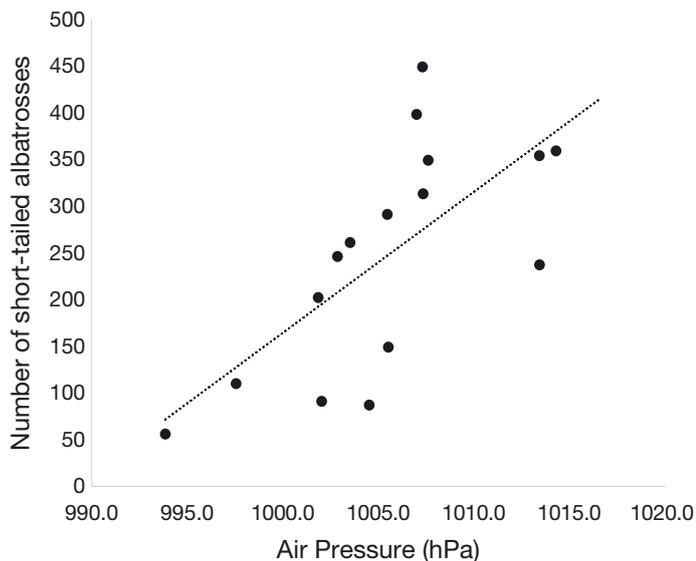


Fig. 10. Relationship between air pressure and number of short-tailed albatrosses on the west side of the Tsubamezaki colony in February 2017. The dashed line indicates the regression line ( $y = 15.09x - 14922$ ,  $r = -0.682$ ,  $p = 0.005$ )

and the fluctuation in numbers from January onwards revealed the incubating period and the guard period, respectively. The stay of the parent birds at the nest for 2 to 3 wk after hatching is thought to be for the protection of small and young chicks. As the chicks grew, the parent birds were more active in providing food for their chicks, thus leaving them alone more often. The decline in the total number of birds indicated that the parents were leaving the colony. Chicks stayed in the colony for 1 mo after their parents left, without any food supply. The timing of these overall movements of the albatrosses corresponded to that observed in previous studies by Fujisawa (1967), Hasegawa (e.g. 2017a,b, 2020), and the Yamashina Institute for Ornithology (e.g. 2018a,b, 2019), which required a substantial effort by the researchers to make long-term observations. Although tracing or monitoring individual birds was difficult from the time-lapse camera data, detailed movements of birds through a single breeding season were more detectable from the photographic images.

Furthermore, by referring to other environmental factors such as weather conditions, we can gain a deeper understanding of behaviors. In our study, we found that synchronized movements or sudden changes in number occurred when the air pressure rapidly declined or the wind speed was high. Albatrosses efficiently extract energy from wind for dynamic soaring, and flight speed depends on wind speed (Richardson et al. 2018). Thus, low air pressure would be suitable for the albatrosses to depart the colony and travel long distances to forage with low energy consumption using dynamic soaring. The main foraging area of the albatrosses is within 30 km of Torishima during the breeding season, although several birds traveled to offshore Chiba Prefecture, meaning that they forage as far as 600 km from the colony (Kiyota & Minami 2008). The low air pressure zone was widely distributed from Torishima to Chiba Prefecture, and the albatrosses could have soared and foraged in an extensive area with similar air pressures. By combining the colony attendance patterns detected from photographic images and weather data, we were able to determine the overall departure and arrival movements of the albatrosses.

#### 4.2. Accuracy of data obtained from photographic images

Several previous studies using time-lapse cameras have discussed accuracy in measuring breeding success (Lorentzen et al. 2010, Merkel et al. 2016, Southwell & Emmerson 2015). From our photographic image analysis during the incubation period, we counted 348 points that were assumed to be nests on the west side of the colony of Tsubamezaki in 2016. According to a field study conducted in the same area in 2016, 376 pairs incubated (Hasegawa 2017a). Considering that the cameras could not cover approximately 20 breeding pairs hidden by the cliff, the current results from photographic image analysis can still be said to be reasonably accurate, with a 7.4% difference. Additionally, we counted approximately 200 chicks just before they started leaving the colony at the beginning of May. According to Hasegawa (2017b), 239 chicks left the colony in 2017. Given that the chicks are mobile and move freely around the colony, potentially beyond the camera's view, counts of chicks in the images at the time of fledging may not accurately reflect the true abundance. However, as discussed later, we assume that the photographic imagery could be improved, with expanded camera coverage or alternative camera vantage points, to provide more accurate fledgling counts.

In the 1960s, a detailed study on short-tailed albatrosses was conducted by Itaru Fujisawa on Torishima (Fujisawa 1967). Fujisawa was a staff member of the weather station on the island who collected data by daily visual observations. He reported that the mean incubation length of one parent was 14–15 d, and the mean total incubation period was 64–65 d. In our study, the mean incubation length of one parent was estimated at 11.8 d, and the mean total incubation period was 65.2 d. As described in our results, synchronized movements, including incubation shifts, depended on weather conditions that are expected to change from year to year. These annual changes may be one reason why incubation shift length differed between our study and Fujisawa's. Conversely, the mean total incubation period reported by visual observations and time-lapse cameras was very similar. The total incubation period is a phenological phenomenon that is unlikely to be greatly affected by weather conditions. The photographic images, thus, can be said to reflect the breeding timing of the albatrosses.

The hatching rate of short-tailed albatrosses has never previously been studied (Hasegawa 2020). This reflects the difficulty of monitoring the number of in-

cubating pairs and pairs with nestlings through a complete breeding season on a remote island. By processing photographic images taken by the time-lapse cameras, we estimated the rate to be 89.9% because 10.1% of pairs failed to hatch their eggs in 2017, even though overestimation cannot be excluded as pairs that failed very early would not be counted as incubating pairs. Hasegawa (2020) suggests that a cause of failure during incubation is eggs being blown out of the nest by strong winds, which often occur during the winter season in Torishima. It is difficult for the albatrosses to put displaced eggs back into their nests because the colony sits on a slope. Hasegawa (2017b) reported that the breeding success rate (fledging rate) was 63.6% in 2017; thus, 36.4% of pairs failed. Based on our results, 10.1% of pairs failed to hatch their eggs, which meant that 36.4% – 10.1% (26.3%) of pairs failed to raise chicks during the guard period in 2017. Thus, time-lapse cameras provide important data that can be used to estimate the breeding success of each breeding stage. In our study, it was difficult to estimate fledging success because the chicks in the photographic images obtained towards the end of the breeding season moved throughout the colony, and we could not distinguish chicks from the study area from those originating outside the study area.

To obtain highly accurate data, the location of the time-lapse cameras is critical. We suggest that the best location would be where the whole colony is seen from above so that the number of birds and their arrival/departure movements can be detected. However, the larger the colony, the wider the angle of view needed, making it difficult to find a good position. Cliff-tops are suitable if they are nearby. In our study, we placed the cameras on a cliff ledge facing the colony. The installation of multiple cameras would make it easier to cover large colonies or separate breeding sites. The location of cameras should be carefully chosen based on colony size, bird size, and safety for researchers and birds.

#### 4.3. Potential of time-lapse cameras

Time-lapse cameras are useful for data collection from seabird breeding sites on remote islands or topographically harsh locations, where access is time-consuming and expensive, and a long-term stay is arduous, and thus baseline information for wildlife is often limited (e.g. Merkel et al. 2016, Black et al. 2017, Black 2018, De Pascalis et al. 2018). It is well known that seabirds play an important role in the marine ecosystem because of their abundant num-

bers, and they are often useful marine bioindicators (Piatt et al. 2007, De Pascalis et al. 2018). Thus, time-lapse cameras could contribute greatly to a better understanding of marine ecosystems and the breeding phenology of seabirds.

In our study, we operated the time-lapse cameras at 1 h intervals, and they lasted for 9 mo without any maintenance, such as replacement of batteries. Nine months were long enough to cover the whole breeding season of short-tailed albatrosses on Torishima. This meant that the time-lapse cameras enabled us to monitor for more than 1 yr with only a few short visits to the colony. However, it should be noted that the higher the frequency of the camera's operation, the shorter the battery life. As described by Merkel et al. (2016), the interval of time should be carefully decided based on the length of the breeding season. With such technological advances as extended battery life and improved storage capacity, camera systems have the potential to be even more powerful and useful (Black 2018). The cameras are often set outdoors for years, so it is vital to protect them from rainwater, strong wind, and salt damage. Good housings are essential, especially where damage by salt from seawater is expected. There are often difficulties with internet connection (e.g. WiFi) on remote islands, but if connections improve, then data could be collected efficiently by utilizing solar power systems and transmitting data via satellites in real time.

In our study, most of the work on the photographic image analyses, such as counting birds, was conducted manually, which was quite time-consuming. Although time-lapse cameras are an efficient way to collect data in lieu of long-term field observations, enormous effort is necessary for the later image processing (Merkel et al. 2016, Black 2018). In our study, we 'sampled' photographic images from the obtained data to observe the trend of movements of short-tailed albatrosses, i.e. several photographic images were not used for the analyses. We attempted to count birds automatically using an image analysis program, but found that several improvements were still required. Identification of birds or detection of white dots as birds was often an issue in the image processing programs in our study. We expect artificial intelligence to provide a solution for such an issue in the future. In addition, as Black (2018) has pointed out, the participation of computer scientists will be required for efficient image data processing.

As mentioned in the Introduction, short-tailed albatrosses breed only on a few islands in the north-western Pacific. The Senkaku Islands in the East China Sea, approximately 1730 km west of Tor-

ishima, host one of these rare colonies. It is known that several albatrosses which hatched on the Senkaku Islands come to breed on Torishima, and they exhibit slightly different behaviors to those born on Torishima (Eda et al. 2016). Therefore, time-lapse cameras would also be useful to monitor the detailed differences in movements to and from the colony, as well as the difference in breeding behavior between these 2 isolated populations.

Time-lapse cameras thus have great potential for collecting baseline information and data on wildlife that have not previously been studied. Concerning seabirds, time-lapse cameras are capable of recording data on colony size, arrival and departure movements of the colony, breeding timing, and the relationship between the number of birds and weather conditions. In addition, they can provide important data on distribution, population size, and even the surrounding environmental conditions such as vegetation, ground surface, local weather, sea conditions, and presence of predators (e.g. Smith et al. 2003, Wanless et al. 2012). All the above are essential for monitoring and managing the conservation of the target species. Along with other recent technologies, such as GPS tracking, satellite images and artificial intelligence, time-lapse cameras are crucial for obtaining a deeper understanding of interspecific and intraspecific behaviours and population dynamics, even regarding the environmental variables at the study sites, that is, the mechanisms of marine ecosystems (Black 2018).

It is, however, important to recognize that several aspects of breeding ecology are difficult to study with time-lapse cameras. These include moving behaviors such as courtship display and bird sounds, particularly when the birds breed in a place with poor visibility and have plumage similar in color to the background. These issues may be overcome by using video; however, this would reduce the operation length of the cameras due to power consumption and recording capacity. Regarding technological advances, an external battery such as a solar battery system and additional data storage device may lengthen the operation (Black 2018). Understanding both the usefulness and limitation of the equipment will be important in developing new technologies essential for future seabird research on remote islands.

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