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Article

The House Crow (*Corvus splendens*): A Threat to New Zealand?

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Abstract: The house crow (*Corvus splendens*), a native of the Indian subcontinent, has shown a rapid expansion of habitat range across Eastern Africa, the Arabian Peninsula, Europe and Asia. It is an adaptable, gregarious commensal bird which is regarded globally as an important pest species due to its impacts on livestock, agricultural and horticultural crops and indigenous fauna and as a fecal contaminator of human environments and water resources. Two Maxent (v3.3.3k) models (A) with presence data in Australia and (B) with simulated entry data locations in New Zealand) and a third ArcGIS model (C) with environmental and social layers) are used to determine an overall suitability index and establish a niche-based model of the potential spatial distribution for *C. splendens* within New Zealand. The results show that New Zealand, particularly the northern regions of North Island, has suitable environments for the establishment of the house crow. In order of suitability Model B showed highest potential land area suitability (31.84%) followed by Model A (13.79%) and Model C (10.89%). The potential for further expansion of this bird's invasive range is high and, if New Zealand is invaded, impacts are likely to be significant.

Keywords: New Zealand; house crow; modeling; spread

1. Introduction

As an island nation, New Zealand is subject to and defined by a range of economic, health and environmental characteristics. The primary industries, such as agriculture, horticulture and forestry, still form the cornerstone of the New Zealand economy [1,2] and protection of these from the impacts of invasive species is fundamental to the maintenance of the country's economic and social wellbeing. Environmentally, as with other similar fragile island ecosystems such as Hawaii, New Zealand possesses a range of unique flora and fauna, which have experienced significantly negative impact by the human mediated introduction of predatory and browsing mammals [3,4]. In addition, protection of human and animal health from diseases transmitted by invasive species is fundamental to New Zealand's social health [5]. Prevention of entry of future invasive species, particularly those of high potential impact, is vital for the protection of all aspects of the environmental and social welfare of New Zealand.

The house crow (*Corvus splendens*), a native of the Indian subcontinent, has shown a rapid expansion of habitat range across Europe, the Middle East, Eastern Africa, the Indian Ocean Islands, East Asia and Australia and the Americas [6,7]. Often mis-identified as other crow species, the sexes are phenotypically similar, although the males may be slightly larger in size, and they have a characteristic smoky-grey collar [7]. It is an adaptable, gregarious, noisy, commensal bird, which only lives in close association with humans in urban/semi-urban areas and is not known to live independently from humans [8,9]. They are also known to be associated with coastal human inhabited areas [8] and, although foraging independently and in small groups during the day, they do exhibit communal roosting at night [10,11].

Despite originating in the Indian subcontinent, the house crow shows ecological plasticity by its wide temperature tolerance which has assisted its spread across tropical, subtropical and even temperate areas. In the Hoek van Holland a breeding colony is known to have survived winter temperatures as low as −8 °C [9].

C. splendens is a general, opportunistic, omnivorous feeder which survives by scavenging on human waste, thieving human food, raiding food crops and damaging livestock [8,12,13]. It is a serious agricultural pest feeding on a range of crops, particularly maize, at different growth stages [12,14–16] and has been observed attacking and sometimes killing livestock and poultry [17]. It is detrimental to indigenous bird species via predation or competitive displacement by attacking and mobbing birds and destroying eggs and nests [17–19]. They have also been known to attack people [20,21] and are a significant human and animal health risk as a fecal contaminator of human environments and water sources [13,18,22]. These crows have also been identified as carriers of human enteric disease organisms such as *Salmonella* spp., *Shigella* serotypes, *Proteus* spp., *Vibrioaceae* spp., *Pseudomonas* spp., *Escherichia coli*, *Campylobacter* spp. [13,23,24], Newcastle disease [25,26] and the potential for spread of bird flu [27]. This bird is globally regarded as an important pest species with significant potential for further global invasion [9,13,21]. Using a risk analysis model, the Vertebrate Pest Committee (VPC) [18] in Australia has classified the house crow as an extreme threat species while the risk of establishment has been determined as a serious risk in Australia [28]. It is regarded as a significant threat to New Zealand [29,30]. However, currently New Zealand does not recognize this species as a potential significant risk and, as such, is not included in any pest management protocol or surveillance strategy.

Human health is a significant factor in the preservation and underpinning of a civil society [31]. The house crow is a known carrier of a range of pathogenic organisms and due to its propensity to solely associate with human populations there is a significant risk of disease transmission by these birds [13,22].

C. splendens has been spread via a number of pathways, mostly human mediated. Introduction to Aden and Zanzibar appears to have been in the late 1800s by the British to assist with refuse disposal [6,20,32] and perhaps later by ships from India [19]. Introductions as biocontrol agents occurred in Klang on the Malaysian Peninsula for caterpillar control [21] and livestock ticks in the Oman [20]. Later introductions of this species, including that in the Netherlands, have in most cases been accidental via ship-assisted transfer [33–35] from the Indian Subcontinent and/or other locations with large introduced house crow populations, such as Aden and Suez [6] or potentially as escaped cage birds [35,36]. Range expansion from these initial introduction locations is thought to have occurred by natural dispersal, such as spread to Singapore from the Malaysian Peninsula [36] and from Dar-es-Salaam to the Tanzanian interior [6].

While sometimes used interchangeably, ecological niche modelling (ENM) and species distribution modelling (SDM) as defined by Owens *et al.* [37] provides a combination of convenient approaches to predict in different spaces (for ENM) or characterize within existing space (for SDM) the potential distribution of species using occurrences or presence data and the conditions of the area where it is found [38,39]. These conditions or predictors are normally environmental variables, abiotic factors and even socio-economic conditions that are important for the species [40–42]. ENM and SDM are being used in a wide variety of domains such as threatened species mapping [43–46], disease vector mapping such as mosquitoes carrying dengue and malaria [47] and invasive species potential distribution [48,49]. ENM has already been used by Nyári *et al.* [9] to predict the global potential invasive range of the house crow. In this paper, the term ENM is used to cover the intent of both definitions.

Due to the need to address the vulnerability of New Zealand as an isolated island nation to the impacts of invasive species, the aim of this paper is to determine the potential suitable range and likely location of establishment of *C. splendens* in New Zealand. This study aims to compare the results of three modelling approaches for the determination of the areas of New Zealand which are potentially favorable for the establishment of the house crow.

2. Results

2.1. Suitability Mapping

The resulting suitability map for Model A is shown in Figure 1. Auckland, Northland and Wellington regions in North Island, New Zealand show the highest level of suitability based on results of the Maxent software, while much of the coastline of North Island and the Nelson, Marlborough and northern Canterbury regions of South Island show moderate suitability. Coastal areas of Australia and New Caledonia also show moderate to high suitability for this species.

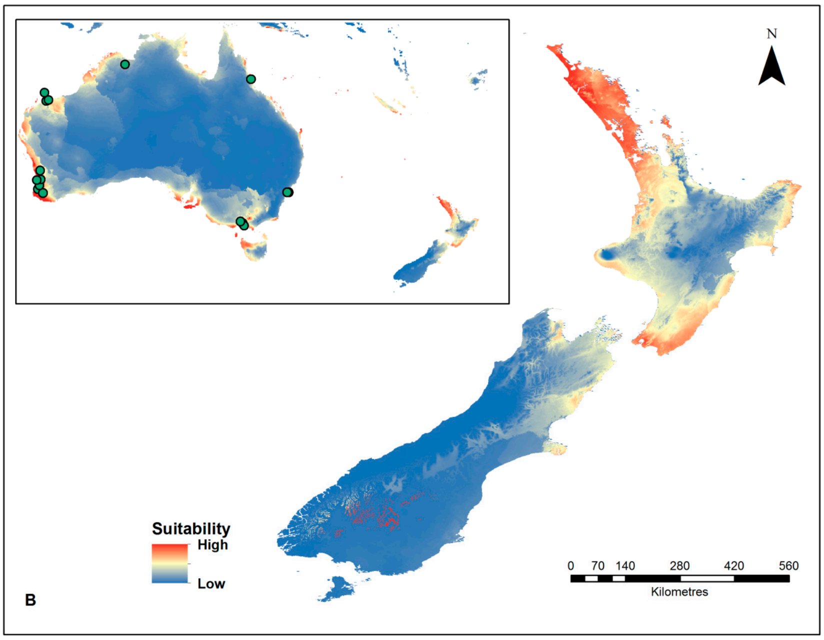

Figure 1. Suitability map (Model A) using presence data from Australian occurrence sites.

2.2. Importance of Environmental Variables

The jack-knife test of variable importance, as shown by the regularized training gain in Figure 2, showed that the environmental variable resulting in the first, second and third highest gains when used solely and when omitted are bio 19 (precipitation of coldest quarter), bio 7 (temperature annual range) and bio 2 (mean diurnal temperature range).

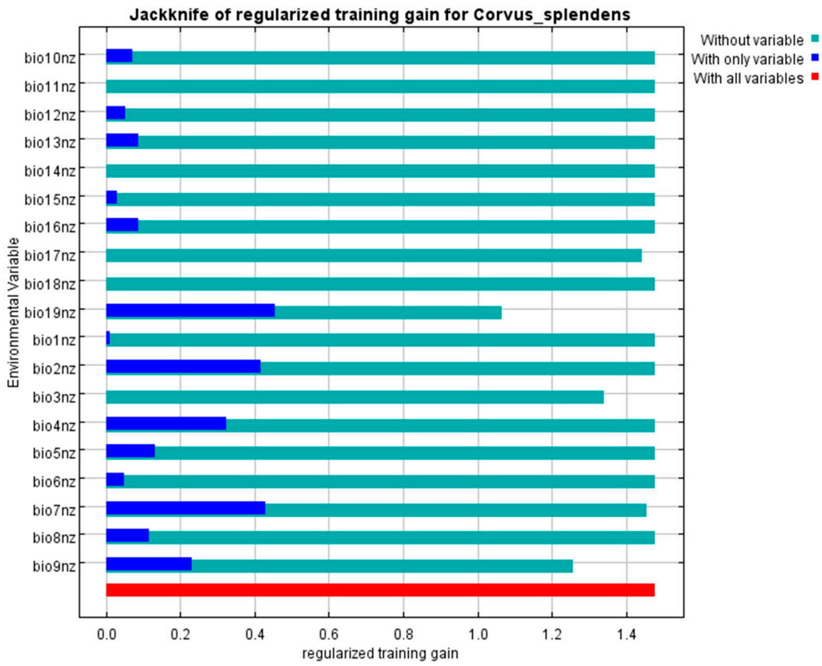

Figure 2. Results showing the importance of environmental layers in the Maxent model (model variables are listed in Table 1).

Table 1. Comparison of models presence/absence prediction for house crow in New Zealand (50% suitability threshold).

Presence/Absence	Model A	Model B	Model C
Presence	13.79%	31.84%	10.89%
Absence	86.21%	68.16%	89.11%

2.3. Scenario Based Models of Habitat Suitability

The scenario based model (Model B) used the major ports as the most likely point of entry to New Zealand and are the points of occurrence for the model. Results of the model (Figure 3) showed the highest levels and greatest areas of suitability in the regions of Northland, Auckland, northern Waikato, coastal areas of Wellington, Manawatu and Taranaki in North Island and Marlborough, Canterbury, Otago and Southland coastlines on the east coast of South Island.

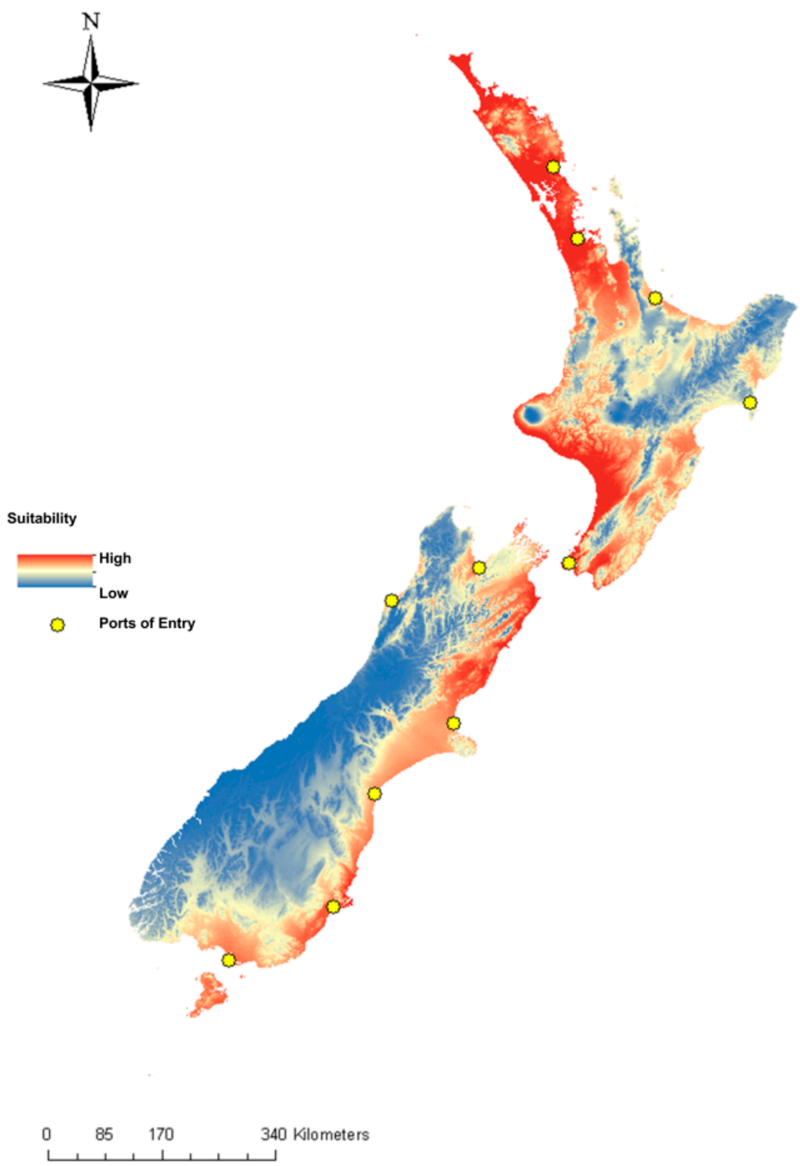

Figure 3. Results of Model B showing the suitability of areas using ports of entry for presence sites modeled using Maxent.

2.4. Raster Mapping of Suitability

Raster map A (increasing elevation from categories 1 to 5) (Figure 4a) shows that the majority of North Island and the coastal regions and plains of South Island, particularly the Canterbury Plains (mid-Central) and the West Coast, as the highest suitability in geographic elevation for the potential habitation by the house crow in New Zealand (dark red areas). High altitude areas such as the Southern Alps are least suitable (Blue areas).

The map for annual temperature (Figure 4b) (increasing temperature from category 1 to 5) shows the largest areas for the most suitable environmental temperature ranges for this species are the Northland, Auckland, Northern Waikato and East Cape. High altitude low temperature environments show least suitability.

Land cover suitability map (Figure 4c) (increasing suitability of land cover from 1 to 5) showed the major cities as providing the most suitable land cover for habitation by the house crow.

The raster map for population (Figure 4d) (increasing population form blue to red) showed highest populations around Whangarei, Auckland, Tauranga, Nelson and Christchurch.

The result of the additive model for the combined environmental factors of elevation, temperature, land cover and population (Figure 4e) show the regions of New Zealand showing greatest area of suitability for the house crow are Northland, Auckland, northern Waikato, coastal Bay of Plenty and Taranaki, southern Manawatu, Hawke's Bay and Wellington in North Island and scattered areas of the eastern coastline of the South Island.

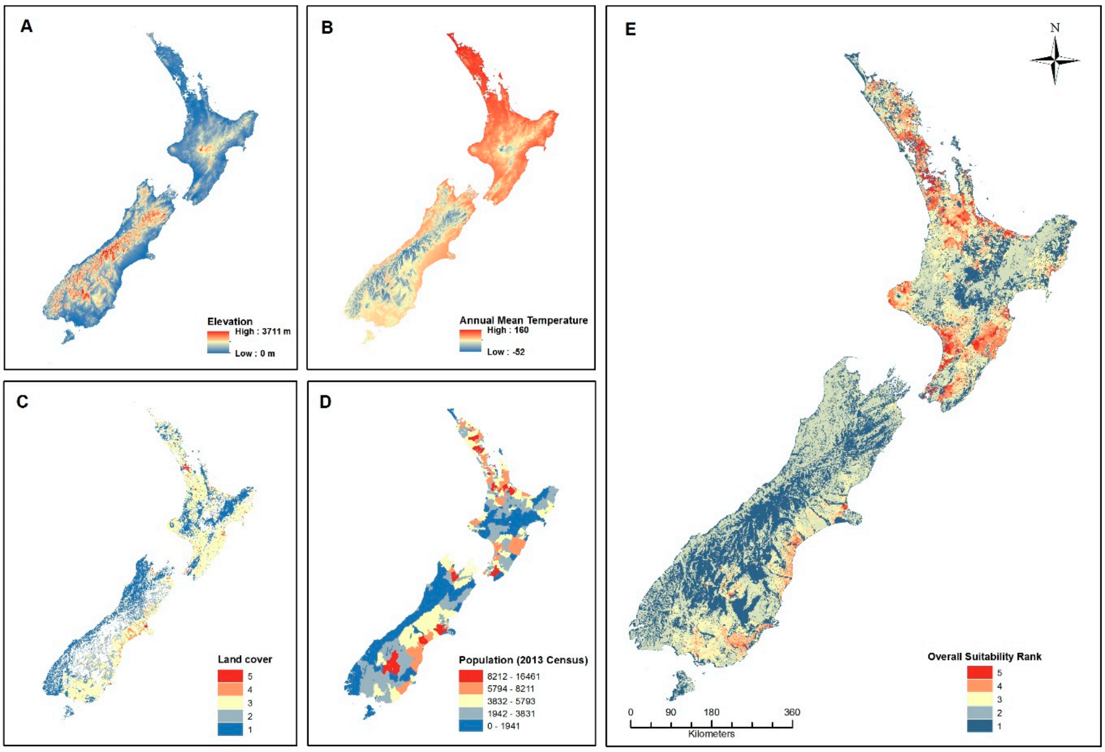

Figure 4. Raster maps (Model C) for the suitability of the environmental factors of elevation (**a**); temperature (**b**), land cover (**c**) and population (**d**) for the generation of the overall map (**e**) for the potential suitable habitat for the house crow in New Zealand.

2.5. Potential Suitable Land Area

The percentage of total land area in New Zealand that is predicted by the three models as potentially suitable for the house crow, using a threshold of 50% for presence/absence, is shown in Table 1. The area predicted for suitability ranging from highest to lowest is Model B (31.84%), Model A (13.79%) and Model C (10.89%).

3. Discussion

This study shows that use of the Maxent model and the reported locations of the house crow in Australia have allowed the prediction of the range of this bird within New Zealand (Figure 1). This use of ecological niche modeling technique is similar to other studies for predicting the potential geographic distribution of a range of plant and animal invasive species such as mammals [50], birds [9,51], plants [52,53], amphibians and reptiles [54,55], insects [56] and fish [57]. Invasive bird species have been shown to have a higher success of establishment and spread in novel areas if the climate match is similar to that of the native range [58–61]. Northland, Auckland and Wellington regions of North Island and coastal areas of the South Island are predicted to have the higher overall suitability for this bird. Temperature seasonality and temperature range (Figure 2) were seen to have the greatest contributing influence on predicted range. *C. splendens* is known to exhibit a wide temperature tolerance from tropic/subtropical climates to temperate climates as found in the Hoek van Holland, where it has been recorded as surviving winter temperatures as low as −8 °C [9]. It has also been reported to inhabit elevations up to 2100 m in its native range [7]. Due to this bird's wide temperature tolerance it is suggested that, if introduced, *C. splendens* has is highly likely to be able to inhabit large areas of New Zealand, particularly North Island. These prediction are also supported by the Raster maps for the suitability of environmental factors of elevation (Figure 4A), temperature range (Figure 2, bio 2 and 7, Figure 4B) and precipitation in annual coldest quarter (Figure 2, bio 19) and temperature (Figure 4B).

Nyári *et al.* [9] mapped the global invasive potential of the house crow using GARP modelling techniques. Although difficult to accurately determine, there was indication from this model that New Zealand was within the potential future range of the house crow using this methodology. The authors also highlighted that, as this species is known to be found only in association with humans, the model predicted that spread would be affiliated with human habitation such as shown in the Arabian Peninsula [9]. Similar predictions were found in our Raster models where land cover (Figure 3C) and population (Figure 3D) were added to the model. Locations around areas of high human habitation; Whangarei, Auckland, Tauranga, Nelson and Christchurch, were of high suitability. Jeschke and Strayer, [62] determined across a range of vertebrate species, that the success of introduction, establishment and spread of an invasive species was significantly influenced by affiliation with humans, while land disturbance and urban affiliation have been factors in the spread of invasive bird species such as the house crow [8,9] and the Common Myna [60,63]. It is, therefore expected that in New Zealand the house crow may potentially establish in these areas of high population, particularly in the North Island.

C. splendens has been regularly recorded on international shipping in Australia [64]. Although natural dispersal has been indicated in previous accounts of the spread of this species [36,65], the natural dispersal of birds from Australia to New Zealand is not seen as a potential risk as crows only range up to 15–20 km [17]. The pet trade is a potential means of dispersal of this species as listings for sales can be readily found on the web [66]. However, the extent of this trading is not known. Although the house crow has been introduced deliberately to novel areas for a number of reasons [6,20], the predominant means of long-distance spread is via shipping [19,33–35]. It can be assumed that, transport has been either as a stowaway on vessels or escape of caged pet birds, although there are no known instances of the latter to date [29]. As such, shipping ports can be regarded as significant risk locations for potential introduction of the species to New Zealand, particularly in view of the rapid expansion of the species range presently taking place in south East Asia [6]. In combination with environmental suitability it is clear that the ports of Auckland and Whangarei are at highest risk within New Zealand (Figure 3). A large proportion of New Zealand imports via shipping originate from areas such as Malaysia, Singapore, United Arab Emirates and Australia [67], which have known established populations of the house crow, therefore, indicating that shipping traffic from these countries will be of high risk of potential invasion of *C. splendens* to New Zealand. As Whangarei, Tauranga and Auckland ports have the highest proportion by weight [68] and value [67] of all goods imported to New Zealand via shipping, these areas have a high environmental suitability for establishment of *C. splendens,* are areas of high human population and are, therefore, locations that can be confidently identified as potentially high risk ports for entry and establishment of this species into New Zealand.

Comparing the three models using a threshold of 50% for presence/absence and reported as percentage of the total area (Table 1), it would appear that Model A, Maxtent model using presence data from Australia, results in a similar area of potential range compared with Model C. However, the distribution in New Zealand varies with Model C showing a higher likelihood of suitability in east coast South Island compared with Model A. This is due to the constraints of the geographical location of the presence data in Australia in Model A and is, therefore, suggested that this model has underestimated the potential distribution of the house crow in New Zealand. A comparison of Models B (Figure 3) and C (Figure 4E) indicate similar regions of suitability within New Zealand, although the potential land area is markedly higher in Model B compared with Model C (Table 1). It is suggested that, due to the known environmental flexibility of this species, that the summative Model C Map E is a conservative prediction of the potential distribution of the house crow in New Zealand under current conditions. The predicted range resulting from Model B may be a more realistic pattern, particularly under the influence of climate change.

The models in the current study predict New Zealand is suitable for the invasion of the house crow and it can be assumed that, due to the island's vulnerability to invasive species, similar significant impacts would be experienced within New Zealand.

Australia recognizes this bird as an "*Extreme*" risk [18] and reports that it is "*regularly detected on international shipping*" [64]. Reporting of this species is encouraged via a national animal pest alert followed by a complete eradication policy [69]. New Zealand, however, does not recognize that this species could be of significant risk to the country let alone include it on any surveillance or pest management policy around the country. Taking into account that *C. splendens* is regarded as a global pest species, the volume of shipping from currently invaded areas such as Singapore, Malaysia and the United Arab Emirates and the environmental niche modeling in this study showing suitability for establishment of this species, it is highly recommended that New Zealand recognize the significance of this bird and include it in future surveillance/control strategies around the country but particularly in the northern regions of North Island.

4. Conclusions

The use of Ecological Niche Modeling in this study has allowed the prediction of the potential suitable range of the house crow in New Zealand. Due to this bird's affiliation with humans, the most likely point of entry and establishment is around the major ports of Whangarai, Auckland and Tauranga. The house crow is regarded as a significant invasive species risk in Australia, however, it is not recognized as such within New Zealand. Due to the close proximity of Australia and the high volume of shipping traffic from currently regions such as Singapore, Malaysia and the United Arab Emirates, it is highly recommended that New Zealand implements surveillance strategies to prevent entry of the house crow to the country.

5. Material and Methods

Maxent software Version 3.3.3k was used for modelling and predicting the potential distribution of the house crow in New Zealand using a region that included its current occurrence in Australia and ArcMap for developing models simulating potential suitability based on probable points of entry into New Zealand as occurrence locations. Maxent produces maps of suitability for different species based on presence data and environmental conditions in areas of known occurrence as determinants of potential distribution in novel areas, *i.e.*, New Zealand [70–72]. The resulting maps show the probability of suitability for each grid cell as a function of the environmental variables. We used the default parameters of Maxent that were shown to have good performance, namely a convergence threshold of 10^{-4} and maximum iteration value of 1000 [71]. The jack-knife procedure built into the software examined the importance of each of the environmental variables by comparing the effects on the model with and without the variable.

Eleven temperature and eight precipitation datasets were obtained from the WorldClim database for the New Zealand region [73]. The available WorldClim data was for monthly temperature and precipitation records from 1950 to 2000 collated from a global network of 4000 climate stations. WorldClim represented biologically relevant parameters derived from annual variation of climatic variables and are commonly used together with occurrence data to map species distribution suitability [74].

Models with different combinations of environmental variables, geographical extent and presence location were developed (Table 2). The first two models, Model A and B employed Maxent to determine the final suitability while Model C used ArcGIS. Model A used instances of reported presence in Australia and data from the Global Biodiversity Information Facility [75] and the environmental layers from Worldclim. Model B is a scenario based model that uses the largest ports of New Zealand as initial occurrence points, representing logical high risk locations of initial invasion pathways, and selected environmental layers based on physiological and environmental factors deemed suitable for house crow population persistence and eventual growth. Model C is a simple additive model that provides an output depicting the overall suitability of areas using the same set of environmental conditions as Model B.

Elevation, temperature, precipitation, land cover and human population were used as environmental layers for Models B and C (Table 2). As temperature and precipitation environmental variables had previously been used for the modeling of potential house crow range by Nyári *et al.* [9] and presence of the bird in its native range has been reported up to elevations of 2100 meters [7], these environmental variables were adopted for this study. The house crow is known to be live in close association with humans in urban/semi-urban areas [8,9], therefore, land cover classifications for New Zealand were selected and ranked (Ranking 5: most suitable—Ranking 1: least suitable) as to preferred habitat for the house crow (Table 3) and areas of high human population were included in the models. The models were then compared using a threshold with raster values less than 50% of the suitability range regarded as absence and values greater than 50% of the suitability range regarded as presence.

Table 2. Environmental variables, geographic extent and presence location used for development of Model A, B and C.

Model	Extent	Presence Data	Environmental Variables
Model A	South Australia and New Zealand	Sourced from GBIF	bio1 = Annual Mean Temperature bio2 = Mean Diurnal Range (Mean of monthly (max temp–min temp)) bio3 = Isothermality (bio2/bio7) (multiplied by 100) bio4 = Temperature Seasonality (standard deviation multiplied by 100) bio5 = Max Temperature of Warmest Month bio6 = Min Temperature of Coldest Month bio7 = Temperature Annual Range (bio5-bio6) bio8 = Mean Temperature of Wettest Quarter bio9 = Mean Temperature of Driest Quarter bio10 = Mean Temperature of Warmest Quarter bio11 = Mean Temperature of Coldest Quarter bio12 = Annual Precipitation bio13 = Precipitation of Wettest Month bio14 = Precipitation of Driest Month bio15 = Precipitation Seasonality (Coefficient of Variation) bio16 = Precipitation of Wettest Quarter bio17 = Precipitation of Driest Quarter bio18 = Precipitation of Warmest Quarter bio19 = Precipitation of Coldest Quarter
Model B	New Zealand	Ports of Entry	(Same as in Model A)
Model C	New Zealand	No presence	Temperature Elevation Land cover Population

Table 3. Land cover rankings generated from WorldClim data for Raster model for the generation of suitable land cover for the house crow in New Zealand.

Land Cover Type	Ranking
Built up areas	5
Dumps	5
Urban areas	5
Transport corridors	4
Major shelter belts	4
Orchards	4
Vineyards	4
Short term rotation cropland	4
High producing grassland	3
Low producing grassland	2
Native forest	1

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Author Contributions

Diane Fraser, Bill Nagle and Colin Ryall conceived the idea for the research, Glenn Aguilar and Diane Fraser designed the modelling experiments; Glenn Aguilar performed the modelling experiments; Glenn Aguilar and Diane Fraser interpreted the data; Diane Fraser wrote the paper and editing of the manuscript was performed by Colin Ryall, Glenn Aguilar, Bill Nagel and Mel Galbraith.

Conflicts of Interest

The authors declare no conflict of interest.

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