Utilisation of terrestrial habitat by Black Brant *Branta bernicla nigricans* after the Great East Japan Earthquake of 2011

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Abstract

On 11 March 2011, the Great East Japan Earthquake hit eastern Japan, causing an enormous tsunami that swept through a wide area of the Pacific coast of Japan. Black Brant *Branta bernicla nigricans*, which forage on sea grass and marine algae in the shallow coastal waters, were one of the many bird species affected by this event. Here we overlay satellite-tracking data upon GIS landform and land-use layers to assess the consequences of the tsunami on habitat utilisation by the geese. Satellite-tracking of Black Brant following the tsunami showed that along the southern Sanriku coast in northern Honshu, where habitat had been affected by the tsunami, the geese exploited not only their traditional coastal areas but also terrestrial sites including paddy fields. Overall, 37 (4.3%) of the 868 satellite locations were confirmed to be in terrestrial habitats, possibly resulting from habitat loss in intertidal areas following the tsunami. Field observations also found geese feeding in flooded paddy fields 2 km inland of the coast. These results illustrate an adaptive behaviour by the geese to large-scale environmental changes.

Key words: Brent Goose, Great East Japan Earthquake, terrestrial habitat utilisation, tsunami.

Disturbance is a key component of ecological systems. In particular, drastic disturbance events such as hurricanes, volcanic eruptions, earthquakes and tsunamis cause serious changes to terrestrial, aquatic, and marine habitats across a wide range of scales (Turner 2010). Studies of the ecological consequences of disturbance lead to insights into how wildlife adapts to new conditions, giving rise to a greater understanding of ecological processes at different spatial and temporal levels.

On 11 March 2011, the Great East Japan Earthquake hit eastern Japan and caused an enormous tsunami, which affected a wide area of the country's Pacific coastline. The earthquake was 9.0 on the Richter scale, the strongest ever recorded in Japan. The size of the tsunami was also unique in historical times in reaching over 39 m above sea level at its peak. Such natural disasters substantially alter ecosystems along the sea coast, and this was the case for the 2011 tsunami. Tidal flats and seaweed beds were destroyed, and fish and other marine organisms disappeared or were drastically decreased in number (*e.g.* Hara 2014; Kanaya *et al.* 2014). As a consequence, fisheries declined, and ecosystem services have deteriorated considerably (Higuchi 2014).

Brent Geese *Branta bernicla* forage on sea grass and marine algae in the subtidal zone and on intertidal mudflats in shallow coastal waters (Ganter 2000) and their wintering locations are characterised by an abundance of these types of vegetation (Reed *et al.* 1998). Seaweed beds, and latterly aquaculture facilities such as fishery rafts in coastal waters, are the original foraging habitats for the geese in Japan. Because of this habitat preference, the Black Brant subspecies *Branta bernicla nigricans* was considered to be one of the birds most likely to be seriously affected by the Great East Japan Earthquake. This was of particular concern because, although Black Brant numbers are increasing in East Asia, with population estimates most recently at *c.* 10,000 birds in Japan and China combined (from Syroechkovskiy 2006; Fujii 2017), the population is still much smaller than that wintering on the western coast of North America (*c.* 150,000 birds; Fox & Leafloor 2018). A recent study has shown that the Japanese population ranged from 2,500 in winter to 3,100–8,600 in spring and autumn, respectively (Fujii 2017), with the birds occurring in Notsuke Bay (eastern Hokkaido) during spring and autumn migrations and in Hakodate Bay (southern Hokkaido), Mutsu Bay and along the southern Sanriku coast (northern Honshu) during winter (Lane & Miyabayashi 1997). The species is listed as "vulnerable" in the Red Data Book of Japan (Ministry of the Environment 2014).

Following the earthquake, Shimada *et al.* (2013) reported that the geese adapted to the resultant large-scale environmental changes by shifting their coastal foraging habitat and overwintering areas, and also found seasonal changes in habitat use by the geese in relation to the availability of food such as seaweed (*e.g.* green laver species such as *Monostroma nitidum*) in fishing harbours and attached to fishery rafts in coastal areas. Moreover, when Shimada *et al.* (2016) used satellite-tracking technology to monitor the seasonal movements and habitat use of Black Brant wintering along the southern Sanriku coast of Honshu Island, the data showed not only coastal but also inland terrestrial habitat use. These latter observations were initially discounted, because Brent Geese had never previously been recorded feeding on inland habitats in Japan, with the result that records were rejected on the assumption that they were location errors associated with the Argos satellite data. On re-considering the data, however, it seemed that several locations were indeed both inland and terrestrial. We therefore analysed patterns of terrestrial habitat use by the satellite-tagged Black Brant to provide further information on how geese have adapted their behaviour in response the large-scale environmental change, which followed the Great East Japan Earthquake and tsunami.

Methods

Nine geese were caught using flat net traps at Oya Beach on the Sanriku coast of northern Honshu, Japan (38.80°N, 141.55°E) in January 2014, approximately three years after the Great East Japan Earthquake and tsunami. Backpack satellite transmitters (platform transmitter terminals; PTTs), weighing 35 gms and with a 180 mm antenna, were attached to five of these birds: four adults and one juvenile (see Shimada *et al.* 2016 for further details). The PTTs operated at a cycle of 10 h on and 24 h off, and the transmission interval was every 60 sec during the on period. Locations were determined by the Argos system, which uses the Doppler shift in radio frequency of transmissions from PTTs during a satellite pass to calculate their location (Argos 1996; CLS 2016). Data were reported as latitude and longitude values (World Geodetic System 1984 datum; WGS84), with location times recorded as Greenwich Mean Time (GMT). Argos classified the accuracy of the birds' locations (location class; LC) as 3, 2, 1, 0, A, B, and Z. The standard deviation of positional error on the latitudinal and longitudinal axes was < 250 m for LC3, 250–500 m for LC2, 500–1,500 m for LC 1, and > 1,500 m for LC 0; the location accuracy for LCs A, B, and Z could not be determined. We therefore used LC 1–3 location data as having acceptable precision for determining the habitat being used by the tracked geese. The earliest date at which the geese left the areas affected by the tsunami for spring migration was 1 April 2014. We therefore analysed location data from the date of capture (21 January 2014) until the end of March 2014, defining this period as the wintering season.

In order to investigate whether the geese used inland habitats only during the day or also at night, the location data (LCs 1–3) were divided into day-time (from 1.5 h before sunrise until sunset) and night-time (from sunset to 1.5 h before sunrise), because Black Brant may start their daytime foraging bouts 1–1.5 h prior to sunrise (*e.g.* Clausen *et al.* 2013). Tide cycles, divided into high and low tide on the basis of daily average tide level, were considered in relation to the location data to assess whether movement to inland sites was associated with conditions at the birds' main coastal feeding areas, for instance if food resources became out of reach during high tides. Association with the lunar cycle was also analysed because the geese may be at greater risk of predation in darkness, so more likely to feed away from the roost at night under moonlight (Owen 1980). Moreover, night foraging was found only at the time of the full moon for Barnacle Geese *Branta leucopsis* wintering in the Dutch Waddenzee, for reasons that remain unclear because the visibility of the moon did not seem to influence the pattern, but which appeared to be closely linked to the lunar cycle (Ydenberg *et al.* 1984). In the current study, the lunar cycle was classified as full moon phase and new moon phase.

Habitat was determined by preparing a vegetation map at a scale of 1:25000 on the basis of surveys conducted from 2000–2012 (Biodiversity Centre of Japan 2017), which gave the most recent vegetation cover. First we grouped vegetation types into six habitat types: farm and grassland, forest, marsh and sand, paddy field, urbanised area, and water body, then we extracted location data points not contained within a water body to determine goose use of terrestrial sites. The tsunami-affected areas, which have been released as GIS data online (Haraguchi & Iwamatsu 2011), were overlaid on the vegetation map. In addition to assessing whether data points were located in terrestrial areas, their distance to the nearest coastline was calculated to within 250 m for LC3, 500 m for LC2 and 1,500 m for LC1 locations. All spatial data preparation was carried out with ArcGIS10.3 (ESRI Inc., Redlands, CA, USA).

In winter 2011/12, the number of Black Brant occurring along the southern Sanriku coast was monitored to assess the effects of the Great East Japan Earthquake and tsunami on the geese (Shimada *et al.* 2013). Several habitats used by the geese were described (*e.g.* fishery harbours and fish farming facilities), and the geese were counted from suitable view points along the sea coast, using a car, whilst recovery construction was underway following the disaster. Regular monitoring has continued since then, with the geese counted once from January to February each year until winter 2016/17.

Results

A total of 868 locations with LCs 1–3 were obtained from the five satellite-tracked Black Brant. Of these, 37 (n = 9 for LC1, n = 20 for LC2 and n = 8 for LC3) were confirmed as occurring in terrestrial areas away from the coast; most locations (831; 95.7%) therefore indicated that the geese were primarily at coastal sites.

Twenty six (70.3%) of the 37 terrestrial locations were recorded during the day-time (Fig. 1). Each of the five tracked geese were recorded on terrestrial habitat on 3–7 occasions in daylight hours, and the percentage of locations for individuals at terrestrial sites ranged from 3.4–8.9%. Fourteen locations (53.8%) were in areas classified as "forest" and four (15.4%) locations were in "urbanised areas", which

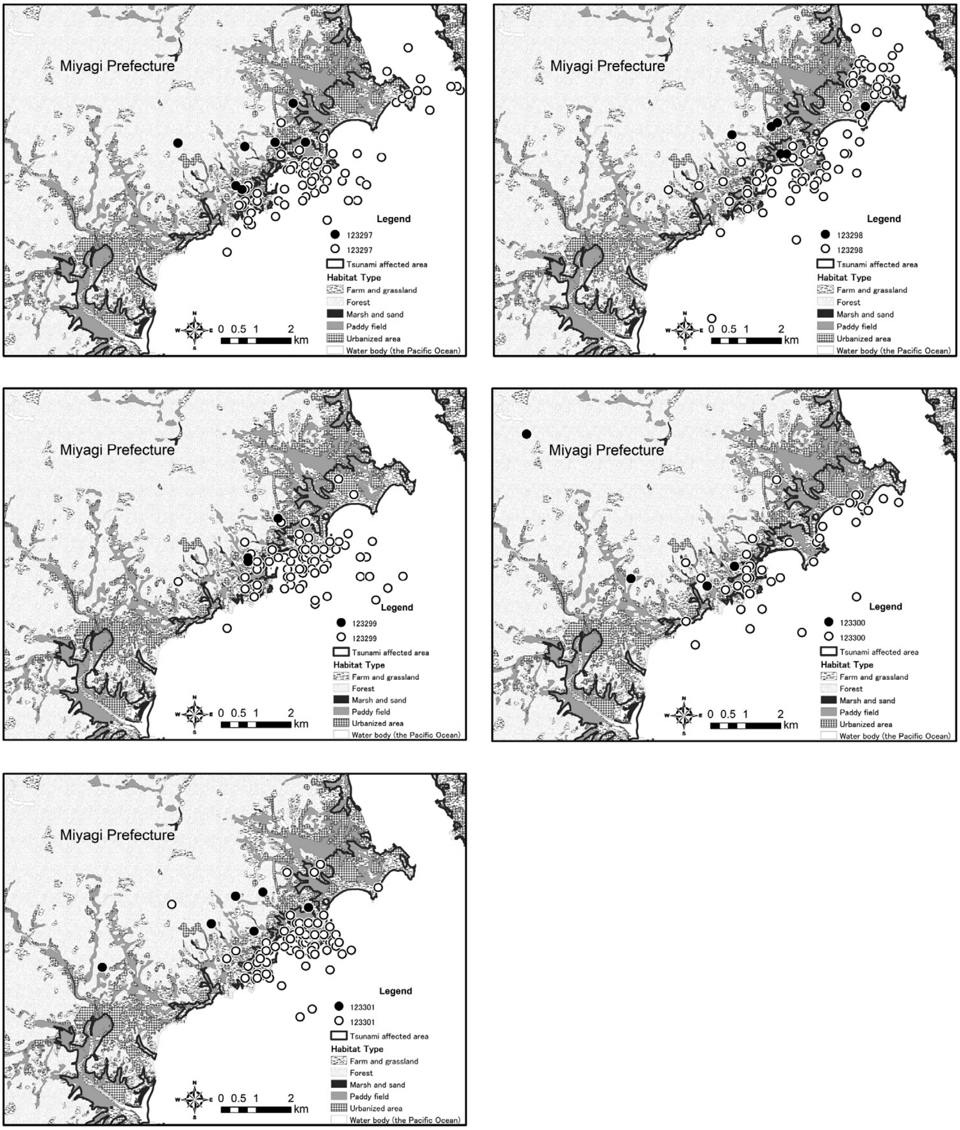

Figure 1. Use of habitats by five satellite-tracked Brent Geese during day-time (*i.e.* from 1.5 h before sunrise to sunset) in winter 2014/15, *c.* three years after the Great East Japan Earthquake and Tsunami. Black dots represent geese on terrestrial habitat; open circles represent geese on coastal habitat. Black solid lines indicate the area affected by the tsunami. Each map represents data from an individual bird, with goose identity code given alongside the dots in the legend.

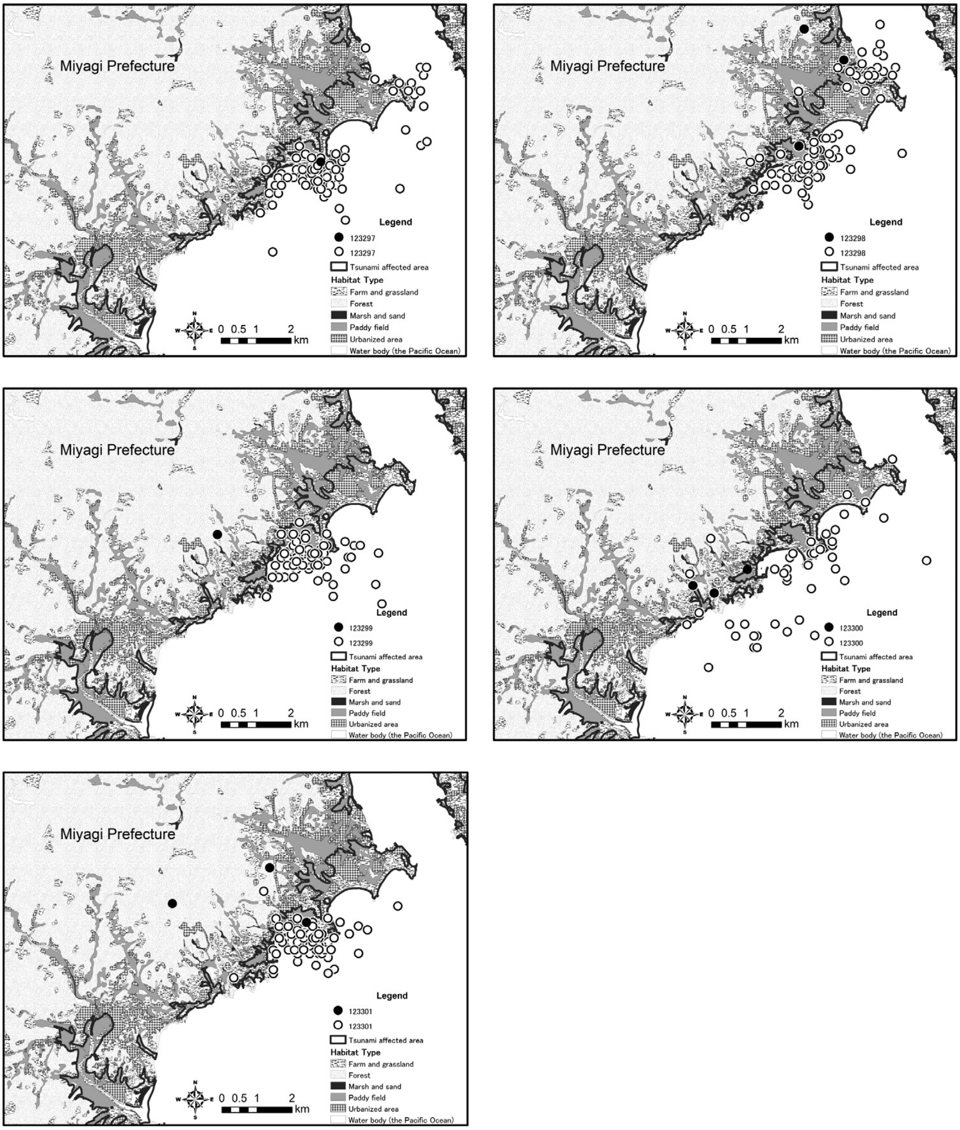

Figure 2. Use of habitats by five satellite-tracked Brent Geese during night-time (*i.e.* from sunset to 1.5 h before sunrise) in winter 2014/15, *c.* three years after the Great East Japan Earthquake and Tsunami. Black dots represent geese on terrestrial habitat; open circle represent geese on coastal habitat. Black solid lines indicate the area affected by the tsunami. Each map represents data from an individual bird, with goose identity code given alongside the dots in the legend.

are unlikely goose habitats. However, these locations were adjacent to wetlands such as paddy fields, and included locations classed as "paddy field" or "farm and grassland" in the range of location errors for lower LCs such as LC0. Seventeen (65.4%) of 26 locations in terrestrial habitat were recorded during periods of highest diurnal tides.

Eleven (29.7%) of the 37 terrestrial locations were recorded during the night (Fig. 2). Each of the five tracked geese were recorded on terrestrial habitat on 1–3 occasions (1.0–5.3% or records) when geese are usually at roost. Of the 11 locations, seven (63.6%) were in areas classed as "paddy field", and four (36.4%) in locations classed as "forest", although these locations were also close to wetlands. Nine (81.8%) and eight (72.7%) of these 11 night-time records of geese in terrestrial habitat occurred during high tide and during the new moon phase, respectively.

Seven Black Brant (two adults and five juveniles) were observed at a flooded area affected by the tsunami on 24 March 2011, immediately after the Great East Japan Earthquake (Y. Suzuki, pers. comm.). The flooded area was 2 km inland from the coast and was originally paddy fields (Fig. 3a). The geese walked and foraged on flooded fields and their ridges during the day (Fig. 3b).

The number of Black Brant wintering along the southern Sanriku coast fluctuated between 280–485 geese (mean ± s.d. = 364 ± 77 geese) during the six years from winter 2011/12–2016/17 inclusive, with no significant decline in numbers over this period (linear regression: $F_{1,5}$ = 0.0087, P = 0.93, n.s. Fig. 4). The proportion of geese observed in fishery harbours however decreased significantly from 0.56 to 0.24 (linear regression (arcsine transformed proportion data): $F_{1,5}$ = 14.15, P = 0.012, Fig. 4).

Discussion

Satellite locations showed that three years after the tsunami, some Black Brant utilised terrestrial areas such as paddy fields and farms that were located away from the

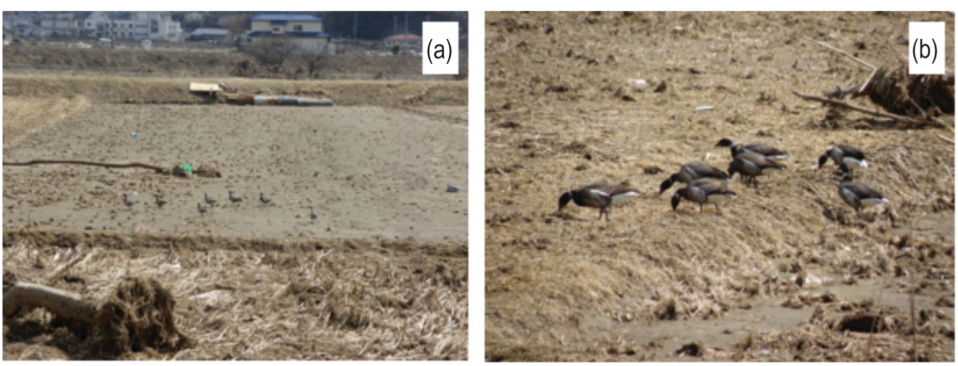

Figure 3. Seven Brent Geese observed at a flooded area (at 38.78°N, 141.48°E) affected by the tsunami, 2 km inland from the coast on 24 March 2011. The geese foraged on vegetation in (a) former paddy fields, and (b) ridges separating the fields. Photographs by Yasushi Suzuki.

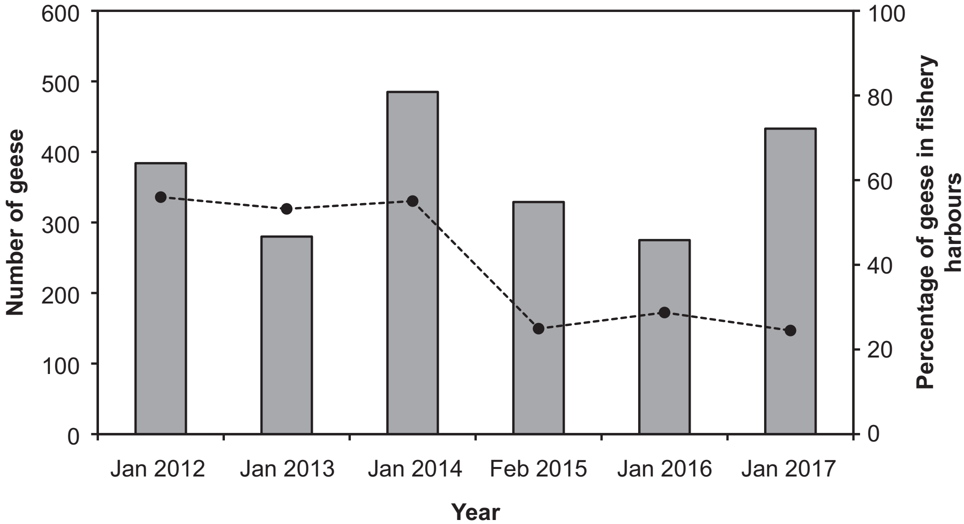

Figure 4. Annual variation in the number of Black Brant counted along the southern Sanriku coast from winter 2011/12–2016/17 (histogram columns) and the percentage of fishery harbours at which the geese were observed (dots and dashed line).

coastal area. Sightings further confirmed the use of inland habitats by these geese in recent years. Prior to the tsunami, Black Brant occurred on inland habitats only as accidental visitors; for instance, with a few individuals recorded every few years in a flock of Greater White-fronted Geese (Miyagi Prefecture Branch of Wild Bird Society of Japan 2002). In Europe, East Atlantic Light-bellied Brent Geese frequently graze on agricultural farmland, and thus fly greater distances (minimum flight distances: average = 6.94km/day, range = 4.64–10.14 km/day; Clausen *et al.* 2013) than Black Brant in Japan (< 2 km from seacoast; Shimada *et al.* 2016). Our results suggest, however, that East Asian Brant now also use terrestrial habitats more consistently, albeit still in relatively low numbers.

Aquaculture facilities such as fishery rafts in coastal waters and seaweed beds provide essential foraging habitats for the geese, and sandy beaches close to these facilities provide drinking, resting and preening habitats (Y. Miyabayashi, unpubl. data). After the tsunami the geese shifted their foraging habitat from aquaculture facilities in coastal waters to wharfs in harbours. These wharfs had subsided during the earthquake and were subsequently inundated by sea water and covered with seaweed, providing a new food resource for the geese (Shimada *et al.* 2013). The current study clearly shows that the geese also used terrestrial areas away from the coastline, and foraged in lowland areas such as those that had been paddy fields before the tsunami.

We found that the geese occupied terrestrial areas not only during the day but also at night, which is similar to results from other Brent Goose studies where Dark-bellied Brent Geese *Branta bernicla bernicla* compensated for increased energy expenditure during the day by increasing their nocturnal feeding (Lane & Hassall 1996). While it may be possible for geese to roost in terrestrial areas, this puts them at risk of predation by mustelids and Red Foxes *Vulpes vulpes*, so it is unlikely that nocturnal terrestrial locations are used as roosting sites. Higher goose use of terrestrial habitat at night under the new moon could be interpreted as an anti-predator adaptation. However, it is more likely that the geese foraged on the fresh regrowth of grass in unmanaged land that regrew rapidly after the disturbance caused by the tsunami, or on grains that remained in the exposed rice paddies after the tsunami, during both the day and night, due to the shortage of food in coastal areas.

Brant Geese numbers have fluctuated in the range of 280–485 geese along the southern Sanriku coast since the tsunami. Unfortunately, there were no previous observational data on their use of terrestrial habitats, despite continuous and regular monitoring since the winter of 2015, but the recent counts suggest that the geese returned to their preferred coastal habitats as soon as they were able to, and then remained there. Furthermore, 82% of agricultural farmlands and 27% of fishery harbours had been restored by February 2015, four years after the tsunami (Miyagi Prefecture 2015), and the recovery of farmlands is likely to have displace geese through the increase in associated human activity. The percentage of fishery harbours at which Black Brant were observed has gradually decreased as wharfs that had subsided following the earthquake were rebuilt. Meanwhile, fishery rafts, one of the original habitats for the geese in Japan, were rapidly reconstructed (50–60% were rebuilt by 2012 and up to 85% were rebuilt by 2013; Fisheries Agency 2014). The geese would likely have avoided agricultural farmlands and fishery harbours with longer term human activity associated with the restoration work, and selected less disturbed fishery rafts, which were rebuilt more promptly. Recovery of seaweed beds and sea grass habitats (Ministry of the Environment 2016) adjacent to fishery rafts would perhaps also have compensated for loss of access to farmlands and fishery harbours as restoration progressed. Thus, it seems that, with the recovery of their pre-tsunami habitats, the geese have returned to their pre-tsunami habitat selection.

Our results demonstrate for the first time the use of terrestrial habitat by Black Brant in Japan, and the plasticity shown by the geese in response to large-scale environmental change. Environmental disturbance events can affect bird populations through habitat change in affected areas. For example, herons and ducks increased in number as a result of the increase in food following flooding in northern Japan (Shimada *et al.* 2000). Bird species' richness was significantly reduced by storms, and windstorms altered bird assemblages from forest species to open-land species in Europe (Thorn *et al.* 2016). Changing disturbance regimes can produce acute changes in ecosystems and ecosystem services over the short (years to decades) and longer term (centuries and beyond, Turner 2010). In the current case of the Black Brant, however, tracked geese were found to spend only a small proportion of their time on new habitats following the tsunami, perhaps because recovery of seaweed beds and sea grass habitats, and the rapid restoration of aquaculture facilities such as fishery rafts, accelerated the return of the geese to their original habitat, once these were restored.

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Photograph: Black Brant wintering along the southern Sanriku coast in northern Japan, by Hiroyoshi Higuchi.

