

IMPACTS OF DEPREDAATION BY LARGE-BILLED CROWS *CORVUS MACRORHYNCHOS* ON THE COLONY OF JAPANESE MURRELETS *SYNTHLIBORAMPHUS WUMIZUSUME* AT EBOSHIJIMA, JAPAN

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ABSTRACT

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Eboshijima, Japan is a small island in the Tsushima Strait that hosts a small colony of Japanese Murrelet *Synthliboramphus wumizusume*, an endangered seabird that breeds in the warm Kuroshio Current region around Japan and South Korea. We conducted a study to investigate the effects of depredation by Large-billed Crows *Corvus macrorhynchos* on murrelets after discovering 29 carcasses and 50 eggshells depredated by crows in four survey plots at Eboshijima in 2022. Trail cameras captured crows during daylight hours from 06h59 to 16h45. To estimate the existing population of Japanese Murrelet and predict scenarios that demonstrate the effects of corvid depredation on the murrelet population, we used a return-time (RET) capture-mark-recapture model. We evaluated the murrelet population using the best-fitting RET model and the capture histories of 187 murrelets mist-netted on Eboshijima during 2013–2022. We then simulated 1 000 iterations of a 50-year population using scenarios based on the parameters obtained from the best-fitting model. Our simulations indicate that corvid depredation could lead to the extirpation of the murrelet population, with no individuals remaining within 17 years. However, by reducing the corvid depredation effect by 50%, the probability of extinction can be lowered to less than 50% over the next 50 years. Therefore, we recommend implementing a crow translocation or removal program to protect the Eboshijima murrelet population. Additionally, further research should be conducted to identify breeding and non-breeding individuals, as well as active nesting sites.

Key words: Japanese Murrelets, *Synthliboramphus wumizusume*, crow depredation, capture-mark-recapture, return-time (RET) model

INTRODUCTION

The Japanese Murrelet *Synthliboramphus wumizusume* (hereafter, murrelet) is a small alcid that breeds on islands in the warm Kuroshio Current region around Japan (BirdLife International 2001, Iida 2008, Yamaguchi *et al.* 2016, Miller *et al.* 2019) and South Korea (Kim *et al.* 2012, Park *et al.* 2013). Owing to decreases in their already small world population, the murrelet is listed as Vulnerable on the IUCN Red List of Threatened Species (BirdLife International 2018) and has been protected as a vulnerable species by the Ministry of the Environment, Government of Japan; in Japan, the species is considered a natural monument (Agency for Cultural Affairs 1997, The Ministry of the Environment 2020). Murrelets breed exclusively on rocky islands where loose colonies or scattered pairs occupy concealed sites such as rock crevices, grass tussocks, tree roots, and sea caves (Austin & Kuroda 1953). The largest breeding colonies are located on many remote islands in Japan, such as Birojima (Otsuki *et al.* 2017), the Izu Islands (Tsurumi *et al.* 2001, Carter *et al.* 2002), and islets off the town of Mugi in Tokushima (Takeishi *et al.* 2018). Although their breeding sites are mostly uninhabited islands, the main threats to the murrelets are human disturbances (Piatt & Gould 1994) and introduced predators (Takeishi 1987, Otsuki *et al.* 2017). Rats *Rattus* spp. have had significant impacts on murrelets at Koyajima (Koyashima) (Takeishi 1987) and may have impacted them at the Izu islands (Tsurumi *et al.* 2001, Carter *et al.* 2002) and Kainagejima (Takeishi *et al.* 2020), while domestic cats have impacted murrelets on Mara

Island, South Korea (Choi & Nam 2017). Native avian predators such as Peregrine Falcons *Falco peregrinus* (Choi & Nam 2015) and several corvid species (e.g., Carrion Crows *C. corone* and Large-billed Crows *C. macrorhynchos*) are also predators of murrelets (Karnovsky *et al.* 2017, Takeishi *et al.* 2020, Whitworth *et al.* 2020, Takeishi 2021).

Murrelets' ground-nesting behavior and lower defense mechanisms against predators make them, and other seabirds, vulnerable to unfamiliar predators (Fitzpatrick & Rodewald 2016). Crows tend to be synanthropic generalist feeders that prey on the eggs, chicks, and adults of many bird species (Madden *et al.* 2015), including seabirds (MacCarone 1992, Rees *et al.* 2015, Maslo *et al.* 2016, Forys *et al.* 2020). Their agility and intelligence make them effective hunters, enabling them to navigate complex environments and quickly pursue prey (Marzluff & Neatherlin 2006, Seed *et al.* 2009). These birds can also gather in large numbers to prey on the eggs of seabirds that nest in colonies (Ewins 1991, Ekanayake *et al.* 2016). In order to effectively mitigate the impacts of this depredation and better understand the underlying mechanisms, it is crucial to carry out research on population viability (Peery & Henry 2010).

Eboshijima was first reported as an Ancient Murrelet *S. antiquus* breeding site in 1923 (Kuroda 1923), and Japanese Murrelets have been documented breeding there since 1990 (Nagata & Onagamitsu 1991, Takeishi & Takeshita 1995, Yamaguchi *et al.* 2016, Okabe *et al.* 2017, Otsuki *et al.* 2017). Breeding surveys were conducted

in the 1990s, specifically in 1992, 1994–1996, and 1998 (Takeishi & Takeshita 1995, H. Okabe, pers. comm.). Okabe *et al.* (2017) estimated 20–30 pairs breeding on Eboshijima even with the presence of Peregrine Falcons as a potential predator. Peregrine Falcons have been documented breeding and preying on murrelets (Okabe *et al.* 2017), but to our knowledge, intense depredation of murrelets has not been reported on this small breeding island.

In this paper, we report high levels of depredation on murrelet adults and eggs by Large-billed Crows at Eboshijima during the 2022 breeding season. We used mark-recapture data to estimate the size of this breeding murrelet colony and to evaluate the impact of Large-billed Crows' depredation on population dynamics. Since 2011, a murrelet banding program at Eboshijima has been conducted along with geolocator tracking of migrating individuals (Yamaguchi *et al.* 2016). The results of this study will contribute to current knowledge of the population status and future impacts on the Eboshijima murrelet population, and it will improve ongoing management and conservation actions for this species.

METHODS

Study area

Eboshijima (33°41'N, 129°59'E; Fig. 1) is located in the Sea of Genkai about 16 km off the coast of northwest Kyushu, between the Itoshima Peninsula and Iki Island. The small islet, which is ~1 ha (0.01 km²) in area, is surrounded by rocky cliffs consisting of columnar joints, with a flat top that includes a lighthouse and associated structures (BirdLife International 2022a). Murrelet breeding areas were limited to crevices in a rock wall, an artificial stone wall, and a part near the root of the O'ahu Sedge *Carex wahuensis*, a tussock-forming grass (Nagata & Onagamitsu 1991).

We conducted a comprehensive survey of the island by establishing four survey plots (Fig. 1a). These plots covered the flat area near the lighthouse on the east side (A), the slopes and open spaces surrounding the central buildings (B), the open spaces around the smallest building on the west side (C), and the lower rock/stone wall and slopes along the pathway (D). Although the border of the island is composed of rocky cliffs, limiting our survey, we believe that our survey included the majority of the potential breeding sites. This is because the columnar joints surrounding the island, as shown in Fig. 1b, did not appear to provide suitable nesting crevices.

Data collection

All murrelet carcasses and eggshells were collected and identified during three periods of the breeding and post-breeding seasons: 29 March, 05 April, and 10 June 2022. A trail camera, Ltl Acorn 6310WMC, was installed approximately 0.5 m above the ground in the flat area of site D on 24 February 2022, to monitor murrelet breeding behavior. The motion-sensor camera trap was set to continuously monitor for movements and record a photo and 10-sec videos whenever movement was detected, followed by a 30-min timeout. All images and videos were inspected to determine the presence of a murrelet and potential avian predators. The identification process was based on either their appearance on the screen or their audible sound.

Murrelet mist-netting and population estimation

We used mist-nets to capture murrelets in their nesting areas during the breeding season (March–May) in 2013–2019 and 2021–2022. The total length of a 12-m mist-net was used at only one capturing station. In most cases, we conducted the survey only once a year, with mist-netting activities typically carried out from dusk until

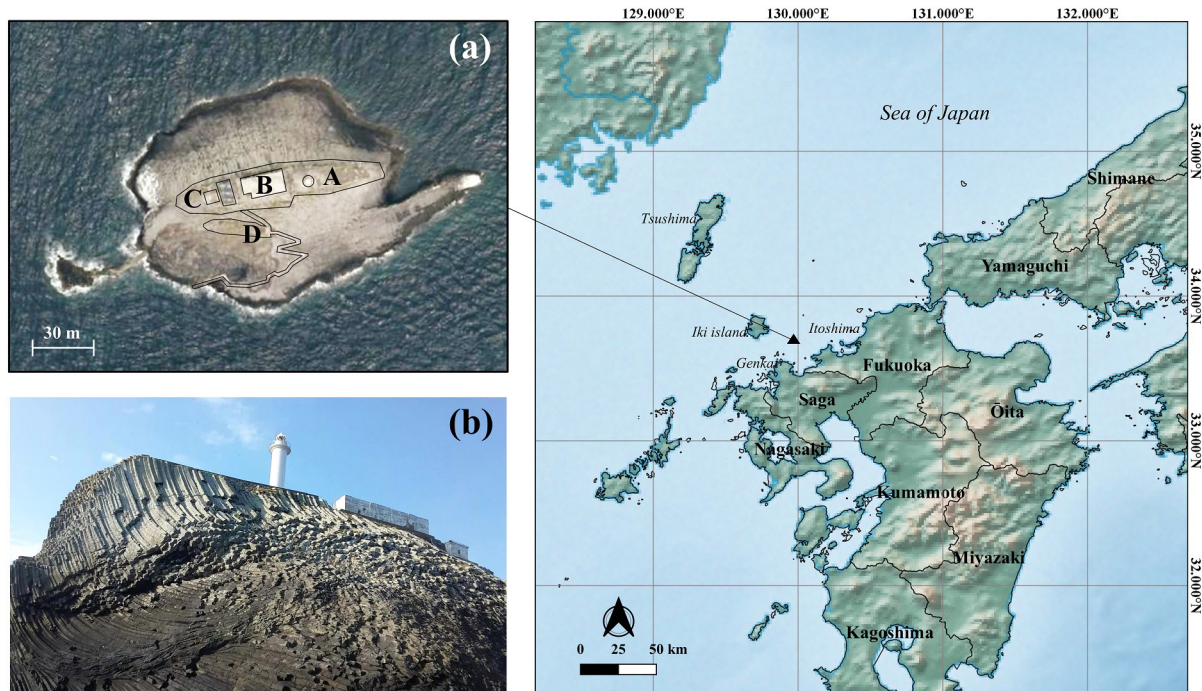


Fig. 1. Location and satellite image of Eboshijima, Japan in the Sea of Genkai off the coast of northwest Kyushu. Inset: the four monitoring plots on Eboshijima (a) and columnar joints surrounding the buildings and area on Eboshijima (b). Map data: Natural Earth and Geospatial Information Authority of Japan.

02h00. During this time, the mist-nets were set up near the bird burrows or other areas where the birds were likely to fly into them. All captured murrelets were banded with unique-numbered rings and weighed. Our attempts to document the presence of the brood patch were hindered by the difficulty in accurately identifying its characteristics, making it impossible to record.

Capture-mark-recapture (CMR) histories of 187 adult murrelets were collected from 2013 to 2022. The return-time (RET) model was applied to estimate recruitment and survival probabilities between consecutive years. A set of RET models was generated by an extended parameterization of the Jolly-Seber Schwarz-Arnason (JSSA) model (Schwarz & Arnason 1996, Pledger *et al.* 2013). The five main parameters of the model were superpopulation (N), entry probability (β), survival probability (ϕ), capture probability (p), and probability of return to breed (τ). These parameters can be time-dependent (t) or constant (c) over time. Annual transitional state probabilities with a maximum of two years between successive breeding years were considered, including: breeding (B), non-breeding (N_1 and N_2), and death (D ; Fig. 2a). The superpopulation was defined as the number of individuals available for capture during 2013–2022, including a summary of at least one primary capture and the estimated recruitment. The entry probability, which estimates the proportion of first-time breeding individuals in the population, was determined. As there is no information available regarding the age of first breeding in this species (BirdLife International 2022b), the maximum number of non-breeding years was set to two years (Fig. 2). The probability an individual breed is a kind of transitional probability. This value is derived from parameters τ , one and two years ago, and ϕ (Fig. 2; the set of parameters are mentioned as M2 hereafter), based on a study by Gaston (1990) that suggested the age at first breeding for Ancient Murrelets is two years.

The parameters were estimated from multinomial log-likelihood functions of RET models using the *optim* function in R (R Core

Team 2020) by adopting the ‘JSreturnFun2.R’ code from Pledger *et al.* (2013). The best fit model with the lowest Akaike Information Criteria (AIC) score was selected from candidate models, ranked using AIC (Anderson & Burnham 1999, Burnham *et al.* 2011, Symonds & Moussalli 2011), and used to calculate weighted averages of the estimated parameters and derive yearly population estimates. Pearson’s χ^2 goodness of fit was employed to compare the expected values calculated using the estimated parameters of the selected model with the observed data. The population size of sample j was estimated using the following correlation (Pledger *et al.* 2013):

$$N_j = \phi_{j-1} N_{j-1} + N(\beta_{j-1}) \text{ for } j = 2, \dots, k$$

in which N_j is the current population in year j , ϕ_j is the survival probability in year j , N is the superpopulation during the study period, β_j is the entry probability in year j , and k is the number of occasion years. Details of the RET model structure and analysis are provided in Appendix 1 (available online).

To assess the impact of depredation by crows, the mortality rate due to corvid depredation ($P_{\text{death-corvid}}$) was calculated by dividing the number of breeders depredated by crows by the estimated population in 2022. Population Viability Analysis (PVA) was conducted using simulations to evaluate the potential effects of changes in corvid depredation on the population growth and the risk of extinction. Calculation of the extinction probability considered when the population size declined to no individuals. Four different scenarios were simulated to assess the impact of corvid depredation: (1) future population with no corvid depredation mortality, (2) future population with a 50% reduction in corvid depredation mortality due to management efforts, (3) future population with corvid depredation at the same level as in 2022 without management efforts, and (4) future population with a combination of corvid depredation and an additional 0.1 mortality caused by other threats, such as bycatch (Piatt & Gould 1994), resulting in even higher mortality rates than observed in 2022.

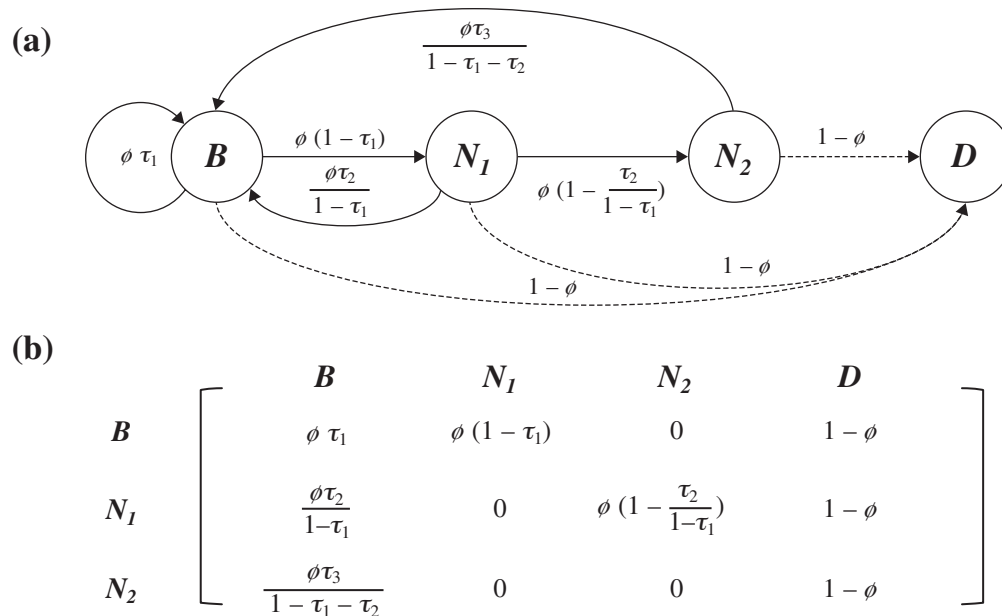


Fig. 2. Conceptual diagram (a) and transitional probabilities for four states (b): breeding (B) to next breeding or non-breeding (N_1 and N_2) or death states (D) of Japanese Murrelet *Synthliboramphus wumizusume* population model.

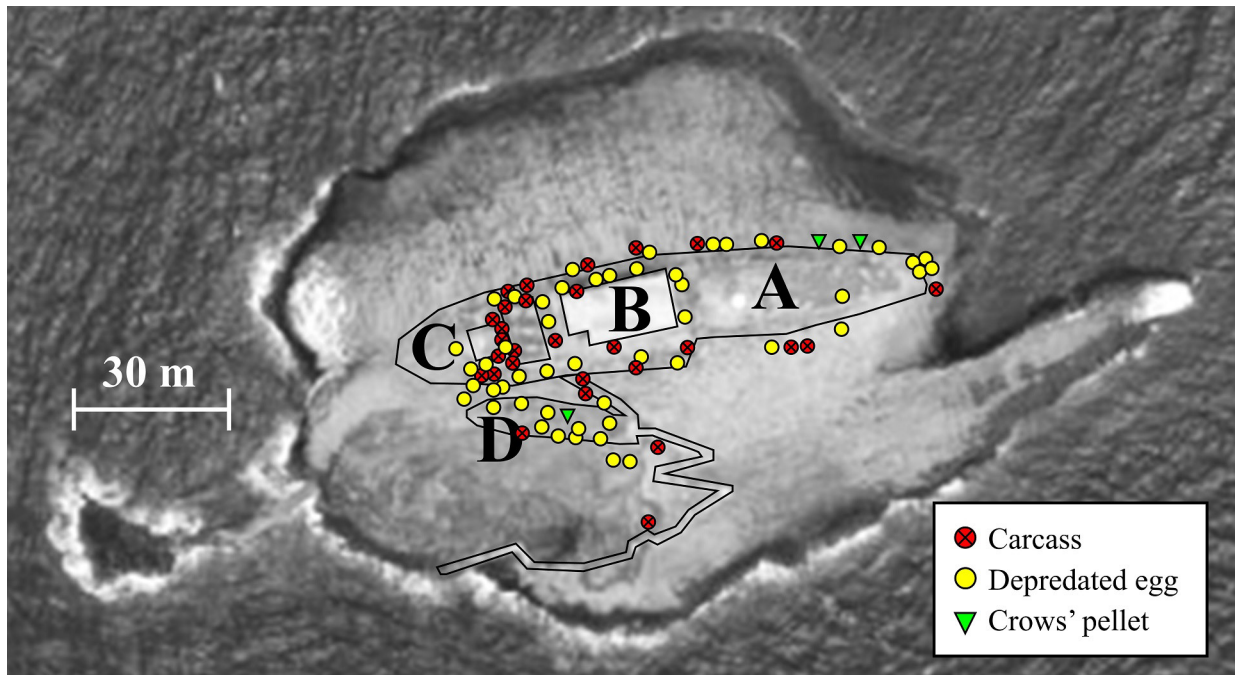


Fig. 3. The detected location of carcasses and depredated eggs of Japanese Murrelet *Synthliboramphus wumizusume* found on Eboshijima, Japan in 2022.

To account for density independence, the proportion of 1000 simulated populations were projected forward 50 years using a simple stochastic model. The population size was calculated using the formula $N_{j+1} + R$, where N_{j-1} represents the population size in the previous year $j-1$, and R represents the number of recruitments from breeders during the current year. To adjust for the assumption that only breeding individuals were depredated by crows, the population size calculation included non-breeders, actively breeding individuals, and the number of breeders lost due to corvid depredation. The breeding state probability vector in the transitional matrix (Fig. 2b) was used to estimate the probability of transitioning to a breeding state (P_{breeder}), and the number of breeders was estimated by multiplying the population size in the previous year by the probability of transitional breeding ($N_{j-1} * P_{\text{breeder}}$). The birth rate was estimated by randomly drawing from a distribution of birth

probability ranging between 0.5 and 1, based on the observed two clutch sizes for a breeding pair. The carrying capacity (K) for this population was set at 250 individuals. The extinction probability was estimated by considering that a population was extirpated if its size declined to less than one individual or if the extinction probability reached one during a 50-year period. Randomness was incorporated by drawing the number of recruits and deaths from a binomial distribution with the expected value based on recruitment rate and mortality due to corvid depredation. The population dynamics were simulated by tracking the survival of breeders and non-breeders, the recruitment of new individuals into the population, and deaths due to corvid depredation.

RESULTS

Depredation by Large-billed Crows

In 2022, for the first time since monitoring began in 2011, depredation by Large-billed Crows on murrelets was observed at Eboshijima. We found 29 murrelet carcasses and 50 depredated eggshells scattered throughout the monitored plots (Fig. 3; Table 1). Crow depredation was visually documented by camera traps. The depredated carcasses had missing body parts or bite marks consistent with crow depredation. The depredated eggs were identified by the absence of the dried membranes that are typically present in hatched eggs. Additionally, eggshell fragments exhibiting distinct holes with signs of pecking or puncture marks from the crow's beak (Fig. 4) were found near the carcasses located near the edge of the rocky cliffs, stone walls, and buildings. Depredated eggs and carcasses were most numerous in plot C where 13 (43%) carcasses and 15 eggs (30%) were found near cracks in the concrete foundation. Similar numbers of carcasses (11–12) and depredated eggs (5–6) were found in the other plots (Table 1). Three regurgitated crow pellets containing cactus seeds and eggshell residues were found, two in plot A and one in plot D (Fig. 3).

TABLE 1
Number of carcasses and depredated eggs of Japanese Murrelet *Synthliboramphus wumizusume* counted by survey at Eboshijima on 29 March, 05 April, and 10 June 2022

Plot	Cover substrates	Number of carcasses	Number of depredated eggs
A	Concrete, rocks, and scattered grasses	5 (17%)	12 (24%)
B	Mostly concrete, few rocks, and scattered grasses	6 (20%)	11 (22%)
C	Concrete, rocks, and scattered grasses	13 (43%)	15 (30%)
D	Mostly rocks and grasses	5 (17%)	12 (24%)
Total		29	50



Fig. 4. Depredated Japanese Murrelet *Synthliboramphus wumizusume* eggs and carcasses found on Eboshijima, Japan during the breeding season in 2022. (Photo credit: Toru Nakahara)

Over 105 nights of monitoring, camera traps captured 59 photos and 63 videos of avian predators (Fig. 5). Two Large-billed Crows were observed as early as 06h59 and as late as 16h45, with 16 instances of crows preying on murrelets recorded on video. On 13 April 2022, a Peregrine Falcon was also detected by the camera at 13h22.

Population of murrelets estimated by ringed data

We analyzed the banding history of 187 murrelets at Eboshijima and recaptured individuals over 62 recapture events during 2013–2019 and 2021–2022 (Appendix 2, available online). Among the eight candidate RET models (Table 2), the lowest AIC-selected model (hereafter, the best model) was included $\{\beta(c), \phi(c), p(t), \tau(M2)\}$. The best model indicated time-dependence of entry probability, while survival and capture probabilities remained constant over time. Model goodness of fit indicated that our data met model

assumptions (count of live adults during the study period: $\chi^2 = 1.26$, $df = 23$, $p = 1.00$ and last capture: $\chi^2 = 4.75$, $df = 9$, $p = 0.86$). The best model (Table 3) estimated an entry probability of 0.07 (95% confidence interval [CI]: 0.07–0.41, standard error [SE] = 0.03), an apparent annual survival probability of 0.78 (95% CI: 0.69–0.84), and a capture probability of 0.39 (95% CI: 0.11–0.70, SE = 0.07). The estimated return breed time probabilities for years j to $j+2$ (τ_1 , τ_2 , and τ_3) were 0.50, 0.24, and 0.26, respectively. The superpopulation and yearly recruitment were estimated to be 331 and 22 individuals, respectively. The average population size, as estimated by the best model, exhibited a decreasing trend over time, which is clearly visible when the values are plotted on a natural logarithmic scale (see Fig. 6). The overall population decline stabilized between 2013 and 2017 (from 138 to 111 murrelets, a 20% decline), but the overall decline leveled off to just 11% (111 to 100 murrelets) from 2017 to 2022.



Fig. 5. Images of a Large-billed Crow *Corvus macrorhynchos* (a) and Peregrine Falcon *Falco peregrinus* (b) captured by a trail camera on Eboshijima, Japan in 2022.

TABLE 2
The return-time (RET) models sorted by Akaike’s Information Criterion (AIC) for estimating population size of the adult Japanese Murrelet *Synthliboramphus wumizusume* ringed dataset in Eboshijima, Japan ($n = 187$)

Model	LogLike	Npar	AIC	AICc	relAIC	relAICc
$\{\beta(c), \phi(c), p(t), \tau(M2)\}$	-260.0039	15	550.0078	559.8037	582.6236	0
$\{\beta(t), \phi(c), p(t), \tau(M2)\}$	-253.9692	22	551.9383	576.0335	599.7748	1.9
$\{\beta(c), \phi(t), p(t), \tau(M2)\}$	-257.3886	22	558.7773	582.8725	606.6138	8.8
$\{\beta(t), \phi(c), p(c), \tau(M2)\}$	-285.3721	14	598.7442	607.1442	629.1856	48.7
$\{\beta(t), \phi(t), p(t), \tau(M2)\}$	-252.4343	29	562.8687	612.5830	625.9259	12.9
$\{\beta(t), \phi(t), p(c), \tau(M2)\}$	-272.9583	22	589.9166	614.0118	637.7531	39.9
$\{\beta(c), \phi(t), p(c), \tau(M2)\}$	-299.9497	14	627.8994	636.2994	658.3409	77.9
$\{\beta(c), \phi(c), p(c), \tau(M2)\}$	-313.6340	6	639.2679	640.7162	652.3142	89.3

^a RET model consists of parameters: β = entry proportion, ϕ = survival probability, p = capture probability, τ = transient probability; with c = constant in time and t = time-dependence.

To determine the proportion of murrelet deaths caused by crows, we used the estimated Eboshijima murrelet population in 2022, which was 100 individuals with 65 transitioning into the breeding state ($P_{breeder} = 0.65$). The number of murrelet carcasses found in monitored plots was used to estimate the number of surviving breeders. Our analysis indicated that crows were responsible for approximately 45% (29/65) of the total breeder individuals ($P_{death-corvid} = 0.45$). We then used this information to predict the extinction probability and the population size in 50 years under four different survival scenarios: (1) no corvid depredation ($P_{death-corvid} = 0$), (2) a 50% reduction in corvid depredation due to management efforts ($P_{death-corvid} = 0.23$), (3) corvid depredation without any management efforts ($P_{death-corvid} = 0.45$), and (4) corvid depredation with other threats ($P_{death-corvid} = 0.55$). Our simulations showed that the Eboshijima population, which was affected by corvid depredation in 2022, is at high risk of extinction in the absence of effective management. Specifically, without any management of corvid depredation, the predicted population with the same level of corvid depredation in 2022 faces a high risk of extirpation (> 90%) within the next 26 years, with the remaining population expected to decline to less than one individual in the next 17 years. Moreover, the population severely affected by corvid

depredation with other factors ($P_{death-corvid} = 0.55$) faces an even higher risk of extirpation (> 90%) within the next 18 years, with the remaining population expected to decline to less than one individual within the next 12 years. However, our simulations also show that effective management of corvid depredation, such as a 50% reduction in corvid depredation ($P_{death-corvid} = 0.23$), can result in a low risk of extinction (extinction probability < 0.5) in the next 50-year period. Moreover, complete elimination of crow effects ($P_{death-corvid} = 0$) led to an increase in the population size over time with zero extinction probability (Fig. 7; Appendix 2).

DISCUSSION

This study provides the first documented evidence of corvids preying on Japanese Murrelets in Eboshijima, based on video

TABLE 3
Parameter estimates and 95% confidence interval using the best return-time (RET) model $\{\beta(c), \phi(c), p(t), \tau(M2^a)\}$ for Japanese Murrelet *Synthliboramphus wumizusume* in Eboshijima, Japan

Parameter	Estimate (standard error)	Lower confidence interval	Upper confidence interval
Entry proportion (β)	0.07 (0.03)	0.07	0.41
Survival probability (ϕ)	0.78	0.69	0.84
Capture probability (p)	0.39 (0.07)	0.11	0.70
Return time probability (τ)	(τ_1) 0.50		
	(τ_2) 0.24		
	(τ_3) 0.26		
Superpopulation (N)	331	253	436

^a M2 is defined by the following states: participated in breeding in a given year, did not participate in breeding a year ago, did not participate in breeding 1 and 2 years ago, and dead.

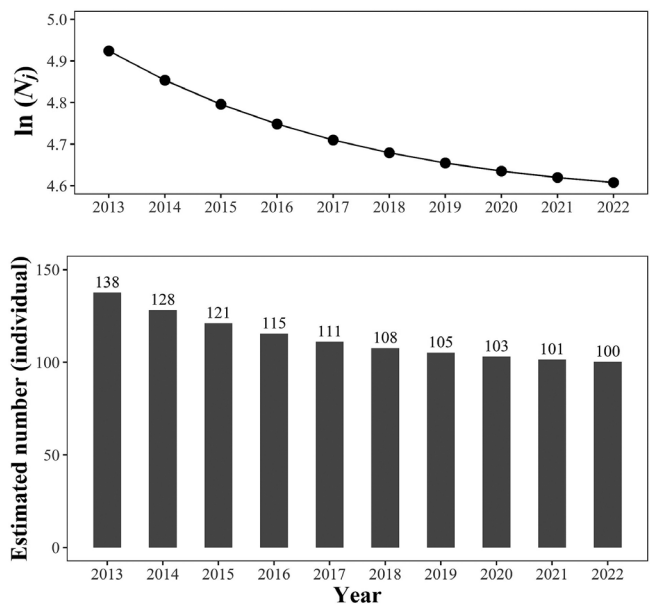


Fig. 6. Natural log of estimated population and number (individual) of Japanese Murrelets *Synthliboramphus wumizusume* on Eboshijima, Japan in 2013–2022, based on mist-net capture histories applied to the best fitting return-time model.

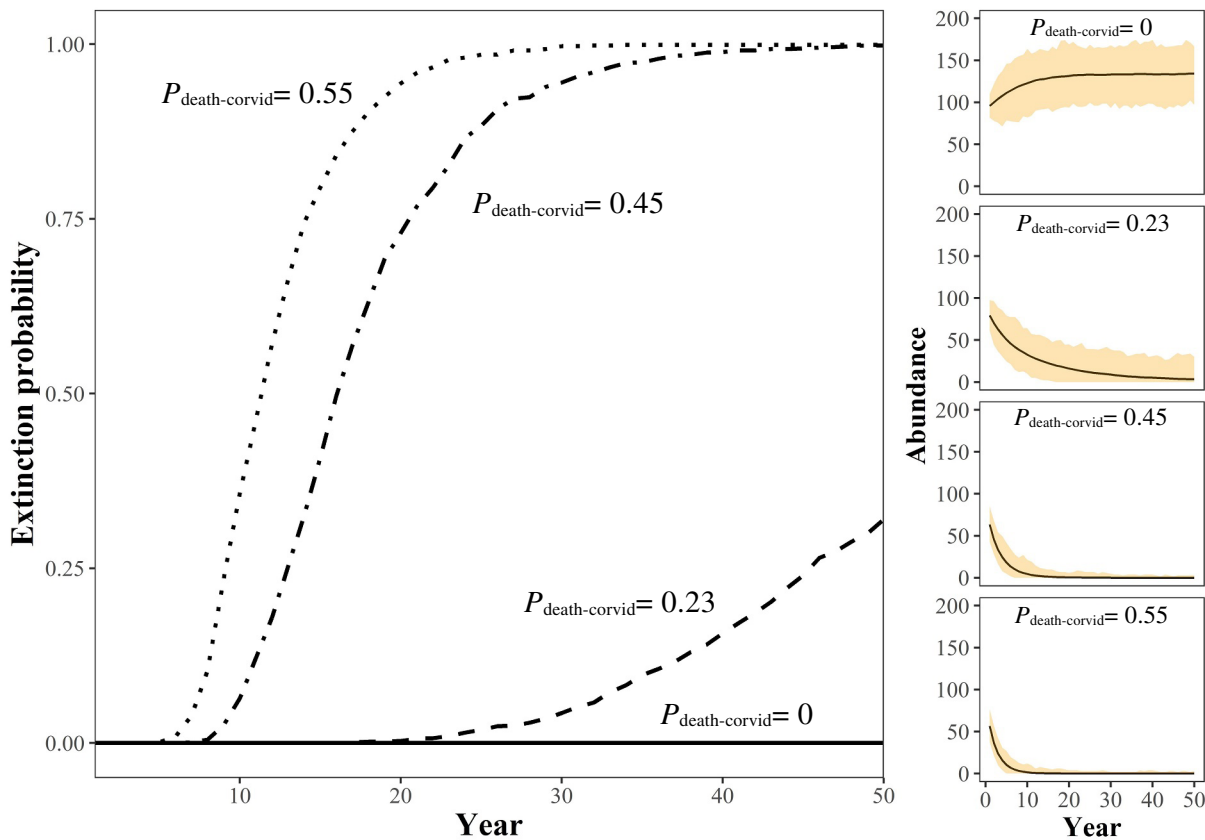


Fig. 7. Probability of extinction in 50 years for Japanese Murrelets *Synthliboramphus wumizusume* under four different scenarios that vary in the effectiveness of corvid depredation control ($P_{\text{death-corvid}}$): (1) 0, when corvid depredation was completely eliminated; (2) 0.23, when corvid depredation was partially managed with a reduction of 50%; (3) 0.45, when corvid depredation continued to effect the population; and (4) 0.55, when the population experienced corvid depredation and other mortality factors.

footage and observation of remains. While corvid depredation has been observed in another murrelet colony on Birojima (Karnovsky *et al.* 2017, Whitworth *et al.* 2020), the only other predator potentially responsible for depredation on the Eboshijima population is the Peregrine Falcon. Although a pair of Peregrine Falcons has long been known to breed on this island (Okabe *et al.* 2017), we found one falcon carcass, which may explain the lack of nesting in 2022. During their breeding season (mid-February to late June), Peregrine Falcons may prevent crows from visiting the island due to their aggressive territorial behavior, which overlaps with the murrelets' breeding season (late February to early May). The absence of Peregrine Falcons and the prevalence of Large-billed Crows have contributed to high depredation rates in this murrelet breeding colony (Burgas *et al.* 2021). It is possible that visits by Large-billed Crows are related to shore fishing activities on Eboshijima, as observed on Birojima and other islands (Otsuki *et al.* 2017, Takeishi *et al.* 2020). If this is the case, murrelet depredation by crows is likely to recur in the future if falcons do not return to breed.

This study provides valuable insights into the Japanese Murrelet population on Eboshijima, including the first quantitative estimate of their numbers and an estimated annual survival probability between 2013 and 2022 that ranges from 0.69 to 0.84. These estimates are comparable to those of other alcid species, such as Ancient Murrelets *S. antiquus* (0.77–0.88; Gaston 1990), Kittlitz's Murrelets *Brachyramphus brevirostris* (0.80, SE = 0.33; Kissling *et al.* 2015), and Marbled Murrelets *B. marmoratus* (0.845–0.90; Beissinger

1995). Annual survival probabilities for long-lived seabirds are influenced by several factors, including changing environmental conditions (Sandvik *et al.* 2005, 2012, Schmidt *et al.* 2015), food availability (Jenouvrier 2013), and heterogeneity in quality and reproductive costs (Lescroël *et al.* 2009). Nevertheless, further research is necessary, especially for other breeding colonies and non-breeding seasons, to gain a more comprehensive understanding of the species' survival probability.

Our estimates of annual survival align with expectations based on the general life history of this species. However, our population estimates for the murrelet population on Eboshijima are subject to potential biases, particularly due to unmodeled heterogeneity in capture probabilities. JSSA models, which we used in our study, are sensitive to such heterogeneity and may overestimate population size when breeders are more likely to be captured (Schwarz & Arnason 1996, Pledger *et al.* 2013). Furthermore, the capture probability of non-breeding individuals may be lower than assumed by the model. During our 10-year study, we detected capture heterogeneity in our selected model, likely due to various factors such as sampling location, weather on survey days, and individual susceptibility to mist-net capture (Remsen & Good 1996, Simons *et al.* 2004, Tattoni & LaBarbera 2022). While higher capture probabilities can enhance the accuracy of survival estimates, incomplete capture-recapture data or significant heterogeneity in capture probability among individuals can still lead to biased estimates of population size. However, survival estimates are less affected by capture probability

heterogeneity because their estimates are based on the number of individuals captured at least once and then recaptured at a later time, regardless of their capture probability. Moreover, we note a concern regarding the potential bias in the model's estimation of the number of non-breeding years, given the lack of data on this species. Factors such as sex-biased reproduction cost, age, and body condition can influence the frequency of return breeding in seabirds (Gauthier-Clerc *et al.* 2001, Le Bohec *et al.* 2007, Berman *et al.* 2009, Giudici *et al.* 2010, Cubaynes *et al.* 2011).

Our previous objective was to determine the breeding status of Japanese Murrelets by observing the presence of a brood patch, a reliable indicator of breeding activity. However, due to difficulties in accurately identifying the brood patch, we were unable to collect any data on its presence. Due to the difficulty in distinguishing between breeders and non-breeders based on physical characteristics, sex, or age, our study was limited in its ability to assess the reproductive status of the population. Our study emphasizes the importance of continued research to advance our understanding of the reproductive biology of this species. It is essential to acknowledge the considerable uncertainty associated with estimating and simulating population dynamics, particularly in identifying breeding individuals and distinguishing them from non-breeders.

Our findings underscore the severe impact of corvid depredation on the Eboshijima murrelet population, with significant implications for both extinction risk and population size over time. The results suggest that reducing corvid depredation by 50% could markedly reduce the risk of extinction over the next 50 years, from over 90% to less than 50% if current survival rates remain unchanged. However, the population remains highly vulnerable to other sources of mortality when exposed to corvid depredation and could face extirpation within the next two decades without intervention. The situation could worsen if corvid depredation is combined with other threats, such as bycatch, disease, or oil spills, potentially leading to the loss of this unique and endangered species.

Conservation implementations

Japanese Murrelets face various ecological conditions during their non-breeding period due to their seasonal movement (Yamaguchi *et al.* 2016), and they are potentially at greater risk of encountering threats when they breed in areas close to the mainland (Miller *et al.* 2019). The presence of predators such as corvids can dramatically increase the risk of nest depredation, limiting recruitment of the next generation. Active translocation or removal of crows may be necessary to mitigate this risk, and control measures should be initiated to eliminate refuse that may attract crows to the island. Additionally, artificial nests or reducing access to potential nesting sites could be considered. Further research on murrelet breeding behavior can help develop management strategies to control human-induced avian predators. Given the complexity of predicting population dynamics, ongoing monitoring and adaptive management strategies are crucial to ensure the survival of the murrelet population on Eboshijima.

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