

Research Article

Anthropogenic not climatic correlates are the main drivers of expansion of non-native common myna *Acridotheres tristis* in JordanFares Khoury^{1,*}, Muna Saba² and Mohammed Alshamli³¹Department of Biology and Biotechnology, American University of Madaba, Madaba, Jordan²Amman, Jordan³Biology Department, College of Science, Imam Abdulrahman Bin Faisal University Basic and Applied Scientific Research Center, Imam Abdulrahman Bin Faisal University, Saudi ArabiaAuthor e-mails: f.khoury@aum.edu.jo (FK), sabamuna20@gmail.com (MS)

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Received: 16 November 2020**Accepted:** 26 April 2021**Published:** 17 May 2021**Handling editor:** Amy Davis**Thematic editor:** Catherine Jarnevič**Copyright:** © Khoury et al.This is an open access article distributed under terms of the Creative Commons Attribution License ([Attribution 4.0 International - CC BY 4.0](https://creativecommons.org/licenses/by/4.0/)).**OPEN ACCESS****Abstract**

The common myna was first recorded in Jordan in 2010, in the Jordan Valley just north of the Dead Sea, as a result of secondary expansion of an invasive population from a neighboring country. After initial establishment, it rapidly spread throughout many parts of the country. This included apparent jump dispersals of 20–60 km to towns located in the desert along highways. The common myna is thus able to become fully invasive in arid and semi-arid environments under the influence of human factors. The results of a Maxent model trained with data from the invaded region (the southern Levant) and the native range suggest that the common myna's expansion and current distribution is driven mainly by anthropogenic factors rather than climatic variables. This study provides a nationwide baseline about the distribution of the invasive common myna, and potential for further spread as a baseline for monitoring and prioritizing actions to control spread and impacts. The rapid expansion of common myna in Jordan, which is apparently enhanced by the influx of dispersing birds from neighboring countries, necessitates more attention and urgent action and coordination at various levels.

Key words: biological invasions, Middle East, Indian myna, SDM**Introduction**

The transport and trade of animals has facilitated the spread of non-native and invasive species, at global scale (Blackburn et al. 2009). One of the most harmful invasive bird species is the common myna (*Acridotheres tristis* Linnaeus, 1766) that is originally native to Central and Eastern Asia (Lowe et al. 2000). It has invaded various non-native parts of Asia and all other continents, except for the Antarctica (Feare and Craig 1999). Although the impacts of introduced birds on native species are generally considered to be weak (Koenig 2003; Blackburn et al. 2009; Lowe et al. 2011; Sol et al. 2012), negative impacts of common myna have been reported on the native avifauna, e.g. its competition for nesting cavities with native birds (Grarock et al. 2012; Charter et al. 2016; Feare et al. 2017; Rogers et al. 2020), nest predation of eggs and chicks (Blanvillain et al. 2003; Orchan et

al. 2013; Hughes et al. 2017; Hart et al. 2020) and disturbance causing nest abandonment by other birds (Komdeur 1996). The ability to become established and expand in its non-native range is often related to considerable habitat modifications caused by human activities (Feare and Craig 1999; With 2002; Peacock et al. 2007; Garrock et al. 2014). Urbanization and farming offer new ecological opportunities for the behaviorally flexible common myna including the presence of suitable structures (e.g. those important for nesting) and a variety of food resources combined with the lack of natural predators and native competitors (Duncan et al. 2003; Sol et al. 2012). As urban and rural encroachment and fragmentation of natural habitats is currently ongoing, the common myna, which is often considered an urbanized bird, is expected to continue its global expansion (Møller et al. 2015; Cohen et al. 2019; Hart et al. 2020).

The common myna was introduced to various parts of the Middle East (Holzapfel et al. 2006), and expanded during the last decade into Jordan from Israel and the Palestinian territories (PNA) (Khoury and Alshamliah 2015; Cohen et al. 2019), although a few sporadic introductions (or escapes) cannot be totally ruled out in Jordan. The Ministry of Environment in Jordan has recently recognized the threat of invasive species on ecosystem services and initiated a “National Dialogue towards a Regulatory Framework on Invasive Species in Jordan” (ESP 2014), with the goal of raising awareness about the potential threats of introductions and biological invasion and compiling a list of potentially harmful alien species. A list of invasive or potentially invasive species in Jordan including the common myna was produced by Eid et al. (2020). Here we provide the first study on the dynamics of initial spread of an invasive species in Jordan. Our data represents a chronological demonstration of the expansion of the common myna in the country in recent years. We also used a species distribution model to identify potentially suitable habitats and assess current anthropogenic and environmental drivers of expansion. SDMs are generally useful for informing decisions such as prioritizing actions for management, and supporting regulatory decision-making (Rödder et al. 2008; Franklin 2010; Araújo et al. 2019; Sofaer et al. 2019). The model we present here was trained with occurrence data pooled from the native range and the invaded region because such combinations provide more accurate predictions of invasive species’ potential distributions in non-native areas (Broennimann and Guisan 2008). We used climatic variables that are relevant to Jordan, and human landscape modifications as additional factor. Incorporating the human effects on the landscape into distribution models was shown to considerably increase the reliability of predictions regarding potential spread of exotic species at the local or regional levels (c.f. Ibáñez et al. 2009). This work provides the baseline for monitoring and managing the spread and adverse effects of this invasive species in Jordan, and as part of regional efforts to control the spread of common myna in the Middle East.

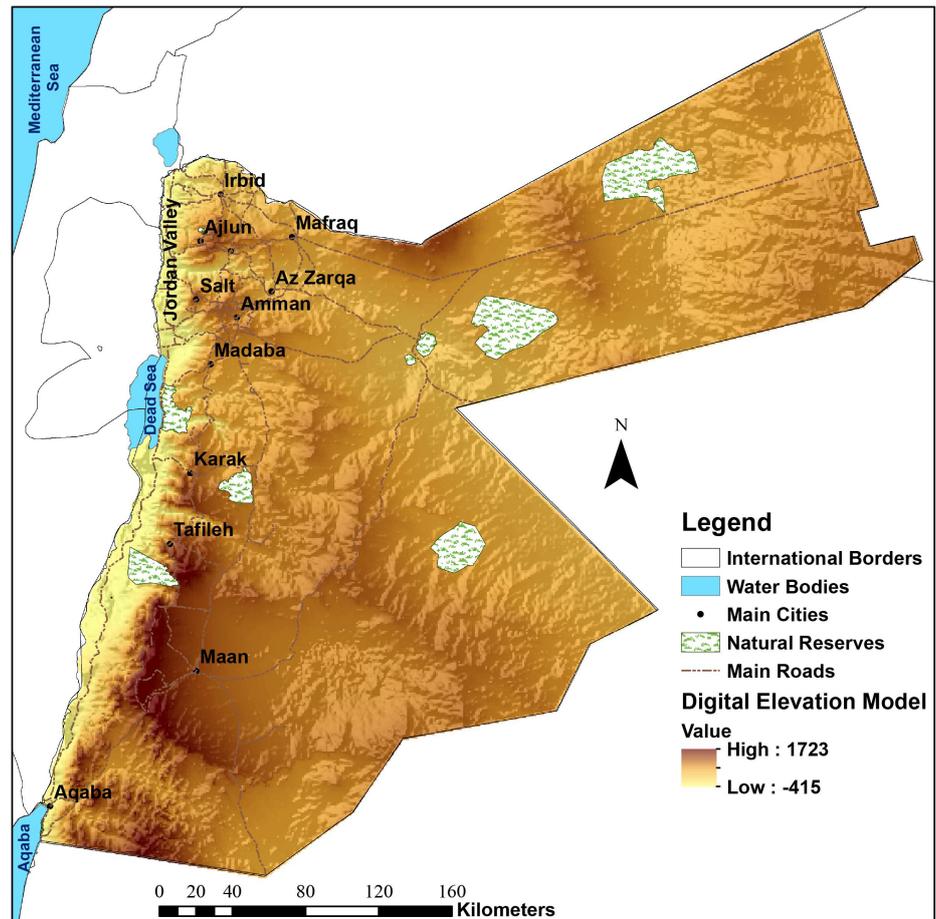


Figure 1. Map of Jordan showing elevation, major cities, main roads and highways, and nature reserves. The area with lowest elevation is the Rift Valley including the Jordan Valley, Dead Sea and Wadi Araba (between Dead Sea and the Gulf of Aqaba). The northern highlands extend from Irbid in the north to Madaba in the south. The southern highlands are located south of Karak. The central and eastern parts comprise mostly of flat and hilly desert.

Materials and methods

Jordan's climate: Jordan lies on the crossroad between three continents and different biogeographical zones (Andrews 1995). Its topography is characterized by altitudinal gradients ranging from 400 m below sea level to 1800m above sea level, these gradients being steepest along the rift margins (Figure 1). The climate is essentially of Mediterranean type with cool rainy winters and hot dry summers. However, the east and south, c. 75% of the country's area, has a desert climate with less than 200 mm average annual precipitation. In addition, the highlands and rift margins in the west have climates varying from arid to semi-arid and sub-humid with mild or cool, rainy winters and hot summers. The low-lying Jordan Valley along the western border, characterized by a semi-arid or arid, subtropical climate, has been mostly transformed to a rural landscape. For more details about climate of Jordan, see Waitzbauer and Petutschnig (2004).

Data collection and analysis: Presence-only occurrence data was obtained by the authors during regular field trips and bird surveys carried out in various parts of Jordan in the last two decades. Direct searches of common

myna were carried out during 2015–2020 to cover potentially suitable, and otherwise rarely visited areas; the searches were carried out by slowly driving and frequently stopping along roads and tracks in rural and urban areas; the length of a daily search transect varied from 20–80 km. These produced around 40% of all records. Sampling bias to urbanized areas was not considered an issue because the majority of bird surveys and field trips were regularly being carried out in all types of natural and rural habitats; general bird surveys in various parts of Jordan produced 5% of myna records, while the remaining records were collected coincidentally by the authors (35%) and birdwatchers and hobby photographers (20%) (Citizen Science) through the Jordan Bird Records Committee (Jordan BirdWatch 2020; eBird 2020; GBIF 2020), social media platforms (e.g. Jordan Birdwatching Club 2020) and direct communication. We considered records from March–August, i.e. during the main breeding season for the model construction. Coordinates were taken on site, but a few locations had to be georeferenced according to the name and spatial description provided by observers. We produced maps to demonstrate the rapid spread in intervals of 2–3 years (2010–2012; 2013–2014; 2015–2016; 2017–2018 and 2019–2020). Succeeding intervals included the records of previous intervals because regular field visits to areas where mynas were previously established confirmed the continued presence at same sites, despite of occasional short distance relocations of nesting sites and apparent changes in numbers observed; therefore the accumulative pattern of occurrences with time. We used the machine learning method and software Maxent (Phillips et al. 2006) for constructing a species distribution model that includes data from the southern Levant region (Jordan, Palestine, Israel) and the native range. Although over 1000 observations are documented, the number of spatially distinct occurrences of common myna in Jordan were around 130 sites by the year 2020 but for the model these were filtered to 71 (see below). Due to its assumed secondary expansion from the west, we also included for training the model occurrence data from Israel and Palestine (PNA) (68 occurrences), in addition to records from its native range (108 occurrences, i.e. after thinning) obtained from the “Global Biodiversity Information Facility” (GBIF 2020). To minimize the effects of sampling bias and overfitting of the model due to locally high population densities, records were thinned in two steps: we filtered occurrence data so that a minimum distance of three kilometers was maintained between records, because this has been reported as the average distance mynas usually cover while foraging (Feare and Craig 1999; Burstal et al. 2020). Then, a cluster analysis was carried out for the remaining occurrence locations (coordinates) based on Euclidean distances (Stiels et al. 2011) with the software xlstat (XLSTAT by Addinsoft 2020). This produced a few clusters with records having over 98% similarity, from which occurrence data were randomly removed, leaving a maximum of three in each cluster. We used a variety of

Table 1. Estimates of percent contribution and permutation importance (see text) of the environmental variables to the Maxent model.

Variable (code)	Percent contribution	Permutation importance
Human modification (humlc)	50.0	38.1
Maximum temperature of warmest month (bio5)	16.0	7.8
Annual precipitation (bio12)	13.2	15.0
Mean Diurnal Range [Mean of monthly (max temp – min temp)] (bio2)	11.4	8.4
Minimum Temperature of coldest month (bio6)	4.5	25.2
Precipitation seasonality (bio15)	4.2	1.7
Annual Mean Temperature (bio1)	0.6	13.9

abiotic environmental variables as possible predictors. Climatic variables were derived from WorldClim dataset (WorldClim 2020; see Table 1) that reflect recent (near-current) conditions. This has the limitation of predicting only recent–current distribution and spread that may be continuing in the near future without considering possible effects of climate change. We excluded elevation (DEM) and thirteen of the bioclimatic variables that correlate strongly with others within Jordan ($r \geq 0.8$), and by choosing the most relevant for Jordan according to our ecological experience. The spatial correlations among the variables were calculated using R, version 3.6.2 (R Core Team 2019). The threshold when collinearity begins to severely distort model estimation and subsequent prediction is usually $r > 0.7$ (Dormann et al. 2013). Variables included six climatic conditions, mainly temperature and precipitation averages and their extremes and seasonal or diurnal variations, in addition to human modifications (Table 1). We used a cumulative measure of the human modification of terrestrial landscapes, which is based on modeling the physical extents of anthropogenic factors and their estimated impacts with a median year of 2016 (Kennedy et al. 2020). The anthropogenic stressors considered in this measure included five major categories for which global spatial data on indicators at resolution of 1 km² were available: (a) human settlement (population density, built-up areas), (b) agriculture (cropland, livestock), (c) transportation (major roads, minor roads, two tracks, railroads), (d) mining and energy production (mining, oil wells, wind turbines), and (e) electrical infrastructure (powerlines, nighttime lights) (Kennedy et al. 2019). The inclusion of this non-climatic variable follows field observations and initial Maxent trials using data from Jordan only which indicated a close association of invading common mynas with modified or disturbed habitats. All variables had the same resolution of approximately 1 km². In Maxent, we used the “cloglog” output which provides “estimates of occurrence probabilities” ranging from 0 to 1 (Phillips et al. 2017) and with a regularization factor (beta multiplier) of 1.5 (after trials with various values; Merow et al. 2013). Ten replicate models were generated with cross-validation. Each of the runs had 222 occurrence locations for training and 25 for testing, and 10,000 background sites randomly selected in each run. We present the average distribution model and AUC of the ten replicates. We used the area under the Receiving Operator Curve (AUC) to assess model accuracy or model performance.

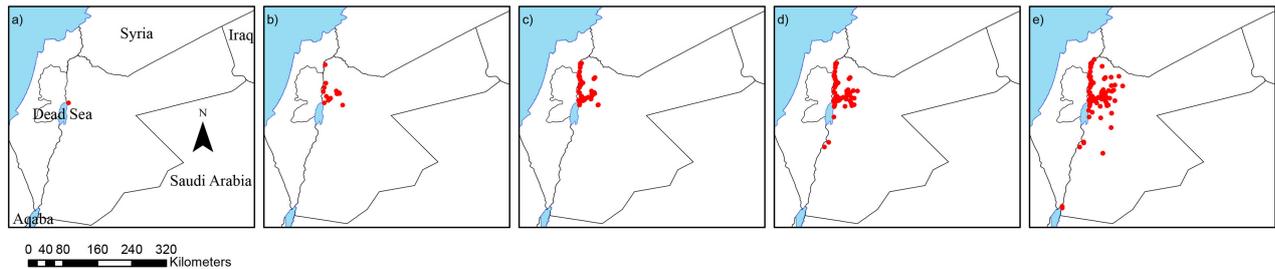


Figure 2. Occurrence records of common mynas in Jordan during the time intervals (a) 2010–2012, (b) 2013–2014, (c) 2015–2016, (d) 2017–2018, (e) 2019–2020.

The percent contribution and permutation importance of each variable is given, in addition to results of the jackknife test (Phillips et al. 2006). Values shown are averages over replicate runs.

Results

The first record of common myna was in 2010 in the Jordan Valley, just north of the Dead Sea (Figure 2a). This is apparently where initial establishment occurred in Jordan. The species expanded westwards around the year 2013 (Figure 2b, c). Indications of another major wave of expansion in Jordan was observed after 2016, perhaps after an increase in the local myna's population sizes in the rural and urban areas of the northwestern highlands and adjacent, low-lying Jordan Valley, as indicated by a rise of occurrences in these areas. The northwestern parts of Jordan are highly urbanized and intensive farming is widespread in some landscapes. A rapid spread which may have been due to jump dispersals (long distance dispersals over substantial distances, Wilson et al. 2009) was also observed in recent years to sites which were separated by 20–60 km from the nearest previously colonized area (Figure 2b–e). The recent expansion across inhospitable environment (where mynas were absent) to distant sites was evident along desert highways in towns or facilities where mynas appeared to find suitable conditions. By early 2020, the species dispersed into areas that range in altitude from 400 below sea level to 1050 above sea level.

The Maxent model (Figure 3) shows the current potential distribution of the common myna in Jordan, based on estimated probabilities of suitable environmental conditions. The model has a high accuracy and low deviation among the replicates as indicated by an AUC of 0.921 ± 0.023 . Human modification of terrestrial lands has the highest contribution and permutation values, and according to the Jackknife test (Figure 4) the highest gain when used in isolation, indicating it is the most influential driver of mynas predicted distribution (Table 1). Climatic variables had also some effect, but appear to be smaller in comparison to the anthropogenic factors.

Discussion

Chronology of spread

The first recorded occurrence of common myna in Jordan was north of the Dead Sea in the eastern Jordan Valley which coincided with the expansion

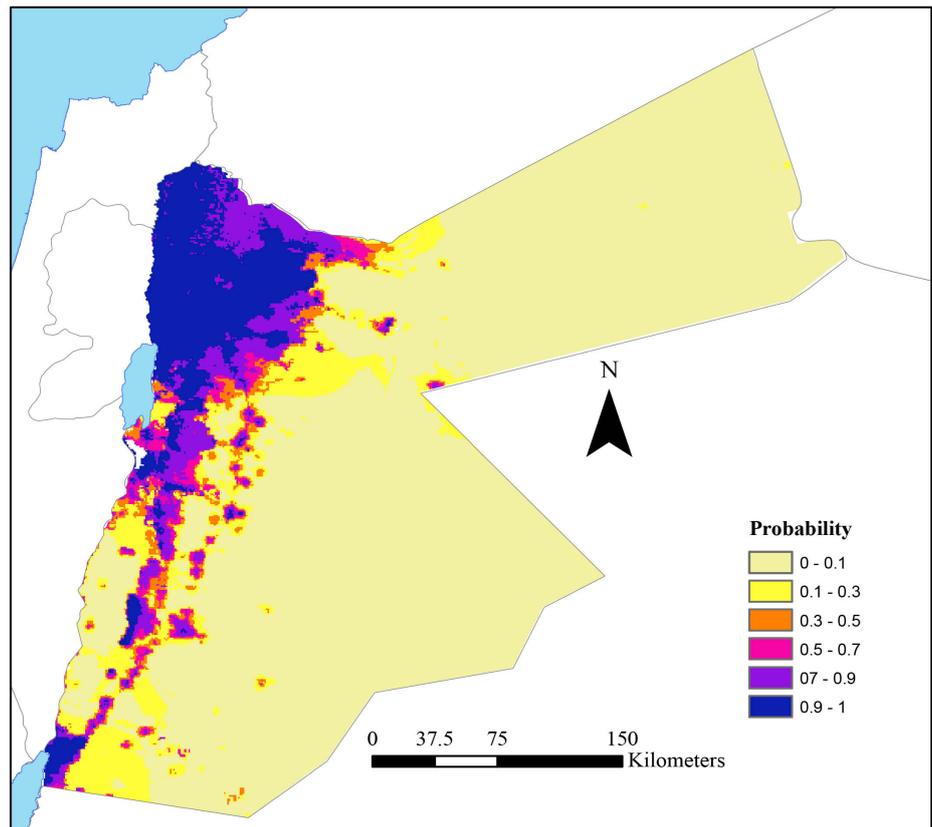


Figure 3. A map of average probabilities for suitable areas for current and potential common myna presence based on the MaxEnt model that included occurrence data from the region and the native range. Legend contains color code representation of probabilities.

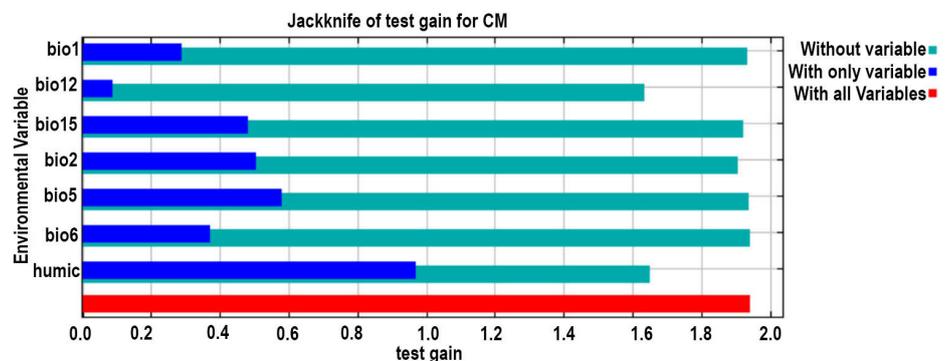


Figure 4. The average results over ten replicate runs of the jackknife test of variable importance (see variables in results/text). The environmental variable with highest gain when used in isolation is human modification of terrestrial lands (humlc; see Table 1 for meaning of abbreviations).

of the species into the western part of the Jordan Valley in Israel and Palestinian territories (PNA) (Holzapfel et al. 2006; Cohen and Dor 2019). Similarly, the myna recently expanded into the port city of Aqaba following the expansion of the species in Israel to Eilat. The few reports of isolated single and possibly locally introduced or escaped individuals did not lead to local establishment according to the authors' knowledge. The spatial and temporal patterns of occurrences are strong evidence of secondary expansion from Israel and Palestine (PNA). The distribution model also indicates potential spread from Saudi-Arabia into eastern and southern

Jordan (or vice versa). The common myna has been introduced and is established in many parts of Saudi Arabia since several decades (Holzapfel et al. 2006), but as yet has not been recorded in the northern region close to Jordan (Alshamlh *in litt.*).

The invasion theory states that the process leading to expansion includes a repeating series of events or phases: introduction, establishment, population growth, and then expansion into further areas, with each phase depending on and influenced in terms of time and magnitude by the previous one (Duncan et al. 2003). Time lags of one or more years between phases (Grarock et al. 2013) are frequent and can be explained by the time it takes (a) for the species to get established after introduction and (b) for the population to grow after its establishment, thus becoming a source of dispersing individuals that form the new front of expansion. The spread of common myna into the interior parts of Jordan appears to follow this pattern. After the initial spread from the Jordan Valley towards Amman, it took only two years until the wave of expansion advanced into further urban and rural areas.

Environmental drivers

The current distribution and spread of the common myna in Jordan was predicted in the distribution model mainly in transformed landscapes. Common mynas were observed in built and intensively cultivated landscapes, frequenting gas stations, parking lots, road sides, marginal or abandoned land in cities, irrigated grass lawns, edges of fields, and other open spaces where it usually feeds on arthropods and scavenges on food waste of humans. Nest sites included crevices in buildings, outdoor lamps, concrete poles, and weep holes in bridges and supporting walls. Common mynas are generally considered commensals of humans and their distribution is known to be influenced by anthropogenic factors in its non-native range (Holzapfel et al. 2006; Peacock et al. 2007; Grarock et al. 2014; Hart et al. 2020). Sol et al. (2012) found that common mynas have behavioral adaptations that facilitate survival in urbanized environments avoided by most native species, such as the tendency to be opportunistic foragers. Three climatic variables in our study had at least 10% contribution or permutation importance in the model. Higher minimum temperatures, moderately high maximum temperatures, and small diurnal ranges in temperature increase probability of occurrence. Low minimum temperature during winter may thus limit common myna's establishment in Jordan above 1200 m a.s.l. and the preferences for higher minimum temperatures may also be the reason for its unsuccessful establishment in the cooler temperate climates of Europe and Australia (Martin 1996; Holzapfel et al. 2006). According to our observations, the common myna seems to be most frequent in the Jordan Valley, a low-lying agricultural area with many villages and towns and a sub-tropical climate (Waitzbauer and Petutschnig 2004), most similar to conditions found in its

native range in southern Asia. This area was considered a national “hotspot” for the establishment of several exotic animal species (Khoury et al. 2012). Nevertheless, the potential effects of climatic variables should be examined with caution when attempting to identify proximal / local drivers of spread in non-native ranges. The common myna is known to have a relatively broad climatic tolerance both in its native and non-native ranges (Feare and Craig 1999; Peacock et al. 2007; Cohen et al. 2019), partly because urban and some rural habitats offer a range of suitable microclimates and resources similar to the sub-tropical and tropical climates of the original native range (Martin 1996; Holzapfel et al. 2006). Conditions in urban areas provide microclimates and the opportunity of evading the effects of extreme cold or hot and dry weather conditions (Pell and Tiedemann 1997), in addition to other advantages such as food availability for the opportunistic omnivorous mynas (Sol et al. 2012) and lack of avian predators (Møller and Ibáñez-Álamo 2012). A preference for regions with higher precipitation can be compensated for in the arid parts of the non-native range by the presence of water and irrigation in artificial habitats.

Predicted current distribution and potential for further spread

The Maxent model predicts widespread distribution in the western parts of Jordan, which is extensively urbanized and transformed by farming. This area includes Mediterranean-type landscapes ranging from open evergreen woodland to Batha semi-steppe of the highlands and higher rift margins, and semi-arid to arid steppes, in addition to the subtropical, low-lying landscape of the Jordan Valley, much of which was transformed to farmland (Albert et al. 2004). As expected (and discussed in the last section), the common myna’s widespread occurrences demonstrates a broad tolerance to the range of bioclimatic variation due to human factors (c.f. Holzapfel et al. 2006). The myna is unlikely to occur or expand in the vast, relatively undisturbed and non-urbanized desert of eastern and southern Jordan, or the in the steppes of the highlands above 1200 m a.s.l. except for local establishment events in towns and military facilities that are located along main roads and highways. Common mynas are known to exist in semi-arid to arid areas both in their native range (Martin et al. 2018) and in non-native desert areas of the Middle East (Jennings 2010) as long as suitable conditions exist. The appearance and establishment of breeding pairs was recorded in Jordan at distances of 20–60 km in towns or facilities along desert highways, possibly as a result of jump dispersals, and suggesting the ability to disperse fairly long distances over inhospitable environments. Adult common myna pairs are usually known to have a sedentary nature with movements that are limited to a few kilometers between the roost and feeding sites (Feare and Craig 1999), but mynas are able to travel longer distances in one jump. Displaced adult common mynas were recorded covering distances up to 40 km while homing, and mynas were observed

dispersing over the sea between islands 100 km apart (Peneaux and Griffin 2015). Expansion waves usually have a gradual spatial pattern away from a core area, but individuals at the wave front disperse faster, are more exploratory (Burstal et al. 2020) and may have the ability or tendency to carry out long distance jumps to favorable habitats, thus supporting the invasive capacity of the species. Studies on common mynas have revealed individual variation in morphological, dispersal-relevant traits that are significantly correlated with distance from the range core (Berthouly-Salazar et al. 2012; Ewart et al. 2019; and Phillips et al. 2008; Phair et al. 2018, for other invasive species). A possible explanation for the long-distance dispersals within Jordan is the existence of a genetically-based variation in dispersal behavior or abilities among individuals. This can be expected in Jordan even during the early stages of invasion due to secondary expansion and continuous immigration of mynas from neighboring countries, without the founder effects expected in local introductions (c.f. Ewart et al. 2019).

The common myna can be currently categorized in Jordan as a fully invasive species, necessitating control of spread and/or mitigation of negative effects. This categorization is based on Blackburn et al. (2011) and our data showing that individuals are dispersing, surviving and reproducing at multiple sites across a spectrum of habitats and extent of occurrence. Specific knowledge about the local spread and impacts of alien, invasive species is pivotal to improving prevention, control and risk assessment tools (Peacock et al. 2007; Seebens et al. 2018; Sofaer et al. 2019; Blanvillain et al. 2020). The current predicted distribution map could be used to prioritize mitigation or control measures in selected areas such as nature reserves, areas with high biodiversity or that are important for rare and restricted cavity-nesting birds, and where mynas could cause a risk (e.g. airports) and considerable damage to crops such as fruit orchards. According to the authors' knowledge, Nature Reserves in Jordan are not yet affected by the common myna. However, the predicted potential distribution range does include protected areas that are located close to the Dead Sea (e.g. Fifa and Mujib Nature Reserves), and in the northwestern parts of Jordan, in addition to the Azraq wetland Reserve in eastern Jordan. Studies carried out in Australia and South Africa strongly indicate that urbanization at the borders of nature reserves and the establishment of infrastructure within the protected areas increases their vulnerability to invasion (Pell and Tiedemann 1997; van Rensburg et al. 2009). Common mynas have a higher breeding success compared to native species in urbanized areas possibly due to their competitive abilities when it comes to occupying nesting cavities (Lermite et al. 2021). In Jordan common mynas have been observed using only man-made structures for nesting, often used by only one native species (The House Sparrow *Passer domesticus*), but at high densities they may compete for cavities used by various native species (Charter et al.

2016), some of which are rare or have a restricted range in Jordan. This is most likely in the Jordan Valley and its margins where remnant strips or patches of natural habitats, important for native cavity nesting species, are often surrounded by agricultural landscapes or are close to human settlements (Khoury and Korner 2018). Further studies about the myna's impacts on native birds and on agriculture (e.g. fruit production) are thus required before any control measures are planned. The impacts of Common myna on agriculture and biodiversity is well established elsewhere (Lowe et al. 2000; Hart et al. 2020), and evidence for these impacts is being collected in Jordan by the authors in cooperation with Jordan BirdWatch Association. Results will be communicated with the authorities responsible for managing reserves and biodiversity in an attempt to inform about factors increasing the vulnerability of protected areas to invasion and initiate locally suitable control measures. Moreover, the cross-border (secondary) expansion and continuous influx into Jordan probably contribute to population growth and expansion, demonstrating the importance of coordinated action across sectors at the regional level and among neighboring countries (e.g. Epanchin-Niell et al. 2010).

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