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Long-term declines in common breeding seabirds in Japan

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Summary

Global seabird populations are in decline, with nearly half of all seabird species currently in an extinction crisis. Understanding long-term seabird population trends is an essential first step to inform conservation actions. In this study, we assembled historical breeding records of seabirds throughout the Japanese archipelago and quantified the long-term population trends of 10 major breeding seabird species using a hierarchical Bayesian state-space model. The model revealed that six species had increasing or no detectable trends (Short-tailed Albatross *Phoebastria albatrus*, Leach's Storm Petrel *Oceanodroma leucorhoa*, Pelagic Cormorant *Phalacrocorax pelagicus*, Japanese Cormorant *Phalacrocorax capillatus*, Spectacled Guillemot *Cepphus carbo*, and Rhinoceros Auklet *Cerorhinca monocerata*). However, decreasing trends were found not only in nationally threatened species (Common Murre *Uria aalge*, and Tufted Puffin *Fratercula cirrhata*) but also common species that are often described as abundant (Black-tailed Gull *Larus crassirostris* and Slaty-backed Gull *Larus schistisagus*). These declining species have declined to 3–35% of baseline levels over the past 30 years. This study provides the first evidence of long-term declines in common and widespread seabirds in Japan.

Introduction

Over the past century, global seabird populations have undergone catastrophic population collapses and it is estimated that the monitored seabird populations have declined by 69.7% since 1950 (Paleczny *et al.* 2015). Consequently, nearly half of all seabird species around the globe are currently in extinction crisis (Croxall *et al.* 2012). Empirical evidence suggests that documented seabird declines are likely associated with various natural and anthropogenic factors such as predation by introduced predators, decline of prey stocks driven by climate change, harvesting, fisheries bycatch, competition with fisheries for shared prey, marine pollution, and loss of nesting habitats (Frederiksen *et al.* 2004, Lewison *et al.* 2012, Spatz *et al.* 2014). Quantitative estimates of their population status and long-term trends represent an essential first step to inform conservation actions (Paleczny *et al.* 2015). To this end, many seabird population monitoring efforts have been made globally (Wooller *et al.* 1992, Anker-Nilssen and Røstad 1993, Anker-Nilssen 2010).

The Japanese archipelago harbours 40 breeding seabird species including several endemic and rare species such as the recently rediscovered Bryan's Shearwater *Puffinus bryani* (Kawakami *et al.* 2012) and re-described Bannerman's Shearwater *Puffinus bannermani* (Kawakami *et al.* 2018). Hence, Japan is a globally important seabird-rich region (Higuchi *et al.* 1995). Previous studies have roughly summarized the status of Japanese seabirds and suggested potential decreases/increases in species throughout Japan before 1984 (Hasegawa 1984) or locally before 2000 (Osa and Watanuki 2002). However, due to the poor availability and accessibility of

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synthesized seabird breeding records, no nationwide assessment of population trends in Japanese seabirds has been conducted.

Recently, an extensive database covering a range of historical seabird breeding records throughout Japan was made available. This database synthesizes published records in the academic literature and unpublished records compiled by citizen observers and public monitoring projects. The "Monitoring Site 1000" project by the Japanese Ministry of the Environment contributed greatly to this database, with count data for 25 seabird species on a total of 77 islands since 2004 (Ministry of the Environment of Japan 2015). In the current study, we used this database to quantify nationwide population trends (i.e. annual population growth rates) in 10 major seabird species breeding in Japan over the past three decades. We employed a Bayesian state-space modelling approach because it can provide less biased estimates of demographic parameters by accounting for missing values and various types of observational errors (Kéry and Schaub 2012), both of which are typical problems among long-term monitoring data. This study is the first to determine long-term population trends in seabirds breeding in Japan.

Materials and Methods

Japan seabird colony database

We created a database including information on 40 seabird species within Phaethontidae, Diomedeidae, Procellariidae, Hydrobatidae, Sulidae, Phalacrocoracidae, Laridae, and Alcidae, with 3,300 breeding records from a total of 389 colonies with exact locations throughout the Japanese archipelago (Figure 1). The dataset used in this study is based on the latest version of this database (January 2018). The data were collected by various contributors including both citizens and researchers using the following methods: for species that nest on open, flat ground (e.g. albatrosses and gulls), numbers of nests and/or adults during the incubation period were estimated. For most colonies, observers counted these metrics directly. For colonies having areas difficult to access, observers counted numbers of nests and/or adults in multiple plots within a colony, and then the averaged densities were multiplied by the total area of the colony. Both metrics were countable in most cases, but adult counts were often prioritised when nest counts were difficult to obtain. For burrow nesters (e.g. shearwaters, storm petrels, and several alcid species), a stratified sampling method was applied; nests were counted in plots of several square meters (plot sizes varied by species and colony) on multiple habitats with different ground structures (e.g. proportion of vegetation cover) within a colony. The estimated mean density for each habitat was then multiplied by the total area of respective habitat in the colony; these multiplied estimates were then summed. For species that nest on cliffs or rock-ledges (e.g. cormorants and murres), incubating or brooding adults (i.e. nests) were counted using panoramic photographs or sketches from vantage points covering the total area of a colony. For species that nest in crevices on cliffs or rock-ledges (e.g. puffins and guillemots), numbers of active nests were estimated by observing prey-provisioning adults from vantage points within a colony. We also counted adults on the sea near colonies, because these numbers can be positively related to the number of active nests. Hasebe *et al.* (2015) showed that the maximum number of Spectacled Guillemots observed on the sea during the early incubation period was moderately related to the number of active nests. For colonies where multiple counts were performed within a given year, we used the maximum numbers of adults and/or nests as representative.

Population trend analysis

Focal species and study timeframe

Of the 40 species in our database, we focused on 10 species for which we had a reasonable amount of data (Short-tailed Albatross *Phoebastria albatrus*, Leach's Storm-petrel *Oceanodroma leucorhoa*, Japanese Cormorant *Phalacrocorax capillatus*, Pelagic Cormorant *Phalacrocorax*

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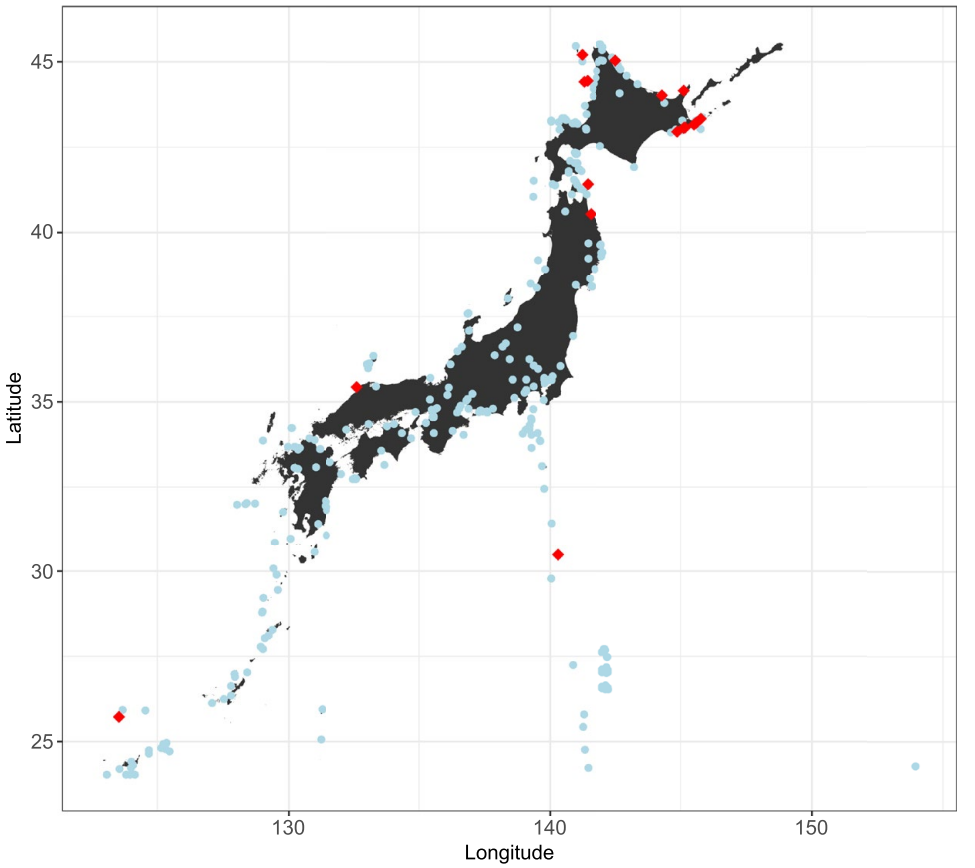


Figure 1. Locations of seabird colonies in Japan. Smaller circles and larger squares indicate all colonies of the 40 species included in the Japan colony database and the focal colonies used in the population trend analysis, respectively.

pelagicus, Black-tailed Gull *Larus crassirostris*, Slaty-backed Gull *Larus schistisagus*, Common Murre *Uria aalge*, Spectacled Guillemot *Cepphus carbo*, Tufted Puffin *Fratercula cirrhata* and Rhinoceros Auklet *Cerorhinca monocerata*. These species were monitored for > 4 years on at least one colony since 1980 using the methods described above (Figure 1, Table 1). Thus, the timeframe of this study was 36 years (1980–2015). Although several focal species (i.e. Short-tailed Albatross, Common Murre, Spectacled Guillemot, Tufted Puffin) are known to have declined by that time (Hasegawa and Degange 1982, Osa and Watanuki 2002), the analysis from the year 1980 can provide a better understanding of how Japanese seabirds responded to recent environmental changes. We analysed a total of 18 colonies where single or multiple species breed (Figure 1). Several focal colonies are exposed to increasing predation threat recently from introduced predators such as rats *Rattus* spp. and/or feral cats *Felis catus* (e.g. Teuri Island, Rishiri Island, and Kabushima Island) (Tomita *et al.* 2010, 2016), as well as native predators such as White-tailed Eagle *Haliaeetus albicilla* (e.g. Teuri Island and Daikoku-jima) (Ministry of the Environment of Japan 2015). Although some other colonies were not included in the analysis, our focal colonies accounted for a substantial portion of the current national population size of each species (Table 1). We therefore presume that our analysis represents the nationwide population trends of each species. Trends of the other 30 species and those

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Table 1. Sample sizes for population trend analysis and estimated population sizes for each focal species. In the "sample size for analysis", numbers of adults and numbers of nests represent sums of the latest counts for all focal colonies. Proportion represents the percentage of the respective national population size of each species. National population size represents the sum of the numbers of nests or adults among all colonies where surveys were conducted after 2000. CR, Critically Endangered; VU, Vulnerable; EN, Endangered; LC, Least Concern.

		Sample size for analysis				Red list rank	
Species	Scientific name	No. of colonies	No. of adults (nests)	Proportion	National population size	National	IUCN
Short-tailed Albatross	*Phoebastria albatrus*	2	1,449 (681)	93.93%	725 nests	VU	VU
Leach's Storm-petrel	*Oceanodrima leurorhoa*	1	886,474 (443,237)	95.74%	462,958 nests		VU
Japanese Cormorant	*Phalacrocorax capillatus*	7	3,288 (1,644)	49.83%	3,299 nests		LC
Pelagic Cormorant	*Phalacrocorax pelagicus*	1	106 (53)	100%	53 nests	EN	LC
Black-tailed Gull	*Larus crassirostris*	10	66,851 (28,432)	57.06%	49,831 nests		LC
Slaty-backed Gull	*Larus schistisagus*	9	7,203 (3,478)	78.05%	4,456 nests		LC
Common Murre	*Uria aalge inornata*	1	35	92.11%	38 adults	CE	LC
Spectacled Guillemot	*Cepphus carbo*	10	995 (262)	92.22%	1079 adults	VU	LC
Tufted Puffin	*Fratercula cirrhata*	4	19	90.48%	21 adults	CE	LC
Rhinoceros Auklet	*Cerorohinca monocerata*	4	976,088 (488,044)	78.43%	622,294 nests		LC

of our focal species before 1980 were not estimated due to substantial data deficiencies within the database.

Bayesian state-space modeling

To estimate temporal trends in seabird populations, we employed a Bayesian state-space model (Kéry and Schaub 2012). The state-space modelling approach is robust against missing values (Clark and Bjørnstad 2004), which are typical in sparse long-term datasets like that used in this study (Terui *et al.* 2018). Furthermore, this modelling approach allowed us to isolate observation errors from state processes (i.e. true population dynamics), leading to less biased estimates of essential demographic parameters (e.g. population growth rates) (Clark and Bjørnstad 2004, Kakinuma *et al.* 2017). These separate models were created as follows.

Observation model

We assumed that nest ($NEST_{tij}$) and adult counts ($ADULT_{tij}$) in year t and colony i for species j followed a Poisson distribution:

$$NEST_{tij} \sim \text{Poisson}\left(\exp\left(\log\, n_{tij} + \varepsilon 1_{tij}\right)\right) \tag{1}$$

$$ADULT_{tij} \sim \text{Poisson}\left(\exp\left(\log\, b_j + \log\, n_{tij} + \varepsilon 2_{tij}\right)\right), \tag{2}$$

where n_{tij} is the "true" nest abundance index, which is estimated using both nest and adult count data. The species-specific conversion parameter, b_j, links the true nest abundance index to adult counts. The log-transformed conversion parameter, log b_j, was drawn from a normal distribution with a hyper-mean of log B and variance of σ_b^2. The parameters $\varepsilon 1_{tij}$ and $\varepsilon 2_{tij}$ are observation errors (year- and site-specific) drawn from normal distributions with a mean of 0 and variance of σ_{nest}^2 or σ_{adult}^2, respectively. The standard deviations, σ_{nest} or σ_{adult}, represent the degree of observation errors caused by either ecological or artificial factors (Kéry and Schaub 2012). Thus, the model enables us to apply both nest and adult count information simultaneously, while accounting properly for the influence of unavoidable observation uncertainties. We incorporated the observation error terms (σ_{nest} or σ_{adult}) because the compiled dataset included observations conducted by various investigators and thus may involve artificial errors that could not be accommodated by a Poisson distribution. For species whose data are confined to either adult or nest abundance only (*C. monocerata, U. aalge, P. pelagicus, P. albatrus, and O. leucorhoa*), the species-specific conversion parameters b_j were drawn randomly from a normal distribution with hyperparameters (log B and σ_b^2). This imputation does not compromise species-specific information, because the model estimates demographic parameters mainly using available data for these focal species (either nest or adult counts).

Process model

We decomposed true nest abundance n_{tij} into its temporal and spatial components. The temporal component captures population trends over observed periods, whereas the spatial component accounts for spatial (among-colony) variation in nest abundance (Amano *et al.* 2012). Specifically, nest abundance in year t at colony i was described as follows:

$$\log n_{tij} = \alpha_{tj} + \beta_{ij}. \tag{3}$$

In equation 4, α_{tj} and β_{ij} are the temporal and spatial components of nest abundance, respectively, for species j. The spatial variation term β_{ij} accounts for among-colony variation in nest abundance and is assumed to follow a normal distribution with a mean of 0 and variance of σ_β^2.

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We then employed a simple exponential growth model to describe seabird population dynamics:

$$\alpha_{(t+1)j} = \log\, r_{tj} + \alpha_{tj}, \quad (4)$$

where the parameter $\log r_{tj}$ is a species- and year-specific population growth rate (log-scale) drawn from a normal distribution as $\log r_{tj} \sim \text{Normal}(\log r_{mean,j}, \sigma_{temp,j}^2)$, where $\log r_{mean,j}$ is the mean population growth rate for species j. The parameter $\sigma_{temp,j}^2$ governs the degree of temporal variation in $\log r_{tj}$. The parameter $\log r_{mean,j}$ was drawn from a normal distribution with hyperparameters $\log r_{global}$ (mean) and σ_r^2 (variance). This hierarchical model structure increases parameter estimate accuracy, as data-poor species can borrow information from data-rich species (Gelman and Hill 2007, Hanioka *et al.* 2018).

Vague priors were assigned for the parameters: i.e. truncated normal distributions for σ_{nest}, σ_{adult}, σ_b, σ_β, $\sigma_{temp,j}$, and σ_r (mean = 0, variance = 1,000, range = 0–100) and normal distributions for $\log B$, α_{1j}, and $\log r_{global}$ (mean = 0, variance = 1000). We fitted the model to the data using the JAGS ver. 4.1.0 software and the "*runjags*" package in R ver. 3.3.1 software, which allowed parallel computation of multiple Markov-chain Monte Carlo (MCMC) chains. Three MCMC chains were run for 22,500 steps with an initial 7,500 burn-in period, and 500 MCMC samples were stored for each chain. Convergence was assessed by determining whether the R-hat indicator of each parameter approached 1 (Gelman and Hill 2007).

Based on estimated nest abundances, we calculated population index as:

$$\textit{Population index}_{tj} = \exp\left(\alpha_{tj}\right)/\exp\left(\alpha_{1j}\right), \quad (5)$$

where the denominator $\exp(\alpha_{1j})$ is the estimated nest abundance in year 1980 for species j. Population indices provide relative measures of population trends in comparison to the base year 1980 (Amano *et al.* 2010). We also estimated averages of log-transformed population growth rates $\log r_{tj}$ (i.e., geometric mean) over 10- (2005–2015), 20- (1995–2015), and 30-year (1985–2015) periods to reveal period-specific population trends.

Results

Four of 10 species (Black-tailed Gull, Slaty-backed Gull, Common Murre, and Tufted Puffin) declined significantly in at least one of the past 10-, 20-, or 30-year periods (Figure 2, Table 2; Table S1 in the online supplementary material). Two alcid species declined steeply during the past 30 years, decreasing to 3% (Common Murre) and 13% (Tufted Puffin) compared to the base year 1980 (Figure 2). Two gull species showed consistent decline throughout all three study periods (Tables 2, Table S1), decreasing to 28% (Black-tailed Gull) and 35% (Slaty-backed Gull) (Figure 2). In contrast, four species (Short-tailed Albatross, Pelagic Cormorant, Rhinoceros Auklet, and Spectacled Guillemot) increased significantly in at least one of the past 10-, 20-, or 30-year periods (Figure 2, Table 2, Table S1). No apparent global trends were observed in the other two species (Leach's Storm Petrel, Japanese Cormorant) throughout the three study periods, but their wide 95% credible intervals suggested that their trends might not be detectable due to data paucity of these species (Figure 2, Table 2, Table S1).

Discussion

Current global efforts to conserve seabirds, including those in Japan, have almost exclusively focused on narrow-ranging rare species with the belief that those species are facing near-future extinction risk. However, the analysis performed using our extensive dataset suggests that, in addition to nationally threatened species (Common Murre and Tufted Puffin), wide-ranging

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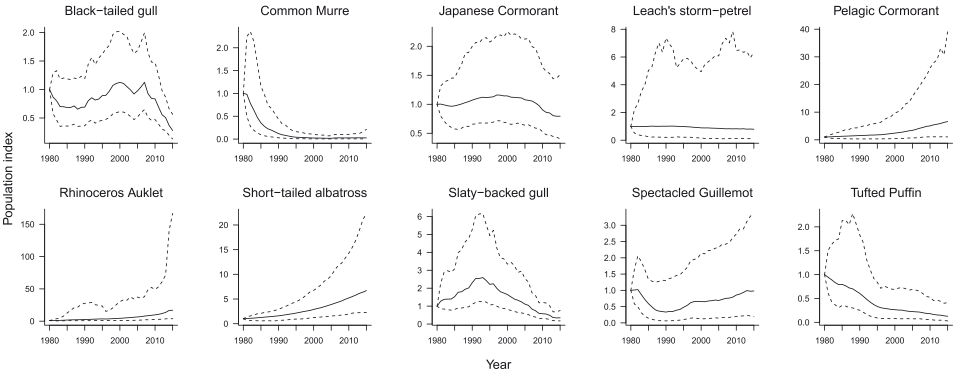


Figure 2. Population indices estimated by the Bayesian state-space model. These indices are relative measures of population trends in comparison to the base year, 1980. Solid lines indicate median estimates; broken lines indicate associated 95% credible intervals.

common species (Black-tailed and Slaty-backed Gull) are also rapidly declining. The declines of common species may deserve attention because they are often dominant in an ecosystem and have effects on ecosystem function and associated ecosystem services (Elliott *et al.* 2010, Inger *et al.* 2015). Although some colonies that were not included in the analysis might show different trends, our results should reflect their nationwide population trends because our focal colonies accounted for the bulk of the current national population size of each species (Table 1).

Our modelling approach integrated nest and adult count data to mitigate the influence of data scarcity on parameter estimates (see Methods). Nevertheless, our results must be interpreted with some caution. As with ordinary statistical approaches, significant population trends, if present, are less likely to be found for species with fewer data. In our dataset, this issue may be relevant for Leach's Storm-petrel and Japanese Cormorant, for which we could not detect any population trends: this result might arise just because of the scarcity of the data (Table 2). The uncertainty of estimated trends in data-poor species can be improved by, at least in part, continued or increased monitoring efforts in the future. Therefore, incorporating further data into the current model may represent an important next step to better assess population trends of Japanese seabirds.

Table 2. Population growth rates (log r_{ij}) averaged for 10- (2005–2015), 20- (1995–2015), and 30-year (1985–2015) periods estimated by the Bayesian state-space model. Median values and 95% credible intervals of posterior distributions are shown. Significance indicated in bold.

	10-year period			20-year period			30-year period		
Species	Median	2.50%	97.50%	Median	2.50%	97.50%	Median	2.50%	97.50%
Black-tailed Gull	**−0.12**	**−0.18**	**−0.07**	**−0.06**	**−0.09**	**−0.03**	**−0.03**	**−0.05**	**−0.01**
Common Murre	0.04	−0.14	0.25	−0.02	−0.12	0.08	**−0.09**	**−0.15**	**−0.02**
Japanese Cormorant	−0.03	−0.10	0.01	−0.02	−0.05	0.01	−0.01	−0.02	0.01
Leach's Storm-petrel	−0.01	−0.18	0.16	−0.01	−0.10	0.06	−0.01	−0.08	0.05
Pelagic Cormorant	0.06	−0.04	0.16	**0.07**	**0.01**	**0.12**	**0.06**	**0.01**	**0.10**
Rhinoceros Auklet	0.09	−0.03	0.30	**0.08**	**0.01**	**0.15**	**0.07**	**0.02**	**0.12**
Short-tailed Albatross	0.06	−0.02	0.13	**0.06**	**0.02**	**0.10**	**0.06**	**0.02**	**0.09**
Slaty-backed Gull	**−0.12**	**−0.19**	**−0.05**	**−0.09**	**−0.13**	**−0.06**	**−0.05**	**−0.07**	**−0.03**
Spectacled Guillemot	0.03	−0.04	0.11	**0.04**	**0.00**	**0.08**	0.02	−0.01	0.04
Tufted Puffin	−0.06	−0.16	0.02	−0.05	−0.09	0.00	**−0.06**	**−0.10**	**−0.03**

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Drivers associated with the detected trends in focal species

Drivers associated with the detected trends in our focal species have not been fully addressed. However, the results of the current study allow us to suggest some contributing factors to these trends, which are not mutually exclusive.

Species with decreasing population size

The declines in two gull species over the past three decades might be associated with elevated predation by introduced and/or native predators. For example, many colonies of both gull species are exposed to increasing predation pressure from the native White-tailed Eagle due to its population expansion in northern Japan since the 1990s (Ministry of the Environment of Japan 2015). Predation by foxes and feral cats on adult Black-tailed Gulls has also been observed recently in several colonies (Tomita *et al.* 2010, 2016).

The declines in gulls might also be linked to a reduction in prey availability associated with decadal-scale changes in atmospheric and ocean temperatures in the Pacific Ocean (Chavez *et al.* 2003). For example, Japanese populations of the Japanese sardine *Sardinops melanostictus*, a main prey of Slaty-backed Gulls (Watanuki 1988), collapsed in the late 1980s when local waters in the north-west Pacific warmed and became unproductive (Wada and Jacobson 1998). Additionally, local stock of the sandlance *Ammodytes personatus*, which is the major diet of Black-tailed Gulls around Teuri Island, collapsed in the mid-1990s and never recovered. In parallel with these collapses, the population declines in Slaty-backed Gull and Black-tailed Gull have been observed on its historically largest colony (Daikokujima Island) and one of the largest colonies (Teuri Island), respectively (Figure S1).

The nationally threatened Common Murre and Tufted Puffin have experienced declines in the last 30-year period, but not in the past 10- and 20- year periods. Previous studies have suggested that drastic declines in both species occurred before our study timeframe, likely due to driftnet entanglement (Osa and Watanuki 2002). The influence of driftnet entanglement on these species around Japan is underappreciated but is expected to become weaker in the future. For example, salmon driftnet fishery in the Sea of Japan, which is reported to severely impact the population of Common Murre on its largest national colony (Teuri Island) (Osa and Watanuki 2002), had declined since the mid-1970s and the operation ended officially in 2011 (Mizusawa 2011). Moreover, driftnet fishery in Japan's Exclusive Economic Zone in the north-west Pacific Ocean, which might have negative impacts on the populations of Tufted Puffin in eastern Hokkaido, has been declining gradually since the mid-1990s (Kataoka and Mizuno 1999). However, despite the current implementation of conservation efforts for both species (Kataoka and Mizuno 1999, Hasebe *et al.* 2012), our results suggest that their population sizes in Japan are considerably reduced and approaching extirpation, although the Common Murre population on Teuri Island has been reported to be gradually recovering (Hasebe *et al.* 2012).

Species with increasing population size

The positive population growth of the Short-tailed Albatross is consistent with that reported in previous studies (Finkelstein *et al.* 2010), and may be attributable to intensive conservation efforts on the Torishima colony (e.g. nest site enhancements, decoy deployment) (Hasegawa and Degange 1982, Sato *et al.* 1998, Melvin *et al.* 2003, Sato 2009, Finkelstein *et al.* 2010). Additionally, reduced mortality by fisheries bycatch in their wintering areas may be contributing to population improvement (Zador *et al.* 2008). Increasing trends among the other three species support the findings of previous local studies of the Pelagic Cormorant and Rhinoceros Auklet (Watanuki *et al.* 1988, Osa and Watanuki 2002) and of the largest Teuri Island Spectacled Guillemot colony (Hasebe *et al.* 2015). It may also be possible that the positive trends in Rhinoceros Auklet and Spectacled Guillemot reflected to the recent declines in sympatric Black-tailed and Slaty-backed

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Gulls for two reasons. First, both Rhinoceros Auklet and Spectacled Guillemot might experience "predator release" on their colonies because gulls impede feeding rate of these Alcidae species as well as predate their eggs, chicks and adults (Finney *et al.* 2001, Senzaki *et al.* 2014). Second, the declines in gulls might increase at-sea food availability of shared prey such as the sandlance and the Japanese anchovy *Engraulis japonicus* (Takahashi *et al.* 2001, Yoda *et al.* 2012). These factors might have positive effects on survival, reproduction, and ultimately population growth in Rhinoceros Auklet and Spectacled Guillemot. However, we acknowledge that the drastic Spectacled Guillemot decline occurred before our study timeframe (before 1980), and the current population size of this species is not still attaining historical levels (Senzaki *et al.* 2015).

Future research directions and implications for conserving Japanese seabirds

Despite increasing monitoring efforts for seabirds in Japan during the past several decades (Kazama *et al.* 2010), we were unable to estimate population trends in most species breeding in Japan due to data deficiency and unreliability. Thus, the following issues must be addressed in future studies to better guide conservation efforts for Japanese seabirds.

First, the ongoing Monitoring Site 1000 project plays a pivotal role in seabird monitoring in Japan. Focal colonies are mainly selected as subjects for narrow-ranging rare species as well as many common and wide-ranging species. However, for some colonies of wide-ranging species, surveys or estimates of total numbers of nests have not been conducted due to lack of manpower or data deficiencies for the total breeding area (e.g. Brown Booby *Sula leucogaster*, Streaked Shearwater *Calonectris leucomelas*, and Wedge-tailed Shearwater *Puffinus pacificus*). Thus, in addition to the Monitoring Site 1000 project, it may be important to establish monitoring systems in cooperation with local governments, local conservation organisations, and other groups that conduct research at these breeding sites. Moreover, it is important to collect population demographic data such as adult survival and recruitment. These data allow us to estimate more reliable long-term persistence of each species (Genovart *et al.* 2018, Sanz-Aguilar *et al.* 2009, 2016).

Second, natural and/or anthropogenic drivers of common seabird declines must be identified. Although an array of factors have been suggested as potential threats, such environmental data are not available for most seabird colonies (Jones *et al.* 2016; but see Emura *et al.* 2015). For example, seabird bycatch from commercial fisheries is believed to have substantial negative impacts on populations in many seabird species such as albatrosses and petrels (Croxall *et al.* 2012). However, there are very limited data on seabird bycatch around Japan, especially in the coastal zone that most breeding seabirds in Japan depend heavily on for foraging, despite the fact that coastal fisheries such as fixed-net fishery operate commonly in the coastal zone across Japan (Ministry of Agriculture, Forestry and Fisheries 2019). This data deficiency limited our ability to quantify the impacts of environmental factors. Therefore, another important task is to monitor potential threats to seabird populations while compiling relevant existing data. Filling this gap will also allow us to examine why some species have declined while others do not.

Finally, applying modern technical or statistical methods to current monitoring programmes may facilitate the accurate estimation of population trends in species that are difficult to monitor using traditional methods. For example, we were unable to estimate trends in most nocturnal burrow-nesting species (e.g. Ancient Murrelet *Synthliboramphus antiquus*, Japanese Murrelet *Synthliboramphus wumizusume*, Band-rumped Storm-petrel *Oceanodroma castro*). However, Oppel *et al.* (2014) estimated the population size of a nocturnal species (Cory's Shearwater *Calonectris borealis*) at one of its colonies by combining acoustic monitoring and habitat mapping. Other examples include a mark–recapture method to correct nest occupancy rates (Sutherland and Dann 2012) and aerial/satellite-based digital image surveys (Buckland *et al.* 2012, Fretwell *et al.* 2012). Nevertheless, given the limited budgets and time available for monitoring and practical conservation efforts, further discussion and empirical evidence are clearly needed to determine which research avenues and conservation targets, including those discussed above, should be prioritised (Brooke *et al.* 2017).

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Supplementary Material

To view supplementary material for this article, please visit https://doi.org/10.1017/S0959270919000352

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References

Amano, T., Okamura, H., Carrizo, S. F. and Sutherland, W. J. (2012) Hierarchical models for smoothed population indices: The importance of considering variations in trends of count data among sites. *Ecol. Indic.* 13: 243–252.

Amano, T., Székely, T., Koyama, K., Amano, H. and Sutherland, W. J. (2010) A framework for monitoring the status of populations: An example from wader populations in the East Asian-Australasian flyway. *Biol. Conserv.* 143: 2238–2247.

Anker-Nilssen, T. (2010) Key-site monitoring in Røst in 2009. In *SEAPOP Short Report 12-2010*.

Anker-Nilssen, T. and Røstad, O. W. (1993) Census and monitoring of Puffins Fratercula arctica on Røst, N Norway, 1979-1988. *Orins Scand.* 24: 1–9.

Brooke, M. de L., Bonnaud, E., Dilley, B. J., Flint, E. N., Holmes, N. D., Jones, H. P., Provost, P., Rocamra, G., Ryan, P. G., Surman, C. and Buxton, R. T. (2017) Seabird population changes following mammal eradications on islands. *Anim. Conser.* 21: 3–12.

Buckland, S. T., Burt, M. L., Rexstad, E. A., Mellor, M., Williams, A. E. and Woodward, R. (2012) Aerial surveys of seabirds: The advent of digital methods. *J. Appl. Ecol.* 49: 960–967.

Chavez, F. P., Ryan, J., Lluch-Cota, S. E. and Niquen, M. C. (2003) From anchovies to sardines and back: Multidecal change in the Pacific Ocean. *Science* 299: 217–221.

Clark, J. S. and Bjørnstad, O. N. (2004) Population time series: Process variability, observation errors, missing values, lags, and hidden states. *Ecology* 85: 3140–3150.

Croxall, J. P., Butchart, S. H. M., Lascelles, B., Statersfield, A. J., Sullivan, B., Aymes, A. and Taylor, P. (2012) Seabird conservation status, threats and priority actions: a global assessment. *Bird Conserv. Internatn.* 22: 1–34.

Elliott, G. P., Wilson, P. R., Taylor, R. H. and Beggs, J. R. (2010) Declines in common, widespread native birds in a mature temperate forest. *Biol. Conserv.* 143: 2119–2126.

Emura, N., Furuya, W., Ando, H. and Deguchi, T. (2015) Monitoring of avifauna to estimate the effect of ecological restoration in Mukojima, Bonin Islands. *J. Yamashina Inst. Ornithol.* 46: 89–100.

Finkelstein, M. E., Wolf, S., Goldman, M., Doak, D. F., Sievert, P. R., Balogh, G. and Hasegawa, H. (2010) The anatomy of a (potential) disaster: Volcanoes, behavior, and population viability of the short-tailed albatross (Phoebastria albatrus). *Biol. Conserv.* 143: 321–331.

Finney, S. K., Wanless, S., Harris, M. P., and Monaghan, P. (2001) The impact of gulls on puffin reproductive performance: An experimental test of two management strategies. *Biol. Conserv.* 98: 159–165.

Frederiksen, M., Wanless, S., Harris, M. P., Rothery, P., and Wilson, L. J. (2004) The role of industrial fisheries and oceanographic

https://doi.org/10.1017/S0959270919000352 Published online by Cambridge University Press

change in the decline of North Sea black-legged kittiwakes. *J. Appl. Ecol.* 41: 1129–1139.

Fretwell, P. T., LaRue, M. A., Morin, P., Kooyman, G. L., Wienecke, B., Ratcliffe, N., Fox, A. J., Fleming, A. H., Porter, C. and Trathan, P. N. (2012) An emperor penguin population estimate: The first global, synoptic survey of a species from space. *PLoS One* 7: e33751. doi:10.1371/journal.pone.0033751

Gelman, A. and Hill, J. (2007) *Data analysis using regression and multilevelhierarchical models*, Vol. 1, New York: Cambridge University Press, NY, USA.

Genovart, M., Bécares, J., Igual, J. M., Martínez-Abraín, A., Escandell, R., Sánchez, A., Rodríguez, B., Arcos, M. A., and Oro, D. (2018) Differential adult survival at close seabird colonies: The importance of spatial foraging segregation and bycatch risk during the breeding season. *Glob. Change. Biol.* 24: 1279–1290.

Hanioka, M., Yamaura, Y., Yamanaka, S., Senzaki, M., Kawamura, K., Terui, A. and Nakamura, F. (2018) How much abandoned farmland is required to harbor comparable species richness and abundance of bird communities in wetland? Hierarchical community model suggests the importance of habitat structure and landscape context. *Biodivers. Conserv.* 27: 1831–1848.

Hasebe, M., Aotsuka, M., Terasawa, T., Fukuda, Y., Niimura, Y., Watanabe, Y., Watanuki, Y. and Ogi, H. (2012) Status and Conservation of the Common Murre *Uria aalge* Breeding on Teuri Island, Hokkaido. *Ornithol. Sci.* 11: 29–38.

Hasebe, M., Fukuda, Y., Senzaki, M. and Watanuki, Y. (2015) Seasonal variation and inter-annual trends in the number of Spectacled Guillemots at Teuri Island, Hokkaido, Japan. *Japanese J. Ornithol.* 64: 251–255.

Hasegawa, H. (1984) Status and conservation of seabirds in Japan, with special attention to the Short-tailed Albatross. *Status Conserv. world's seabirds. Int. Counc. Bird Preserv. Tech. Pub.* 2: 487–500.

Hasegawa, H. and Degange, A. R. (1982) The short-tailed albatross Diomedea albatrus its status distribution and natural history. *Am. Bird.* 36: 806–814.

Higuchi, H., Minton, J. and Katsura, C. (1995) Distribution and ecology of birds of Japan. *Pacific Sci.* 49: 69–86.

Inger, R., Gregory, R., Duffy, J. P., Stott, I., Voříšek, P. and Gaston, K. J. (2015) Common European birds are declining rapidly while less abundant species' numbers are rising. *Ecol. Lett.* 18: 28–36.

Jones, H. P. *et al.* (2016) Invasive mammal eradication on islands results in substantial conservation gains. *Proc. Natl. Acad. Sci.* 113: 4033–4038.

Kakinuma, K., Terui, A., Sasaki, T., Koyama, A., Jamsran, U., Okuro, T. and Takeuchi, K. (2017) Detection of vegetation trends in highly variable environments after grazing exclusion in Mongolia. *J. Veg. Sci.* 28: 965–974.

Kataoka, Y. and Mizuno, M. (1999) The changes in the number of breeding pairs of Tufted Puffins, Lunda cirrhata, around Kiritappu, Hokkaido. *Strix* 17: 1–14.

Kawakami, K., Eda, M., Horikoshi, K., Suzuki, H., Chiba, H. and Hiraoka, T. (2012) Bryan's Shearwaters Have Survived on the Bonin Islands, Northwestern Pacific. *Condor* 114: 507–512.

Kawakami, K., Eda, M., Izumi, H., Horikoshi, K. and Suzuki, H. (2018) Phylogenetic position of endangered *Puffinus lherminieri bannermani*. *Ornithol. Sci.* 17: 11–18.

Kazama, K., Ito, M., Niizuma, Y., Sakurai, Y., Takada, H., Sydeman, W. J., Croxall, J. P. and Watanuki, Y. (2010) Seabirds as indicators of the state of the marine environment and its conservation. *Japanese J. Ornithol.* 59: 38–54.

Kéry, M. and Schaub, M. (2012) *Bayesian population analysis using WinBUGS / OpenBUGS - a hierarchical perspective*. San Diego: Academic Press.

Lewison, R., Oro, D., Godley, B. J., Underhill, L., Bearhop, S., Wilson, R. P., Ainley, D., Arcos, J. M., Boersma, P. D., Borboroglu, P. G., Boulinier, T., Frederiksen, M., Genovart, M., Gonzalez-Solis, J., Green, J. A., Gremillet, D., Hamer, K. C., Hilton, G. M., Hyrenbach, K. D., Martinez-Abrain, A., Montevecchi, W. A., Phillips, R. A., Ryan, P. G., Sagar, P., Sydeman, W. J., Wanless, S., Watanuki, Y.,

https://doi.org/10.1017/S0959270919000352 Published online by Cambridge University Press

Weimerskirch, H. and Yorio, P. (2012) Research priorities for seabirds: Improving conservation and management in the 21st century. *Endanger. Species Res.* 17: 93–121.

Melvin, E. F., Parrish, J. K., Dietrich, K. S. and Hamel, O. S. (2003) *Solutions to seabird bycatch in Alaska's Demersal Longline Fisheries*. Washington: University of Washington Sea Grant Program. Project A/FP-7.

Ministry of Agriculture, Forestry and Fisheries (2019) *Statistics of Agriculture, Forestry and Fisheries*, Tokyo.

Ministry of the Environment of Japan (2015) *Summary report: Publication of the seabirds survey summary report*. Fujiyoshida.

Mizusawa, T. (2011) Salmon drift net shery of Japan. *Nippon Suisan Gakkaishi*, 77: 915–918.

Oppel, S., Hervias, S., Oliveira, N., Pipa, T., Silve, C., Geraldes, P., Goh, M., Immler, E. and McKown, M. (2014) Estimating population size of a nocturnal burrow-nesting seabird using acoustic monitoring and habitat mapping. *Nature Conserv.* 7: 1–13.

Osa, Y. and Watanuki, Y. (2002) Status of seabirds breeding in Hokkaido. *J. Yamashina Inst. Ornithol.* 33: 107–141.

Paleczny, M., Hammill, E., Karpouzi, V. and Pauly, D. (2015) Population trend of the world's monitored seabirds, 1950-2010. *PLoS One* 10: e0129342. doi.org/10.1371/journal.pone.0129342

Sanz-Aguilar, A., Igual, J. M., Tavecchia, G., Genovart, M., and Oro, D. (2016) When immigration mask threats: The rescue effect of a Scopoli's shearwater colony in the Western Mediterranean as a case study. *Biol. Conserv.* 198: 33–36.

Sanz-Aguilar, A., Massa, B., Lo Valvo, F., Oro, D., Minguez, E., and Tavecchia, G. (2009) Contrasting age-specific recruitment and survival at different spatial scales: A case study with the European storm petrel. *Ecography* 32: 637–646.

Sato, F. (2009) Increase in pairs of the short-tailed albatross Diomedea albatrus at an artificial breeding ground. *J. Yamashina Inst. Ornithol.* 40: 139–143.

Sato, F., Momose, K., Tsurumi, M., Hiraoka, T., Mitamura, A. and Baba, T. (1998) The first breeding success in the Short-tailed Albatross colony restoration project on Tori-shima, using decoys and vocal lure. *J. Yamashina Inst. Ornithol.* 30: 1–21.

Senzaki, M., Hasebe, M., Kataoka, Y., Fukuda, Y., Nishizawa, B. and Watanuki, Y. (2015) Status of the Spectacled Guillemot (Cepphus carbo) in Japan. *Waterbirds* 38: 184–190.

Senzaki, M., Suzuki, Y., and Watanuki, Y. (2014) Foraging tactics and success of inter- and intra-specific kleptoparasites on Rhinoceros Auklets Cerorhinca monocerata. *Ornithol. Sci.* 13: 1–8.

Spatz, D. R., Newton, K. M., Heinz, R., Tershy, B., Holmes, N. D., Butchart, S. H. M. and Croll, D. A. (2014) The biogeography of globally threatened seabirds and island conservation opportunities. *Conserv. Biol.* 28: 1282–1290.

Sutherland, D. R. and Dann, P. (2012) Improving the accuracy of population size estimates for burrow-nesting seabirds. *Ibis* 154: 488–498.

Takahashi, A., Kuroki, M., Niizuma, Y., Kato, A., Saitoh, S., and Watanuki, Y. (2001) Importance of the Japanese anchovy (Engraulis japonicus) to breeding rhinoceros auklets (*Cerorhinca monocerata*) on Teuri Island, Sea of Japan. *Mar. Biol.* 139: 361–371.

Terui, A., Ishiyama, N., Urabe, H., Ono, S., Finlay, J. C. and Nakamura, F. (2018) Metapopulation stability in branching river networks. *Proc. Natl. Acad. Sci.* 115: E5963–5969.

Tomita, N., Mizutani, Y., Fujii, H., Sugiura, R., Yanai, T., Asano, M. and Niizuma, Y. (2010) Mortality of adult Black-tailed Gulls Larus crassirostris on Kabu Island, Aomori Prefecture. *Japanese J. Ornithol.* 59: 80–83.

Tomita, N., Sato, F. and Iwami, K. (2016) Impact of cats on breeding Black-tailed Gulls on Tobishima Island, Yamagata, Japan. *J. Yamashina Inst. Ornithol.* 37: 123–129.

Wada, T. and Jacobson, L. D. (1998) Regimes and stock-recruitment relationships in Japanese sardine (*Sardinops melanostictus*), 1951-1995. *Can. J. Fish. Aquat. Sci.* 55: 2455–2463.

Watanuki, Y. (1988) Regional difference in the diet of slaty-backed gulls breeding around Hokkaido. *J. Yamashina Inst. Ornithol.* 20: 71–81.

https://doi.org/10.1017/S0959270919000352 Published online by Cambridge University Press

Watanuki, Y., Kondo, N. and Nakagawa, H. (1988) Status of Seabirds breeding in Hokkaido. *Japanese J. Ornithol.* 37: 17–32.
Wooller, R. D., Bradley, J. S. and Croxall, J. P. (1992) Long-term population studies of seabirds. *Trends Ecol. Evol.* 7: 111–114.
Yoda, K., Tomita, N., Mizutani, Y., Narita, A., and Niizuma, Y. (2012) Spatio-temporal responses of black-tailed gulls to natural and anthropogenic food resources. *Mar. Ecol. Prog. Ser.* 466: 249–259.
Zador, S. G., Punt, A. E. and Parrish, J. K. (2008) Population impacts of endangered short-tailed albatross bycatch in the Alaskan trawl fishery. *Biol. Conserv.* 141: 872–882.

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