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Controlling trapping, overgrazing and invasive vegetation are key to saving Java's last population of the Black-winged Myna

ABSTRACT

The Black-winged Myna (*Acridotheres melanopterus*) is a Critically Endangered passerine endemic to the islands of Java and Bali, Indonesia. Illegal trapping to supply the cage-bird trade has led to its near-total extinction, with the global population estimated to number fewer than 100 individuals. We estimated the current range and population size of the species at Baluran National Park, which supports Java's last known population, and used species distribution modelling to evaluate potential suitability of currently unoccupied areas across the park to identify priorities for management intervention. We estimate that the Black-winged Myna population numbers 179 individuals (95% CI: 111–288; density: 14.3 ± 3.5 individuals km^{-2}) and that its current range is 12.3 km^2. Our model indicated that some 72 km^2 of the park (30% of total area) has potentially suitable habitat for the species, and we infer that the principal cause for the disparity between its current and potential range is trapping, compounded by savanna loss and degradation due to illegal domestic cattle grazing and the spread of invasive thorny acacia (*Vachellia nilotica*). The partial clearance of acacia in recent years appears to have assisted a modest population recovery by the myna. Its further population growth and range expansion in Baluran depends on effective management of illegal poaching, further clearance of acacia, and easing domestic cattle grazing pressure on areas of savanna, particularly through engagement with communities living inside the park. Any actions that increase the size of the Black-winged Myna population are likely to benefit other threatened savanna-dependent wildlife in the park, notably banteng (*Bos javanicus*) and Green Peafowl (*Pavo muticus*). While our models and recommendations may be applicable to other protected areas in Java, and indeed other threatened myna species, trapping and habitat change may have site-specific dimensions, especially outside of protected areas, and thus demand local bespoke solutions.

Keywords: Black-winged Myna (*Acridotheres melanopterus*); Asian songbird crisis; Critically Endangered; Indonesia; Java; Baluran;

LAY SUMMARY

- The Black-winged Myna, confined to Java and Bali in Indonesia, is threatened with extinction due to illegal trapping for the cage-bird trade. Baluran National Park supports the last known population on Java.
- We estimated the number of mynas in the park, mapped where they occur, and assessed their habitat to determine how much of it is currently unoccupied.
- There are around 180 Black-winged Mynas in the park, indicating recent population growth. However, they occupy <20% of the potentially suitable habitat, restricting further population growth.
- Trapping is the foremost factor holding back the mynas, but overgrazing by domestic livestock and invasion by thorny acacia negatively affect the potentially suitable habitat.
- Thorny acacia eradication must continue. Working with the human communities living in the park is key to alleviating the grazing pressure and addressing the trapping issue.

ABSTRAK (BAHASA INDONESIA)

Jalak putih (*Acridotheres melanopterus*) adalah burung berkicau endemik di pulau Jawa dan Bali, Indonesia, yang berstatus Kritis. Selama beberapa dekade terakhir, penangkapan ilegal untuk memasok perdagangan burung dalam sangkar telah menyebabkan kepunahan dengan populasi global diperkirakan berjumlah kurang dari 100 individu. Kami melakukan estimasi sebaran dan ukuran populasi spesies saat ini di Taman Nasional Baluran, yang mendukung populasi liar terakhir yang diketahui di Jawa, serta menggunakan pemodelan distribusi spesies untuk mengevaluasi potensi kesesuaian area yang tidak ditempati Jalak putih di seluruh Taman Nasional untuk mengidentifikasi prioritas intervensi pengelolaan. Estimasi populasi Jalak putih di TN Baluran berjumlah 179 individu (95% CI: 111–288; kepadatan: 14,3 ± 3,5 individu km^{-2}) dan sebarannya saat ini adalah 12.3 km^2. Pemodelan kesesuaian habitat menunjukkan bahwa sekitar 72 km^2 dari taman nasional (30% dari total luas) berpotensi sesuai untuk spesies tersebut, dengan kesimpulan bahwa penyebab utama perbedaan antara sebaran saat ini dan potensi sebaran adalah penangkapan, ditambah dengan degradasi dan hilangnya savana akibat penggembalaan sapi lokal ilegal serta penyebaran akasia berduri yang invasif (*Vachellia nilotica*). Namun, pembukaan sebagian akasia berduri tampaknya telah membantu pemulihan populasi secara sederhana. Pertumbuhan populasi dan perluasan sebaran jalak putih di Baluran, tergantung pada pengelolaan perburuan liar yang efektif, pengurangan akasia berduri yang terus berlanjut, serta mengurangi tekanan penggembalaan ternak lokal di daerah savanna terutama melalui keterlibatan masyarakat yang tinggal di dalam kawasan. Setiap tindakan untuk meningkatkan jumlah Jalak putih, kemungkinan besar akan menguntungkan satwa liar lain yang berstatus terancam dan bergantung pada savana di dalam kawasan, terutama banteng (*Bos javanicus*) dan merak hijau (*Pavo muticus*). Sementara model dan rekomendasi ini mungkin bersifat umum dalam penerapannya pada kawasan lindung lainnya di Jawa, serta spesies Jalak lainnya yang terancam, namun masalah penangkapan dan perubahan habitat yang terjadi bersamaan mungkin bersifat spesifik lokasi, terutama di luar kawasan konservasi, dan mungkin pada gilirannya menuntut solusi lokal yang tepat.

INTRODUCTION

Biological diversity is being eroded at an unprecedented rate and wildlife trade is a main underlying cause, contributing to enormous declines in species abundance, loss of ecosystem function, and increased risks to human health through zoonotic diseases (Pimm et al. 2014, Dirzo et al. 2014, Benítez-López et al. 2017, Aguirre et al. 2020). Nearly a fifth of all extant vertebrate species are traded, mostly in and from the tropics, with birds and mammals being disproportionately affected (Wyler and Sheikh 2008, Barber-Meyer 2010, Scheffers et al. 2019). Southeast Asia, one of the most biodiverse regions on earth, has among the highest proportion of threatened species for most higher classes of animals (Myers et al. 2000, Sodhi et al. 2010, Hughes 2017). Throughout the region, the trade in wild-caught songbirds—prized for their vocal ability, plumage, rarity and cultural significance—is having a massive effect on wild populations (Nijman

2010, Lee et al. 2016, Symes et al. 2018, Indraswari et al. 2020). The resulting 'Asian Songbird Crisis' has left many species facing extinction, while for many others the damage trade has wrought on their populations is still poorly understood due to insufficient monitoring (Eaton et al. 2015, Shepherd and Cassey 2017, Bergin et al. 2018, Marshall et al. 2020). Indonesia, particularly its most populous island of Java, is widely regarded as the epicenter of the bird trade in Southeast Asia, with millions of birds sold annually at markets irrespective of their legal status and an estimated 70 million cage-birds kept in one-third of Java's 36 million households (Chng and Eaton 2016, Harris et al. 2017, Marshall et al. 2020). Almost half of Indonesia's 64 globally threatened songbirds (order Passeriformes) are threatened primarily by trade, and most of them occur on Java (IUCN 2021).

There are several patterns of decline exhibited by species under heavy pressure from habitat loss and trapping: some show dampened population densities across their range (Laaksonen and Lehikoinen 2013) while others collapse into just a few strongholds (Abram et al. 2015, Annorbah et al. 2016). The role of formally protected areas in the conservation of endangered wildlife is also varied, ranging from absolutely critical (Prakash et al. 2019, Ghosh-Harihar et al. 2019) to relatively secondary (Agardy et al. 2003, Kamp et al. 2015). A number of conservation strategies may be useful for songbirds in Indonesia. Some species, such as the Bali Myna (*Leucopsar rothschildi*), survive almost exclusively in formally protected areas (Jepson 2016) but other species survive in refuges outside of protected areas (Kurniandaru 2008, Yong et al. 2018). The latter, which may fall under the umbrella of 'other effective area-based conservation measures' (OECMs; Jonas et al. 2014), can include temples and other culturally important sites, small islands, tourist facilities and privately guarded sites, where work with local communities/authorities underpins the maintenance of socio-ecological conditions that support the survival of key species, intentionally or otherwise (Negi 2010, Li et al. 2014, Dolman et al. 2021).

The Black-winged Myna (*Acridotheres melanopterus*), endemic to the Indonesian islands of Java, Bali and Madura, now primarily survives in formally protected areas, but was once widespread in the lowlands, predominantly savannas and cultivated areas up to 1,200 m in West Java and reportedly 2,400 m in East Java (Feare & Craig 1998; Collar et al. 2001). It has been present in both domestic and international trade for decades, despite its protection under Indonesian law since 1979 (Minister of Agriculture, Decree no. 757/Kpts/Um/12/1979). It is, however, domestic trade that is largely responsible for the precipitous decline of the wild population, which began in the 1960s but was most pronounced in the 1990s, and the sharp decline in numbers traded in the 2000s gave a clear indication that wild populations were vanishing because of trapping (Collar et al. 2001, 2012; Eaton et al. 2015, Shepherd et al. 2016, Nijman et al. 2018).

Although small numbers may persist in recently unsurveyed areas including some nature reserves, the only known wild population of Black-winged Myna left on Java occurs in Baluran National Park, East Java (Winnasis et al. 2020, eBird 2021), while a small number persist at two sites in Bali, with 35 birds at Bali Barat National Park (Brillianti et al. 2019) and 12 at another unspecified site (Eaton et al. 2015). The small number of birds known from two sites near Jakarta, Java (Eaton et al. 2015) are unlikely to persist (TMS pers. obs.). At Baluran, the population has been extremely low over the past decade: the largest flocks observed in 2009 and 2010 numbered 25 and 12 individuals, respectively (Winnasis et al. 2011, Eaton et al. 2015), although in 2016 a flock of 37 was recorded (BirdLife International 2021). Accordingly, the global population size of wild Black-winged Mynas is considered to be below 100 individuals, probably around 85. This circumstance indicates a clear and urgent need to carry out a thorough ecological assessment of the species to inform its conservation management strategy (Lee et al. 2016). We therefore sought to (1) document its current distribution and estimate its population size within Baluran National Park; (2) use species distribution modelling to identify potentially suitable areas that should be prioritized for appropriate management; and (3) identify the barriers to population expansion in different parts of the park and recommend interventions that can break these down.

METHODS

Study area

Baluran National Park (BNP; 7°50’S 114°22′E) is situated on the north-eastern tip of Java, with a land area of 264 km^2 (Figure 1). It was first established as Baluran Game Reserve in 1937 by the Dutch colonial government owing to the large mammals found there—banteng (*Bos javanicus*), Javan rusa (*Rusa timorensis*), feral water buffalo (*Bubanus bubanus*), dhole (*Cuon alpinus*), Javan leopard *(Panthera pardus melas*) and the now extinct Javan tiger (*Panthera tigris sondaica*) (Whitten et al. 1996). The park is in one of the driest parts of Java, receiving <1,500 mm of rainfall a year, most falling between December and February (Winnasis et al. 2011); a pronounced May–October dry season, in combination with fire and herbivory, maintains the savanna-like landscape in the north and east of the park (Pennington et al. 2018). Mount Baluran (1,247 m), a dormant volcano, dominates the center of the park and is cloaked in tropical evergreen and dry deciduous forest.

The residents of Karang Tekok village to the north-west and Wonorejo village to the south-east have always utilized BNP to trap and hunt wildlife and to collect wood, seeds, fodder, honey and tamarind fruit (*Tamarindus indica*), and they also start fires both accidentally and deliberately (Whitten et al. 1996, Sabarno 2002). Overall, hunting and trapping still represent the greatest threat to wildlife in BNP: the Green Peafowl (*Pavo muticus*), an Endangered species, has declined at BNP, partly because adults and chicks are trapped and sold either alive as pets or dead as food (Winnasis et al. 2011). At least 23 other bird species are known to have been trapped within BNP, mostly alive using mist-nets (Winnasis et al. 2011), and hunters have been prosecuted for poaching East Javan langurs (*Trachypithecus auratus*), a globally Vulnerable species (Nijman 2020). Five guard posts control the main entry points and regular patrols are conducted, but a public road bisects the west side and the park’s long coastline offers great ease of access from the sea.

The savanna in the north of BNP has been significantly altered since 1975, when a commercial license was awarded to replace native trees with an agati or turi (*Sesbania grandiflora*) plantation, a pulpwood species used in paper production (Pudyatmoko et al. 2018). The plantation workers have remained in the park despite the license expiring in 2000, and now graze herds of cattle across the savanna and grow crops along the coast (Wianti 2014). More cattle kept by residents of Karang Tekok village on the park's boundary also enter the northern savanna to graze daily (Prijono 2014). In total, almost four thousand cattle and over a thousand goats subsist on the northern savanna (Prijono 2014, Pudyatmoko 2017). The park's savanna is also threatened by the spread of thorny acacia (*Vachellia nilotica*), which was planted at Bekol in 1969 to prevent fire from spreading into teak (*Tectona grandis*) plantations (Sutomo et al. 2016).

Classifying the park's habitats

We generated a contemporary land-cover map for BNP based on cloud-free LANDSAT 8 imagery (30 m resolution) from October 2018. Some recent burns on the image were removed using neighbor-based interpolation. Training data were obtained using field data collected in September–November 2018 by classifying land-cover types visually with descriptions employed in previous land-cover maps (Supplementary Material Table S1), and by Google Earth image interpretation, which was used to increase the sample size of the smallest classes to address the potential training data imbalance (Millard and Richardson 2015). We selected the following nine land-cover types for the classification, modified from the latest BNP land-cover map (Baluran National Park 2008) and using relevant descriptions (Supplementary Material Table S1): open savanna, savanna woodland, dry deciduous woodland/shrubland, dry deciduous forest, thorny acacia scrub, teak plantation, tropical evergreen forest, beach forest, and mangrove forest. The difficult terrain on Mount Baluran made field data collection impossible there, but the tropical evergreen forest on its slopes could be delimited from Google Earth images and was therefore included in the training data.

Training data were used to build a random forest (RF) classification model (Breiman 2001). The environmental variables we used were bands 1–7 of the LANDSAT 8 imagery; normalized difference vegetation index (NDVI); the Global Land Analysis and Discovery (GLAD) laboratory's Global Forest Canopy Height 2019 product (Potapov et al. 2021); wetness, brightness and greenness indices; and topography (elevation, slope and aspect) calculated from the Shuttle Radar Topography Mission (SRTM) digital elevation model with 30 m resolution (van Zyl 2001). Analysis was carried out in R (R Core Team 2020) using packages 'raster' v3.3.13 (Hijmans 2020), 'randomForest' v.4.6.14 (Breiman 2001) and 'sf' v0.9-7 (Pebesma 2018). As a dimension reduction procedure, we ran the RF classification 25 times and recorded the five most important variables for each iteration. A Spearman's rank correlation analysis was then used to measure pair-wise correlations and if any of the five most important variables were highly correlated ($r_s > 0.90$) with lower-ranked variables, the latter were removed (Millard and Richardson 2015). The model was tuned by selecting the number of trees to grow and variables sampled at each split that minimized the out-of-bag error rate. The final RF classifier grew 1,000 trees and two variables were randomly sampled at each split.

Population size and range estimation

To estimate the current range of the Black-winged Myna in BNP we included all records from line transect sampling and incidental observations during the fieldwork period from March 2018 to March 2019, as well as one observation by a proficient local birdwatcher (Heru Fitriadi) and 19 observations by experienced members of the Copenhagen Zoo project staff at BNP, who carried out a survey in November 2017. We removed six outlying records from the current range estimate (see Figure 1) because they were over 4 km from the main cluster of observations, and were never of more than two birds which, given the sociality of mynas, suggests they were exploratory movements by dispersing birds. Moreover, we visited the area of these sightings monthly during the fieldwork period and only recorded mynas on two occasions, indicating that the southern area of the park did not form part of the species' home range. We constructed a minimum convex polygon around the remaining occurrences (Burgman and Fox 2003) in R with a 200-m buffer to provide a final range estimate.

Based on the pre-existing land-cover map a total of 36 distance sampling line transects with a combined length of 73.5 km were run across BNP to sample each land-cover type except for tropical rainforest, which we considered unsuitable for Black-winged Mynas (Collar et al. 2001). Line transects were distributed following a stratified sampling approach (Buckland 2004), whereby more transects were located in the east of the park to focus survey effort on the area expected to contain most of the Black-winged Myna population (Winnasis et al. 2011). Within what were classified as open habitat types (open savanna and savanna woodland) line transects were assigned randomly; in woodland (classified as closed habitat), transects followed narrow tracks made by humans or large mammals, as attempts to penetrate the dense understory, especially during the wet season, risked disturbing the target species before detection (Buckland 2001). Line transects outside our estimated Black-winged Myna range were excluded from the distance analysis and subsequent population density estimate because no encounters were recorded on any of these. Most transects were walked in both wet and dry seasons, but eight were only walked in the dry season. Twenty-one transects with a combined length of 29.1 km (mean length: 1.4 km) were included in the final analysis, giving a total effort of 50.6 km (Figure 1).

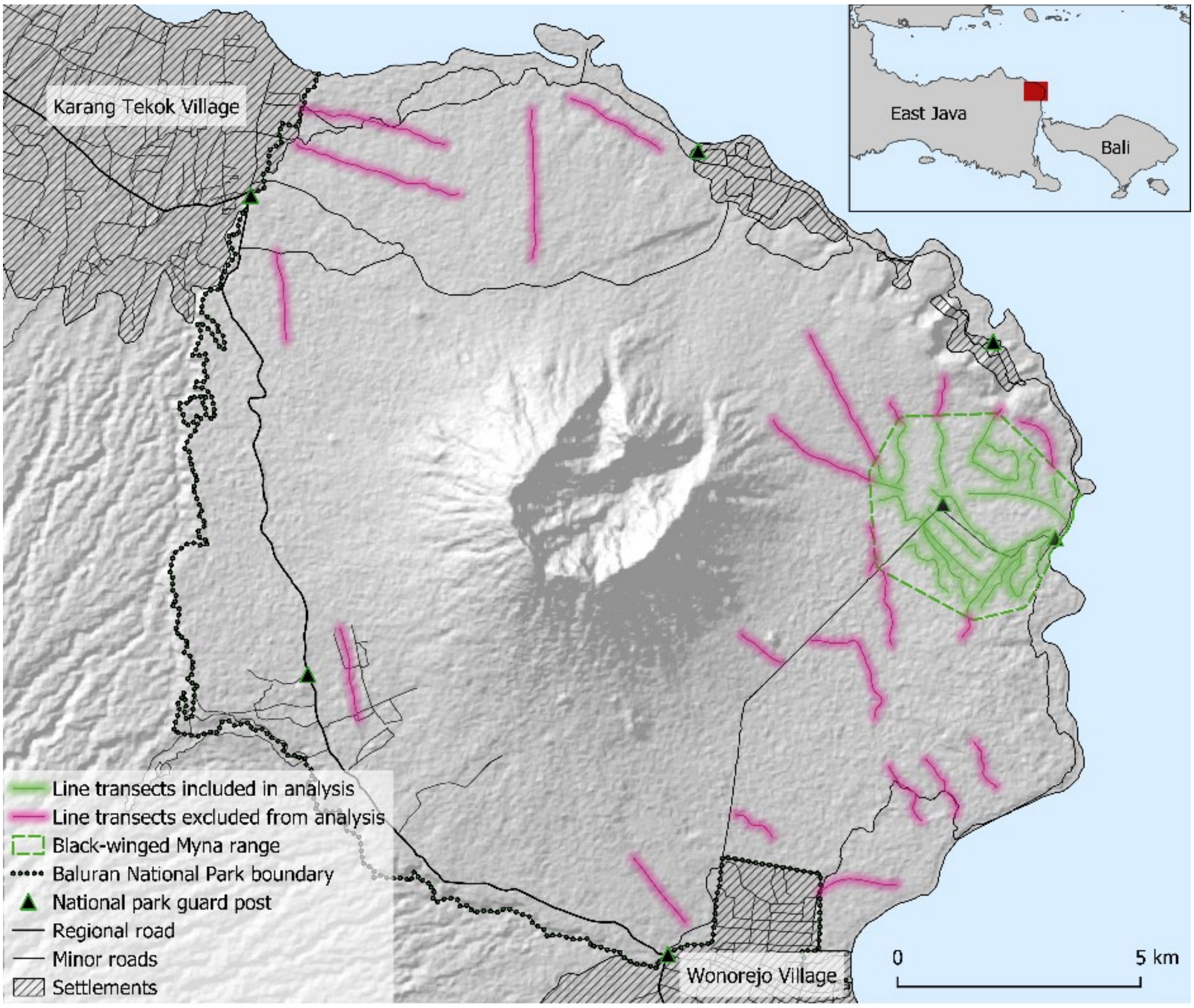

Figure 1. Baluran National Park, East Java, showing the location of all line transects, of which those in green were included in the Black-winged Myna population density analysis because they were inside the species' estimated range (green dashed line).

Distance sampling was undertaken at the end of the wet season and beginning of the dry season from March 28 to May 30, 2018 (hereafter referred to as wet season sampling because in May the vegetation is still lush and the understory dense), and in the dry season from October 5 to November 21, 2018. Sampling was conducted between 06h00 and 12h00 by one of two experienced observers (TMS, PGA) following the standard protocol for line-transect distance sampling (Buckland 2001, Buckland et al. 2008). We walked transects at ~1.5 km h^{-1} and each was preceded by a 200-m 'burn in'—the first section of a transect (not included in its reported length) which is walked but encountered birds are not recorded in an attempt to equalize the effects of observer disturbance across the transect (Buckland 2004). Birds seen only in flight were ignored, but those seen taking off or landing (i.e. using the habitat) were recorded. We used laser rangefinders (Hawke LRF 400) to measure distances and targeted the nearest visible object when no clear line of sight was available (Buckland et al. 2008). Distance sampling analysis followed standard methods (Buckland 2001) and was carried out in R (R Core Team 2020) using package 'Distance' v1.0.2 (Miller et al. 2019). Detection data were right-truncated at 135 m after discarding the furthest 5% of detections from the transect. Group sizes for aural-only detections were replaced by the average of all groups of known size. We generated a two-level open vs. enclosed habitat covariate for the detection function. The final model for the detection function was selected based on minimum Akaike Information Criterion (AIC) and after confirming that the detection function curve fitted the observed data (Supplementary Material Table S2 and Figure S1).

Estimating habitat suitability

We used species distribution modelling (SDM) to estimate the habitat suitability for Black-winged Myna within each 30 m pixel across BNP (Araújo and Guisan 2006). Three environmental covariates were used in the models: an NDVI layer generated from LANDSAT 8 imagery; the land-cover classification raster covering the park (Figure 2); and a habitat openness layer, for which each pixel represented the proportion of open vs. enclosed habitat pixels in the 0.56 km^2 (25 × 25 pixels) surrounding the target pixel. Black-winged Myna occurrences (n = 339) were filtered to include just one per pixel, resulting in 291 pixels containing presences across the raster layer.

We used R packages 'raster' v3.3-13 and 'biomod2' v3.4.6 (Thuiller et al. 2020) to model Black-winged Myna distribution. During the data formatting procedure in biomod2, we set the number of pseudo-absences (PAs) to 5,000 and created five sets of PAs (biomod2 generated a total of 24,122 unique PAs) using the 'disk' algorithm with the minimum distance to presences set to 75 m (Chefaoui and Lobo 2008, Thuiller et al. 2020). We ran three different SDM algorithms available in biomod2 on the five presence/PAs datasets: generalized linear model (GLM), generalized additive model (GAM), and maximum entropy (MaxEnt). Models were calibrated using 80% of the data and the remainder were used to evaluate model performance. Every algorithm was run five times with each PA dataset (total number of runs for each algorithm = 25).

SDM algorithms were evaluated using area under the curve (AUC) values calculated in biomod2. All of the algorithms performed well (AUC > 0.80) and were used to produce full models without data partitioning. Variable importance values on a scale from 0 to 1 were calculated for each algorithm, higher values indicating greater influence in the model. We then aggregated the models by algorithm and generated algorithm-specific projections of habitat suitability across BNP in order to calculate algorithm-specific model averages, which were used to evaluate how well individual algorithms discriminated between presences and PAs based on Tjur's R^2 (Tjur 2009).

For the final output, an ensemble of the projections was generated with the SDM algorithms using mean-weighting based on the algorithms' AUC value. This raster map provided raw suitability values for each pixel in BNP on a scale of increasing suitability from 0 to 1. We generated a binary raster of unsuitable and suitable habitat using a threshold value, which was the minimum suitability value at a pixel including a Black-winged Myna presence after excluding the lowest 10th percentile of suitability values from pixels with presences. Final maps from the analysis were generated using QGIS v3.10.3.

RESULTS

Black-winged Mynas were recorded a total of 339 times during fieldwork, with all but six records in the Bekol, Balanan and Bama areas in the east of the park (Figures 2, 4). Based on the occurrence data gathered, we estimate that the current range for Black-winged Myna covers 12.3 km^2 (<5% of the park's area). The land-cover types with most occurrences were open savanna (37.8%), followed by savanna woodland and dry deciduous woodland/shrubland (both 20.6%), thorny acacia scrub (19.8%; but see the discussion), beach forest (0.9%) and dry deciduous forest

(0.3%); the full land-cover classification map is shown in Figure 2. Of the outlying occurrences excluded from the range estimation, three were in savanna 4 km south of Bekol, and three were near the cultivated land adjacent to Wonorejo village, 6 km south of the current range. The largest groups recorded were seen gathering before dusk, with the highest record being of 97 individuals on 26 September 2018, when birds flew to roost in ten groups (maximum single group size = 25 individuals).

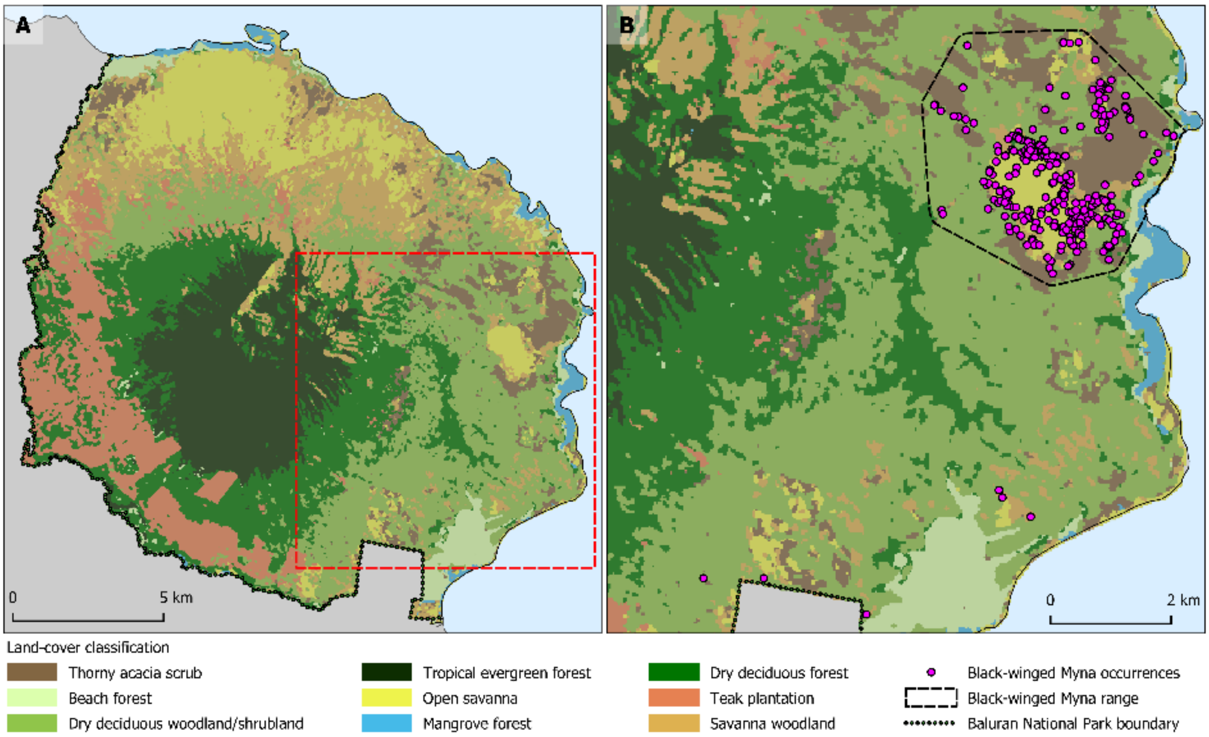

Figure 2. (**A**) Land-cover classification for Baluran National Park; and (**B**) all Black-winged Myna occurrences (magenta circles) recorded and the occupied range (black dashed line) overlaid on land-cover types. The extent of (**B**) is shown by the red dashed line in (**A**).

Black-winged Mynas (median group size = 2) were detected on 56 occasions during line-transect distance sampling over the wet (n = 30) and dry (n = 26) seasons. The average encounter rate was 2.9 ± 0.7 individuals km^{-1}, with the highest encounter rate in savanna woodland followed by open savanna, and the lowest in dry deciduous woodland/shrubland and thorny acacia scrub; birds were not detected in the other land-cover types during line-transect distance sampling

(Table 1). Detection probabilities were described best by a uniform key function with one cosine adjustment term (Supplementary Material Table S2 and Figure S1). Population density was highest in savanna woodland (34.4 individuals km^{-2}, 95% CI: 13.5–88.0) and lowest in dry deciduous woodland/shrubland (10.9, 95% CI: 4.6–25.9), and the overall population density in the current range was 14.3 individuals km^{-2} (95% CI: 8.8–23.1) (Table 1). We estimate the overall population size to be 179 individuals (95% CI: 111–288).

Table 1. Estimated Black-winged Myna population density and abundance within its estimated range for each land-cover type in which birds were detected during line-transect distance sampling.

Land-cover type	Area within current range (km^2)	Encounter rate individuals km^{-1} ± SE	Density individuals (95% CI)	Abundance individuals (95% CI)
Savanna woodland	0.8	5.8 ± 2.7	34.4 (13.5–88.0)	28 (11–70)
Open savanna	2.1	3.6 ± 1.8	21.0 (7.8–57.0)	44 (16–120)
Dry deciduous woodland/shrubland	5.3	1.9 ± 0.8	10.9 (4.6–25.9)	58 (24–137)
Thorny acacia scrub	4.1	2.0 ± 0.8	12.0 (5.6–25.6)	49 (23–105)
Total/overall	12.3	2.9 ± 0.7	14.3 (8.8–23.1)	179 (111–288)

All the SDM algorithms performed well based on AUC values (Table 2). The Tjur's R^2 values for all three algorithms were similar and showed a high level of discrimination between pixels with occurrences and pseudo-absences. Variable importance values for models produced by each algorithm showed that land-cover type had the greatest influence in models produced by all algorithms (Supplementary Material Table S3), and relative differences in variable importance for the models produced by GAM and GLM were similar. The influence of land-cover type and habitat edge was similar in the MaxEnt model, while NDVI had a relatively small influence.

Table 2. Calculated AUC, sensitivity, specificity and Tjur's R^2 values of SDM algorithms used to estimate Black-winged Myna habitat suitability. Values of AUC, sensitivity and specificity are averages ± SD across the five different datasets included, each comprising Black-winged Myna presences (n = 291) and 5,000 pseudo-absences. Tjur's R^2 values were calculated from model averages for each SDM algorithm after projecting the models across the raster surface for the study area. The highest values for each metric are shown in bold.

SDM algorithm	AUC	Sensitivity	Specificity	Tjur's R^2
GLM	**0.88 ± 0.02**	86.9 ± 6.43	**76.3 ± 6.95**	0.46
GAM	0.87 ± 0.01	**89.3 ± 5.13**	72.4 ± 6.58	**0.48**
MaxEnt	0.87 ± 0.02	87.5 ± 5.27	73.4 ± 6.75	0.46

The final ensemble model had a Tjur's R^2 value of 0.47 and discriminated well between areas we expected to be suitable (savanna-type land-covers) and unsuitable (closed-canopy areas) for Black-winged Myna. Large areas of potentially suitable habitat (values of >0.6) are predicted across the north of the park, where open savanna and savanna woodland dominate, while there are smaller areas of suitable habitat surrounding the savanna in the south-east of the park (Figure 3). The central areas of large open savannas are deemed less suitable than the edges. The areas of highest suitability adjoining the current range of Black-winged Myna are distributed to the north and north-west.

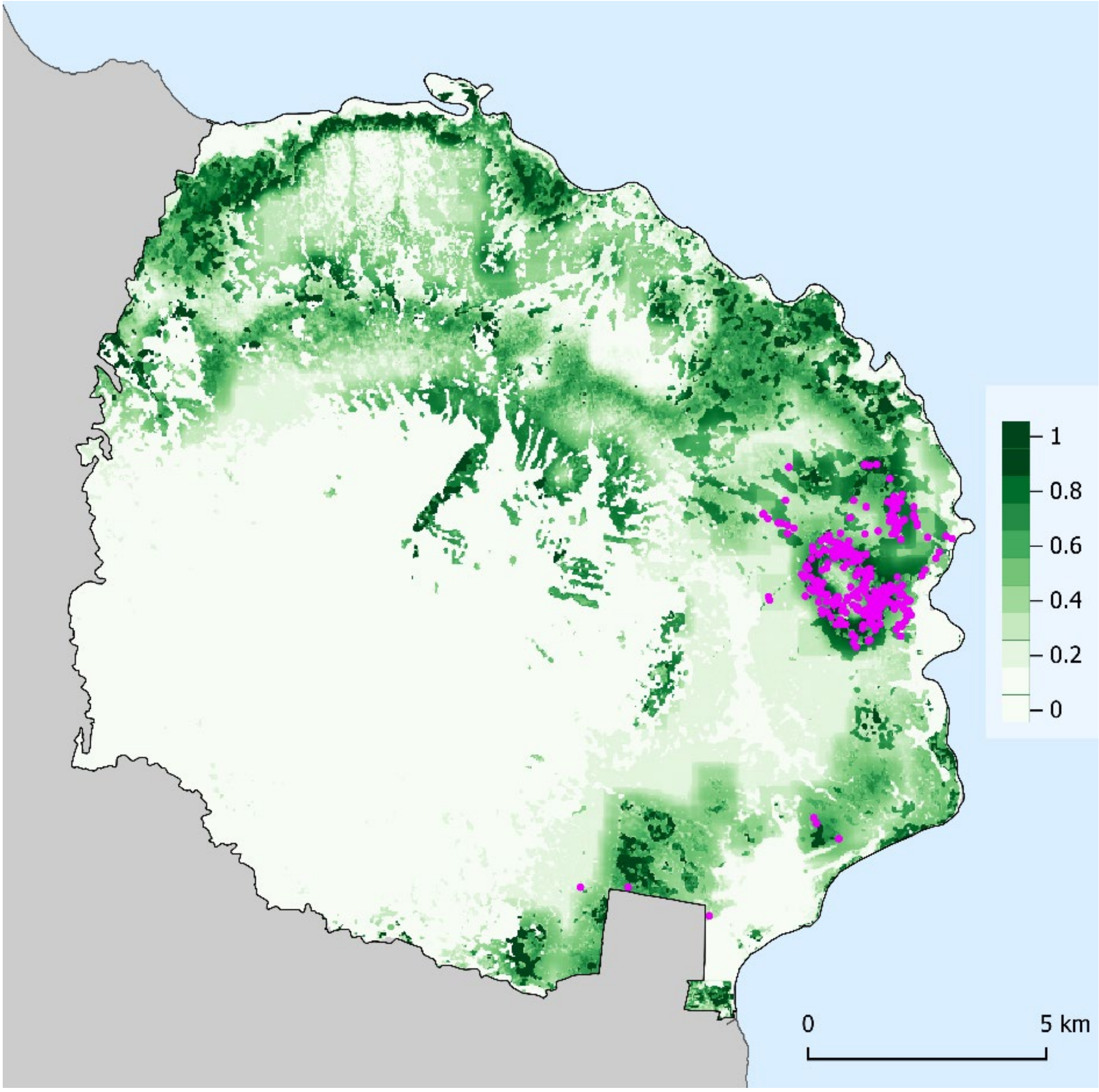

Figure 3. Baluran National Park habitat suitability map for Black-winged Myna, with values on a scale of increasing suitability from 0 to 1. Magenta circles show the actual Black-winged Myna occurrences that were used in species distribution modelling.

We then delimited the potentially suitable area for Black-winged Myna across BNP from the suitability raster using the calculated threshold (Figure 4). This final output indicated that there are an estimated 72.1 km^2 of potentially suitable habitat for Black-winged Mynas, mainly to the north-west of the current range and mostly within open savanna and savanna woodland. Of the potentially suitable habitat, 89% lies within 5 km of the coast at elevations below 300 m. Much of the potentially suitable area is close to the roads and settlements that occur in the north of BNP.

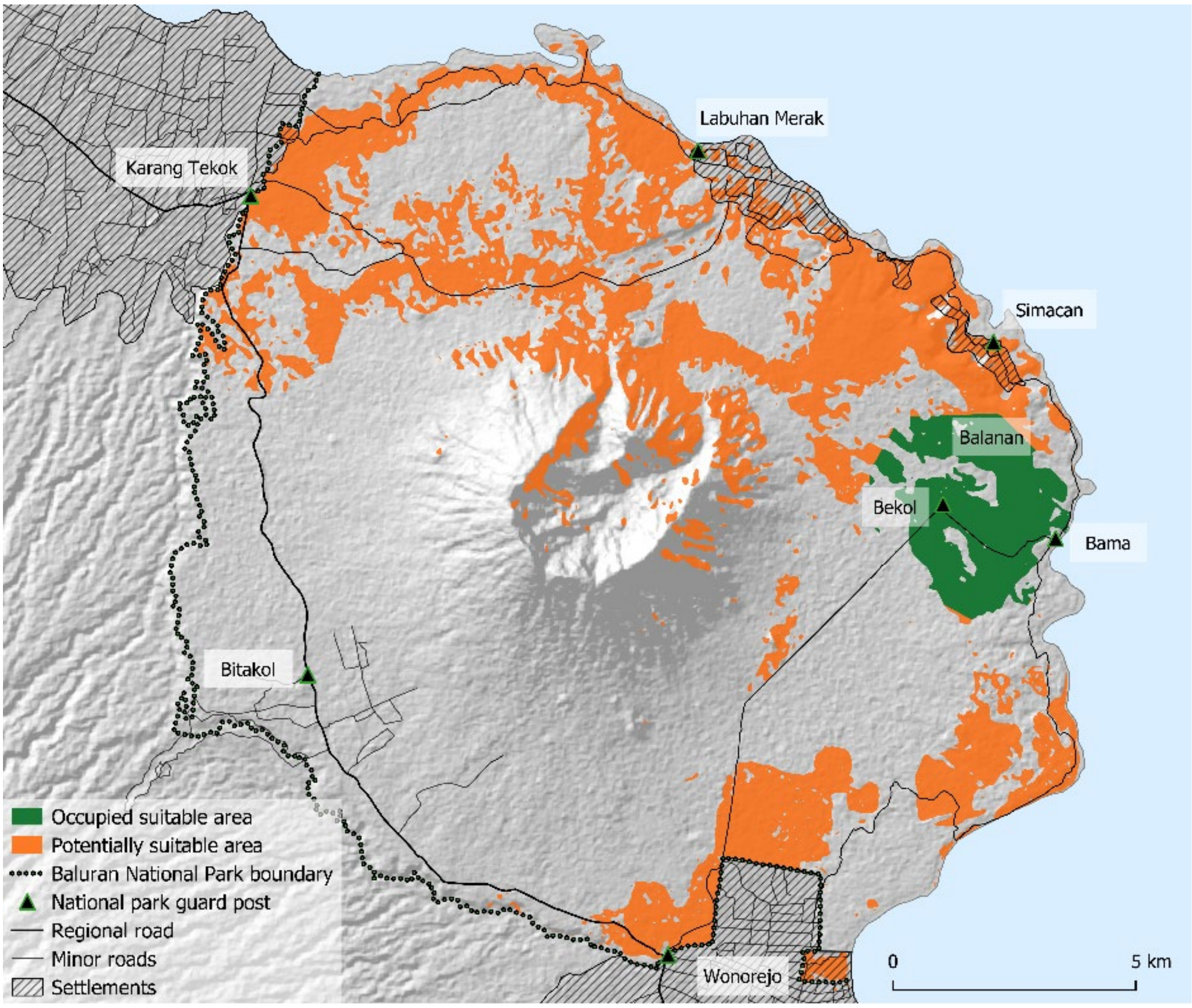

Figure 4. Baluran National Park, showing predicted suitable habitat for Black-winged Mynas that is currently occupied and unoccupied.

DISCUSSION

The once widespread but now Critically Endangered Black-winged Myna has been extirpated from localities throughout its range on Java and Bali after decades of overexploitation for the cage-bird trade (Eaton et al. 2015, Shepherd et al. 2016, Nijman et al. 2018). This first comprehensive assessment of its status at Baluran National Park, the home of the only known wild population on Java, reveals that fewer than 200 individuals are confined to 12.3 km^2 of savanna and shrubland in the east of the park, an area six times smaller than the 72.1 km^2 of potentially suitable habitat identified by our species distribution model. While some of the potentially suitable habitat is located on Mount Baluran at higher elevations than the species currently occurs at in the park, it is within the species' historically reported altitudinal range of 0–2,400 m (Collar et al. 2001). Although formal population assessments have not been published, a comparison of our population estimate with the maximum flock size of 37 birds recorded in 2016 (BirdLife International 2021) suggests that there may have been recent population growth. Our model delineates areas where management for Black-winged Mynas should be prioritized, and if conditions could be improved across the entire potentially suitable habitat, with a population density matching the average estimated for its current range, BNP might be able to support a population in excess of 1,000 Black-winged Mynas. However, there remain at least three significant barriers to such population recovery—trapping, overgrazing and invasive thorny acacia.

There are, however, several difficulties associated with building distributional models for species with small remnant populations that were once widespread and have declined due to multiple and concurrent factors. These difficulties may help to explain why the species is currently not occupying habitat identified by our model as suitable. First, it is possible that part of the population occupies suboptimal habitat constituting a demographic 'sink', where mortality exceeds productivity (Howe et al. 1991), in which case our model may have considered suboptimal habitat suitable for the species. Second, characterizing trapping pressure is difficult and direct indices are seldom available (but see Biddle et al. 2021). Metrics of remoteness (distance from roads or human settlements) may explain, to some degree, such anthropogenic pressures at a large scale (Benítez-López et al. 2017, Shaney et al. 2017, Symes et al. 2018), but fail to account for spatially discrete forms of anthropogenic protection that benefit some species such as guarding (Demerdzhiev et al. 2014); tourism, as on Komodo (Reuleaux et al. 2020); community-based conservation (Watson et al. 2007); and special land status such as sacred groves (Plieninger et al. 2020). The mynas at BNP appear to benefit from a combination of guarding and tourism (or even research) activities, for which spatial data reflecting the complexity of the situation were not available. Third, the myna population in BNP is clumped, so projecting this distribution onto other parts of the—albeit relatively small—park needs to be done with care, as habitat and other relationships may not hold in other areas. This caveat extends to other protected areas in East Java (e.g., Meru Betiri and Alas Purwo National Parks), and especially to non-protected areas, where habitat associations and trapping pressures may be different. In fact, the lack of studies when the species was still common means that its true habitat preferences remain uncertain, but they may have included a wider range of habitats than those present in BNP, although probably not closed-canopy woodland. Nevertheless, the model built for Baluran is a starting point for use in other protected areas in East Java, and the habitat associations resemble those of the nearby remnant populations of Black-winged Myna around Bali Barat National Park (TMS pers. obs.).

The most likely constraint on the size of the myna population in BNP is trapping for the domestic pet trade. Black-winged Mynas have been heavily trapped and traded over four or five decades for cage-bird markets across Java (Collar et al. 2001, Shepherd et al. 2016, Nijman et al. 2018); such is their value that seven years ago 151 individuals were stolen in a highly organized raid on a well-guarded conservation breeding center (Tritto and Sözer 2014). Recently, mynas explicitly identified as trapped in Baluran have been openly advertised for sale online (Bruslund et al. 2021). Evidence from our study suggests that the species persists only in the small area where we found them because birds there are afforded protection against trapping. This likely comes from three sources: the heavy park staff presence at Bekol, which houses an office, conservation breeding enclosure and guard post; tourist activity, which is centered around Bekol and Bama and which saw visitors rise from 39,874 in 2013 to 245,901 in 2020 (Padmanaba et al. 2017; BNP unpublished data); and the presence of park staff, contract workers and the Copenhagen Zoo project team performing savanna restoration at Balanan. Elsewhere in the park trappers may be less constrained, owing to the much less frequent presence of guards and tourists.

A second constraint on Black-winged Mynas at BNP is savanna degradation and disturbance resulting from the 5,000 domestic livestock grazing and browsing some 56 km^2 of the park's northern savannas (Pudyatmoko 2017), representing 21% of the park's total area. Just over half of the 4,000 cattle and all of the goats are kept by inhabitants of the settlements along BNP's northern coast from Labuhan Merak to Simacan, with the remainder kept by residents of Karang Tekok village (Pudyatmoko 2017). Most of the livestock belong to a few members of the local elite and are loaned to keepers under a *gaduh* system, whereby owners take the profit from cattle sold for slaughter and keepers retain calves born on pasture, with a ten-fold difference in annual profit in favor of owners (Wianti 2014, Pudyatmoko et al. 2018). Low-intensity grazing can be beneficial for many starlings and mynas because it maintains a low sward height (Fuller et al. 2013), providing birds with access to surface and topsoil invertebrates (Heldbjerg et al. 2016, van Balen and Collar 2021), while manure increases food availability by promoting plant and invertebrate abundance and diversity (McNaughton 1985, Steinauer and Collins 1995, Plantureux et al. 2005). Indeed, like other *Acridotheres*, Black-winged Mynas commonly associate with large herbivores, feeding on invertebrates from the ground they disturb (Collar et al. 2001). However, the current high intensity of grazing by domestic livestock in the northern savannas of BNP probably greatly exceeds former natural levels based on the maximum recent population sizes for the entire park of water buffalo (1,293 in 1984; Suhadi 2009) and banteng (267 in 2000; Winnasis et al. 2011), and the graziers who accompany livestock are a source of disturbance to wildlife (Pudyatmoko 2017). The resulting soil impoverishment (Dormaar and Willms 1998, Villamil et al. 2001) and atrophied biodiversity (Olff and Ritchie 1998, Dhaou et al. 2010) associated with intensive grazing seriously reduces the habitat suitability for Black-winged Myna and other savanna-dependent wildlife.

That the recent clearance of thorny acacia within the Bekol area has coincided with an apparent population upturn of Black-winged Mynas (our population estimate of around 179 individuals is substantially higher than the maximum flock sizes reported in the 2010s) suggests that thorny acacia is a poor habitat for the species, despite the relatively high usage registered in our results, caused by birds perching in acacias fringing open foraging areas. Thorny acacia spreads rapidly, replacing savanna with impenetrable thickets and reducing the food available to savanna-dependent wildlife (Kriticos et al. 1999, Dhileepan 2009, Zahra et al. 2020). Dense stands had engulfed the savanna at Bekol, Balanan and Kramat by 1993, covering an estimated 12 km^2 (Schuurmans 1993 in Setiabudi et al. 2013), and despite restoration attempts since 1985, with some of Bekol savanna successfully cleared (Zahra et al. 2020), by 2014 the overall acacia cover had increased (Sutomo et al. 2020). Since 2016, thorny acacia clearance at Balanan has restored 3.6 km^2 of grassland (Copenhagen Zoo 2021), which has been used by Black-winged Mynas, including for breeding (TMS pers. obs.). Our habitat classification indicated that there are at least another 12 km^2 of thorny acacia within BNP in monospecific stands, most of which are close to the current Black-winged Myna range and Simacan settlement (Figure 4); efforts to clear this are therefore a priority and could double the habitat immediately available to the species.

If birds (re)colonize this area, guard patrols must of course follow. Such protection could be supported by the mapping of nesting and particularly roosting areas, which are probably where most trapping is done; well-protected nest-boxes could be deployed to encourage dispersing birds, as practiced in early reintroduction attempts (Tritto 2014), particularly as the myna's natural cavity nest sites may have been reduced in number by the removal of dead trees for fuelwood near settlements (TMS pers. obs.). Patrolling also needs to target beaches, land access points, and the northern settlements where mynas and Baluran's other key species are suspected of being smuggled out of the park (Winnasis et al. 2011).

A crucial underpinning of any conservation management of Black-winged Mynas will be engagement with the park's human communities, especially those at Simacan and along BNP's northern coast. Such work has been instrumental in protecting species facing similar anthropogenic pressures elsewhere: the Philippine Cockatoo (*Cacatua haematuropygia*) was trapped almost to extinction until a conservation program trained and employed ex-trappers as wardens and involved local communities in wildlife monitoring (Widmann et al. 2006). Communities living inside BNP could likewise be recruited to support a nestbox and monitoring scheme for Baluran's mynas in a type of payment for ecosystem services arrangement (Ferraro 2011). In 2016 BNP established a 20 km^2 'special use zone' in a bid to settle a long-standing dispute over the communities' land rights (Mulyana et al. 2010, Wianti 2014, Pudyatmoko et al. 2018), which suggests that local goodwill might allow such a project to be implemented. Nevertheless, further negotiations are essential to achieve a significant but equitable reduction in grazing pressure in the 56 km^2 of highly degraded northern savanna, for example, by keeping cattle in enclosures and providing alternative livelihoods (Pudyatmoko et al. 2018).

Protected areas are understandably the first option considered when seeking to preserve species, because they provide a pre-existing legal, geographical, organizational and social framework for the endeavor, and often also because they are the last places where the species of concern survive. With the western form of Black-winged Myna, nominate *melanopterus*, apparently extinct in the wild and the Bali form *tertius* not known to number more than 35 inside Bali Barat National Park, Baluran National Park represents by far the most important opportunity to save the Black-winged Myna from the trapping pressure that is driving it to extinction. The cases of the Javan Pied Starling (*Gracupica jalla*), now almost certainly extinct in the wild (van Balen and Collar 2021), and the Bali Myna, once thought extinct in the wild and now surviving only through intensely managed reintroductions (Jepson 2016), serve as examples of what the near future could hold for the Black-winged Myna without effective action.

At Baluran, there is scope to increase its small population by habitat restoration and enhancement, elevated protective vigilance and strong community engagement, building on established models trialed elsewhere in the world. Nevertheless, open-country starlings and mynas tend to make medium-distance movements to forage and explore (Bruun and Smith 2003, Minderman et al. 2010, Astudillo et al. 2019), so protected areas cannot be expected to harbor them indefinitely. In the longer term, therefore, such species, especially if under pressure from trapping, will have to be conserved by management strategies that embrace adaptation and improvisation, taking advantage of the various types of security provided by mining or geothermal operations (Randriamamonjy et al. 2015, Devenish et al. 2021), religious sites (Colding and Folke 1997), tourist resorts (Moritz et al. 2017) and organic farming, all of which may to some extent be leveraged to create appropriate socio-ecological conditions to allow them to survive within working landscapes. Other interventions proposed for exploited wider-ranging species include demand reduction (Burivalova et al. 2017, Marshall et al. 2020), commercial breeding (Jepson et al. 2011) and better enforcement of trade laws (Nijman 2010), and all of these measures could be applied in the case of the Black-winged Myna, whose recovery in Baluran could also be abetted by supplementations of captive-bred birds. What can be achieved at Baluran in the next decade may therefore point the way for many species recoveries, not just of threatened songbirds and not just in protected areas, across Indonesia and indeed the world.

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