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INSIGHTS

Using public surveys to reliably and rapidly estimate the distributions of multiple invasive species on the Andaman archipelago

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ABSTRACT

To effectively manage multiple biological invasions, information on their distributions must be generated rapidly and over large spatial scales. Using public surveys in a false-positive occupancy framework, we reliably estimate the distributions of three synanthropic invasive species on the Andaman Islands.

Key words: citizen science; false-positive model; island invasives; key informant survey; occupancy.

Global awareness on the economic and ecological impacts of biological invasions has prompted biodiverse countries to prioritize invasive species and characterize their dispersal pathways for effective management. Tropical developing countries harbor a significant proportion of biodiversity but lack research on biological invasions (Nuñez & Pauchard 2010). To manage biological invasions, strategies which gather information on invasives rapidly, reliably, and at large spatial scales are crucial (McGeoch *et al.* 2016). Specifically for established invasive populations, knowledge of distribution and factors mediating dispersal is critical for their management (Simberloff 2003, Hulme 2009). Demarcating distribution across large spatial scales is effort intensive (Danielsen *et al.* 2005), but this effort can be offset by incorporating observations from public surveys (Karanth *et al.* 2009, Zeller *et al.* 2011) or citizen science programs (Crall *et al.* 2015). Information from local communities could be particularly reliable when invasive species are found in close association with human habitation and/or interact with humans, either positively or negatively. Synanthropic invasives species (SIS) occur in human-modified landscapes (Rebele 1994, Marzluff 2001), which offer relatively low predation pressure and seasonal variations of resource availability (Jokimäki *et al.* 1996, Gering & Blair 1999, McKinney & La Sorte 2007). The association of SIS with humans not only aids in their extra-range dispersal (Wilson *et al.* 2009) but might also help them spread in the invaded range.

Occurrence information from the public has been incorporated in occupancy modeling frameworks (Karanth *et al.* 2009, Pillay *et al.* 2014). However, such information is prone to false-positive errors arising from misidentification, confusion over locality, and sometimes deliberate falsification (Pillay *et al.* 2014). Recent advances in modeling of public survey data have made it possible to reliably estimate occupancy without compromising on precision (Miller *et al.* 2011, Ferguson *et al.* 2015).

We estimated the distribution of three major SIS of the Andaman archipelago, the Common Myna (*Acridotheres tristis*; hereafter, myna), the House Sparrow (*Passer domesticus*; hereafter, sparrow), and the giant African snail (*Achatina fulica*; hereafter, snail) that are reportedly widespread (Ali 2006, Rajan & Pramod 2012). We gathered detection/non-detection data of these species through key informant interviews in 88 sites on the eight inhabited islands of the Andaman archipelago (Appendix S1). Myna was introduced into the Islands in 1867, sparrow in 1882 (Lever & Gillmor 1987), and snail in 1940s (Ali 2006). We interviewed key informants comprising of farmers, plantation workers, and aqua-culturists, from January to March and September to December 2015. Additionally, we obtained detection/non-detection data for myna (65 sites), sparrow (39 sites), and snail (29 sites) through systematic visual encounter surveys and opportunistic records. We corrected the informant data for false-positive detections in an occupancy framework and estimated the distribution of the three species.

Myna is a globally successful invasive species and is known to compete with native birds for food, territory, and nesting sites (Harper *et al.* 2005, Dhami & Nagle 2009, Grarock *et al.* 2014); economic loss due to crop depredation is also reported (Heather & Robertson 2000). In the Andaman Islands, myna may compete with native species of family Sturnidae and Psittacidae (Rajan & Pramod 2012). Sparrows are successful global invaders owing to their generalist diet (Gavett & Wakeley 1986) and impact native birds by competing for nesting sites (Gowaty 1984). Snails are introduced throughout the tropics and subtropics (Simberloff & Gibbons 2004) and prefer modified landscapes, forest edges, plantations, and agricultural lands (Raut & Barker 2002). They are known to alter nutrient cycle, spread plant pathogens (Raut & Barker 2002), and are vectors of *Angiostrongylus cantonensis,* a

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parasitic nematode which causes eosinophilic meningitis (Alicata 1966).

For occupancy analysis, we constructed a data matrix consisting of key informant interviews (uncertain data) and one field observation (certain data) per site. We executed multi-method false-positive models (Miller *et al.* 2011) and single-season constant detection models (MacKenzie *et al.* 2002) in program PRESENCE 6.4 (Hines 2010). We constructed both types of models with three site covariates signifying susceptibility to invasion—distance to nearest port, distance to nearest major town, and distance to nearest major road. For false-positive models, we assumed that 'certain data' did not contain false-positives. To model this assumption, we fixed the parameter '*b*' (probability that a detection is classified as certain when the site is occupied and the species is detected) for all occasions to 0 and '*P*10' (probability of detecting the species at a site when the site is unoccupied) for field observation to 0. The detection probability (*P*) of field observations was kept equal to that of key informant observations, as we did not carry out multiple field surveys of the same site. In all, we constructed eight models for each species.

Model selection was based on Akaike information criterion (AIC, Burnham & Anderson 2002). We estimated occupancy rate (ψ), true-positive probability (P_{11}), false-positive probability (P_{10}), and associated 95% confidence intervals for all three species. Site-specific occupancy could only be estimated for myna and sparrow, as models with site-specific covariates were not selected as the best model in case of snail. We assigned site-specific occupancy values to categories (of equal widths and extreme points) based on the range of values obtained. Based on this categorization, we created distribution maps for myna and sparrow. All GIS-based analyses were performed in ArcGIS v. 10.3.1. We estimated Global Moran's I (Moran 1950) and Getis-Ord G (Getis & Ord 1992) to determine whether site-specific occupancy values were correlated and whether high occupancy values or low occupancy values clustered together. Such positive correlation may be expected for invasions with relatively few 'long-distance jump dispersal' events in comparison with 'leading edge dispersal' (as in Wilson *et al.* 2009). The required distance matrices for this test were calculated with respect to the covariate of the best model chosen for each species.

We interviewed 840 respondents for myna, 832 for sparrow, and 830 for snail, with an average of 9.49 (SD = 0.1, range = 3–10) interviews per site (Appendix S1). We did not elicit a response from 10 informants on myna, 21 on sparrow, and four on snail. Number of respondents who provided information on time of introduction was 256 for myna, 78 for sparrow, and 279 for snail. Respondents mentioned specific time periods in 111 cases for myna, 26 for sparrow, and 56 for snail. Total number of detection/non-detection varied between species, with highest detections of snail and lowest detections of sparrow (Appendix S1). The naive occupancy, based on the combined dataset of field and key informant observations, was highest for snail (98% of sites), followed by myna (84%) and sparrow (64%, Appendix S1).

The false-positive models best explained the detection/non-detection observations for all three species (Table 1). Snail was most ubiquitous with 90 percent occupied site, followed by myna (60%) and sparrow (34%, Table 1). The standard models over-predicted the occupancy of myna by 40 percent, of sparrow by 91.18 percent, of snail by 8.89 percent with respect to false-positive models (Table 1). The 95% confidence interval on occupancy estimates of both models did not overlap each other in case of myna and sparrow but for snail. The probability of false-positive detection varied between species (Table 1). A false-positive model, with distance to nearest major road as a covariate, best explained the detection/non-detection of myna, while the same model with distance to nearest port as a covariate was chosen as the best model in the case of sparrow (Table 1). Moran's I test of site-specific occupancy values suggested spatial autocorrelation to be present in case of both myna (Moran's $I = 0.21$, $Z = 1.99$, $P = 0.046$, $N = 88$) and sparrow (Moran's $I = 0.72$, $Z = 4.98$, $P < 0.001$, $N = 86$). While sites with high occupancy were clustered around the ports in the case of sparrow ($G < 0.001$, $P < 0.01$, $N = 86$; Fig. 1B), high and low occupancy value sites were interspersed along major roads in the case of myna ($G < 0.001$, $P = 0.682$, $N = 88$; Fig. 1A)

COMMON MYNA

Nine sites on Middle Andaman Island had 'low occupancy' (0.5 to 0.69; Fig. 1A). All sites of Neil, Havelock, and Long Islands also had 'low occupancy' (Fig. 1A), even though myna has been observed near the ports and adjacent township (Table S1). Overall, occupancy was 'low' in 77 percent of sites in the study area (Fig. 1A). We recorded recent colonizations (2010–2015) of villages on the southern tip of North Andaman Island and on the northern and the southern tip of Middle Andaman Island. Inter-island transport of myna as pets and hitchhikers was also reported. Spread of myna from the port town of Diglipur to villages in North Andaman Island, post-1990–95 was also mentioned by the interviewees (Fig. 1A).

HOUSE SPARROW

Respondents reported sparrow's occurrence in villages of all islands except Long Island. Sparrow had 'low occupancy' in 49 percent of sites with site-specific occupancy values ranging from 0.1 to 0.29 (Fig. 1B). Temporary occurrence at three sites was reported; recent arrival in markets of Little Andaman (2013) and North Andaman (2010–11) was also noted. We recorded one instance of an individual hitchhiking on a ferry, while one respondent reported intentional release of 4–5 individuals in North Andaman Island. Respondents remarked on the association of sparrow with ration shops and facilitation of its dispersal by road.

GIANT AFRICAN SNAIL

Snail occurred on all islands and was ubiquitous across sites. Nineteen respondents reported dispersal of snail by transport of

TABLE 1. *Models explaining the occurrence of three synanthropic invasive species on the Andaman archipelago, along with estimates of occupancy, true-positive detection probability, and false-positive detection probability. Site-specific covariates include distance to nearest port/town/major road.*

Model	AIC	Occupancy (ψ)	True-positive (P_{11})	False-positive (P_{10})
Common myna				
1 group, Constant P	988.72	0.84 (0.75–0.90)	0.74 (0.71–0.77)	–
psi(port), p(.)	1000.18	Site-specific	0.72 (0.69–0.75)	–
psi(town), p(.)	1009.28	Site-specific	0.72 (0.69–0.75)	–
psi(road), p(.)	1036.56	Site-specific	0.72 (0.69–0.75)	–
False-positive	805.74	0.60 (0.49–0.70)	0.90 (0.87–0.93)	0.20 (0.16–0.26)
False-positive[psi(port)]	803.52	Site-specific	0.90 (0.87–0.93)	0.21 (0.16–0.26)
False-positive[psi(town)]	805.92	Site-specific	0.90 (0.87–0.93)	0.21 (0.16–0.26)
False-positive[psi(road)]*	796.43	Site-specific	0.90 (0.87–0.93)	0.20 (0.16–0.26)
House sparrow				
1 group, Constant P	897.79	0.65 (0.54–0.74)	0.42 (0.38–0.46)	–
psi(port),p(.)	903.08	Site-specific	0.40 (0.36–0.44)	–
psi(town),p(.)	901.24	Site-specific	0.40 (0.36–0.44)	–
psi(road),p(.)	907.43	Site-specific	0.40 (0.36–0.44)	–
False-positive	852.59	0.34 (0.22–0.48)	0.60 (0.51–0.68)	0.10 (0.07–0.15)
False-positive[psi(port)]*	847.13	Site-specific	0.62 (0.53–0.71)	0.11 (0.08–0.16)
False-positive[psi(town)]	853.14	Site-specific	0.59 (0.51–0.67)	0.10 (0.07–0.14)
False-positive[psi(road)]	851.36	Site-specific	0.64 (0.55–0.72)	0.13 (0.10–0.17)
African snail				
1 group, Constant P	489.85	0.98 (0.91–0.99)	0.93 (0.91–0.95)	–
psi(port),p(.)	553.06	Site-specific	0.90 (0.88–0.92)	–
psi(town),p(.)	553.06	Site-specific	0.90 (0.88–0.92)	–
psi(road),p(.)	586.03	Site-specific	0.92 (0.90–0.94)	–
False-positive*	409.97	0.90 (0.81–0.95)	0.96 (0.95–0.97)	0.30 (0.21–0.42)
False-positive[psi(port)]	479.48	Site-specific	0.82 (0.77–0.86)	1.00 (0.00–1.00)
False-positive[psi(town)]	479.36	Site-specific	0.81 (0.77–0.85)	1.00 (0.00–1.00)
False-positive[psi(road)]	467.43	Site-specific	0.96 (0.95–0.97)	0.31 (0.21–0.43)

*Indicates the best model based on AIC values.

sand, stones, and rods, while 17 mentioned inter-island and mainland-island dispersal through plants, seeds, and compost; a case of dispersal for consumption was recorded. Respondents who voluntarily declared damage to pulse, grain, and vegetables were in all 175 of 753 who reported their presence.

We demonstrate that the distribution of SIS can be reliably estimated from public surveys using false-positive models. While this method has been adopted for estimating the distribution of large vertebrates of a region (Pillay *et al.* 2014), we apply it for the first time to estimate distribution of SIS in a large spatial scale. The use of false-positive models instead of standard occupancy models removed false-positive bias from occupancy estimates (Miller *et al.* 2011, Pillay *et al.* 2014, Ferguson *et al.* 2015). The high rate of false-positive detection for sparrow may be due to its morphological similarity with the White-rumped Munia *Lonchura striata fumigata*, leading to frequent misidentifications. However, for species with true occupancy close to 1 (*e.g.*, snail), it is not an effective model as it requires unoccupied sites to estimate false-positive probability (Royle & Link 2006, Miller *et al.* 2011).

The study finds distribution patterns unique to each of the three major SIS of the Andaman Islands. Myna's invasion may be ongoing given the recent colonization of sites on the northern and southern tip of Middle Andaman Island. Dispersal along forest edges created by major roads as well as through pet trade might augment the dispersal of myna (Table 1; Hone 1978). Sparrow's distribution seems to be more likely in sites with ports and granaries (Table 1; Magudu & Downs 2015). Intentional release and hitchhiking on ferries might drive long-distance dispersal of sparrows, and edge habitats along roads may help them cross barriers of contiguous evergreen forests (D'Amico *et al.* 2013). The clustered pattern of sites with high occupancy values of sparrows indicates a few long-distance dispersal events followed by leading edge spread. Snail is most ubiquitous of the three species, probably owing to frequent human-mediated spread through the agriculture and construction sector (Thiengo *et al.* 2007).

We did not extrapolate our results to predict occupancy at un-sampled sites as our study covered most villages except five, however, occupancy modeling allows for such estimation

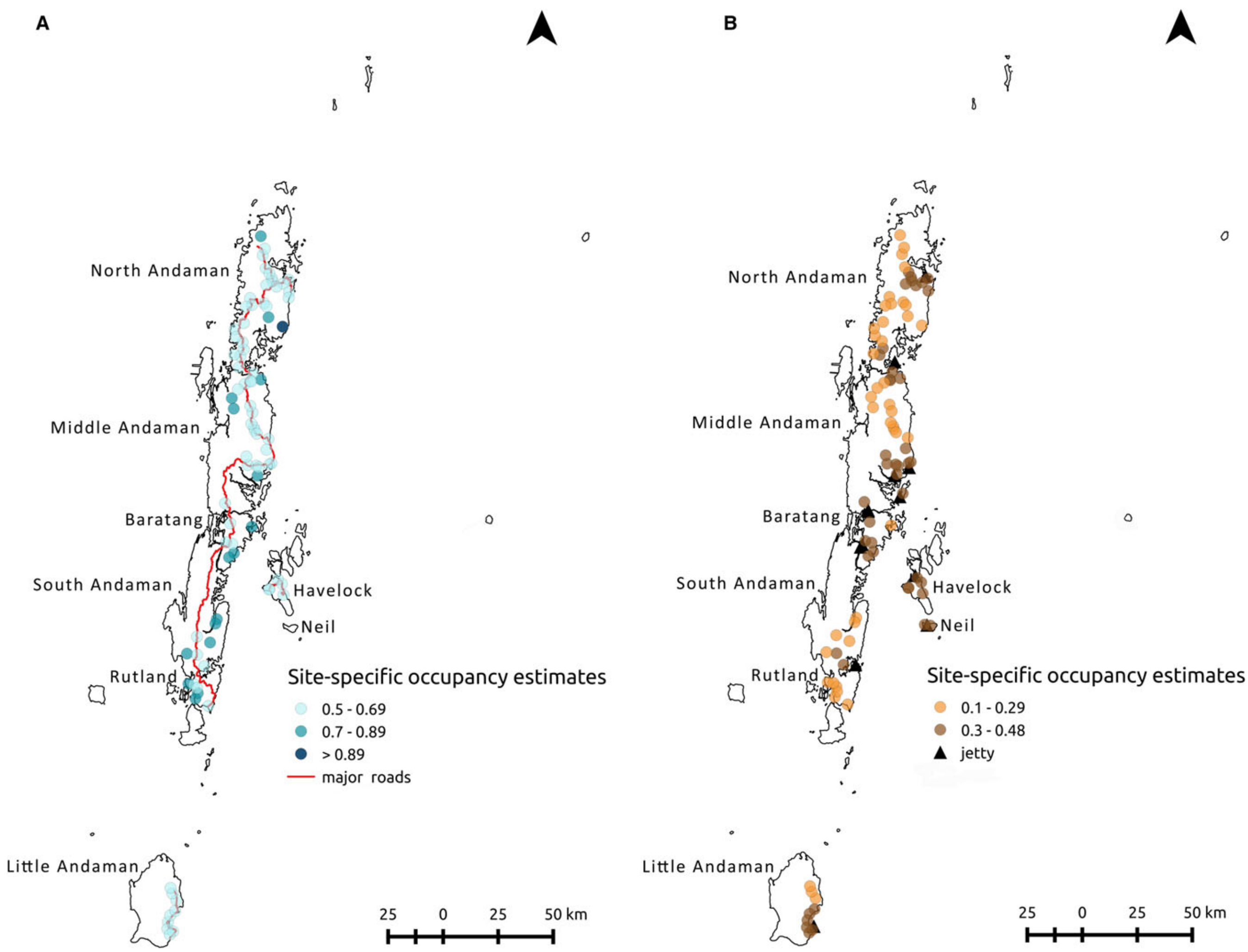

FIGURE 1. Site-specific occupancy estimates of (A) common myna *Acridotheres tristis* and (B) house sparrow *Passer domesticus*, at 88 sites on the Andaman archipelago. The best predictor of occupancy is distance of site to nearest major road for common myna, and distance of site to nearest port for house sparrow.

(Mackenzie & Royle 2005). Incorporating suitable site-specific and survey-specific covariates can provide improved occupancy estimates for false-positive models (Miller *et al.* 2011). Although time since introduction could influence the response rate of public for SIS surveys, we find response rates to be similar between long-standing invasions (*e.g.*, myna, sparrow, and snail) and a recent invasion of a SIS, the Indian bullfrog *Hoplobatrachus tigerinus* (NPM, unpublished data). Therefore, the method is scalable to other invasive species that have interactions (positive or negative) with the public or with a subset of key informants. Given the urgency in generating baselines for invasive species in developing countries, this cost-effective and rapid approach would be useful to generate reliable data over large spatial scales.

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DATA AVAILABILITY

Data available from the Dryad Digital Repository: https://doi.org/10.5061/dryad.2r7d8 (Mohanty *et al.* 2018).

SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article:

APPENDIX S1. Details of the study area and methods used in the study.

TABLE S1. *Data on observations of common myna* (Acridotheres tristis), *the house sparrow* (Passer domesticus) *from Andaman archipelago, collated from ebird (*www.ebird.org*).*

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