EFFECTS OF LANDSCAPE CHANGE AND FACTORS LIKELY TO INFLUENCE FUTURE AVIFAUNA POPULATION CHANGE ON POHNPEI ISLAND

FINAL PROJECT REPORT

Submitted by:
Pablo C. Oleiro (MS Student)
Dylan C. Kesler (Principal Investigator)
Department of Fisheries and Wildlife Sciences
University of Missouri, Columbia, MO 65211

Prepared in partnership with:
Eugene Joseph, Conservation Society of Pohnpei
D. Brian Lynch, College of Micronesia

Describing research conducted under a cooperative agreement between the Pacific Islands Climate Change Cooperative and the Curators of the University of Missouri, Columbia (Agreement No. 12170BG102).

During the period 2011 through 2013

Submitted to:
Dr. Jeff Burgett, Science Coordinator
Pacific Islands Climate Change Cooperative
677 Ala Moana Blvd, Suite 320
Honolulu HI 96813

TABLE OF CONTENTS

PUBLIC SUMMARY

Islands exhibit the planet's most unique flora and fauna, but biodiversity on islands is also vulnerable to the impending forces of global change. The Micronesian high island of Pohnpei exemplifies the diversity of oceanic islands, as it is home to the world lowest montane-cloud forest, vast mangrove forests, and 6 endemic bird species. We conducted a survey to assess the status of Pohnpei's current bird population. We estimated detection rates across elevation zones, habitat-specific occupancy rates for 13 species, and habitat specific densities for 10 species. We coupled results with data from previous surveys to assess the potential impacts of vegetation change on Pohnpei avifauna during the last three decades. We created computer models to estimate total extant populations of 10 species and to simulate the effect of potential future anthropogenic and climate-driven landscape change on Pohnpei avifauna. We used a series of 1,000 simulated possible future conditions that incorporated ranges of expanded and new agricultural plots and secondary vegetation. We also simulated the effects of climate-driven changes to upland vegetation and of sea level rise on mangroves. This work allowed us to identify key forces affecting each bird species, and sea level rise and the associated changes to mangroves were found to most impact 7 of 10 species analyzed. Further, the expansion of anthropogenic vegetation ranked first or second in 5 of the 10 species. Together, results indicated that protection of mangrove systems, and regard for native vegetation in areas near existingsettlements, are valid future courses for conservationists. Because birds can be use as forest-health indicators we believe that special attention should be lent to future forest management plans. Considering that many islands across the Pacific have identical or similar habitats and congeneric bird species, we further believe the tools we developed could be applied to bird conservation elsewhere.

TECHNICAL SUMMARY

Pacific Island Climate Change Cooperative (PICCC) provided funding to conduct an avian survey in the Island of Pohnpei, Federated States of Micronesia, and to model potential impacts of large-scale ecological changes on the island's avifauna. Spatially explicit data from bird surveys conducted in 1983, 1994 and 2012 were used in combination with vegetation information from 1975, 1994 and 2005. Occupancy and density estimates were derived from the 2012 avian survey data. Density models were used in simulations to identify key climate-driven and anthropogenic processes likely to most affect Pohnpei birds in the future. Original research objectives and accomplishments included:

Objective 1. *Conduct a 2012 bird survey for Pohnpei avifauna.*

We surveyed 247 stations on 19 transects between January and March 2012. Each station was surveyed 4 times to satisfy occupancy protocol.

Objective 2. *Use distance sampling technique to determine weather historic declining bird population trends are present, stabilized, or increased.*

Distance measures from past surveys were determined to be biased, so we elected to conduct similar analyses using detection rate evaluations. Results indicted continued declines for most species.

Objective 3. *Evaluate geographic patterns in bird community structure and population density using occupancy modeling.*

Bird community structure and population density were analyzed using both occupancy and distance-based methods. Distance-based methods yielded better resolution, so they are presented herein.

Objective 4. *Combine bird occupancy and density models with island-wide vegetation models to identify areas and habitats of conservation importance.*

Habitats and locations of conservation importance were identified using distance based models, which showed finer resolution than the occupancy models.

Objective 5. *Use results from three decades of bird surveys, occupancy models and vegetation change models to compose predictive models for Pohnpei's avifauna.*

Predictive models were developed using both distance and occupancy models. Distance models showed better resolution and were thus used for subsequent simulations.

Objective 6. *Integrate predictive models into a GIS-based tool that can be used to forecast spatially-explicit population changes of avifauna due to future anthropogenic or climate changes.*

The predictive GIS tool was developed, and integrated into a Microsoft Access database tool, which was used in simulations to evaluate potential relative influence of global change factors.

Objective 7. *Simulate potential future climate change scenarios and evaluate predicted impacts on island avifauna.*

We simulated 1000 potential futures, each with different levels of landscape impacts from sea level rise, climate-driven alterations to upland undisturbed vegetation, anthropogenic expansion of agriculture and secondary vegetation. Simulations were used to evaluate the relative influence of each factor on each of 10 bird species for which density models were developed.

Scientific Contribution

We conducted the most recent and most complete survey of Pohnpei avifauna. Further, we analyzed data using current density and occupancy modeling techniques and results from our work indicated continued and substantial population declines in most of the island's birds. Declines, most often occurred in elevation zones within which substantial anthropogenic impacts have occurred. Survey data were then used to develop occupancy and density models that illustrated differential associations between birds, landscape components, and habitats. Those associations provided insights into which species might be affected by global change forces that alter the island's ecological conditions. By linking density models with the geographic distribution of habitats on Pohnpei, we were then able to evaluate predicted distributions of 10 of the island's native forest bird species, and to derive empirical population estimates for each.

Linked density-habitat models were then used to develop a simulation analyses to assess the potential future effects of global change on each species. Results from simulations of 1,000 potential future scenarios indicated that, although the magnitude and strength differed among species, sea level rise (7 of 10 species), and the expansion of impacted vegetation near current human development (5 of 10 species), are the two factors most likely to substantially impact Pohnpei birds in years to come. And for the same reason, these factors may be key for conservation focus in order to preserve biodiversity on Pohnpei. Furthermore, models developed under the effort described herein are already being employed to assess potential conservation strategies for other US listed species in other regions (e.g. *Todiramphus cinnamominus*).

PURPOSE AND OBJECTIVES

Among the regions of Micronesia, Melanesia and Polynesia there are more than 25,000 islands ranging in size from large islands (> 35,000 km^2) to sandspits, and in elevation from low atolls to high snow-capped volcanic peaks. Unique assemblages of insular biota have been shaped by degree of isolation from other landmasses, and by size and ecological complexity (MacArthur and Wilson 1967, Steadman 2006). The flight and dispersal abilities have permitted birds to reach and colonize the most isolated of islands, and as such the island environments. Making islands environments and their associated avian species assemblages, a unique opportunity to study endemism, biodiversity, ecology and evolution (Whitaker and Fernandez-Palacios 2007).

Most islands have evolved under stable climates buffered by oceanic conditions, and for the same reason their endemic species and systems are considered vulnerable to foreign forces (Loope and Giambelluca 1998). When compared to continental populations of flora and fauna, insular species are extant only in small populations and constrained to discrete ranges, and many have lost their ability to cope with continental predators, pathogens and competitors. These characteristics make island biota susceptible to ecological changes (Steadman 1989), including habitat alterations, invasive species, pollution, human settlements and overexploitation of natural resources (Gaston 2002, Wilson 2002, Blackburn et al. 2004).

Habitat degradation and human-associated processes are considered to be principal causes of wildlife extinctions and population declines (Diamond 1989, Wilson 2002). These effects are especially profound on oceanic islands where human settlement is associated with the introduction of invasive species and with the subsequent changes to undisturbed habitat and local fauna. Island birds, especially endemic species, are going extinct at a rate many times greater than continental species (Temple 1985, Frankham 1998), comprising 90% of the recorded avian extinctions occurring in recent history (Myers 1979, Frankham 1998).

Already affected by anthropogenic processes, islands are considered to be particularly vulnerable to Global Change. Changing climates and anthropogenic forces alter conditions in such a way that there could be detrimental consequences to habitats and fauna (Loope and Giambelluca 1998). Sea level rise, changes in rainfall and drought patterns, and storm frequency and intensity are predicted to greatly impact islands. Climate change and anthropogenic processes are likely to continue modifying habitats, and it is thus expected that insular bird populations will be altered as well (Jankowski et al. 2010).

Global change factors are predicted to impact the island of Pohnpei in Federated States of Micronesia (Australian Bureau of Meteorology and CSIRO 2011). Located in the Caroline archipelago, Pohnpei is the highest (>770 masl) island in the nation (Fig 1.). Pohnpei's topography and climate conditions (> 1,000 cm of annual precipitation) support several types of forests including mangroves and the world lowest cloud forest (Merlin and Raynor 2005). These forests provide habitat for many resident, migrant, and vagrant bird species (Baker 1951, Pratt et al. 1987). Among Pohnpei's 24 forest-dwelling birds 6 species are endemic. Two species (*Rukia longirostra* and *Aplonis pelzeini*) are listed as critically endangered under the U.S. Endangered Species Act, *Aplonis pelzeini* also is listed as critically endangered under the International Union for the Conservation of Nature (IUCN) Red List of Endangered Species (IUCN 2013). In addition IUCN lists *Gallicolumba kubaryi* is listed as vulnerable and four more species are classified as near threatened (Table 2)(ESA; United States of America 1973, IUCN 2013).

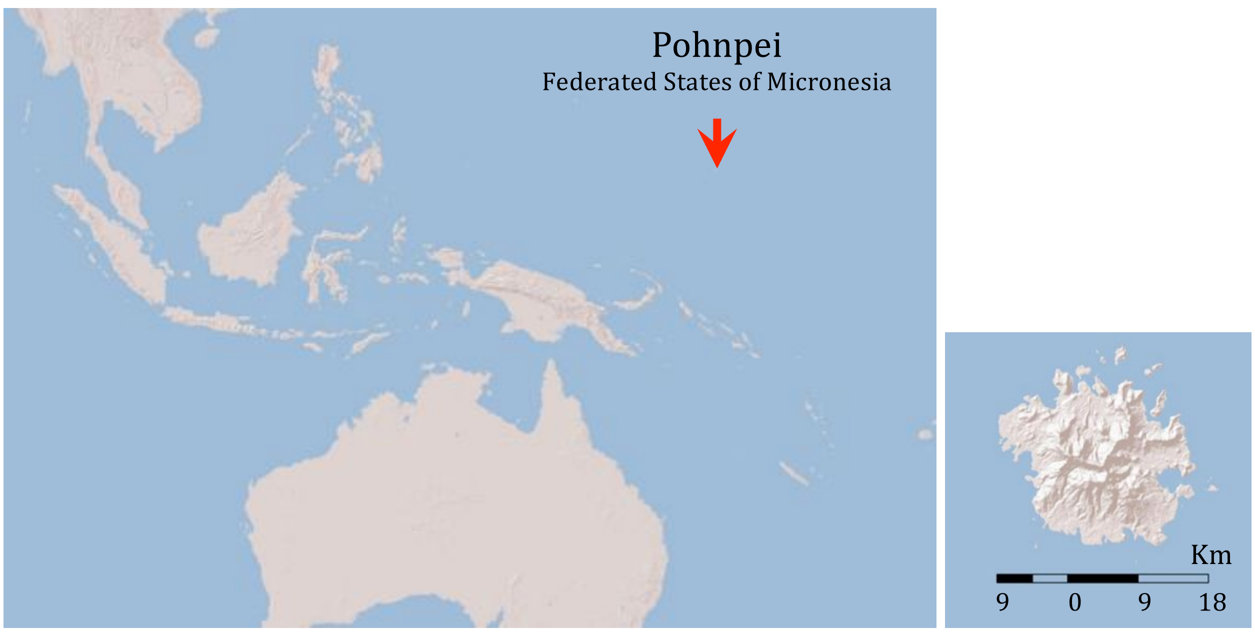


Figure 1. Global locator for Pohnpei Island, Federated States of Micronesia

Anthropogenic processes and Pohnpei

Pohnpei has been affected by anthropogenic factors for centuries. Pohnpei's settlers utilized the island forests since first arrival, building materials and firewood were obtained from mangrove forest, and croplands and housing displaced undisturbed forests in the lowlands (Raynor 1994). Pohnpeian traditional forestry practices and natural resources uses were considered to benefit biodiversity (Brosi et al. 2007), but in recent years living styles have changed and impacts have increased. One of the greatest changes in Pohnpei's landscape documented the loss of 36% of native undisturbed vegetation, apparently to Sakau (*Piper piper)* and other plantation crops (Trustum 1996, Buden 2000, Merlin and Raynor 2005).

Pohnpei's human population increased after 1975 and stabilized in recent years (MacLean et al. 1986, Merlin et al. 1992, Office of Budget, Planning and Statistics 1994, Buden 2000). Simultaneously, Pohnpei residents have been abandoning traditional farming techniques for processed and imported foods (Lee et al. 2001) and for agriculture facilitated by mechanized tools (chainsaws). In some areas, the abandonment of farming has benefitted forests that were allowed to revert to less disturbed states. However, changes in culture regarding sakau use have caused greater impacts. With increased sakau values, sakau plantations were being cultivated at higher elevations and farming thus impacted more undisturbed vegetation (Merlin and Raynor 2005). Further, droughts during the last three decades destroyed family sakau plantations, resulting in the commercialization of the plant by those who managed to maintain production.

Demand for the root beverage also shifted farms to higher elevations where humidity and clouds are constant. Sakau farms are currently found at all elevations, including some of the highest cloud forested ridges (>650 masl). This farming has created gaps and fragmentation in highest forests (Merlin and Raynor 2005, P. Oleiro pers. obs.). Local agencies have invested in conservation solutions, but the underpinning anthropogenic processes are nonetheless likely to continue and possibly increase. As with other Pacific islands, the expansion of roads, trails, and the number of motor vehicles lent more access to previously remote areas of the undisturbed vegetation (Naylor et al. 2002, Merlin and Raynor 2005). Recent observations on Pohnpei verified continued expansion of anthropogenic impacts with new large clearings (Oleiro, per sobs). Other large-scale impacts have also been proposed for Pohnpei and other Micronesian islands, including the development of large resorts golf courses, and reservoirs.

These anthropogenic processes have been considered as possible causes for avian population declines. A comparison between the 1983 and 1994 bird survey results illustrated a striking decrease in the island's avifauna populations, many of which showed a 78% to 80% decline in the overall abundance (Buden 2000). Encounter rates for 14 forest dweller species decreased by more than 50% and detections did not increase for any species. A similar overall decline (68%) was documented in mangrove habitats (Buden 2000). The declines appear to align with the conversion of much of the island's undisturbed forest to anthropogenic habitats during the same time period (Trustum 1996). Buden (2000) speculated that invasive species might also impact bird populations, but he concluded that habitat alterations were more likely to have caused the avifaunal changes.

Climate change and Pohnpei

Ballick (2009) suggest that under previously established criteria (e.g. Myers et al. 2000), the Pohnpei endemic plant community could make the island as one of world's top five conservation biodiversity hotspots. Pohnpei's unique forests support a rich forest avian community with 25% comprised of endemic species (Pratt 1987). However, the great endemism of Pohnpei is also at risk of changing climates and the associated ecological process alterations. Although models are generally course for the Central Pacific, climate projections for the region indicate increased sea levels rise, elevated rainfall amounts in the dry season, decreased rainfall in the wet season, and increased storm frequencies and intensities (Manton et al. 2001, Timm and Diaz 2009, Australian Bureau of Meteorology and CSIRO 2011).

Even though Pohnpei is a high volcanic island with the majority of its habitats well above sea level, sea level rise is nonetheless considered a major threat. Elevated sea levels, combined with an increase in daily and seasonal wave and storm action, have potential to penetrate the island's natural protective barrier reef. The Federated States of Micronesia has predicted sea level rises that are higher (0.39 in per year) than the global average (Australian Bureau of Meteorology and CSIRO 2011). Further, the island is surrounded by an outer reef barrier and fringe reefs that protects > 5,500 hectares of mangrove forest (c.18% of Pohnpei undisturbed forest habitat), which does not grow when exposed to open ocean. When combined with predicted increased storm frequencies and intensities, elevated sea levels may overtop the protecting reef and impact mangroves directly. Several of the island's bird populations appear to be highly dependent on mangrove habitats (Engbring et al. 1990, Buden 2000), and populations of those species would thus likely be affected by changes in sea level and mangrove loss. For example, the endemic *Trichoglosus rubiginosus* is a mangrove associated species and is most likely to be affected.

The island also supports the world's lowest montane cloud forest, galleries forest, palm forest and dwarf forest (Merlin and Raynor 2005). All of the Pohnpei forests evolved under the island's unique precipitation, cloud-moisture content, and temperature patterns. Projections for the region indicates impending changes in that rainfall frequency and intensity (Australian Bureau of Meteorology and CSIRO 2011). Precipitation and droughts patterns will be more likely to be intensified, with the presence of larger number of alternating drought and heavy rain days. With extreme rainfall events, flooding and landslide dangers could also intensify and remove considerable tracks of undisturbed forest. Further, altered periodicity of precipitation could change arthropod phenology and community structure, which has the potential to impact endemic insectivores like *Myiagra pluto*, *Rhipidura kubaryi*, *Rukia longirostra*, *Zosterops cinereus*, *Zosterops semperi* and *Aerodramus vanikorensis* (Şekercioğlu et al. 2012).

With a mean daily variation of <1^0 C, Pohnpei's flora and fauna has evolved under very stable conditions. According to previous publications (Australian Bureau of Meteorology and CSIRO 2011), mean temperature has been increasing and days of intense high temperatures will be more frequent and severe in Pohnpei, and these changes too may affect habitats and Pohnpei birds. Griffiths et al. (2005) proclaimed that increases in mean temperature are predictors of extreme temperature changes. Loope and Giambelluca (1998) describe that frequent extreme weather events have profound effects in tropical forest like those found on Pohnpei. Changes in weather patterns can intensify the expansion of invasive species, earlier colonizers, fire and lower cloud-water content, affecting the canopy and understory forest as well avifauna directly and indirectly (Loope and Giambelluca 1998, Denslow 2003). Tropical birds may be directly affected because their lower basal metabolic rates. Tropical species evolved in regions with little season variation, making them susceptible to extreme weather condition changes (McNab 2009, Şekercioğlu et al. 2012).

Climate and habitat change synergies

The island of Pohnpei is also at risk of synergies between local anthropogenic factors and larger climate-driven changes. The impact on bird populations of anthropogenic development, including urbanization and expanded sakau agriculture, would likely be exaggerated by climate change. Reductions in mangrove forests and lowland forests brought about by sea level rise, may cause people to seek resources from undisturbed vegetation. Roads and settlements, most of which are currently near sea level, may be moved to higher ground. Many staple crops such as swamp taro (*Cyrtosperma merkusii*) depend on fresh water and are thus located in low areas that are susceptible to flooding and sea level rise (Ballick 2009, Spennemann 2009). Thus, forces associated with changing climates might also push agricultural development higher into currently undisturbed forests, and the removal of undisturbed vegetation may exasperate the likelihood of catastrophic landslides.

Previous avian surveys

In 1983 the USFWS conducted a comprehensive assessment of bird populations in the four states of the Federated States of Micronesia; Pohnpei, Yap, Chuuk and Kosrae (Engbring et al.1990).

In 1994 a repeat survey was conducted on Pohnpei following the same general protocols used previously (Buden 2000). Both studies employed multiple observers to record bird observations at stations situated approximately every 200m along transects distributed throughout the island. At each station, observers recorded aural and visual observations of birds during 8-minute observation periods. Engbring et al. (1990) followed variable circular plot methods (Reynolds et al. 1980) determining effective detection distance for each species to estimate bird densities, which were combined with the areas surveyed to develop overall population estimates. Further, Buden (2000) reported results in two elevation zones (above and below 200 meters above sea level) for each species, and compared his records to Engbring et al. (1990). Buden (2000) also reported the mean number forest-dwelling birds detected at each station in six elevation zones and he compared those to the previously survey. Results of that comparison indicated catastrophic population declines in every one of the Pohnpei species surveyed, with a mean decline of >50% in 14 of 29 surveyed species.

Pohnpei undisturbed vegetation is unique, bearing >110 endemic plant species. The island's avifauna evolved in a matrix of island climax forest composed of gallery forest, palm forest and dwarf forest, among others (Raynor1994, Merlin and Raynor 2005). Pohnpei's unique climatic conditions helped to shape habitat configuration and composition, such that the island had large tracts of productive forest. Pohnpei highlands (>200m elevation) are now publicly held, and have been protected by local government and conservation entities (e.g., Conservation Society of Pohnpei, Merlin and Raynor 2005). Lowlands are mostly held in private ownership, or are managed by the community and villages. Habitats on Pohnpei have changed substantially since the first bird surveys (Trustum 1996), with increased anthropogenic incursion, and those alterations may have affected faunal populations (Saunders et al. 1991, Murcia 1995, Watson et al. 2004).

Assessing the impacts of change on Pohnpei avifauna

Impending changes to the Pohnpei landscape have the potential to impact the island's avifauna. We initiated a study to address the lack of information about how local habitat changes and large-scale climate-driven changes might affect bird populations on the island. Further, we aimed to assess the relative influence of multiple factors on bird populations, and to identify which forces are most likely to be effective for future conservation focus. First we assessed contemporary avian populations and compared those with past estimates (Enbring et al. 1990, Buden 2000) to determine whether the previously reported trends continued into the present. Those population trends were then compared with changes in Pohnpei habitats that occurred between 1975 and 2002. We also compared those population changes to alterations in the island's avian habitats.

In a second project phase we used data from our 2012 surreys to develop occupancy and density estimates (Reynolds et al. 1980, MacKenzie 2006) for species for which we possessed enough data (13 and 10 respectively). The models elucidated habitat relationships for each species, which shed light on how habitat changes brought about by anthropogenic activities or by climate change might impact contemporary bird populations on the island. We developed an avian habitat model of Pohnpei, to which we linked the density functions for each species. Those linked models provided a way to make spatially explicit population estimates for ten of the island's birds.

In a third project phase, we developed predictive models to assess the relative influences of anthropogenic and climate mediated changes on Pohnpei avifauna. Our objective was to identify which factors warranted future conservation focus. We considered the influences of agricultural expansion, the establishment of new agriculture plots in remaining undisturbed forest patches, the expansion of secondary vegetation in areas where it already exists, and the establishment of new patches of secondary vegetation in currently undisturbed portions of the island. Climate-driven changes to forests, such as landslides or tree mortality, will likely cause the establishment of secondary vegetation. Finally, we considered the potential impacts of sea level rise, as it may be experienced through the loss of mangrove forests. Bird-habitat relationships, as established through the density functions described above, were used to construct predictive population models for ten of Pohnpei's bird species. To identify the factors most likely to affect the avifauna under a range of potential anthropogenic and climate change futures, we conducted a simulation analysis. Our analysis predicted avian populations under simulated future landscapes with 1,000 combinations of 1) agricultural expansion in existing locations; 2) agricultural development in new areas; 3) sea level rise; 4) drought; 5) changes in the island's precipitation regimes; and 6) combinations of these factors.

These items were briefly described in the proposal submitted to PICCC at the onset of the project with the following set of objectives. Each objective is also followed with commentary about the degree to which it was addressed and/or enhancements that made during the course or our work.

Objective 1. Conduct a 2012 survey of bird populations on Pohnpei.

We conducted 2012 avian surveys on the islands of Pohnpei and Kosrae, and Pohnpei data were fully treated in accordance with objectives stated in our 2010 proposal. Although Kosrae was not originally included in the proposal, funding from PICCC was used to parley support from another sponsor for that work. Kosrae had been surveyed once previously. We did not fully treat Kosrae survey data here, but we hope to obtain additional resources in the future to do so.

Objective 2. Use distance techniques to determine whether Pohnpei bird populations have declined, stabilized, or increased.

We used distance techniques to evaluate population densities during each of three survey periods, but after analyses were complete, results indicated substantial differences in the detection functions during each period (direct comparison made between 2012 and 1994 raw data). In 2012, our survey crews used laser range finders, and we believed that data collected in 1994 without the equipment caused differences that had the potential to substantially bias density estimates, results, and conclusions. Thus, we elected to follow Buden (2000) and compare the rate of bird detections (calls per unit time) across the three survey periods. The rate comparison was completed successfully and is presented herein.

Objective 3. Evaluate geographic patterns in bird community structure and population density using occupancy modeling.

We developed geographic pattern maps based on occupancy modeling, but found that the presence/absence probability surfaces of occupancy models provided substantially less information than geographic pattern maps based on density models. Occupancy models are particularly useful for species that are difficult to detect, which did not characterize many of *the Pohnpei species. In fact, occupancy models converged for only 3 more species than did density models. Thus, we present both occupancy and density models, and we related only density models to geographic structure. Further, density models were used to develop contemporary population estimates for each of the 10 species by applying models to spatially explicit resource distributions.*

Objective 4. Combine bird occupancy models with island-wide vegetation change models to identify areas and habitats of conservation importance.

As with objective 3, we found that density models provided better resolution than occupancy, and that density was a more straight-forward metric than occupancy for identifying effects on bird populations. Density models allowed comparisons of island-wide bird populations after simulated global change. Results of those models are provided below.

Objective 5. Use results from three decades of bird surveys, occupancy models and vegetation change models to compose predictive models for Pohnpei's avifauna.

We present results from the evaluation of how vegetation change across three decades is linked to changes in bird detection rates. Results generally paralleled those of contemporary density models, but they were at a much lower resolution (fewer strong correlations were identified). Thus, predictive models used in simulations were based on density equations derived from our 2012 survey.

Objective 6. Integrate predictive models into a GIS-based tool that can be used to forecast spatially-explicit population changes of avifauna due to future anthropogenic or climate changes.

A GIS-based tool was developed using MS Access and ESRI ArcMap (10.3) to forecast spatially explicit population changes of avifauna under potential future anthropogenic and climate-driven changes. Model development required the finalization of occupancy and density models. Then simulation model validation required much additional work that delayed the final simulation model and simulations required many days because we elected to use model-averaging, which required modeling as many as 18 outcomes for each species, during each of the 1000 considered future scenarios, in each of the 47,000 island cells. Thus, this portion of the project was delayed into Fall 2013. Nonetheless, all results have been compiled and are included below.

Objective 7. Simulate potential future climate change scenarios and evaluate predicted impacts on island avifauna.

Each of the 1000 considered future landscape scenarios were used to predict model-averaged bird populations under those conditions, and results were used to identify climate and anthropogenic factors most likely to affect each species.

ORGANIZATION AND APPROACH

Study Site

Research was conducted on the island of Pohnpei, Federated States of Micronesia (6º52' N, 158º13' E; Fig.1). Pohnpei is circular with an approximate diameter of 20 km circumscribing the highest peak in the Micronesian chain (c.800 m, Engbring et al. 1990). Lowland coastal plateau and mangrove forests surround inner areas of higher elevation. We conducted point transect surveys throughout the island and in all elevation zones. Vegetation on Pohnpei has been summarized elsewhere (Mueller-Dombois and Fosberg 1998, Buden 2000), but in short, early succession and agricultural forest vegetation include lower canopy (2–20 m) hibiscus (*Hibiscus tiliaceus*), banana (*Musa sapientum*), coconut (*Cocos nucifera*), breadfruit (*Artocarpus altilis*), and sakau (*Piper methysticum*). Climax forests have higher canopy (25–30 m) dominated by mango (*Mangifera indica*), dohng (*Campnosperma brevipetiolata*), sadak (*Elaeocarpus carolinensis*), karara (*Myristica insularis*), ais (*Parinari laurina*), and tree ferns (*Cyathea* spp.; Mueller-Dombois and Fosberg 1998, Buden 2000). Mangroves cover approximately 55 km^2 of the island and composed by *Rhizophora apiculata*., *Bruguiera* gymnorrhiza, *Sonneratia alba*, *Xylocarpus granatum* and *Nypa frutycans*. Mangroves almost form a uniform belt around the island, in some cases reaching 2 km wide (Buden 2000, BallicK 2007). Additional characteristics of the island have been described elsewhere (McClean et al. 1998, Buden 2000, Kesler 2002, 2006a, 2006b).

Pohnpei Avian Habitats

We obtained vegetation metrics and classifications from survey records available for the island of Pohnpei. Digital data were obtained from four previous vegetation surveys, which documented the structure of Pohnpei habitats in 1975 (MacLean et al. 1986), 1995 (Newson et al. 2003), 2002 (Newson et al. 2003), and 2005 (USDAFS 2005). Vegetation models from 1975, 1995, and 2002 were derived using similar techniques, whereas the model from 2005 employed a different remote sensing technique. Pohnpei's maps included polygons illustrating vegetation coverages in fourteen different classifications including agroforest, atoll forest, coconut plantation, cropland, grassland or savanna, mangrove, marsh, palm forest, secondary vegetation, swamp forest, undisturbed vegetation, urban and water. These categories represent all habitats present on Pohnpei and described as primary vegetation. Data also included area, perimeter, crown closure (low <30%, 30% < medium < 70%, high < 70%) and tree size categorized by diameter at breast high (DBH: short ≤ 12.5 cm, 12.5 cm ≤medium ≤ 30 cm, tall ≥30 cm). Among the c.3,883 polygons, the mean area and perimeter were c.9.15 hectares and c.1600 m respectively.

We amalgamated vegetation categories from each map into four larger habitat classes that were relevant to bird populations. Habitat classes included undisturbed vegetation, secondary vegetation, mangroves, and agroforest (Figure 2, Table 1). *Undisturbed vegetation* habitats were comprised of merged vegetation polygons of upland forest, palm forest, dwarf forest and atoll forest. *Secondary vegetation* habitat included merged polygons of undisturbed disturbance and anthropogenic habitats including those labeled as secondary vegetation, cropland, grassland or savanna, barren, and urban land. The *mangrove* habitat category included the amalgamation of polygons representing areas with water-obligated vegetation including mangroves and several small patches of inland water (often emergent vegetation), swamp forest, and marsh habitats. The *agroforest* habitat category incorporated polygons of vegetation managed for subsistence and commercialization of staple crops (e.g. banana [*Musa* spp.] and breadfruit [*Artocarpus* spp.]), which were classified as agroforest, plantation forest and coconut plantation. The amalgamation of vegetation polygons was conducted because many of the fourteen primary vegetation types did not appear to represent substantially different habitats for island avifauna. However, the resulting four spatially explicit representations of habitats on Pohnpei have biological relevance to the island's birds. The maps (1975, 1995, 2002, and 2005) of Pohnpei with avian habitat classifications were each composed of c.2,000 polygons (Figure 3).

Bird surveys

Two avian surveys were conducted on Pohnpei prior to our 2012 work. Engbring et al. (1990) conducted the first systematic survey for the Federated States of Micronesia in 1983. Engbring et al. (1990) used variable distance circular plot methods (Reynolds et al. 1980) during 8-minute point counts at each station. The group surveyed 458 stations on 19 transects, using multiple observers (2) at each station. Stations were approximately 200m apart and roughly half survey stations were located above, and half below, 200 m in elevation. Most transects started at high elevation and ended at lower elevations. The group reported avian density and abundance for 6 elevation zones (mangrove, 0-100m, 100-200m, 200-400m, 400-600m and 600-800m), and in 4 Pohnpei municipalities (Sokehs, Uh, Kitti and Madolenihmw). We used data published in the associated report (Engbring et al. 1990) for comparisons.

The second systematic survey was conducted in 1994 (Buden 2000). Buden followed protocols similar to those used by Engbring et al. (1990). Buden (2000) surveyed 303 stations in 19 transects. Buden (2000) did not estimated species density and abundance. He calculated 2 different encounter rates; birds per station at 6 elevation zones and birds per hour above and below 200m, and compared those results to Engbring's survey (Buden 2000). Dr. Buden provided additional information about previous survey and transect locations and data during our 2012 visit to the island (Buden, pers. com).

We conducted surveys of Pohnpei birds in 2012 and compared our observations with those collected previously. We surveyed 247 stations on 19 transects from January to March 2012. Similar to previous studies (Engbring et al. 1990, Buden 2000) we selected transect areas across the whole of the island to obtain an accurate representation of the diverse habitats. Transect routs were set to replicate the approximate travel paths used by surveyors in 1983 and 1994. Along each transect, survey stations were separated by >200 m, which we determined using global positioning systems (GPS; Garmin Ltd., Olathe, Kansas). We surveyed 19 transects across Pohnpei, 4 transects were located in mangrove habitats and 15 were distributed in midland and upland areas. Transect locations included all major undisturbed and anthropogenic habitats on Pohnpei, and were distributed on costal areas, low areas, valleys and high mountain ridges. Transect routs were dictated somewhat by the local topography because of dangerous terrain and impassably dense vegetation. Observations on upland transects depended on favorable weather conditions and accessibility.

Survey protocols were similar to those used previously (Kesler and Haig 2007a). In short, at each survey station we conducted eight minutes variable-distance circular plot point counts surveys (Buckland et al. 1993, Buckland et al. 2001). A single observer recorded the first detection (visual or aural) for each single individual for all species encountered and measured radial distance to the first detection with the aid of a rangefinder (Nikon Rifle Hunter, Nikon Inc., Melville, NY). When topography or vegetation made impossible the use of rangefinders, observer-bird distances were estimated. Observers also recorded start time, date, wind (Beaufort scale, Lusk et al. 2000), rain (no rain, medium rain, heavy rain), and ambient noise (low 1 to 10 high). We also recorded vegetation metrics including forest overstory density (spherical densitometer) and stocking rate (2 factor wedge prism) at each survey station (Lemmon1956, Wensel et al. 1980). Surveys began at sunrise and no surveys were initiated after 11:00 h. To create species detection-history and facilitate the use of occupancy methods, each station was surveyed 4 times. No station was surveyed more than once on any given day. To hone species identification and standardize protocols and techniques, mainland observers spent one week training and working with colleagues from Conservation Society of Pohnpei, prior to the onset of surveys. Teams comprised of Pohnpei residents and mainland surveyors were present for all surveys.

Avian habitat model

We developed a spatially explicit model of avian habitats on Pohnpei. Using ArcGIS (ESRI 2011) we constructed a spatial representation of Ponhpei composed of cells (hexagons) with the same area (0.786 ha) as was assessed for each avian survey station (based on circle around stations with 50 m radius). Each hexagonal cell (hereafter "cell") was assigned a unique identification number and vegetation metrics were calculated. For each cell we assessed percentage of habitat types within, number of habitat patches (PN) and the length of habitat edge (LNEdge) along patch boundaries. The process was applied to each of the four vegetation models. The 2005 Pohnpei habitat map included 46,982 cells, each with a mean of 0.12 (0.26 SD) ha agroforest, 0.40 (0.35 SD) ha undisturbed vegetation, 0.11 (0.22 SD) ha secondary vegetation, and 0.154 (0.30 SD) ha mangrove forest. Additionally cells had a mean of 1.44 (0.62SD) habitat patches within, and 17 m of habitat edge.

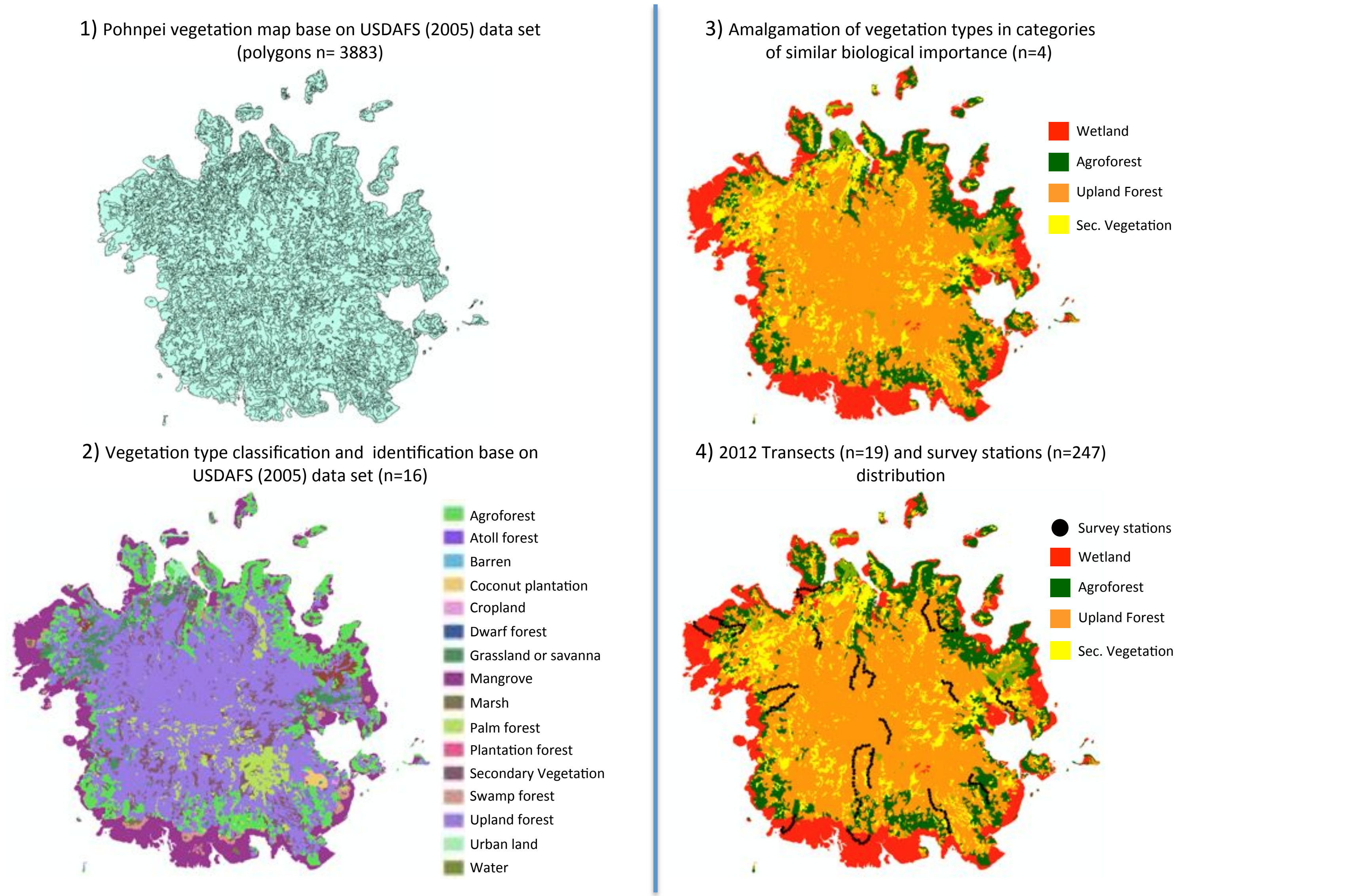


Figure 2. USDA Forest Service Data Set (2005) for Pohnpei. Amalgamation of 16 vegetation types into 4 avian habitat categories with biological relevance to the 2012 avian survey (Upland, Mangrove, Secondary Vegetation and Agroforest).

Table 1. Biologically relevant variables used to model the relationship between avian occupancy and density on the island of Pohnpei, Federated States of Micronesia. Habitat designations were drawn from USDA Forest Service Remote Sensing Applications Center for Federated States of Micronesia Historic Vegetation Digitization Project (2005), and the GIS was used to assess habitat composition within 50 m of observation stations. Habitat polygons were amalgamated into functional habitat types with relevance to birds (see above). Measures for the remaining variables were collected by observers during site visits.

Variable	**Description**
Mangrove	<u>% area within 50 m of observers</u>. Mangrove and wetland represents c.19 % of Pohnpei undisturbed forests. Mangrove has unique characteristics and may be greatly affected by sea level rise and anthropogenic processes. We identified mangrove and wetland habitats by amalgamating areas classified by USDAFS (2005) as mangroves, marshes, swamp forest and fresh water bodies.
Agricultural forest (AgroFo)	<u>% area with 50 m of observers</u>. Agricultural forest incudes areas with subsistence or commercial staple crops mixed with undisturbed forest. Agricultural forest patches are used by several Pohnpei bird species, especially those that consume fruit. We identified agricultural forest habitats by amalgamating habitat polygons identified as agroforest, plantation forest, cropland and coconut plantation in the USDAFS (2005) data set.
Undisturbed vegetation (intercept)	<u>% area with 50 m of observers</u>. Upland and undisturbed forest habitats are common in Pohnpei higher elevation zones and in isolated patches in lowland areas. Although we did not directly include undisturbed vegetation in modeling efforts, the habitat type was represented with intercept variables and it factored into simulation scenarios. We identified undisturbed vegetation habitats by amalgamating upland forest, palm forest, dwarf forest and atoll forest from the USDAFS (2005) data set.
Secondary Vegetation (SecVeg)	<u>% area with 50 m of observers</u>. Secondary vegetation represents anthropogenic habitats (e.g., savannah) and early colonizers and invasive species (e.g. *Hibiscus spp*. and *Merremia peltata*). We identified secondary vegetation habitat on Pohnpei by amalgamating habitat polygons designated as secondary vegetation, grassland or savanna, barren, urban land from the USDAFS (2005) data set.
Patch number (PN)	<u>*N patches within 50 m of observers.*</u> The number of discrete habitat patches within a 50 m radius of the survey station. Patch number was included in modeling efforts to represent habitat heterogeneity/fragmentation at sites were surveys were conducted.
Habitat edge (LNEdge)	<u>*Length of habitat edge within 50 m of observers (log transformed).*</u> The length of habitat edge (boundary between two habitat patches), as identified by the GIS. Some species use habitat edge (e.g. foraging perches) whereas others may be negatively affected by edge habitat.
Crown closure (CanCvr)	<u>*% forest crown closure at survey station.*</u> Crown closure was measured using a densitometer, and values represent the gap fraction in overhead canopy. Some birds may dependent on older growth forest or forest with higher density canopy (only used in occupancy models).
Canopy height (CanHt)	<u>*Height (m)*</u>. Observers used laser range finders to estimate the maximum height of canopy at each survey station. Stations with higher canopy may be characterized by more complex understories (only used in occupancy models).
Stocking Rate (StockRt)	<u>*Rate (number of treem^2/ha).*</u> Stocking rate was measured with a 2-factor wedge prism. Stocking rate provides an index of the number of trees (DBH>8 in). Birds dependent on larger or older growth trees may be more likely to occupy sites with higher stocking rates (only used in occupancy models).

Bird population metrics
We used three measures to assess bird populations and species habitat associations, including detection rates (observations per unit time), species occupancy (probability that a species occupied a station), and population density (estimated density of birds per unit area). We estimated the detection rate for each species (mean number of birds detected per 8-minute observation period) at 6 different elevation zones including mean sea level (MSL), >0 to 100 m, 101 to 200 m, 201 to 400 m, 401 to 600 m, and > 600 m (Table 2). This approach enabled us to compare detection rates from our 2012 surveys to those reported from 1983 and 1994 efforts.

1) Detection rates – We evaluated the relationship between habitat change and Pohnpei bird populations that has occurred over the course of the last three decades. Vegetation models from 1975, 1995, and 2002 were constructed using a similar technique, so the three were employed in the assessment of historic patterns. For each vegetation model, we derived measures for each variable (Table 1) within each 0.786 ha hexagonal cell. We then derived the mean cell values for each variable in each of 6 elevation zones, including sea level (Mangrove), 0-100, 101-200m, 201-400m, 401-600m, and 601-800m. Those mean values were used to model detection rates for 22 species for which data were available for the 1983, 1994, and 2012 surveys. Although habitat models and bird surveys were not perfectly aligned temporally, we assumed that later vegetation assessments reflected later patterns, and thus were better associated with later bird populations. For each species, we used generalized linear mixed models (proc glimmix; SAS 9.3; Statistical Analysis System, Cary, NC), to assess relationships. Each of the 3 habitat types was available in all elevation zones (undisturbed vegetation, agricultural forest, and secondary vegetation), and the two landscape measures of patch number and habitat edge, were fitted to detection rates. We did not evaluate mangrove effects because it only occurs at sea level. We included elevation zone as a random effect to account for repeated measures, and we used a Poisson response distribution in the modeling.

2) Occupancy models – To evaluate bird-habitat relationships using contemporary data, we developed occupancy functions for Pohnpei's native avifauna. Occupancy (Ψ) or probability of occurrence is utilized in ecology and conservation as a quantifying tool, and is defined as the probability that a specific area is occupied by the species of interest (MacKenzie et al. 2006). Occupancy modeling is commonly used when species are rare or difficult to detect, and when species have a detection probability < 1. Rare or secretive species may not de detected at the time of surveys, and occupancy modeling provides a solution to false absences by creating a detection history for each survey location and species (Bayley and Peterson 2001, Kéry 2002, MacKenzie et al. 2002, Royle and Nichols 2003, Dorazio et al. 2006). We developed occupancy models for 13 species for which we obtained enough data (n > 40 detections) including *Ptilinopus porphyraceus*, *Ducula oceanica*, *Trichoglossus rubiginosus*, *Toriramphus reichenbachii*, *Myigra pluto*, *Rhipidura kubaryi*, *Acrocephalus syrinx*, *Aplonis opaca*, *Myzomela rubratra*, *Zosterops semperi*, *Zosterops cinereus, Coracina tenuirostris* and *Rukia longirostra*.

Occupancy modeling followed a two-stage process. The first stage included developing a detection function (p) to account for nuisance variables, factors related to effectiveness of survey efforts. Environmental and anthropogenic factors with the potential to affect bird detections during surveys included rain (no rain, light rain and heavy rain), wind (modified Beafourt scale), ambient noise (1-10 being 10 the loudest), ordinal day, survey time (minutes after sunrise) and cloud cover. Observer identification was included as a covariate to account for difference among experience and skills (Alldredge et all. 2007, Kendrick et all. 2013). These covariates were included in a series of models with all possible combinations of nuisance variables. We used *occu* function from package "unmarked" (Fiske and Chandler 2011) and MuMIn package (Bartoń 2012) to obtain top ranked model coefficients. Models were ranked using a modified Akaike's information criterion (AICc; Burnham and Anderson 2002) and the top-ranked model was considered best approximating. Variables from that model were then incorporated into the development of occupancy functions relating biological factors with the probability of site occupancy.

In the second analysis stage biologically relevant site covariates were developed for each survey station (table 1) using observer records and the geographic information system (GIS; ArcGIS, ESRI 2011). Within 50 m of observers, we assessed: 1) the percent area comprised of mangrove habitat; 2) the percent agroforest habitat; 3) the percent secondary vegetation; 4) the number of habitat patches; and 5) the length of edge habitat (as defined by abutting habitats). From survey records we also drew 6) estimated canopy height at the survey station; 7) canopy closure at the survey station; and 8) estimated tree stocking rate using a 2 factor wedge prism. We evaluated all possible combinations of biologically relevant variables (with undisturbed vegetation fitting as intersect). Each species was analyzed individually and models that did not converge where eliminated. For each species, biologically relevant models were then ranked by AICc value, and those within 2 AICc units of the top-ranked model (ΔAICc < 2) were considered to be competing for best approximating (Burnham and Anderson 2002). When more than one model was identified in the top-ranked set for a species, we model-averaged parameter estimates to create a model-averaged Ψ function (Table 6).

2) Density models – We modeled density for each of the 10 Pohnpei bird species. To estimate species density functions, we used R statistical software (Team 2012) and package unmarked (Royle et al. 2004, Fiske and Chandler 2011) in program RStudio (2012) and a distance-based approach. Density functions were developed for each species in a two-step process similar to that used for occupancy, and using data collected in the first visit to each survey station in 2012. We identified nuisance variables associate with each survey. In short, survey data were fitted to all possible linear combinations of nuisance variables, which were then ranked by resulting AICc values, and the top-ranked models were selected to represent *p*. We used function *distsamp* from package unmarked in R to estimate distance detection functions and densities for each species at each survey station, densities and detection function analysis followed a Poisson distribution (Royle et al. 2004, Fiske and Chandler 2011, Kendrick et al. 2013). To eliminate outlier effects we omitted detections with distances >90th percentile.

In the second analysis stage, covariates from the top ranked detection (*p*) model were used along with biologically relevant site covariates. Site covariates included mangrove, agroforest (AgroFo), secondary vegetation (SecVeg), number of discrete vegetation patches (PN) and amount of internal edge in the surveyed area (LNEdge). We used MuMIn package (Bartoń 2012) to obtain top ranked model coefficients and fix parameters to the global abundance site model. We then used *dredge* function from MuMIn package to create all possible linear combinations of biologically relevant site covariates. We used a model ranking analysis similar to that described above to identify best approximating model(s) (Δ AIC<2). We used model averaging to identify density functions.

Linking Pohnpei vegetation models with avifauna
The USDAFS (2005) Pohnpei vegetation model was linked to species-specific density functions that were developed from survey data. Distance analyses (described above) yielded a density function, or several functions in the case of competing models, representing the quantitative relationship between the density of each bird species and habitat metrics at each survey station. Cells in the Pohnpei avifauna habitat model were developed based on the same habitat metrics used in the density and occupancy models so that a linkage could be made between the density functions and cell conditions. The predicted number of individual birds residing within each cell in the avifauna habitat model was be estimated simply by applying density functions to measures of features from that cell (Figure 3).

For each of the ten species for which density models were developed, we estimate the number of individuals in each of the 0.786 ha cells, and then we summed the totals for all cells to estimate population densities. We applied density functions for each species to all cells in the Pohnpei avian habitat model (mapped in Appendix B). When results of the model ranking analysis indicated that there were more than one density model competing for best approximating, we applied all models with AICc <2 to the cells and model averaged results using estimated model weight (w_i) to derive a model averaged density for each individual species, and for each habitat cell. By summing the number of individuals for all cells, an estimate of total population size was derived for each Pohnpei bird species.

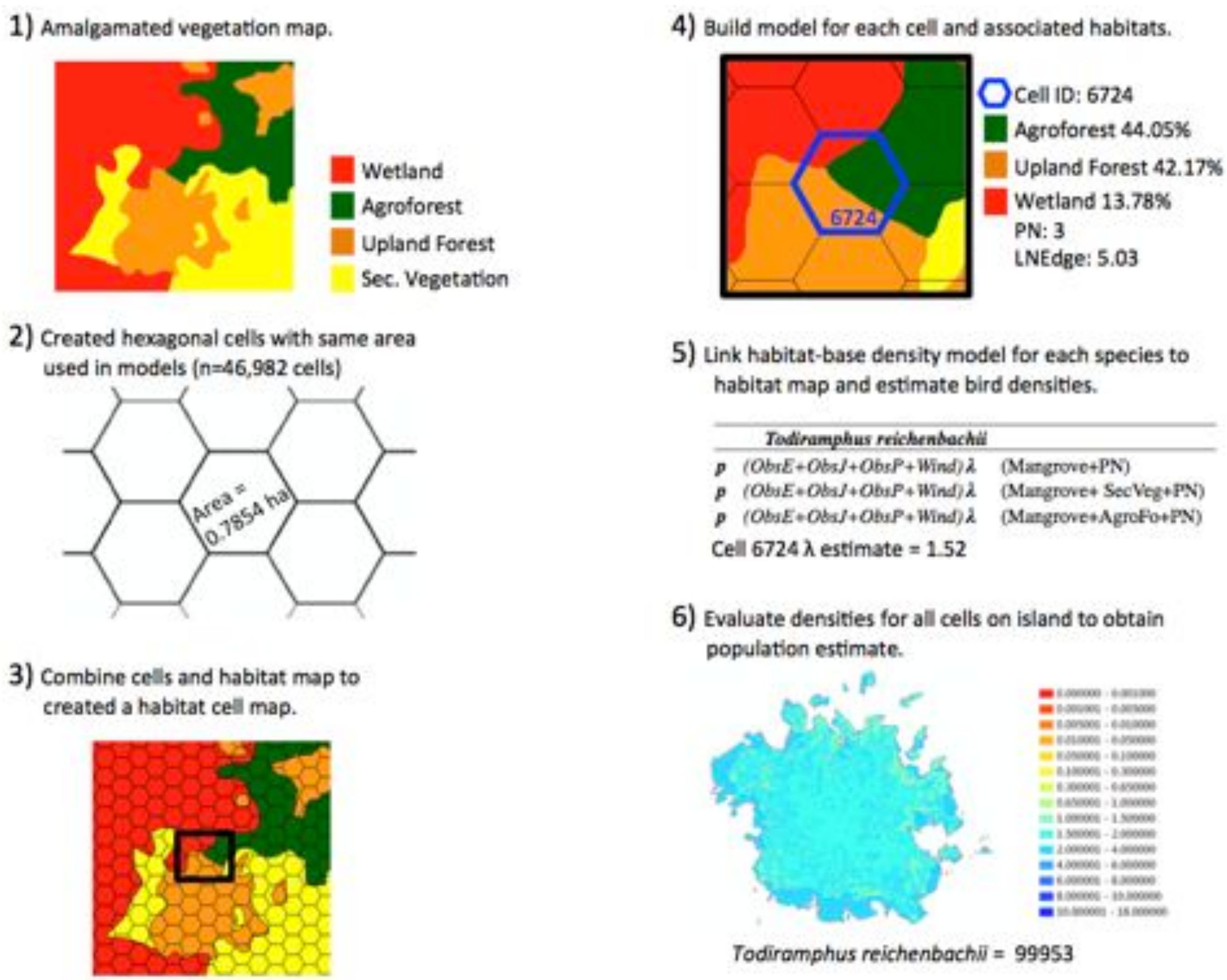


Figure 3. Example of process used to synthesize density models and avian habitat models for the island of Pohnpei. Habitat information from remote sensing vegetation surveys (USDAFS 2005) and distance-based point transect avian density survey models were used to design a spatially explicit set of species-specific population density models.

Activating the Pohnpei avian habitat model

Future habitats on Pohnpei will likely differ from those currently occurring on the island because anthropogenic and climate change factors will alter conditions. To evaluate which factors are most likely to affect each of the Pohnpei birds, we altered the Pohnpei avifauna habitat model so that it reflected a range of potential future scenarios, and then we re-estimated bird populations under the simulations of perturbed conditions.

We used peer-reviewed literature and expert opinion to identify reasonable ranges of potential habitat effects that might be encountered on the island of Pohnpei in the future. The end-goal of our analysis was not to identify precisely what might comprise Pohnpei bird populations, but rather to identify *which* factor, or factors, is likely to exert force on bird populations. We aimed to identify factors toward which future conservation management could be applied. Thus, we identified broad ranges of changes that might be associated with future conditions. We considered 5 primary factors, including sea level rise, climate-altered vegetation, secondary vegetation expansion, agricultural forest expansion, and the establishment of new agricultural forest. We then developed ranges of conditions that might be expected for each of these factors during the next 100 years. Values were intended to be broad and to encompass the breadth of conditions that might be encountered by Pohnpei bird populations under a number of future scenarios.

Agricultural habitats on Pohnpei are currently being developed for food and for sakau production. The expansion of agroforest habitats has the potential to influence birds in two ways. An expansion of existing agroforest patches occurs when undisturbed vegetation surrounding agricultural areas is removed to expand existing plots. Similarly, new agricultural plots can be established by clearing undisturbed vegetation. New agriculture plots are frequently located in areas with undisturbed forest types (Merlin and Raynor 2005, Ballick 2009). The two patterns of development have the potential to affect Pohnpei avifauna differently. An expansion of existing agricultural plantations would functionally remove undisturbed vegetation and expand forest edge slightly. The expansion of existing plots for staple crops often follows this process. However, expansion of existing plots is unlikely to impact undisturbed vegetation in new areas currently characterized by little habitat fragmentation, and sakau plantations are often established in previously undisturbed regions. Thus, new agricultural plots have the potential to affect what are currently large and unbroken patches of habitat, to fragment undeveloped landscapes, and new patches can introduce forest edge to locations where it may not yet exist. We elected to represent agricultural habitat changes in the model in two ways.

1) Agricultural expansion – We simulated agricultural expansion by allowing the model to expand existing patches of agricultural habitat into patches of undisturbed forest, so that they encompassed 0-90% of the remaining non-agricultural habitat within a cell that already contains some agricultural habitat. Consider for example, a scenario that started with a cell with 10% agricultural forest and 90% undisturbed vegetation. If the scenario simulated an agricultural expansion of 50%, the perturbed simulation would result in a total of 55% agricultural forest ($0.10 + [0.90 \times 0.50] = 0.55$). The simulation would reduce the proportion of undisturbed vegetation for the cell accordingly. We did not predict that establishment of agriculture in areas with secondary vegetation.

2) Agricultural establishment – We simulated the establishment of new patches of agriculture in a randomly selected subset of cells, including those in currently undisturbed portions of the island. Random subsets of cells, ranging from 0-100%, were drawn from all portions of the island with elevations > 5 m. Agricultural plots are rarely established in mangroves or in secondary growth on Pohnpei. For each selected cell, a random plot-size was simulated with areas from 0-3,927 m^2 (50% area of total cell), and the habitat patches within the cell were then assessed to determine whether the selected cells contained enough undisturbed habitat to allow the development of the new agricultural patch. If so, a new circular patch was applied, and an equal area of undisturbed vegetation habitat was removed. Habitat edges and patch numbers were also modified in the cell's record.

3) Secondary vegetation expansion – We predicted that secondary vegetation would likely expand under the range of future conditions Pohnpei might experience. Secondary vegetation is common on the island in locations where anthropogenic activities, such as farming or urban development, has disturbed native habitats and then the areas were abandoned. Secondary vegetation has also developed in areas where wildfires previously occurred, where landslides occurred, or where there was tree mortality. We thus predicted that under future scenarios that include substantial anthropogenic development and altered climates, with increased likelihoods for drought and with altered precipitation, secondary vegetation could expand in areas where it already exists.

We simulated the expansion of secondary vegetation using an approach much like that applied to the expansion of agricultural plots. As with the agricultural expansion, we simulated the expansion of secondary vegetation by expanding existing patches into 0-90% of the area within the same cells where it already exists. Secondary vegetation was expanded only into areas not already classified as agriculture or secondary vegetation. Impacted vegetation patches were reduced in size accordingly. Secondary vegetation expansion was not applied to mangrove sites.

4) Climate impacts on vegetation – Altered precipitation regimes and increased storm frequencies have the potential to greatly impact Pohnpei forested habitats. Pohnpei is currently relatively unaffected by the mid-Pacific typhoons that have changed habitats on other islands (e.g. Chowdhury et al. 2010, Kauffman and Cole 2010). However, under climate-altered scenarios, Pohnpei may experience increased storms. Similarly, droughts and altered temperatures may cause landslides and tree mortality in currently undisturbed areas. We simulated climate impacts on vegetation by converting portions of undisturbed vegetation to secondary vegetation. Similar to the establishment of agricultural plots, we randomly selected subsets of cells (0 - 100%) from the island > 5 m above sea level. For each selected cell, an impact area (ranging from 0 - 3,927 m^2; 50% area of total cell) was randomly selected from a uniform distribution. Then, habitat patches within the random subsets of cells were assessed to determine whether there was enough undisturbed vegetation to convert to secondary vegetation. The model established round secondary vegetation patches within undisturbed vegetation patches, if the undisturbed vegetation patches were large enough. Commensurate lengths of habitat edge and patch numbers were added to the cell records to accommodate the round impact sites.

5) Sea level rise – Sea level rises have the potential to overtop Pohnpei's surrounding protective reefs and allow increased wave action, which is predicted in association with elevated storm frequencies and intensities. These activities may negatively impact mangrove forests on

Pohnpei. Thus, we included mangrove habitat impacts into our simulation models. We simulated mangrove losses in a range from 0-100%. For each future scenario, a random impact percentage was drawn from a uniform distribution. Cells in the Pohnpei avian habitat model were then randomly selected if their elevation was at sea level, and they were converted to water in the model. Unlike the simulations of agricultural habitats and secondary vegetation described above, mangrove habitats that were identified for removal were not converted to other vegetation types, and they were thus lost from the available areas altogether.

Simulating potential future scenarios

We derived a version of the Pohnpei avian habitat model in Microsoft Access (Microsoft Corporation, Redmond, WA), and linked each cell to the variables described above, such that potential future Pohnpei landscapes were simulated, representing scenarios of various amounts of anthropogenic change and climate change. Within the aforementioned ranges, values were selected randomly for each variable, and together the variables were then applied to alter the Pohnpei avian habitat model. For example, a null model, representing the current habitat conditions included no agroforest expansion, no agricultural forest establishment, no expansion of secondary forest, no climate effects resulting in secondary forest, and no sea level effects on mangroves. For each simulation, the computer drew random numbers from within the ranges for each variable, and then applied the modifications to existing Pohnpei habitats (Figure 4). For example, simulation ID 336 included an expansion of agricultural forest in to 42% of the undisturbed habitats in cells where it is already found, 28% of the island may also receive randomly sized patches of newly established agriculture, secondary vegetation may expand into 66% of the unexpected habitats in cells where it already existed, and 22% of the Pohnpei cells might receive new randomly sized patches of secondary forest that associated with climate-driven vegetation change. In the scenario, 96% of the mangrove might also be lost to factors associated with sea level change.

We identified 1,000 plausible future scenarios for Pohnpei's avian habitats, each incorporating a combination of anthropogenic and climate-driven changes. We considered that those scenarios represented the range of possible conditions, and combinations of conditions, that the island might encounter under the many simulated futures. We then fitted the density function (or the set of functions competing for best approximating) for each species to each cell in the perturbed future scenario models. We summed results for all cells in each model to derive an estimated population size for each of 10 bird species, in each simulated future scenario.

To evaluate the influence of each factor on Pohnpei bird populations, while accounting for the spatial distribution of habitats on Pohnpei, and while multiple factors were operating simultaneously, we used methods similar to life stage simulation analysis (Wisdom and Mills 1997, Wisdom et al. 2000). Life stage simulation analyses are designed to assess factors most linked to population change under situations in which many life stages may be affecting populations simultaneously (e.g. Kesler and Haig 2007b, Kesler et al. 2012). By using the technique on Pohnpei bird populations, we were able to evaluate the relative influence of each factor while simultaneously preserving the spatially explicit relationships between birds and habitats on the island. We used linear regression to fit input values for each of the variables in each scenario to the associated estimated population sizes for each species. The regressions yielded two metrics useful for identifying which factors most influenced the bird populations. Slope (m) indicated the magnitude of effect for each factor. Relationships were not perfectly linear because multiple factors affected estimated population sizes in each of the simulated scenarios, thus the r^2 value was associated with the strength of each relationship. We concluded that anthropogenic or climate change factor with the highest r^2 value was the factor most associated with population change.

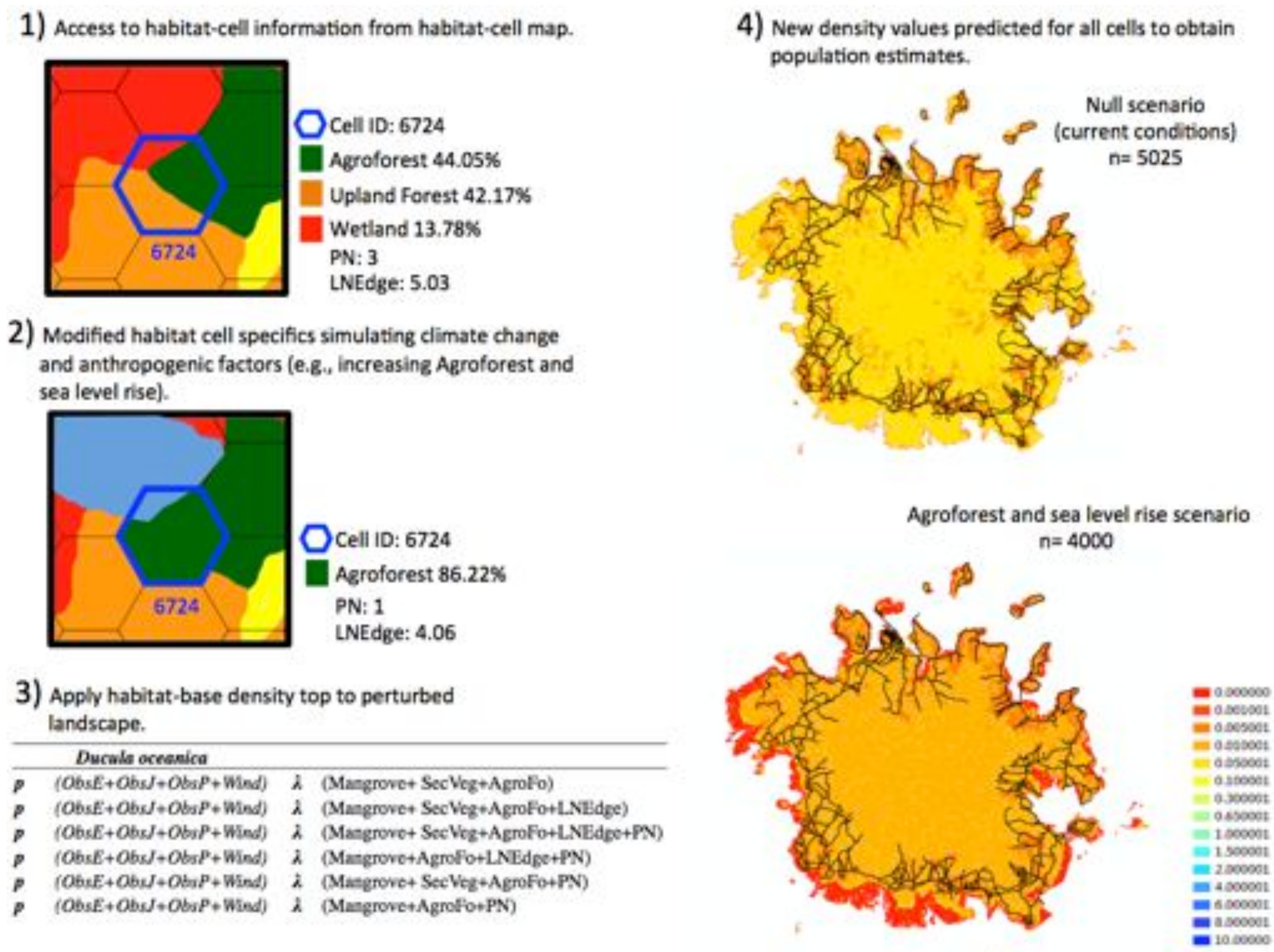


Figure 4. Example of process used to simulate effects of future climate and anthropogenic habitat changes. Existing landscape configurations and compositions were altered to reflect changes. Avian population models were then fitted to the altered landscapes and populations were recalculated. We simulated avian populations under 1000 plausible combinations of anthropogenic and climate change conditions, and then evaluated the associations between each factor and the resulting bird population changes.

PROJECT RESULTS

Avian population change 1983-2013

We compared the rate at which observers detected each species in 2012 with detection rates reported for surveys in 1983 (Enbring et al. 1990) and 1994 (Buden 2000). Detection rates (birds/ 8 minutes) for each species, and comparisons between earlier surveys and our 2012 work, are reported in Tables 2 and 3. Species with apparent declines between the survey in 1994 and the 2012 survey included *Trichoglossus rubiginosus* (-20.4%), *Todiramphus reichenbachii* (-15.%), *Myiagra pluto* (-19.1%), *Acrocephalus syrinx* (-77.3%), *Aplonis opaca* (-21.6%), *Myzomela rubratra* (-22.4%), *Zosterops semperi* (-34.7%), *Lonchura hunsteini* (-69.5%). Species that increased over the same period included *Rukia longirostra* (359%), *Ducula oceanica* (220%), *Ptilinopus porphyraceus* (60.3%), *Rhipidura kubaryi* (10.83%) and *Zosterops cinereus* (117%). Further, detection rates for many species differed among elevation zones (Table 3). Several species were not detected in specific elevation zones in previous surveys but were detected in 2012. On the contrary, species were detected in previous surveys at specific elevation zones but not detected in 2012. Despite our substantial survey efforts, and those of observers in past surveys, some species are not well represented. For example, *Asio flammeus* was not detected during surveys in 2012. Nonetheless, we know that the birds persist on Pohnpei because observers encountered an owl pellet, and the species was detected outside of the survey when travelling between sites.

Mean cell vegetation values for the six Pohnpei elevation zones are depicted in table 4, and bird-habitat associations are provided in table 5. The coarse scale of the historic records analysis may have hindered our ability to detect trends, because most species did not show significant relationships. Of the relationships that were significant, however, detection rates for *Anous spp., M. rubratra, P. porphyraceus, T. rubiginosus*, and *Z. cinereus* were all negatively associated with the mean proportion of agriculture and secondary vegetation in regions during the associated vegetation assessment. With the exception of *M. rubratra*, all of these species also showed positive associations with undisturbed habitats. Results also indicated a positive association between habitat edge and the habitat heterogeneity for *P. porphyraceus*. The combination of a positive association between undisturbed habitats, and habitat edges provides an interesting example of an edge-dependent species that could be negatively impacted by anthropogenic change. The results provided a link between habitat changes that have occurred on the island between 1975 and present, and the changes in bird during the same time period.

Occupancy models and results

To evaluate bird-habitat relationships, we developed occupancy functions for 13 of Pohnpei's native species (Figure 5; Appendix A, Table A2). Detection functions differed among species, as observer was included in the top model for 7 of the 13 species; ordinal day was included in the top for *T. reichenbachii, C. tenuirostris*, *Z. cinereus* and *R. longirostra*; noise was included for *M. rubratra*, *Z. semperi and Z. cinereus*; wind was included *P. porphyraceus*, *T. reichenbachii* and *C. tenuirostris*; cloud cover was included for *R. longirostra*, *Z. cinereus*, *A. opaca* and *R. kubaryi*; rain was included in *P. porphyraceus*, *T. reichenbachii, A. opaca* and *M. rubratra*; and minutes after sunrise was included in *R. kubaryi* top detection model (Appendix A-Table A2).

We used model selection to identify occupancy functions with biologically relevant metrics for each species. Seven models competed for best approximating occupancy function for

C. tenuirostris; 6 models competed for best approximating for *Z. cinereus* and *Z. semperi*; 5 models competed for *R. kubaryi*, *P. porphyraceus*, *R. longirostra* and *T. rubiginosus*; four models competed for *A. syrinx*, 2 models competed for *A. opaca* and *T. reichenbachii*; and 1 top-ranked model was identified for *M. rubratra*. There were 18 models competing for occupancy functions for *D. oceanica*.

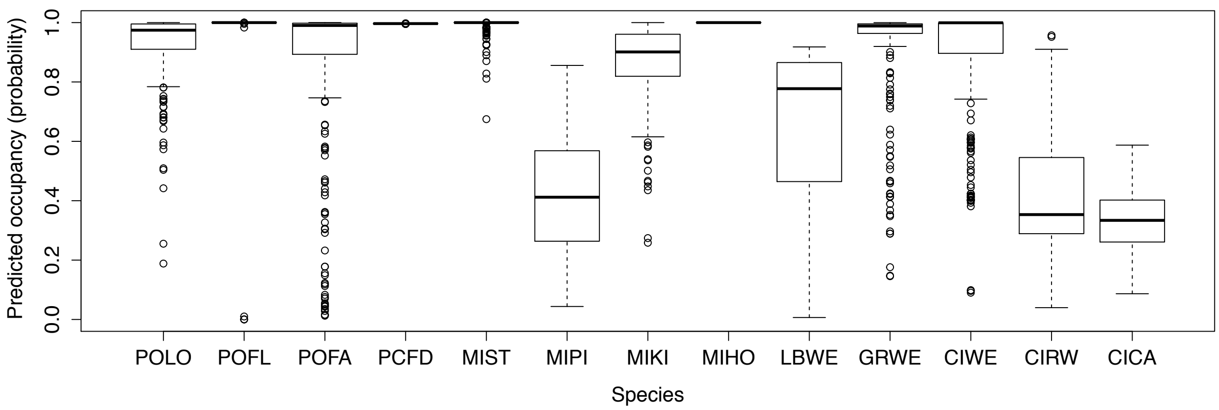


Figure 5. Model-averaged avian species occupancy Ψ estimates predicted for 247 survey stations distributed throughout the island of Pohnpei, Federated States of Micronesia. Occupancy functions were derived from repeat survey visits to the sites in 2012. Occupancy estimates near 1 indicate a high probability that a species occupied a particular station, after accounting for the confounding influences of nuisance variables, and even if that species was not detected there. Species predicted to ubiquitous and common throughout the island are represented by distributions clustered in high values. Those rare are represented by lower means and distributions, and species associated with specific or widely distributed habitats are represented with broad distributions.

Model averaged parameter estimates and their associated 95% confidence intervals provided insight into the magnitude and strength of effect for each variable on each species' probability of occupying survey stations. Positive parameters indicated positive associations, and 95% confidence intervals that do not overlap with zero indicated significant relationships (Table 6). The amount of mangrove habitat within 50 m of observers was negatively associated with occupancy in four species. As mangrove habitat increased, occupancy probabilities declined for *A. syrinx* (β = -0.77, 95% CI -1.36 to -0.19), *Z. cinereus* (β = -1.62, 95% CI -2.61 to -0.63), *R. longirostra* (β = -1.61, 95% CI -2.25 to -0.97) and *R. kubaryi* (β = -1.78, 95% CI -2.53 to -1.03). Results showed that the occupancy models for all species except *M. rubrata*, *A. opaca* and *T. reichenbachii* included the proportion of surrounding agroforest habitat within 50 m of observers, but all 95% confidence intervals overlapped with 0. Similarly, secondary vegetation was included as a parameter in models for 9 species, but confidence intervals overlapped 0. The occupancy functions for 8 species included a parameter associated with tree stocking rate measures at survey stations. The parameter estimate for *Z. cinereus* was significantly positive (β = 1.012, 95% CI 0.09 to 1.95), indicating that as basal area increased the birds were more likely to occupy stations. Parameter estimates for *T. reichenbachii* (β = -0.94, 95% CI -1.54 to -0.34) and *T. rubiginosus* (β = -1.06, 95% CI -1.77 to -0.36) indicated a negative association with tree stock-rate. Canopy height was positively and significantly associated with occupancy in *T. reichenbachii* (β = 0.76, 95% CI 0.12 to 1.39), *D. oceanica* (β = 0.59, 95% CI 0.18 to 0.99), *R. kubaryi* (β = 1.96, 95% CI 0.73 to 3.20) and *T. rubiginosus* (β = 1.48, 95% CI 0.64 to 2.33).

Canopy cover parameters were also significantly associated with occupancy in *R. longirostra* (β = 0.71, 95% CI 0.31 to 1.12). Occupancy was negatively associated with canopy cover for *A. syrinx* (β = -0.76, 95% CI -1.37 to -0.14), indicating that the birds were more likely to occupy sites with open canopy. Parameter estimates for the length of habitat edges at survey stations were for *R. longirostra* (β = 0.46, 95% CI 0.006 to 0.9) and *R. kubaryi* (β = 0.95, 95% CI 0.26 to 1.65). The number of discrete habitat patches within a 50 m radius of observers was associated with 4 species, *D. oceanica, Z. semperi, Z. cinereus and R. longirostra*, however all CI overlapped zero and were not significant.

Table 2. Detection rates (birds/8 minutes) at 6 different elevation zones for the 2012 avian survey. A total of 247 stations distributed in: 47 stations in Mangrove, 47 stations between 0-100m, 64 stations between 101-200m, 49 stations between 201-400m, 21 stations between 401-600m and 19 stations >600m.

Species	**Mangrove**	**0-100**	**101-200**	**201-400**	**401-600**	**601-800**
P. lepturus	0.043	0.043	0.000	0.102	0.000	0.053
E. sacra	0.000	0.000	0.000	0.000	0.000	0.000
Anous spp.	0.426	0.213	0.375	0.327	0.238	0.053
G. alba	0.660	0.319	0.063	0.286	0.095	0.000
G. kubaryi	0.000	0.000	0.047	0.020	0.000	0.053
P. porphyraceus	2.021	2.128	2.656	2.612	2.714	1.947
D. oceanica	0.234	0.021	0.125	0.551	0.905	0.474
T. rubiginosus	3.340	2.277	1.109	0.918	0.857	0.789
A. flammeus	0.000	0.000	0.000	0.000	0.000	0.000
A. vanikorensis	0.043	0.298	0.313	0.551	0.714	0.000
T. reichenbachii	1.681	0.553	0.766	0.531	0.619	0.105
C. tenuirostris	0.043	0.000	0.031	0.020	0.000	0.158
M. pluto	0.468	0.851	0.781	0.837	0.762	0.737
R. kubaryi	0.298	1.021	0.719	0.898	0.381	0.211
A. syrinx	0.000	0.000	0.016	0.061	0.048	0.000
A. opaca	1.191	1.468	1.594	2.224	1.905	1.579
A. pelzelni	0.000	0.000	0.000	0.000	0.000	0.000
M. rubratra	3.255	2.596	2.469	2.429	2.143	1.579
Z. semperi	0.000	0.064	0.109	0.102	0.000	0.526
Z. cinereus	0.766	2.000	2.172	2.286	1.762	1.421
R. longirostra	0.000	0.383	0.797	1.265	1.619	2.105
E. trichroa	0.000	0.021	0.047	0.000	0.000	0.000
L. hunsteini	0.000	0.085	0.016	0.000	0.000	0.000

Table 3. Comparison of avian detection rates (detections/unit time) observed in 1983, 1994, and 2012 on the island of Pohnpei, Federated States of Micronesia. Numbers in each column represent the % change when compared to 2012. Negative values indicate declines since previous surveys and positive values represent higher detection rates in 2012.

Species	Mangrove		0-100		101-200		201-400		401-600		601-800	
	vs 1983	vs 1994	vs 1983	vs 1994	vs 1983	vs 1994	vs 1983	vs 1994	vs 1983	vs 1994	vs 1983	vs 1994
Phaethon lepturus	-86.63	-89.06	-86.83	19.15	-	-	-86.78	-21.43	-	-	-93.07	-81.58
Egretta sacra	-	-	NA	-	-	NA	NA	NA	-	NA	-	NA
Anous spp.	-90.64	-69.96	-96.70	-48.20	-94.25	-39.54	-95.72	-51.65	-91.52	-45.58	-96.24	+
Gygis alba	-49.09	-12.06	-61.22	257.45	-89.63	-67.08	-58.28	15.79	-43.49	-23.81	-	NA
Gallicolumba kubaryi *	NA	NA	-	NA	-75.63	23.44	+	-21.43	NA	NA	+	+
Ptilinopus porphyraceus	-33.63	69.22	-87.52	13.48	-84.50	1.37	-81.92	1.08	-81.96	35.71	-78.83	240.79
Ducula oceanica	-14.18	321.28	-74.85	19.15	-48.68	9.72	-12.60	371.43	61.05	382.54	-1.32	+
Trichoglossus rubiginosus (E)	-17.43	67.02	-69.11	13.83	-86.50	-31.53	-90.42	-58.40	-89.92	-63.59	-79.86	-49.76
Porzana cinerea	NA	-	NA	-	NA	NA	NA	NA	NA	NA	NA	NA
Asio flammeus	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Aerodramus vanikorensis	87.23	-78.12	-73.29	-12.21	-59.38	-43.89	-37.41	-41.88	63.00	471.43	-	NA
Todiramphus reichenbachii (E)	-66.23	40.72	-79.09	-16.27	-58.24	26.01	-69.30	-37.14	-66.41	-30.90	-93.58	-75.44
Coracina tenuirostris	-37.59	+	NA	NA	-59.38	146.88	-87.48	-60.71	-	-	+	+
Myiagra pluto (E)	-54.23	-26.73	-78.97	-11.74	-82.18	-29.87	-77.22	-17.40	-71.86	-14.95	-56.14	-14.04
Rhipidura kubaryi (E)	-51.46	-2.51	-74.47	16.72	-75.94	5.15	-63.12	32.97	-67.08	-34.69	-73.68	47.37
Acrocephalus syrinx	NA	NA	-	-	-96.19	-96.14	-82.93	-73.81	-47.02	-61.90	NA	NA
Aplonis opaca	-74.05	-20.57	-84.17	-47.30	-83.66	-45.02	-73.18	-33.61	-73.13	-5.74	-80.26	22.81
*Aplonis pelzelni (E)***	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Myzomela rubratra	-78.23	-38.96	-80.43	-38.92	-77.40	-26.40	-78.22	-25.50	-80.99	-14.99	-83.76	10.53
Zosterops semperi	-	NA	-94.32	-10.64	-93.86	-58.85	-91.14	-34.52	-	-	228.95	+
Zosterops cinereus	-80.18	206.38	-78.51	4.67	-74.53	36.17	-65.01	10.00	-54.55	51.02	-58.69	397.37
Rukia longirostra (E)	NA	NA	46.43	436.17	17.28	949.22	-42.94	323.60	-61.78	94.29	-49.39	-7.89
Erythrura trichroa	NA	NA	-86.17	-85.11	NA	270.31	NA	NA	NA	NA	NA	NA
Lonchura hunsteini	NA	NA	-90.03	-56.67	-84.77	-82.37	-	-	NA	NA	NA	NA

NA: no comparison, insufficient data available; - : Species detected in 1983 and 1994, not detected in 2012;+ : species detected in 2012 and not detected in previous surveys
*: Vulnerable, **: Critically endangered (IUCN 2013); (E): Endemic to Pohnpei

Table 4. Index values for habitats in six elevation zones, as derived from vegetation coverages on Pohnpei Island in 1975, 1995, and 2002. Units include the mean proportion of area within 0.76 ha evaluation cells for each elevation zone. Variable values are defined above.

Elevation Zone	Habitat Edge (LNEdge)			Number of Patches (PN)			% Agroforest			% Secondary Vegetation			% Undisturbed Vegetation			% Mangrove		
	1975	1994	2002	1975	1994	2002	1975	1994	2002	1975	1994	2002	1975	1994	2002	1975	1994	2002
Mangrove	0.734	0.839	0.860	1.190	1.213	1.221	0.055	0.062	0.067	0.031	0.035	0.037	0.016	0.012	0.011	0.895	0.887	0.882
0-100	2.506	2.029	2.075	1.709	1.523	1.545	0.314	0.582	0.573	0.180	0.205	0.205	0.378	0.101	0.109	0.129	0.112	0.112
101-200	2.137	2.001	2.018	1.557	1.495	1.502	0.130	0.459	0.432	0.165	0.275	0.287	0.704	0.266	0.281	0.001	0.000	0.000
201-400	2.081	1.850	2.000	1.515	1.455	1.493	0.018	0.199	0.176	0.128	0.183	0.220	0.853	0.617	0.604	0.000	0.000	0.000
401-600	1.486	1.302	1.327	1.352	1.304	1.319	0.000	0.017	0.017	0.015	0.028	0.036	0.979	0.949	0.941	0.006	0.006	0.006
601-800	1.060	1.549	1.502	1.249	1.366	1.357	0.000	0.000	<.001	0.009	0.016	0.016	0.991	0.984	0.984	0.000	0.000	0.000

Table 5. Habitat relationships identified through analysis of historic vegetation and bird survey data. Vegetation coverages from 1975, 1995, and 2002 were paired with bird survey data from 1983, 1994, and 2012. Data were divided into six functional elevation zones and assessed for correlational changes. Results with "+" indicate positive association with bird detection rates, whereas those with "-" are negative associations and "0" indicates no association. *P*-values < 0.05 are denoted with one mark, those < 0.01 are denoted with two marks, and those < 0.001 are denoted with three. Only species for which models converged are illustrated.

Species	Undisturbed	Agriculture	Secondary Vegetation	Edge (LnEdge)	Patch Number (PN)
A. opaca	+	--	--	0	0
A. syrinx	0	0	0	0	0
A. vanikorensis	0	0	0	0	0
Anous spp.	+++	---	--	0	0
C. tenuirostris	0	0	0	0	0
D. oceanica	0	0	0	0	0
E. sacra	0	0	0	0	0
E. trichroa	0	0	0	0	0
G. alba	0	0	0	0	0
G. kubaryi	0	0	0	0	0
L. hunsteini	0	0	0	0	0
M. pluto	0	0	0	0	0
M. rubratra	0	---	--	0	0
P. cinerea	0	0	0	0	0
P. lepturus	0	0	0	0	0
P. porphyraceus	+++	---	---	+	++
R. kubaryi	0	0	0	0	0
R. longirostra	0	0	0	0	0
T. reichenbachii	0	0	0	0	0
T. rubiginosus	++	--	--	0	0
Z. cinereus	++	--	-	0	0
Z. semperi	0	0	0	0	0

Density models and results

In addition to the occupancy models described above, we used distance analysis (Buckland et al. 2001) to evaluate the association between habitat characteristics and bird densities on Pohnpei. We modeled density for 10 species for which enough detection data were available. Detection functions included observer identification for 7 of 10 species, Null was the top detection model for *A. opaca* and *M. rubratra*; wind was the top model for *R. kubaryi,* and rain was only included for *R. longirostra* (Appendix A-Table A1). Noise, day, minutes from sunrise, ordinal date did not converge and were thus not considered further. Results from the model ranking analysis for density indicated that three biologically relevant models competed for best approximating for *Z. cinereus*, *M. rubratra*, *T. reichenbachii*, *A. opaca* and *R. kubaryi*, six models competed for *D. oceanica*, *P. porphyraceus* had four models; five models competed for *R. longirostra*, eight models competed for *M. pluto* and nine models for *T. rubiginosus* (Appendix A, Table A1). Model-averaged parameter estimates for species density analysis are provided in table 7.

Results indicated that, after accounting for the effects of nuisance variables and individual species detection probabilities, the proportion of agricultural forest within 50 m of observers was associated with the bird population density in 9 of 10 species. The 95% CI for three species did not overlap with zero, including *M. rubratra*, which was predicted to be in higher densities in agricultural forest ($\beta = 0.30$, 95% CI 0.02 to 0.59), and two species found in lower densities in agricultural forest, including *D. oceanica* and *R. kubaryi* (β = -3.9, 95% CI -6.43 to -0.35; β = -0.90, 95% CI -1.80 to -0.01 respectively). The amount of forest edge within 50 m of survey stations was included as a parameter in the model-averaged density models for 6 species, although the 95% CI for all overlapped with zero. The number of discrete habitat patches within 50 m of survey stations was included as a parameter in the density models for 8 species, and 95% CI for two species indicated significantly negative relationships. Densities of *Z. cinereus* (β = -0.27, 95% CI -0.5 to -0.04) and *T. reichenbachii* (β = -0.35, 95% CI -0.51 to -0.19) declined as the number of habitat patches increased. Secondary vegetation was significantly associated with increased density in *Z. cinereus* (β = 0.9, 99.9% CI 0.48 to 1.31), and with decreased densities of *M. rubratra* (β = -0.66, 95% CI -1.24 to -0.09) and *A. opaca* (β = -1.14, 95% CI -1.88 to -0.40). The area of secondary vegetation within 50 m was included in model-averaged results for the rest of the species, however the 95% CI overlapped with zero and were not significant.

Mangrove habitats were associated with model-averaged density functions for all species, but only significantly so for 6 species. Mangrove was associated with higher densities of *M. rubratra* (β = 0.38, 95% CI 0.16 to 0.60) and *T. rubiginosus* (β = 0.99, 95% CI 0.72 to 1.27). The area of mangrove within the survey site was negatively associated with densities of *Z. cinereus* (β = -1.3, 95% CI -1.79 to -0.82), *A. opaca* (β = -0.68, 95% CI -1.06 to -0.30), *R. kubaryi* (β = -2.81, 95% CI -4.43 to -1.19) and *M. pluto* (β = -0.66, 95% CI -1.22 to -0.11). Confidence intervals for the rest of the species overlap with zero and were not significant.

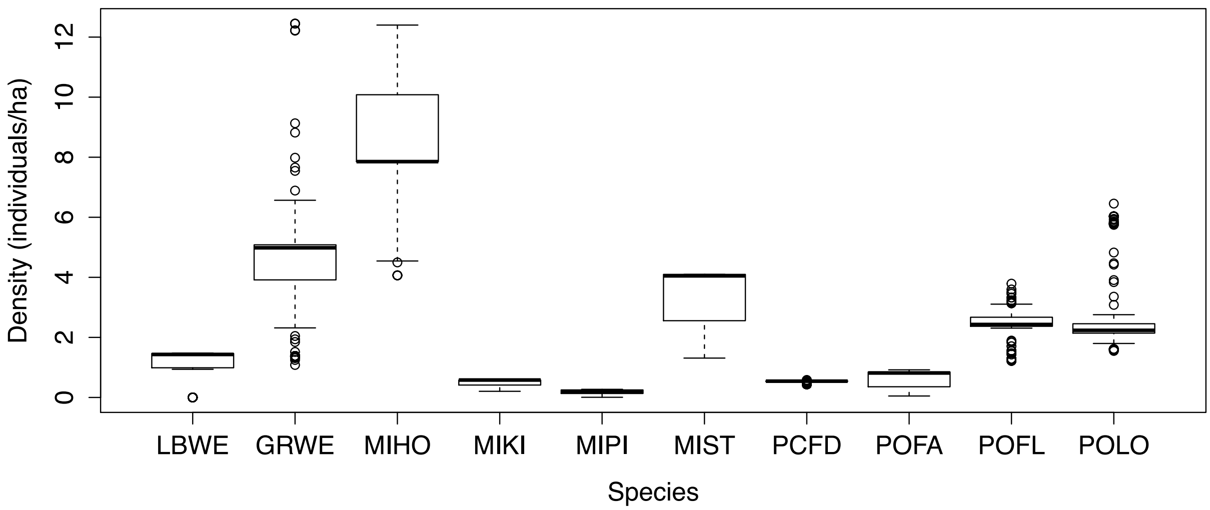


Figure 6. Model-averaged avian species density estimates predicted for 247 survey stations distributed throughout the island of Pohnpei, Federated States of Micronesia. Density functions were derived from variable distance point transect observations at sites in 2012. Density functions account for the confounding influences of nuisance variables, detectability of individual species, and site habitat characteristics. Species predicted to ubiquitous and similarly dense throughout the island are represented by narrow distributions. Rare species are represented by lower means and distributions, and species associated with specific or widely distributed habitats are represented with widely spread distributions.

Population estimates for Pohnpei avifauna

We linked the Pohnpei avian habitat model with the distance-based avian density functions to estimate the total populations of birds on Pohnpei, after accounting for the spatial distribution of habitats on the island. Results for the ten species for which density functions were identified, indicated the population of *Z. cinereus* was 166,235, *R. longirostra* was 36,123, *M. rubrata* was 302,955, *T. reichenbachii* was 17,375, *D. oceanica* was 5,025, *A. opaca* was 115,587, *P. porphyraceus* was 18,784, *R. kubaryi* was 22,263, *M. pluto* was 87,242, and *T. rubiginosus* was 100,803 (Table 8). The spatial distribution of each population on Pohnpei differed with respect to habitat associations (Appendix B). In general, species associated with mangrove habitats (e.g., *M. rubrata* and *T. rubiginosus*) were predicted to be most numerous in the mangroves that surround the island at sea level. Habitat fragmentation, and the associated habitat heterogeneity and increased edge habitats, was most numerous in regions of the island between 0 and 200 m amsl and in the northwestern portion of the island near the main town of Kolonia. Accordingly, high densities of *Z. cinereus* and *P. porphyraceus* were projected for 0-200 m amsl, whereas *A. opaca* was not. On the contrary, *D. oceanica* and *Z. cinereus* are species associated with little fragmentation and reduced agricultural forest were predicted to be in highest densities in mangroves and in higher elevation zones (Appendix B).

Table 6. Model averaged occupancy parameter estimates for Pohnpei avifauna, as derived from repeated surveys conducted throughout the island in 2012. Values in red are significant at the 0.001 confidence level, those in blue are significant at the 0.01 confidence level, and values in green are significant at the 0.05 confidence level. Positive values represent positive associations between covariate and species densities, and values indicate lower densities in association with covariates.

Species	Intercept	AgroFo	Stocking rate	Canopy Ht.	Canopy Cvr.	Sec. Veg	Mangrove	LN Edge	PN
P. porphyraceus	5.76 (1.03)	0.63 (1.04)		0.69 (0.63)		0.59 (2.60)	0.58 (2.0)		
D. oceanica	-0.46 (0.17)	-0.21 (0.17)	0.27 (0.20)	0.59 (0.21)	0.43 (0.23)	-0.3 (0.21)	0.18 (0.17)		-0.31 (0.18)
T. rubiginosus	6.79 (53.80)	-0.12 (0.24)	-1.06 (0.36)	1.48 (0.43)	0.20 (0.38)	1.43 (1.66)	7.85 (115.53)	-0.17 (0.32)	
T. reichenbachii	3.35 (2.20)		-0.94 (0.31)	0.76 (0.33)		0.71 (0.88)	3.18 (4.71)		
C. tenuirostris	-0.8 (0.61)	-0.2 (0.29)	0.17 (0.35)	-0.59 (0.35)	0.79 (0.44)	-0.29 (0.36)		-0.22 (0.29)	
M. pluto	293.3 (658.70)	-22.9 (57.20)	46.3 (164.20)	149.2 (327)	-26.2 (66)				
R. kubaryi	4.1 (0.91)	1.26 (1.04)	-0.43 (0.36)	1.96 (0.63)	0.19 (0.35)	0.21 (0.32)	-1.78 (0.38)	0.95 (0.35)	
A. syrinx	-0.4 (0.42)	0.61 (0.42)	-0.21 (0.32)	0.14 (0.29)	-0.76 (0.31)	0.11 (0.23)	-0.77 (0.30)		
A. opaca	46.87 (195.53)			-2.75 (1.82)			-19.19 (85.95)		
M. rubratra	11.6 (20.70)						0 (20.70)		
Z. semperi	109.07 (155.63)	-50.11 (71.44)			-3.45 (2.89)	-29.87 (83.26)	-58.52 (86.5)		-7.14 (15.30)
Z. cinereus	7 (9.28)	0.5 (0.70)	1.01 (0.47)		0.49 (0.41)	11.97 (28.86)	-1.62 (0.50)		0.27 (0.49)
R. longirostra	0.53 (0.26)	-0.11 (0.20)		-0.23 (0.23)	0.71 (0.21)		-1.61 (0.33)	0.46 (0.23)	-0.25 (0.21)

Table 7. Model averaged density parameter estimates for Pohnpei avifauna, as derived from distance analysis of variable distance point transect surveys conducted in 2012. Values in red are significant at the 0.001 confidence level, those in blue are significant at the 0.01 confidence level, and values in green are significant at the 0.05 confidence level. Positive values represent positive associations between covariate and densities, and values indicate lower densities in association with covariates.

Species	Intercept	AgroFo	Sec. Veg	Mangrove	PN	LN Edge
P. porphyraceus	-0.64 (0.11)		0.08 (0.20)	-0.21 (0.13)	0.08 (0.08)	0.01 (0.02)
D. oceanica	-1.35 (0.45)	-3.39 (1.55)	-1.52 (0.94)	-0.3 (0.37)	-0.43 (0.39)	0.09 (0.06)
T. rubiginosus	0.66 (0.21)	-0.5 (0.30)	-0.5 (0.45)	0.99 (0.14)	0.25 (0.15)	-0.03 (0.03)
T. reichenbachii	-0.2 (0.11)	0.06 (0.13)	-0.09 (0.19)	-0.22 (0.11)	-0.35 (0.08)	
M. pluto	0.78 (0.23)	-0.25 (0.30)	0.45 (0.32)	-0.66 (0.28)	0.22 (0.14)	-0.036 (0.04)
R. kubaryi	-0.13 (0.22)	-0.9 (0.45)	0.22 (0.39)	-2.81 (0.83)		-0.05 (0.04)
A. opaca	1.42 (0.12)	-0.21 (0.20)	-1.14 (0.38)	-0.68 (0.19)	-0.05 (0.12)	
M. rubratra	1.98 (0.13)	0.3 (0.14)	-0.66 (0.30)	0.38 (0.11)	0.14 (0.09)	
Z. cinereus	1.9 (0.17)	0.24 (0.18)	0.9 (0.21)	-1.3 (0.25)	-0.27 (0.12)	-0.02 (0.03)
R. longirostra	0.36 (0.15)	-0.54 (0.32)	-0.68 (0.41)	-45.8 (200.35)		0.03 (0.04)

Population responses to anthropogenic and climate change

In the final analysis we identified the factors with the greatest potential to affect each species under the range of potential future scenarios. Results for 10 species with predictive density functions provided insight into the magnitude of effect (slope) and the tightness of the association (r^2 value). We simulated 1,000 potential future scenarios, which were each randomly drawn from realistic anthropogenic- and climate-driven condition shifts and from within the ranges of realistic values for Pohnpei. We used top-ranked density model(s) to estimate the spatially explicit bird populations for each scenario. Results indicated that for most species there was one driving factor that was most associated with population declines (Appendix B), but that the primary factors differed among species (Table 9). Results from the entire set of potential future scenarios indicated that, on average, each species was predicted to decline by a mean of 7.6% (SD 9.6%). Predicted population change was most closely associated with sea level rise in all but three species, including *Z. cinereus, R. longirostra* and *R. kubaryi* (Table 9). Population change was most strongly associated with climate-driven vegetation change in *Z. cinereus* (r^2 = 0.36), with the establishment of new agricultural plots in *R. kubaryi* (r^2 = 0.37), and with the expansion of anthropogenic secondary vegetation in *R. longirostra* (r^2 = 0.92).

Most factors were associated with population declines in Pohnpei avifauna populations (Table 9), but in several species there were associations with population increases. There were positive slopes associated with anthropogenic vegetation in *Z. cinereus* (m = 0.069, r^2 = 0.268), *M. pluto* (m = 0.224, r^2 = 0.057), and *P. porphyraceus* (m = 0.001, r^2 = 0.003). The establishment of new patches of secondary vegetation through climate-driven disturbance, was associated with positive population responses in *P. porphyraceus* (m = 0.008, r^2 = 0.006), *R. kubaryi* (m = 0.012, r^2 = 0.094), *M. pluto* (m = 0.052, r^2 = 0.235), and *T. rubiginosus* (m = 0.028, r^2 = 0.013), although relationships were not strong in any but edge-foraging *M. pluto*. The expansion of existing agriculture was associated with population increases in *M. rubrata* (m = 0.022, r^2 = 0.013), *A. opaca* (m = 0.003, r^2 = 0.0003), *P. porphyraceus* (m = 0.007, r^2 = 0.010), and *M. pluto* (m = 0.047, r^2 = 0.026). The establishment of new agriculture patches was associated with population increase *M. rubrata* (m = 0.018, r^2 = 0.011), *A. opaca* (m = 0.007, r^2 = 0.004), *P. porphyraceus* (m = 0.001, r^2 = 0.000), *M. pluto* (m = 0.019, r^2 = 0.031), and *T. rubiginosus* (m = 0.0004, r^2 = 0.005). However, none of the positive relationships were the strongest for any species, suggesting that under any of the potential future scenarios we considered, bird populations were predicted to decline.

Table 8. Pohnpei avian population estimates for surveys conducted in 1983 and 2012. Estimates for 1983 were published by Engbring et al. 1990. Both studies follow variable distance point count protocols. Estimates for 2012 were obtained using package “unmarked” in RStudio (2012).

Species	1983	2012	Pop. % Difference
Z. cinereus	284,858	166235	58.36%
R. longirostra	31,623	36123	114.23%
M. rubratra	358,065	302955	84.61%
T. reichenbachii	12,942	17375	134.25%
D. oceanica	822	5025	611.31%
A. opaca	236,427	115587	48.89%
P. porphyraceus	27,557	18784	68.16%
R. kubaryi	193,579	22263	11.50%
M. pluto	143,579	87242	60.76%
T. rubiginosus	88,107	100803	114.41%

Table 9. Results from regressions relating characteristics of 1,000 simulated landscapes altered by anthropogenic and climate change factors. Simulations applied population density models to each landscape to estimate the total population of each species under the perturbed conditions. Population estimates were then regressed against input values for each factor to identify the magnitude of the relationship (slope) and the strength of the association between factors and population change (r^2). Results are presented below. Negative slope values indicate population declines associated with factors, and higher r^2 values indicate stronger relationships. (*) indicates species largest r^2 value factor.

r^2 values (strength of association)

Species	Anthropogenic Vegetation	New agricultural Establishment	Agricultural Expansion	Vegetation Change	Sea Level Rise
P. porphyraceus	0.001	0.000	0.007	0.006	0.986*
D. oceanica	0.384	0.029	0.050	0.001	0.555*
T. rubiginosus	0.004	0.000	0.001	0.013	0.973*
T. reichenbachii	0.051	0.042	0.005	0.283	0.620*
M. pluto	0.224	0.031	0.047	0.235	0.420*
R. kubaryi	0.012	0.378*	0.313	0.094	0.153
A. opaca	0.381	0.004	0.000	0.104	0.522*
M. rubratra	0.057	0.011	0.013	0.007	0.923*
Z. cinereus	0.268	0.183	0.000	0.358*	0.114
R. longirostra	0.919*	0.001	0.061	0.000	0.003

Slope values (direction and magnitude of association)

Species	Anthropogenic Vegetation	New agricultural Establishment	Agricultural Expansion	Vegetation Change	Sea Level Rise
P. porphyraceus	0.003	0.001	0.010	0.008	-0.106
D. oceanica	-0.121	-0.030	-0.044	-0.006	-0.133
T. rubiginosus	-0.017	0.005	-0.011	0.028	-0.251
T. reichenbachii	-0.036	-0.030	-0.011	-0.077	-0.117
M. pluto	0.057	0.019	0.026	0.052	-0.071
R. kubaryi	-0.005	-0.024	-0.025	0.012	-0.016
A. opaca	-0.080	0.007	0.003	-0.037	-0.086
M. rubratra	-0.046	0.018	0.022	-0.014	-0.168
Z. cinereus	0.069	-0.052	-0.001	-0.072	-0.041
R. longirostra	-0.046	-0.001	-0.012	0.000	-0.003

Analysis and Findings

Population change

Results illustrating bird population declines align with information presented previously for Pohnpei, and for other islands. Banko et al. (2013), Craig (1994) and Amar et al. (2009) reported similar downward trends in bird populations on Hawai'i and Rota, and Buden (2000) reported substantial 67-80% declines in Pohnpei's birds. Buden (2000) reported results over an 11-year period, whereas our results reflect changes across an 18-year period for the same island. Nonetheless, the declines we detected were not as severe as those reported for Pohnpei by Buden (2000), and we report several substantial population increases. Perhaps the rate of decline in Pohnpei bird populations has been reduced in recent years.

The Buden (2000) evaluation of bird population change on Pohnpei between 1983 and 1994 indicated substantial downward trends in all the cited species. His study showed >50% decline in 17 species and >80% decline for *R. longirostra, Z. cinereus* and *Z. semperi*. Among the plausible explanations for change, Buden (2000) identified alterations and reduction of undisturbed forest as a most reasonable cause. During the same time period, human populations on the island increased by c.75% (Department of Economic Affairs 2002), which brought about landscape modification (Trustum 1996). Our results indicated further avian population changes between 1994 and 2012 on Pohnpei. Several general patterns were apparent in our results when compared to those of Buden (2000). When detection rates were analyzed and compared by elevation zone *D. oceanica, Z. cinereus* and *P. porphyraceus* showed larger detection rates in all elevations zones. *M. rubratra* and *A. opaca* only showed detection rates increases above >600m. The endemic *M. pluto* and *R. kubaryi* detection rates showed different patterns, in that *M. pluto* declined in all elevation zones, and *R. kubaryi* declined in mangroves but increased detection rate in all the others elevation zones. Detecting rates for *C. tenuirostris* showed a an increaser in mangroves, between 101-200 m and > 600 m; and detection rates declined at the 401-600 m zone. *Trichoglosus rubiginosus* showed a detection rate increase in mangroves and areas < 100m, nevertheless areas above 100 m showed a mean -50.8% decline. Mangrove habitats, and top elevation zones, are rarely used by Pohnpei residents, which may provide insights into the apparent stability of the areas. Furthermore, declining detection rates for several species in middle and higher elevation zones could indicate populations responses to the use and transformation of Pohnpei highland forest.

To be comparable to earlier efforts, our analysis of historic trends was restricted to the use of detection rates (number of birds detected per unit time) because those were reported for earlier surveys. Unfortunately, the use of detection rates does not provide the flexibility of more recent approaches (e.g. variable distance point transect surveys), and therefore we were restricted in our ability to estimate confidence intervals or make statistical trend assessments. Nonetheless, we worked diligently to ensure that our approach was similar to that used previously. We discussed past surveys with Dr. Buden and others, and we were provided with suggestions for ways in which we could best replicated those works (e.g. D. Buden provided suggestions on survey locations). Thus, although we cannot provide a measure of error for our results, we are confident that the greater patterns illustrated in the three surveys are realistic representations of Pohnpei bird declines.

Habitat associations
Previous studies (Engbring et al. 1990, Buden 2000), suggested that Pohnpei bird populations were distributed differentially about the island, and that there were associations with habitats and regions. Our study further indicates strong habitat associations in nearly every species. For example, *M. pluto, A. opaca, M. rubratra, Z. cinereus*, and *T. rubifinosus* were all strongly associated with undisturbed Pohnpei habitats because occupancy and density functions included significantly positive intercept parameters.

Oceanic island species are often habitat generalists, and some have speculated that the pattern is because in recent evolutionary history they had the ability to colonize islands after dispersal events from source populations (Diamond 1970). Forest birds on oceanic islands are all descendants of dispersers from continental regions. After a viable founder cohort arrived on vacant islands, many species experienced little ecological pressure to drive the sorts of evolutionary specialization characteristic of continental areas (Slikas et al. 2000, Coyne and Price 2000). Somewhat to the contrary, our results indicate that although Pohnpei species are indeed island species with related taxa elsewhere in Oceania, Pohnpei avifauna have apparently specialized on particular suites of ecological characteristics on the island. Further, on an island with low predation pressure (Kesler and Haig 2007c), the substantial coexistence of closely related taxa (*Z. semperi* and *Z. cinereus*, and *R. longirostra*) indicates the types of divergence and ecological specialization illustrated by our models. *Rukia longirostra* was associated with undisturbed climax forest while *Z. cinereus* was associated with undisturbed forest and secondary vegetation as well. Analysis for *R. longirostra* and *R. kubaryi*, both endemic, showed a significant association to undisturbed habitat and habitat edge indicating that the area and habitat matrix is extremely important for their populations.

Factors affecting populations
We studied the potential effects of anthropogenic and climate change on Pohnpei's avifauna by simulating 1,000 possible future landscapes, and then we modeled bird population responses to change with the intent of identifying which factor(s) is/are most likely to affect bird populations under future global change.

Results indicated that sea level rise, and the associated loss of mangrove habitat, was most closely associated with population declines in 7 of the 10 species for which models were developed. Pohnpei boasts some of the most extensive oceanic island mangrove forests in the Pacific. However, mangrove habitats are threatened widely by human overharvest, fragmentation and natural disturbances. Our simulation results seems somewhat counterintuitive, however, because parameters in density functions indicated that only *T. rubiginosus* and *M. rubratra* were predicted to be in higher densities in mangroves than in other habitat types, and yet five other species showed substantial population declines in simulations that included mangrove loss. The simulation model implemented impacts to mangroves with a mechanism that reduced the total island habitat area because impacted mangrove habitats were not converted to other habitat types. On the contrary, the simulation model implemented conversions of undisturbed habitats to secondary vegetation and agricultural vegetation by removing undisturbed habitat and replacing the areas with the alter habitat types.

Our simulations indicated that enlargement of secondary vegetation or establishment of new patches of secondary vegetation in otherwise contiguous undisturbed vegetation has the potential to negatively impact populations of *R. longirostra*, *D. oceanica*, and *A. opaca*. Secondary vegetation is a combination of earlier native colonizers and introduced vegetation, whereas agroforest is fully anthropogenic the removal and fragmentation of undisturbed vegetation for agroforestry also aids to the dispersal of secondary vegetation (Muniappan et al. 2002, Ballick 2009). Secondary vegetation could spread by climate-driven or human-caused disturbances such as wind-throw, single and multiple tree mortality, landslides, or desiccation.

Drought or wildfire may also bring about changes in Pohnpei's vegetation communities that result in secondary vegetation. Pohnpei's unique flora includes > 109 plant species endemic to the island (Merlin and Raynor 2005). The island's vegetative community has evolved under specific climate conditions, including 4.8 m in average rainfall (up to 10 m in higher elevations) and monthly average temperatures varying < 1^{0} C (Laird 1982, Buden 1990, Balick 2009). If global change, including extended drought or increased storm intensity/frequency, became more common on Pohnpei, fires could occur or tree health may decline allowing invasive species to spread (Lohse et al. 1995, Loope and Giambelluca 1998, Banko et al. 2013). In addition, extended drought periods are expected to alter vegetation and arthropod phenology as bird-prey/habitat interaction as well. In Hawai'i the endemic Palila population dynamic was altered when mãmane pods (Palila's chief food source) declined after long drought periods (Lindsey et al. 1997, Banko et al. 2002a, Banko et al. 2013).

The expansion and establishment of new agricultural plots on Pohnpei also has the potential to impact native avifauna. The ecological mechanisms and the functional application in our models were similar to the mechanisms used for the simulating secondary vegetation. Further, within any particular simulation, our implementation prescribed first expanding secondary vegetation and then expanding agricultural plots if substantial undisturbed habitat remained in cells. Thus, the overall impacts of agriculture were likely to be less severe than those of secondary vegetation. Nonetheless, parameter estimates for the model averaged density function for *R. kubaryi* indicate that densities are higher with increased secondary vegetation (although not significantly so), but significantly negatively effected by agricultural forest. Accordingly, results from the spatially explicit simulations of perturbed landscapes indicated that agricultural establishment and expansion is most likely to impact populations of *R. kubaryi*.

Our simulation modeling included 1,000 scenarios with variables randomly drawn from predefined ranges. If simulations were conducted using different ranges of values, or if different rules were included in simulations, different results might be expected. For example, the simulation program first impacted undisturbed habitats with agricultural development and then followed with secondary vegetation. If those two processes had been reversed in the models, perhaps results would have indicated stronger effects of agriculture. Similarly, we restricted the maximum size of new agricultural patches and the establishment of new secondary vegetation patches to 50% of any cell. If those restrictions were altered, we would expect corresponding changes in predicted populations. Nonetheless, because of the strength of the relationship between sea level change (mangrove habitat loss) and population change, we do not anticipate substantial differences in conclusions if the ranges of any factors were reconsidered.

Vulnerable species

Results from our simulations of 1,000 plausible future scenarios indicated that, in order of impact, overall population declines affected *D. oceanica* (mean decline 17% across all scenarios), *T. rubiginosus* (mean -14%), and *T. reichenbachii* (mean -12%) the most; and least effected were *Z. cinereus* (mean -3%), *R. kubaryi* (mean -3%), and *M. pluto* (mean +1%). Our models predicted that two of the most vulnerable populations (*D. oceanica* and *T. reichenbachii*) are also two of the least common species on the island (estimated total populations of 5,025 and 17,375, respectively). Thus, future scenarios causing declines in the birds should be noteworthy so as to avoid placing the populations in danger of extinction. As illustrated above, both species appear particularly susceptible to mangrove losses that may occur with sea level changes. Similarly, *T. rubiginosus*, was predicted to be substantially affected by the loss of mangrove habitats. Unlike territorial species that might suffer population changes in direct proportion to habitat changes (e.g. *T. reichenbachii*), *T. rubigniosus* may not be so closely linked to unit-area changes because the birds range widely (pers. obs). In fact, *T. rubiginosus* is highly mobile and major portions of the population may depend on mangroves during portions of the annual cycle, and then move to uplands at other times. If the birds that we detected in upland areas are also dependent on mangroves during other times, our estimates of population impacts from sea level change are biased low.

Another vulnerable group includes rare species and/or species with small populations. *D. oceanica* and *T. reichenbachii* have the smallest populations and both have strong associations to agroforest and mangroves, respectively. Given that agroforest areas are increasing and mangroves are predicted to be affected by further anthropogenic forces and sea level rise, population management should be considered for these species. On Pohnpei, trail and road construction and the expansion of settlements and agriculture into previously remote areas accelerated the fragmentation of Pohnpei's forests. These processes have the potential to affect both species. Further, *C. tenuirostris* is affected by fire (Valentine et al. 2007) and the associated vegetation disturbances. Pohnpei fires are mostly of anthropogenic origin and occur between January and March. Fires are utilized to maintain and open grasslands and attract the introduced Philippine deer (*Rusa Marianna*). Fires have the potential to affect birds by habitat fragmentation, aiding to invasive species occurrence and altering food availability. Merlin and Raynor (2005) suggest that Pohnpei short-eared owl could be affected the most from this disturbance. Climate-drive changes in precipitation patterns may increase droughts periods allowing locals to use fire more frequently and therefore intensify the impact pressure on island avifauna populations.

Additionally, special attention should be lent to Pohnpei endemic species. Density and occupancy analyses indicated that 4 of 8 species have significant positive associations with undisturbed habitat are endemic to Pohnpei (Table 6 and 7). Occupancy modeling indicated that the volume of undisturbed habitat is associated with *R. kubaryi* presence; and density analysis indicated that undisturbed habitat volume has a significant effect in density estimates for *R. longirostra*, *M. pluto* and *T. rubigniosus*. Compared to the last population estimates *R. kubaryi* (-88.5%) and *M. pluto* (-39.3%) suffered large population declines.

CONCLUSIONS AND RECOMMENDATIONS

We conducted an analysis of avifauna population changes on the island of Pohnpei, Federated States of Micronesia. We surveyed the island using occupancy and density modeling protocol, modeled habitat features associated with species-specific occupancy and density, and then used those models to predict contemporary populations and identify factors likely to drive Pohnpei's bird population changes under a range of potential future conditions. Survey results indicated declines in most Pohnpei bird populations, and that declines are particularly evident in elevation zones between sea level (above mangrove habitats) and < 600 m. These same zones included areas heavily impacted by anthropogenic activities. Similar to results from studies on other Pacific islands, Pohnpei species showed a range of responses to habitat changes, indicating that we cannot attribute population decline to any single factor.

Our results further illustrated habitat associations in many of Pohnpei's species, and they indicated that if habitats are altered by anthropogenic forces, changing climates, or sea level rise, bird populations on the island are likely to be impacted. Under most simulated future scenarios, bird populations declined. When considered as a whole, our simulation results helped to identify that sea level rise is most closely associated with detectable population change in 7 of the 10 Pohnpei bird species for which we could develop density models, and that the expansion of anthropogenic secondary vegetation in areas where impacts already exist, is either first or second most closely associated with population change in 5 of the 10 same species.

Together, our results indicate that Pohnpei avifauna remain sensitive to alterations in habitat, and that future changes to the island landscape brought about by changing climates and increased human populations have the potential to continue impacting Pohnpei avifauna. Thus, practitioners can consider ways to mange for the potential impacts of each force in order to aim conservation efforts at select species of interest. Protection of mangrove habitats seems to be an important first step. We provide additional species-specific information and recommendations in appendix B.

Future research may be aimed at the very rare species that were not addressed in this analysis, most often because they were detected so rarely that quantitative models did not converge. Additional work might also address habitat-species interactions, species-specific studies of movement, and interspecific interaction, especially for endemic species and those with very small populations.

OUTREACH

Our work has already extended to local conservation and governmental entities on the island of Pohnpei and elsewhere. The 2012 bird surveys were conducted in conjunction with the Conservation Society of Pohnpei (CSP), which provided local guides, ground support, and invaluable information on Pohnpei. Prior to our arrival, CSP coordinated with the Pohnpei State Department of Forestry, and major traditional leaders to provide support and land access. Those early contacts fostered connections and project participation from many who later took ownership of portions of the program. Outreach activates were exemplified by:

1. 2011-2012 Conservation Society of Pohnpei Annual Report: we officially presented our project to the people of Pohnpei, community chiefs and to CSP partners in conservation.
2. Radio broadcast: to reach the general public a communication letter describing our project was broadcasted on the local radio station before and during our survey.
3. Memorandums: we provided published materials to landowners and general public during surveys, which described how and why surveys were occurring.
4. In partnership with CSP we provided an Avian and Vegetation Survey Technique Workshop for CSP Terrestrial Department and Pohnpei Department of Land and Natural Resources officers. The workshop included:
    - Basic avian survey techniques (e.g., variable-distance point counts)
    - Radio telemetry example for various taxa

- Vegetation survey techniques, including plan identification, and forest measure data collection

Preliminary project results were presented directly to local conservation practitioners and other interests at various professional meetings and public talks including:

1. Oleiro, P. C., D. C. Kesler and E. Joseph. 2013. Pohnpei 2012 bird survey preliminary analysis and avian population responses to climate change and anthropogenic landscape alterations. Presentation given at the Governors Palace, Kolonia, Pohnpei, Federated States of Micronesia. (invited oral presentation).
2. Oleiro, P. C. and D. C. Kesler. 2013. Avian Population Responses to Climate Change and Anthropogenic Landscape Alterations in Pohnpei, Micronesia. Presentation given at the 1st PICSC/PICCC Science Review Symposium, Honolulu, HI.
3. Oleiro, P. C. and D. C. Kesler. 2013. Pohnpei 2012 bird survey preliminary analysis and avian population responses to climate change and anthropogenic landscape alterations in Pohnpei, Micronesia. Presentation given at the U.S. Fish and Wildlife Service Pacific Region Office, Honolulu, HI. (national oral presentation).
4. Oleiro, P. C. and D. C. Kesler. 2013. Avian ecological response to anthropogenic and climate changes in an oceanic landscape. American Ornithologists Union and Cooper Ornithological Society Joint Meeting, Chicago, Il. (national oral presentation).
5. Oleiro, P. C. and D. C. Kesler. 2013. Avian ecological response to anthropogenic and climate changes in an oceanic landscape. River Bluffs Audubon Society. Guess speaker. Jefferson City, MO, USA. (regional oral presentation).

Finally, project findings will be shared with the scientific community and conservation organizations including PICCC, Birdlife International and CSP. Findings are considered to be part of at least two chapters of Pablo C. Oleiro M.S. thesis at the Fisheries and Wildlife Department, University of Missouri. Currently, three peer review publications are being develop from the data obtained and analysis conducted.

ACKNOWLEDGMENTS

We thank everyone who has helped make this a successful project. Thank you to Pacific Islands Climate Change Cooperative and to University of Missouri for sponsoring this research. We thank the members of partnering organizations including Conservation Society of Pohnpei and College of Micronesia. Individuals from each provided valuable help and local knowledge, especially to F. Sohl Obispo, E. Joseph, R. Andreas, N. Daniel, R. Lengsi, P. Eperiam, A. Jonathan, K. Olpet, L. Yamada and P. Shed. Field technicians A. Yorks, E. Buechley and J. Drake were key to data successes. We thank D. Buden for sharing his knowledge regarding Pohnpei biota and his experiences with previous surveys, and W. Raynor for his unwavering support of our efforts with Pohnpei conservation projects. Residents of Pohnpei made our experience and work possible and they shared valuable insights. We thank everyone who reviewed drafts and provided constructive criticism. Finally we extend our gratitude to fellow graduate students, office mates and lab members R. Stanton, J. Cunningham, A. McKellar, W. Beaty, A. Alba, S. Pennington, C. Starbuck, M. Roach, K. Womack and E. Pherigo. Special thanks to N. Sievert, S. Kendrick and F. Thompson who provided invaluable technical guidance with data analyses.

LITERATURE CITED

Amar, A., F. Amidon, B. Arroyo, J. A. Esselstyn, and A. P. Marshall. 2008. Population trends of the forest bird community on the Pacific island of Rota, Mariana Islands. The Condor, 110:421-427.

Australian Bureau of Meteorology and CSIRO. 2011. Climate Change in the Pacific: Scientific Assessment and New Research. Volume 1: Regional Overview. Volume 2: Country Reports.

Baker, N., M. Beger, C. McClennen, A. Ishoda, and F. Edwards. 2011. Reimaanlok: A National Framework for Conservation Area Planning in the Marshall Islands. Journal of Marine Biology 2011, 1:11.

Baker, R. H. 1951. The avifauna of Micronesia, its origin, evolution, and distribution. University of Kansas. Museum Natural History, Lawrence, Kansas, USA.

Balick, M. J. 2009. Ethnobotany of Pohnpei: Plants, people, and island culture. Philosophy East and West. University of Hawai'i Press, Honolulu, Hawai'i, USA.

Banko, P. C., P. T. Oboyski, J. W. Slotterback, S. J. Dougill, D. M. Goltz, L. Johnson, M. E. Laut, and T. Colleen Murray. 2002. Availability of food resources, distribution of invasive species, and conservation of a Hawaiian bird along a gradient of elevation. Journal of Biogeography 29:789-808.

Banko, P. C., R. J. Camp, C. Farmer, K. W. Brinck, D. L. Leonard, and R. M. Stephens. 2013. Response of palila and other subalpine Hawaiian forest bird species to prolonged drought and habitat degradation by feral ungulates. Biological Conservation 157:70-77.

Bartoń, K. 2012. MuMIn: multi-model inference. R package version, *1*(2).

Bayley, P. B., and J. T. Peterson. 2001. An approach to estimate probability of presence and richness of fish species. Transactions of the American Fisheries Society 130:620-633.

Blackburn, T. M., P. Cassey, R. P. Duncan, K. L. Evans, and K. J. Gaston. 2004. Avian extinction and mammalian introductions on oceanic islands. Science, 305:1955-1958.

Brosi, B. J., M. J. Balick, R. Wolkow, R. Lee, M. Kostka, W. Raynor, and D. LEE LING. 2007. Cultural Erosion and Biodiversity: Canoe-Making Knowledge in Pohnpei, Micronesia. Conservation Biology 21: 875-879.

Buden, D. W. 2000. A comparison of 1983 and 1994 bird surveys of Pohnpei, Federated States of Micronesia. The Wilson Bulletin 112:403-410.

Buckland, S. T., D. R. Anderson, K. P. Burnham, J. L. Laake, D. L. Borchers, and L. Thomas. 2001. Introduction to Distance Sampling: Estimating Abundance of Biological Populations. Oxford University Press, Oxford, United Kingdom.

Burnham, K. P., and D. R. Anderson. 2004. Multimodel inference understanding AIC and BIC in model selection. Sociological methods & research, 33:261-304.

Chowdhury, M. R., P. S. Chu, X. Zhao, T. A. Schroeder, and J. J. Marra. 2010. Sea level extremes in the US-Affiliated Pacific Islands—a coastal hazard scenario to aid in decision analyses. Journal of Coastal Conservation 14: 53-62.

Denslow, J. S. 2003. Weeds in paradise: thoughts on the invasibility of tropical islands. Annals of the Missouri Botanical Garden 90:119-127.

Department of Economic Affairs, Federated States of Micronesia. 2002. Federated States of Micronesia: 2000 Populationand Housing Census Report. FSM National Government. Federated States of Micronesia.

Dorazio, R. M., J. A. Royle, B. Söderström, and A. Glimskär. 2006. Estimating species richness and accumulation by modeling species occurrence and detectability. Ecology 87:842-854.

Engbring, J., F. L. Ramsey, and V. J. Wildman. 1990. Micronesian forest bird surveys, the federated states: Pohnpei, Kosrae, Chuuk, and Yap. Report to the U.S. Fish and Wildlife Service. U.S. Fish and Wildlife Service, Honolulu, Hawai'i, USA.

ESRI 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.

Frankham, R. 1998. Inbreeding and extinction: island populations. Conservation Biology 12:665-675.

Fiske, I. and R. Chandler. 2011. unmarked: An R package for fitting hierarchical models of wildlife occurrence and abundance. Journal of Statistical Software, 43:1-23.

Gaston, K. J., T. M. Blackburn, and K. K. Goldewijk. 2003. Habitat conversion and global avian biodiversity loss. Proceedings of the Royal Society of London. Series B: Biological Sciences, 270:1293-1300.

Griffiths, G. M., M. J. Salinger , and I. Leleu. 2003. Trends in extreme daily rainfall across the South Pacific and relationship to the South Pacific Convergence Zone. International Journal of Climatology 23: 847-869.

IUCN 2013. IUCN Red List of Threatened Species. 2013.2. <www.iucnredlist.org>. Accessed 9 Dec 2013.

Jankowski, J. E., S. K. Robinson, and D. J. Levey. 2010. Squeezed at the top: interspecific aggression may constrain elevational ranges in tropical birds. Ecology 91:1877-1884.

Kauffman, J. B., and T. G. Cole. 2010. Micronesian mangrove forest structure and tree responses to a severe typhoon. Wetlands 30:1077-1084.

Kéry, M. 2002. Inferring the absence of a species-a case study of snakes. Journal Wildlife Management 66: 330_ 338.

Kesler, D.C. 2002. Nest Site selection in cooperatively breeding Pohnpei Micronesian Kingfishers (*Halcyon cinnamomina reichenbachii*). Does nest-site abundance limit reproductive opportunities? Dissertation, Oregon State University, Corvallis, USA.

Kesler, D. C., and S. M. Haig. 2007. Territoriality, prospecting, and dispersal in cooperatively breeding Micronesian Kingfishers (*Todiramphus cinnamominus reichenbachii*). The Auk 124:381-395.

Kesler, D. C., and S. M. Haig. 2007a. Multi-scale resource use and selection in

cooperatively breeding Micronesian Kingfishers. Journal of Wildlife Management 71:765-772.
Kesler, D. C., and S. M. Haig. 2007b. Territoriality, prospecting, and dispersal in cooperatively breeding Micronesian Kingfishers. Auk 124:381-395.
Kesler, D. C., and S. M. Haig. 2007c. Conservation biology for suites of species: demographic modeling for the Pacific island kingfishers. Biological Conservation 136:520-530.
Kesler, D. C., R. J. Laws, A. S. Cox, A. Gouni, and J. D. Stafford. 2012. Survival, territory resources, and population persistence in the critically endangered Tuamotu Kingfisher. Journal of Wildlife Management 76:1001-1009.
Laird, W. E. 1982. Soil survey of island of Pohnpei, Federated States of Micronesia. U.S. Department of Agriculture, Soil Conservation Service. U.S. Government Printing Office. Washington, D.C.

Lee, R. A., M. J. Balick, D. L. Ling, F. Sohl,B. J. Brosi, and W. Raynor. 2001. Cultural dynamism and change—an example from the Federated States of Micronesia. Economic Botany 55: 9-13.

Lemmon, P. E. 1956. A spherical densiometer for estimating forest overstory density. Forest Science 2:314-320.

Lindsey, G. D., T. K. Pratt, M. H. Reynolds, and J. D. Jacobi. 1997. Response of six species of Hawaiian forest birds to a 1991-1992 El Niño drought. The Wilson Bulletin 109:339-343.

Lohse, K. A., D. Nulle, and P. M. Vitousek. 1995. 'The Effects of an Extreme Drought on the Vegetation of a Single Lava Flow on Mauna Loa, Hawaii', Pacific Science. 49, 212–220.

Loope, L. L., and T. W. Giambelluca. 1998. Vulnerability of island tropical montane cloud forests to climate change, with special reference to East Maui, Hawaii. Climatic Change 39: 503-517.

Lusk, M., S. Hess, M. Reynolds, S. Johnson. 2000. Population status of the Tinian monarch (Monarcha tatatsukasae) on Tinian, Commonwealth of the Northern Mariana Islands. Micronesica-Agana 32:181-190.

MacArthur, R. H., and E. O. Wilson. 1967. The theory of island biogeography. Princeton University Press, Princeton, New Jersey, USA.

MacKenzie, D. I., J. D. Nichols, G. B. Lachman, S. Droege, J. Andrew Royle, and C. A. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83:2248-2255.

MacKenzie, D. I. 2005. Occupancy estimation and modeling: inferring patterns and dynamics of species occurrence. Elsevier, San Diego, California, USA.

MacLean, C. D., T.G. Cole, C.D. Whitesell, M. V. Falanruw, and A. H. Ambacher. 1986. Vegetation survey of Pohnpei, Federated States of Micronesia. Pacific Southwest Forest and Range Experiment Station. Forest Service, U.S. Department of Agriculture, Berkeley, California.

Manton, M. J., P. M. Della-Marta, M. R. Haylock, K. J. Hennessy, N. Nicholls, L.E. Chambers, and D. Yee. 2001. Trends in extreme daily rainfall and temperature in Southeast Asia and the South Pacific: 1961–1998. International Journal of Climatology 21:269-284.

McNab, B. K. 2009. Ecological factors affect the level and scaling of avian BMR. Comparative Biochemistry and Physiology 152:22-45.

Merlin, M., D. Jano, W. Raynor, T. Keene, J. Juvik, and B. Sebastian.1992. Tuhke en Pohnpei [Plants of Pohnpei]. Environment and Policy Institute of the East-West Center, Honolulu, Hawai'i, USA.

Merlin, M., and W. Raynor. 2005. Kava cultivation, native species conservation, and integrated watershed resource management on Pohnpei Island. Pacific Science 59:241-260.

Murcia, C.1995. Edge effects in fragmented forests: implications for conservation. Trends in Ecology & Evolution 10:58-62.

Muniappan, R., J. Cruz, and J. Bamba. 2002. Invasive plants and their control in Micronesia. Micronesia-Agana 35:85-92.

Myers, N. 1979. The sinking ark. A new look at the problem of disappearing species. Pergamon Press, New York, New York, USA.

Myers, N., R. A. Mittermeier, C. G. Mittermeier, G. A. Da Fonseca, and J. Kent. 2000. Biodiversity hotspots for conservation priorities. Nature 403:853-858.

Naylor, R. L., K. M. Bonine, K. C. Ewel, and E. Waguk. 2002. Migration, markets, and mangrove resource use on Kosrae, Federated States of Micronesia. AMBIO: A Journal of the Human Environment 31:340-350.

Pratt, H. D., P. L. Bruner, and D. G. Berrett. 1987. A field guide to the birds of Hawaii and the tropical Pacific. Princeton University Press, Princeton, New Jersey, USA.

Raynor, B. 1994. Resource management in upland forests of Pohnpei: Past practices and future possibilities. Journal of Micronesian Studies 2:47-66.

Reynolds, R. T., J. M. Scott, and R. A. Nussbaum. 1980. A variable circular-plot method for estimating bird numbers. Condor 82:309-313.

Royle, J. A., and J. D. Nichols. 2003. Estimating abundance from repeated presence-absence data or point counts. Ecology 84:777-790.

RStudio (2012). RStudio: Integrated development environment for R (Version 0.96.122) [Computer software]. Boston, MA. Retrieved May September 15, 2012.

Saunders, D. A., R. J. Hobbs, and C. R. Margules. 1991. Biological consequences of ecosystem fragmentation: a review. Conservation biology 5:18-32.

Spennemann, D. H. 2009. Hindcasting typhoons in Micronesia: Experiences from ethnographic and historic records. Quaternary International, 195:106-121.

Steadman, D. W., T. W. Stafford, D. J. Donahue, and A. J. T. Jull. 1991. Chronology of Holocene vertebrate extinction in the Galápagos Islands. Quaternary research, 36:126-133.

Steadman, D. W. 2006. Extinction and biogeography of tropical Pacific birds. University of Chicago Press, Chicago, Illinois, USA.

Şekercioğlu, Ç. H., R. B. Primack, and J. Wormworth. 2012. The effects of climate change on tropical birds. Biological Conservation 148:1-18.

Team R. D. C. 2012.R: A language and environment for statistical computing. Viena, Austria: R Foundation for Statistical Computing. Retrieved from http://www.R-project.org

Temple, S. 1985. Why endemic island birds are so vulnerable to extinction. Bird conservation 2:3-6.

Timm, O., and H. F. Diaz. 2009. Synoptic-Statistical Approach to Regional Downscaling of IPCC Twenty-First-Century Climate Projections: Seasonal Rainfall over the Hawaiian Islands. Journal of Climate 22:4261-4280.

Trustum, N. A. 1996. Pohnpei's watershed spatial plan and management guidelines. Landcare Research, New Zealand, Ltd. Palmerston North, New Zealand.

United States Department of Agriculture Forest Service. 2005. Federated States of Micronesia Historic Vegetation Digitization Project. USDA Remote Sensing Applications Center, Salt Lake City, UT.

Valentine, L. E., L. Schwarzkopf, C. N. Johnson, and A. C. Grice. 2007. Burning season influences the response of bird assemblages to fire in tropical savannas. Biological Conservation 137:90-101.

Watson, J. E., R. J. Whittaker, and T. P. Dawson. 2004. Habitat structure and proximity to forest edge affect the abundance and distribution of forest-dependent birds in tropical coastal forests of southeastern Madagascar. Biological Conservation 120:311-327.

Wensel, L. C., J. Levitan, and K. Barber.1980. Selection of basal area factor in point sampling. Journal of Forestry 78:83-84.

Wisdom, M. J., and L. S. Mills. 1997. Sensitivity analysis to guide population recovery: prairie-chickens as an example. Journal of Wildlife Management 61:302–312.

Wisdom, M. J., L. S. Mills, and D. F. Doak. 2000. Life-stage simulation analysis: estimating vital-rate effects on population growth for conservation. Ecology 81:628–641.

Wilson, E. O. 2002. The future of life. Knopf, New York, New York, USA.

APPENDIX A. TOP-RANKED OCCUPANCY AND DENSITY MODELS

Table A1. Top-ranked density (λ) function models for 10 species of birds from the island of Pohnpei, Federated States of Micronesia. Models were developed using point-transect survey data collected in 2012. Models were developed in a 2-stage process that included identifying a detection function (p), and then in a second-stage analysis to identify the density function associated with biologically relevant factors. All possible combinations of variables were considered, and those within 2 AICc units (Δ AICc < 2) were considered to compete for best approximating. Only competing models are included below.

	Ptilinopus porphyraceus			**K**	**AICc**	**Δ AICc**	w_i
p	*(ObsE+ObsJ+ObsP)*	λ	(Mangrove)	6	1954	0	0.247
p	*(ObsE+ObsJ+ObsP)*	λ	(Mangrove+PN)	7	1955.1	1.05	0.146
p	*(ObsE+ObsJ+ObsP)*	λ	(Mangrove+LNEdge)	7	1955.8	1.8	0.1
p	*(ObsE+ObsJ+ObsP)*	λ	(Mangrove+SecVeg)	7	1956	1.97	0.093

	Ducula oceanica			**K**	**AICc**	**Δ AICc**	w_i
p	*(ObsE+ObsJ+ObsP+Wind)*	λ	(Mangrove+SecVeg+AgroFo)	9	472.3	0	0.242
p	*(ObsE+ObsJ+ObsP+Wind)*	λ	(Mangrove+SecVeg+AgroFo+LNEdge)	10	472.5	0.22	0.216
p	*(ObsE+ObsJ+ObsP+Wind)*	λ	(Mangrove+SecVeg+AgroFo+LNEdge+PN)	11	473.9	1.56	0.111
p	*(ObsE+ObsJ+ObsP+Wind)*	λ	(Mangrove+AgroFo+LNEdge+PN)	10	473.9	1.63	0.107
p	*(ObsE+ObsJ+ObsP+Wind)*	λ	(Mangrove+SecVeg+AgroFo+PN)	10	474.1	1.74	0.101
p	*(ObsE+ObsJ+ObsP+Wind)*	λ	(Mangrove+AgroFo+PN)	9	474.1	1.81	0.098

	Trichoglossus rubiginosus (E)			**K**	**AICc**	**Δ AICc**	w_i
p	*(ObsE+ObsJ+ObsP+Wind)*	λ	(Mangrove+SecVeg+AgroFo+PN)	10	1371.2	0	0.119
p	*(ObsE+ObsJ+ObsP+Wind)*	λ	(Mangrove+AgroFo+PN)	9	1371.2	0.07	0.115
p	*(ObsE+ObsJ+ObsP+Wind)*	λ	(Mangrove)	7	1371.2	0.08	0.115
p	*(ObsE+ObsJ+ObsP+Wind)*	λ	(Mangrove+AgroFo)	8	1371.5	0.3	0.103
p	*(ObsE+ObsJ+ObsP+Wind)*	λ	(Mangrove+SecVeg+AgroFo+LNEdge+PN)	11	1371.8	0.63	0.087
p	*(ObsE+ObsJ+ObsP+Wind)*	λ	(Mangrove+AgroFo+LNEdge+PN)	10	1372	0.82	0.079
p	*(ObsE+ObsJ+ObsP+Wind)*	λ	(Mangrove+PN)	8	1372.2	1.06	0.07
p	*(ObsE+ObsJ+ObsP+Wind)*	λ	(Mangrove+SecVeg)	8	1373.1	1.9	0.046
p	*(ObsE+ObsJ+ObsP+Wind)*	λ	(Mangrove+LNEdge)	8	1373.1	1.93	0.045
p	*(ObsE+ObsJ+ObsP+Wind)*	λ	(Mangrove+SecVeg+AgroFo)	9	1373.1	1.97	0.045

	Todiramphus reichenbachii (E)			**K**	**AICc**	**Δ AICc**	w_i
p	*(ObsE+ObsJ+ObsP+Wind)*	λ	(Mangrove+PN)	8	2363.6	0	0.394
p	*(ObsE+ObsJ+ObsP+Wind)*	λ	(Mangrove+SecVeg+PN)	9	2365.5	1.93	0.15
p	*(ObsE+ObsJ+ObsP+Wind)*	λ	(Mangrove+AgroFo+PN)	9	2365.5	1.95	0.148

	Myiagra pluto (E)			**K**	**AICc**	**Δ AICc**	w_i
p	*(ObsE+ObsJ+ObsP)*	λ	(Mangrove+PN)	7	999.7	0	0.136
p	*(ObsE+ObsJ+ObsP)*	λ	(Mangrove+SecVeg)	7	999.8	0.04	0.133
p	*(ObsE+ObsJ+ObsP)*	λ	(Mangrove)	6	1000.1	0.43	0.109
p	*(ObsE+ObsJ+ObsP)*	λ	(Mangrove+SecVeg+PN)	8	1000.7	0.99	0.083
p	*(ObsE+ObsJ+ObsP)*	λ	(Mangrove+LNEdge+PN)	8	1000.8	1.05	0.081
p	*(ObsE+ObsJ+ObsP)*	λ	(Mangrove+AgroFo+PN)	8	1001.1	1.36	0.069
p	*(ObsE+ObsJ+ObsP)*	λ	(Mangrove+SecVeg+LNEdge)	8	1001.5	1.74	0.057
p	*(ObsE+ObsJ+ObsP)*	λ	(Mangrove+SecVeg+LNEdge+PN)	9	1001.7	1.96	0.051

	Rhipidura kubaryi (E)			**K**	**AICc**	**Δ AICc**	w_i
p	*(Wind)*	λ	(Mangrove+AgroFo)	5	649	0	0.251
p	*(Wind)*	λ	(Mangrove+AgroFo+LNEdge)	6	649.9	0.89	0.161
p	*(Wind)*	λ	(Mangrove+SecVeg+AgroFo)	6	650.8	1.8	0.102

	Aplonis opaca			**K**	**AICc**	**Δ AICc**	w_i
p	*(Null)*	λ	(Mangrove+SecVeg)	4	1473.5	0	0.327
p	*(Null)*	λ	(Mangrove+SecVeg+AgroFo)	5	1474.4	0.97	0.202
p	*(Null)*	λ	(Mangrove+SecVeg+PN)	5	1475.4	1.92	0.125

	Myzomela rubratra			**K**	**AICc**	**Δ AICc**	w_i
p	*(Null)*	λ	(Mangrove+SecVeg+AgroFo)	5	2070.5	0	0.254
p	*(Null)*	λ	(Mangrove+SecVeg+AgroFo+PN)	6	2070.9	0.38	0.21
p	*(Null)*	λ	(Mangrove+SecVeg+PN)	5	2072.1	1.53	0.118

	Zosterops cinereus			**K**	**AICc**	**Δ AICc**	w_i
p	*(ObsE+ObsJ+ObsP)*	λ	(Mangrove+SecVeg+PN)	8	1661	0	0.325
p	*(ObsE+ObsJ+ObsP)*	λ	(Mangrove+SecVeg+AgroFo+PN)	9	1661.4	0.42	0.263
p	*(ObsE+ObsJ+ObsP)*	λ	(Mangrove+SecVeg+LNEdge+PN)	9	1662.6	1.58	0.147

	Rukia longirostra (E)			**K**	**AICc**	**Δ AICc**	w_i
p	*(ObsE+ObsJ+ObsP+Rain)*	λ	(Mangrove+SecVeg+AgroFo)	9	944	0	0.183
p	*(ObsE+ObsJ+ObsP+Rain)*	λ	(Mangrove+AgroFo)	8	945	1.01	0.111
p	*(ObsE+ObsJ+ObsP+Rain)*	λ	(Mangrove+SecVeg)	8	945.5	1.41	0.09
p	*(ObsE+ObsJ+ObsP+Rain)*	λ	(Mangrove+SecVeg+AgroFo+LNEdge)	10	945.5	1.47	0.088
p	*(ObsE+ObsJ+ObsP+Rain)*	λ	(Mangrove)	7	946	1.98	0.068

Table A2. Top-ranked occupancy (*Ψ*) function models for 13 species of birds from the island of Pohnpei, Federated States of Micronesia. Models were developed using repeated survey data collected in 2012. Models were developed in a 2-stage process that included identifying a detection function (*p*), and then in a second-stage analysis to identify the occcupancy function associated with biologically relevant factors. All possible combinations of variables were considered, and those within 2 AICc units (Δ AICc < 2) were considered to compete for best approximating. Only competing models are included below.

	Ptilinopus porphyraceus			**K**	**AICc**	**Δ AICc**	w_i
p	*(Obs+Wind+Rain+Time)*	*Ψ*	(Null)	8	470.6	0	0.204
p	*(Obs+Wind+Rain+Time)*	*Ψ*	(Mangrove)	9	472.5	1.93	0.078

	Ducula oceanica			**K**	**AICc**	**Δ AICc**	w_i
p	*(Obs)*	*Ψ*	(PN+CanCvr+CanHt)	8	769.5	0	0.052
p	*(Obs)*	*Ψ*	(SecVeg+PN+CanCvr+CanHt)	9	770	0.48	0.041
p	*(Obs)*	*Ψ*	(Mangrove+PN+CanCvr+CanHt)	9	770.2	0.7	0.037
p	*(Obs)*	*Ψ*	(PN+StockRt+CanCvr+CanHt)	9	770.3	0.78	0.036
p	*(Obs)*	*Ψ*	(AgroFo+PN+CanCvr+CanHt)	9	770.3	0.82	0.035
p	*(Obs)*	*Ψ*	(SecVeg+AgroFo+PN+CanCvr+CanHt)	10	770.5	0.98	0.032
p	*(Obs)*	*Ψ*	(SecVeg+AgroFo+CanCvr+CanHt)	9	770.7	1.21	0.029
p	*(Obs)*	*Ψ*	(SecVeg+PN+StockRt+CanCvr+CanHt)	10	771	1.45	0.025
p	*(Obs)*	*Ψ*	(CanCvr+StockRt+Canopy+SevVeg)	9	771	1.47	0.025
p	*(Obs)*	*Ψ*	(SecVeg+AgroFo+StockRt+CanCvr+CanHt)	10	771	1.49	0.025
p	*(Obs)*	*Ψ*	(PN+StockRt+CanHt)	8	771	1.53	0.024
p	*(Obs)*	*Ψ*	(Mangrove+SecVeg+AgroFo+CanCvr+CanHt)	10	771.1	1.59	0.024
p	*(Obs)*	*Ψ*	(AgroFo+StockRt+CanCvr+CanHt)	8	771.3	1.78	0.022
p	*(Obs)*	*Ψ*	(AgroFo+PN+StockRt+CanCvr+CanHt)	10	771.3	1.81	0.021
p	*(Obs)*	*Ψ*	(SecVeg+AgroFo+LNEdge+StockRt+CanCvr+CanHt)	8	771.4	1.88	0.021
p	*(Obs)*	*Ψ*	(Mangrove+PN+StockRtt+CanCvr+CanHt)	10	771.4	1.88	0.021
p	*(Obs)*	*Ψ*	(Mangrove+AgroFo+PN+CanCvr+CanHt)	10	771.4	1.91	0.02
p	*(Obs)*	*Ψ*	(SecVeg+AgroFo+StockRt+CanCvr+CanHt)	8	771.4	1.91	0.02

	Trichoglossus rubiginosus			**K**	**AICc**	**Δ AICc**	w_i
p	*(Obs)*	*Ψ*	(Mangrove+SecVeg+StockRt+CanHt)	9	1149	0	0.251
p	*(Obs)*	*Ψ*	(Mangrove+StockRt+CanHt)	8	1150.7	1.64	0.111
p	*(Obs)*	*Ψ*	(Mangrove+SecVeg+StockRt+CanCvr+CanHt)	10	1150.9	1.86	0.099
p	*(Obs)*	*Ψ*	(Mangrove+SecVeg+LNEdge+StockRt+CanHt)	10	1150.9	1.87	0.099
p	*(Obs)*	*Ψ*	(Mangrove+SecVeg+AgroFo+StockRt+CanHt)	10	1151	1.91	0.096

	Todiramphus reichenbachii			K	AICc	Δ AICc	w_i
p	*(Day+Wind+Rain+Time)*	*Ψ*	(Mangrove+StockRt+CanHt)	9	1183.5	0	0.193
p	*(Day+Wind+Rain+Time)*	*Ψ*	(Mangrove+SecVeg+StockRt+CanHt)	10	1184	0.54	0.148

	Coracina tenuirostris			K	AICc	Δ AICc	w_i
p	*(Day+Wind+Obs)*	*Ψ*	(CanCvr+CanHt)	9	268.3	0	0.08
p	*(Day+Wind+Obs)*	*Ψ*	(CanCvr)	8	269.5	1.19	0.044
p	*(Day+Wind+Obs)*	*Ψ*	(SecVeg+CanCvr+CanHt)	10	269.8	1.47	0.038
p	*(Day+Wind+Obs)*	*Ψ*	(LNEdge+CanCvr+CanHt)	10	269.9	1.54	0.037
p	*(Day+Wind+Obs)*	*Ψ*	(Null)	7	269.9	1.55	0.037
p	*(Day+Wind+Obs)*	*Ψ*	(AgroFo+CanCvr+CanHt)	10	270	1.68	0.035
p	*(Day+Wind+Obs)*	*Ψ*	(StockRt+CanCvr+CanHt)	10	270.2	1.91	0.031

	Myiagra pluto			K	AICc	Δ AICc	w_i
p	*(Day+Rain+Obs)*	*Ψ*	(AgroFo+StockRt+CanCvr+CanHt)		1330	0	0.367

	Rhipidura kubaryi			K	AICc	Δ AICc	*Wi*
p	*(Time+Clouds+Obs)*	*Ψ*	(Mangrove+AgroFo+LNEdge+CanHt)	12	1160.5	0	0.196
p	*(Time+Clouds+Obs)*	*Ψ*	(Mangrove+AgroFo+StockRt+LNEdge+CanHt)	13	1161.4	0.93	0.123
p	*(Time+Clouds+Obs)*	*Ψ*	(Mangrove+LNEdge+CanHt)	11	1162	1.54	0.091
p	*(Time+Clouds+Obs)*	*Ψ*	(Mangrove+AgroFo+LNEdge+Canopy+SecVEg)	13	1162.2	1.74	0.082
p	*(Time+Clouds+Obs)*	*Ψ*	(Mangrove+SecVeg+AgroFo+LNEdge+CanCvr+CanHt)	13	1162.4	1.9	0.076

	Acrocephalus syrinx			K	AICc	Δ AICc	*Wi*
p	*(Day+Wind+Obs)*	*Ψ*	(CanCvr+CanHt)	9	268.3	0	0.08
p	*(Day+Wind+Obs)*	*Ψ*	(CanHt)	8	269.5	1.19	0.044
p	*(Day+Wind+Obs)*	*Ψ*	(SecVeg+CanCvr+CanHt)	10	269.8	1.47	0.038
p	*(Day+Wind+Obs)*	*Ψ*	(LNEdge+CanCvr+CanHt)	10	269.9	1.54	0.037
p	*(Day+Wind+Obs)*	*Ψ*	(Null)	7	269.9	1.55	0.037
p	*(Day+Wind+Obs)*	*Ψ*	(AgroFo+CanCvr+CanHt)	10	270	1.68	0.035
p	*(Day+Wind+Obs)*	*Ψ*	(StockRt+CanCvr+CanHt)	10	270.2	1.91	0.031

	Aplonis opaca			K	AICc	Δ AICc	*Wi*
p	*(Rain+Clouds)*	*Ψ*	(Mangrove+CanHt)	6	1065.5	0	0.203
p	*(Rain+Clouds)*	*Ψ*	(Mangrove)	5	1067.2	1.71	0.086

	Myzomela rubratra			K	AICc	Δ AICc	w_i
p	*(Rain+Noise)*	*Ψ*	(Mangrove)	5	354.8	0	0.124

	Zosterops semperi			**K**	**AICc**	**Δ AICc**	w_i
p	*(Noise+Obs)*	Ψ	(Mangrove+AgroFo+CanCvr+PN)	10	614.1	0	0.113
p	*(Noise+Obs)*	Ψ	(Mangrove+AgroFo+PN)	9	614.2	0.07	0.109
p	*(Noise+Obs)*	Ψ	(Mangrove+SecVeg+AgroFo+PN)	10	615.1	0.96	0.07
p	*(Noise+Obs)*	Ψ	(Mangrove+CanCvr+PN)	9	615.6	1.46	0.054
p	*(Noise+Obs)*	Ψ	(Mangrove+AgroFo)	8	615.8	1.64	0.05
p	*(Noise+Obs)*	Ψ	(Mangrove+SecVeg+AgroFo+CanCvr+PN)	11	616.1	1.94	0.043

	Zosterops cinereus			**K**	**AICc**	**Δ AICc**	w_i
p	*(Day+Noise+Clouds+Obs)*	Ψ	(Mangrove+SecVeg+StockRt)	11	1182.2	0	0.113
p	*(Day+Noise+Clouds+Obs)*	Ψ	(Mangrove+SecVeg+CanCvr+StockRt)	12	1182.4	0.21	0.102
p	*(Day+Noise+Clouds+Obs)*	Ψ	(Mangrove+SrockRt)	10	1182.8	0.65	0.082
p	*(Day+Noise+Clouds+Obs)*	Ψ	(Mangrove+SecVeg+AgroFo+StockRt)	12	1183.8	1.59	0.051
p	*(Day+Noise+Clouds+Obs)*	Ψ	(Mangrove+CanCvr+StockRt)	11	1183.8	1.61	0.051
p	*(Day+Noise+Clouds+Obs)*	Ψ	(Mangrove+SecVeg+StockRt+PN)	12	1184.1	1.9	0.044

	Rukia longirostra (E)			**K**	**AICc**	**Δ AICc**	w_i
p	*(Day+Time+Clouds+Obs)*	Ψ	(Mangrove+LNEdge+CanCvr)	11	971.8	0	0.119
p	*(Day+Time+Clouds+Obs)*	Ψ	(Mangrove+LNEdge+CanCvr+PN)	12	972.8	0.95	0.074
p	*(Day+Time+Clouds+Obs)*	Ψ	(Mangrove+LNEdge+CanCvr+CanHt)	12	973	1.18	0.066
p	*(Day+Time+Clouds+Obs)*	Ψ	(Mangrove+CanCvr)	10	973.7	1.91	0.046
p	*(Day+Time+Clouds+Obs)*	Ψ	(Mangrove+LNEdge+CanCvr+AgroFo)	12	973.7	1.92	0.045

APPENDIX B. SPECIES SUMMARIES

Species conservation summaries are provided below. Each summary begins with an introduction page that includes a compendium of results from our investigation, and a short set of management recommendations. A map follows for the 10 species for which density functions were derived. The map depicts the predicted spatial distribution of individuals on the island of Pohnpei. Spatial distributions were predicted by applying density models, which we fitted to data from variable distance point-transect surveys conducted in 2012, to an avian habitat map based on vegetation coverages presented in USDAFS (2005).

For the ten species for which density functions were available, a third page is attached that includes plotted results from population simulations. Simulations included 1,000 combinations of changes that could be brought about by future climate and anthropogenic landscape changes. Each simulation resulted in a population estimate for each species of birds, which was derived from the integrated spatially explicit habitat and avifauna population density models. Factors with the potential to drive population changes in each species included agriculture expansion, new agriculture plots, anthropogenic landscape change, climate-driven vegetation change, and sea level rise. Input values for each simulation were regressed against predicted population outcomes to obtain measures of the magnitude of effect between factors and bird populations (slope) and tightness of association between the factors and bird populations (r^2 value).

Species Summary: Zosterops cinereus

Common name: Gray White-eye (GRWE)

Estimated population:
Results from a comparison between previous surveys (Engbring et al 1990, Buden 2000) and detections from our 2012 surveys indicated a mean change of -68% and +117%, respectively, in detections rates. Substantial increases were evident at mangroves and elevation zones above 400m.

Significant occupancy features:
Results from occupancy analyses indicated that the probability *Z. cinereus* occupancy at survey stations was significantly positively associated with tree stocking rates, and negatively associated with mangroves, after accounting for confounding factors that could affect detection.

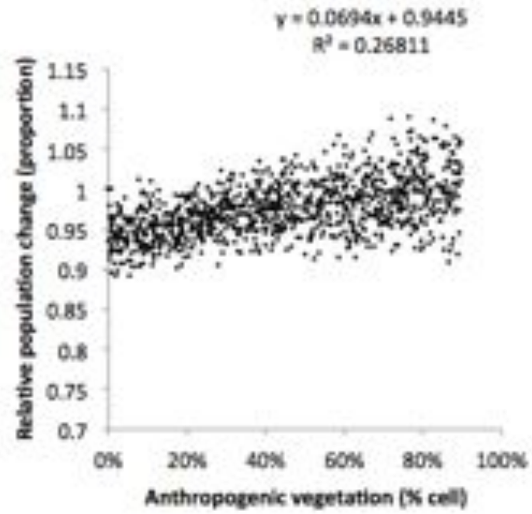
Significant features associated with density:
Results from density analyses indicated that higher densities of *Z. cinereus* at survey stations were positively associated with the intercept (undisturbed vegetation) and secondary vegetation. Further, results indicated that densities were lower at survey stations in mangrove habitat, and at stations with more fragmented habitats.

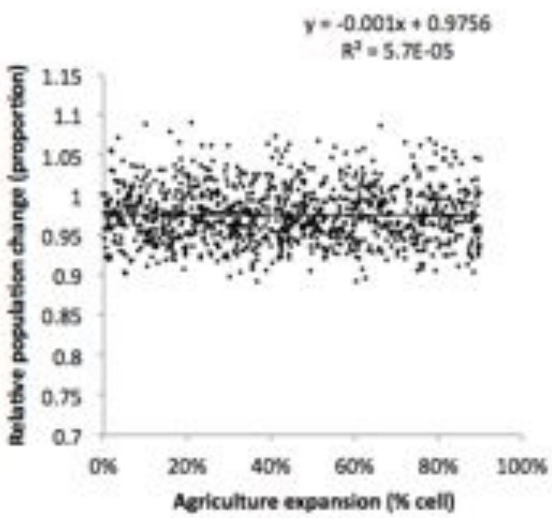
Population change under 1000 future landscape scenarios:
Spatially explicit habitat models linked to density functions for *Z. cinereus* predicted a contemporary population of 166,235 birds on Pohnpei. When density models were applied to 1,000 potential future landscapes with habitat features perturbed by anthropogenic and climate-related factors, results indicated a mean population decline of 3% (SD 7%) in *Z. cinereus* populations.

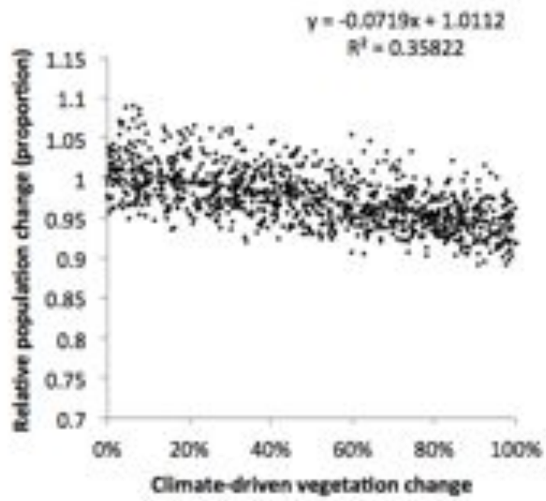
The factor most closely associated with population change in *Z. cinereus* in the simulation analysis was climate-driven vegetation changes to undisturbed habitats on Pohnpei ($r^2 = 0.36$).

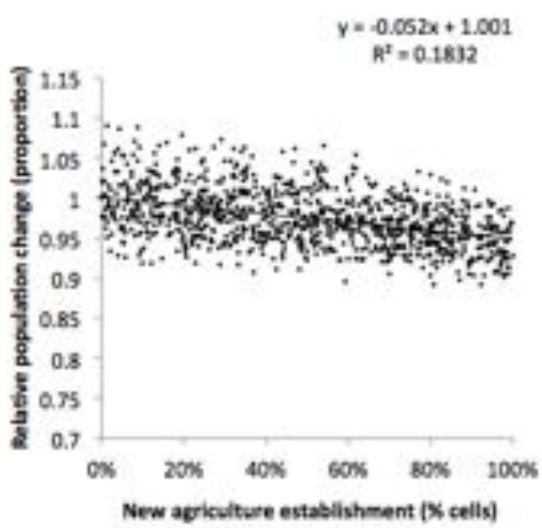
Management recommendations:
Although *Z. cinereus* was detected throughout the island of Pohnpei and the contemporary population is large, results illustrated declines in detection rates since previous surveys, and negative associations with the establishment of secondary vegetation. The population may benefit from upland habitat preservation, and from efforts to restrict the expansion and establishment of secondary vegetation.

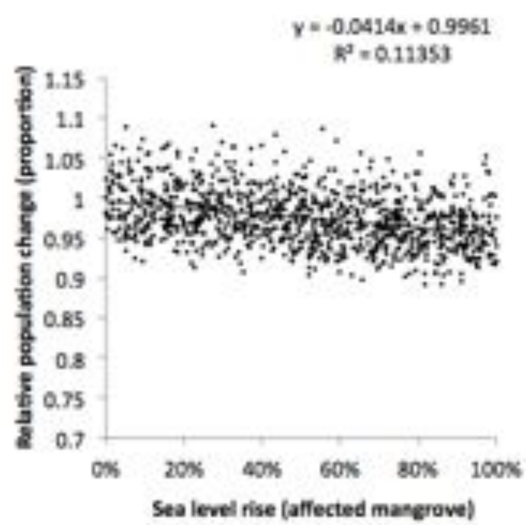
Species: GRWE

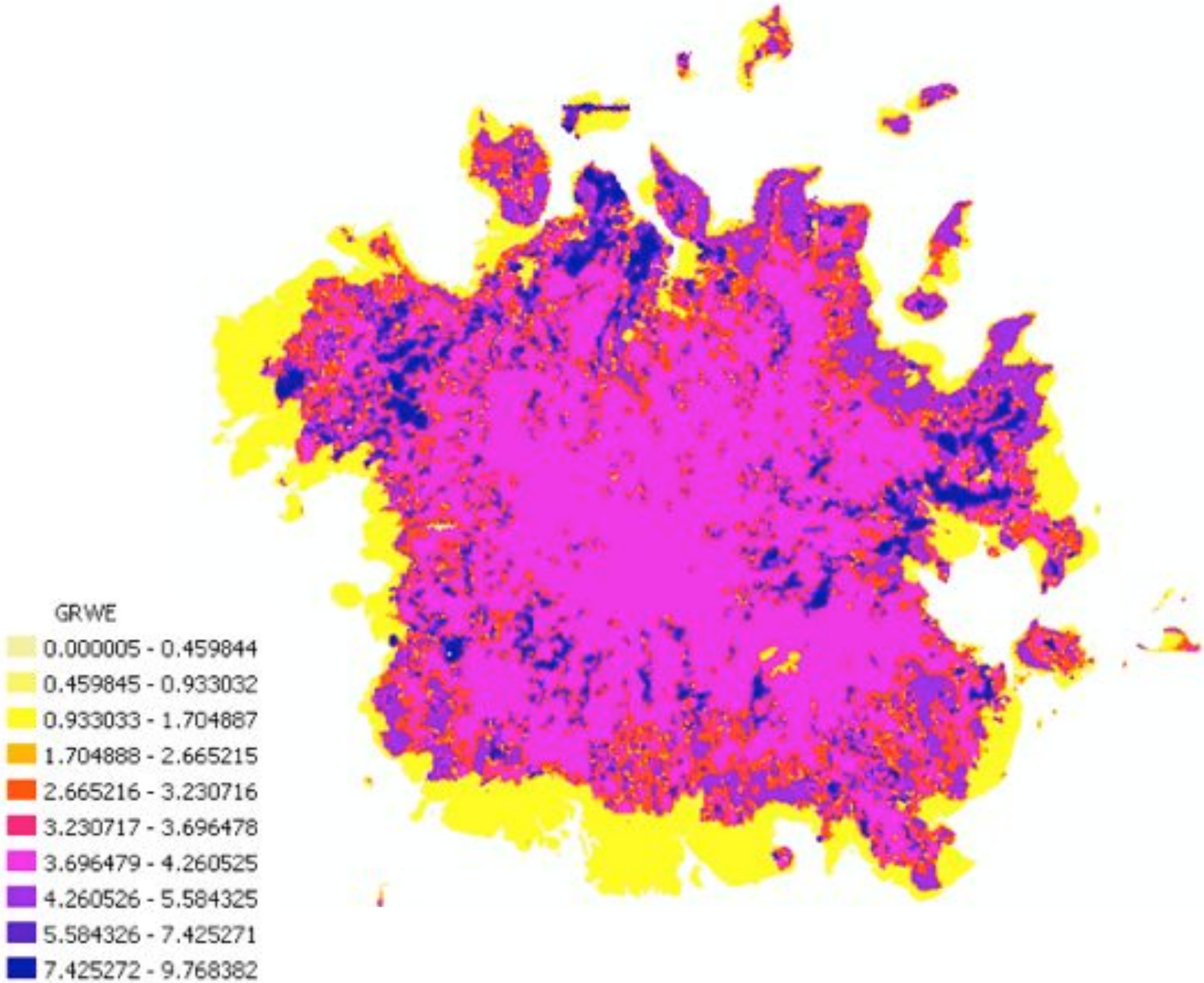











GRWE
0.000005 - 0.459844
0.459845 - 0.933032
0.933033 - 1.704887
1.704888 - 2.665215
2.665216 - 3.230716
3.230717 - 3.696478
3.696479 - 4.260525
4.260526 - 5.584325
5.584326 - 7.425271
7.425272 - 9.768382

Species Summary: Rukia longirostra (Endemic)

Common name:
Long-billed White-eye (LBWE)

Estimated population:
Results from a comparison between previous surveys (Engbring et al 1990, Buden 2000) and detections from our 2012 surveys indicated a mean change in detection rates of -18% and +359%, respectively. Increasing detection rates were observed at lower elevation zones and a slight decline was observed above 600m (-7%).

Significant occupancy features:
Results from occupancy analyses indicated that the probability *R. longirostra* occupied survey stations was significantly and positively associated with forest edge, canopy height and undisturbed vegetation; mangrove was negatively associated with the birds.

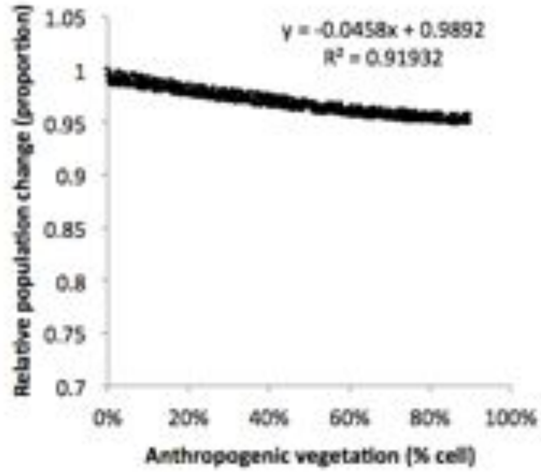
Significant features associated with density:
Results from density analysis indicated higher densities of *R. longirostra* at survey stations were positively associated with the intercept (undisturbed vegetation). Results indicated that densities were extremely low at survey stations in mangrove habitats.

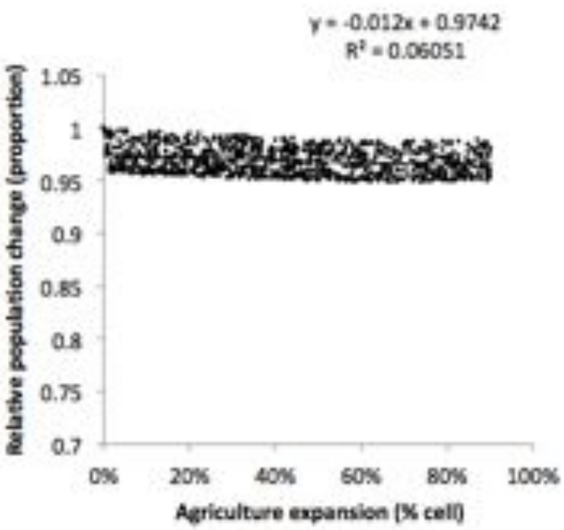
Population change under 1000 future landscape scenarios:
Spatially explicit habitat models linked to density functions for *R. longirostra* predicted a contemporary population of 36,123 birds on Pohnpei. When density models were applied to 1,000 potential future landscapes with habitat features perturbed by anthropogenic and climate-related factors, results indicated a mean population decline of 3.6% (SD 7%) in *R. longirostra* populations.

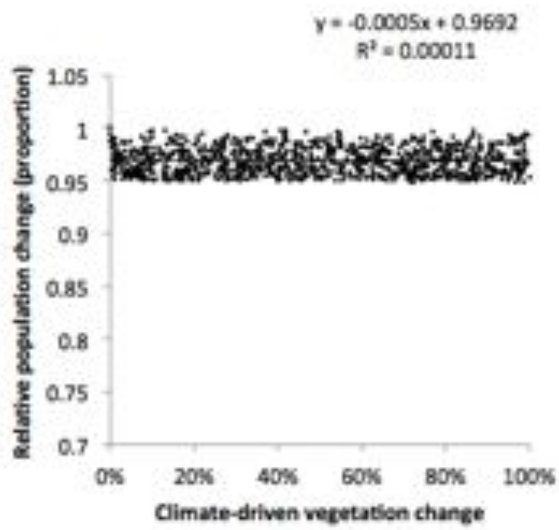
The factor most closely associated with population change in *R. longirostra* in the simulation analyses was Anthropogenic vegetation changes to undisturbed habitats on Pohnpei ($r^2 = 0.91$).

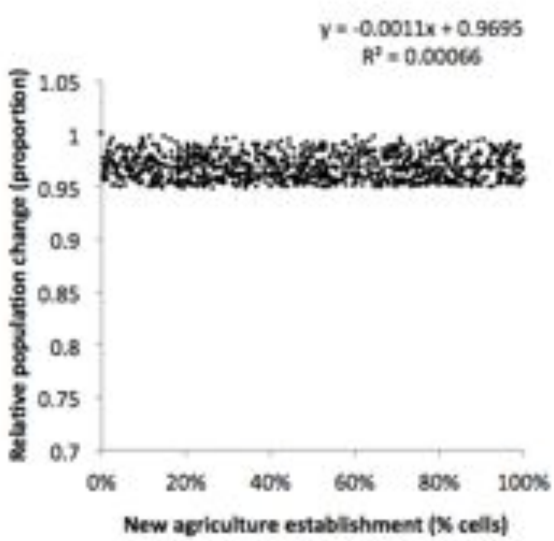
Management recommendations:
Although *R. longirostra* (Pohnpei endemic) was detected throughout the island of Pohnpei and the contemporary population is large, results illustrated changes in detection rates since previous surveys. The species requires additional research attention. However the population may benefit from upland habitat preservation, and from efforts to restrict the expansion and establishment of agroforest or areas where edge effect becomes detrimental to the population.

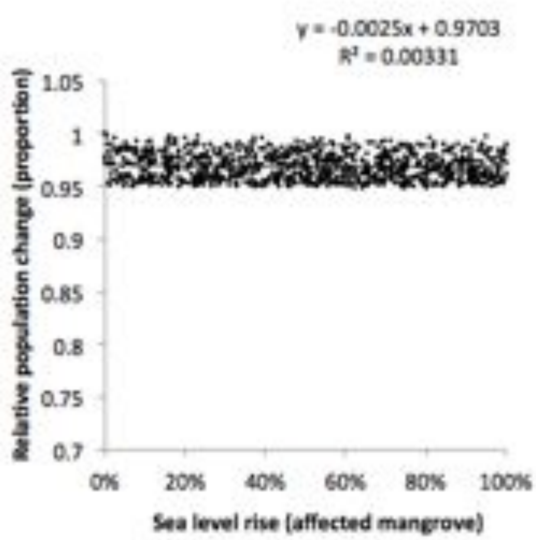
Species: LBWE

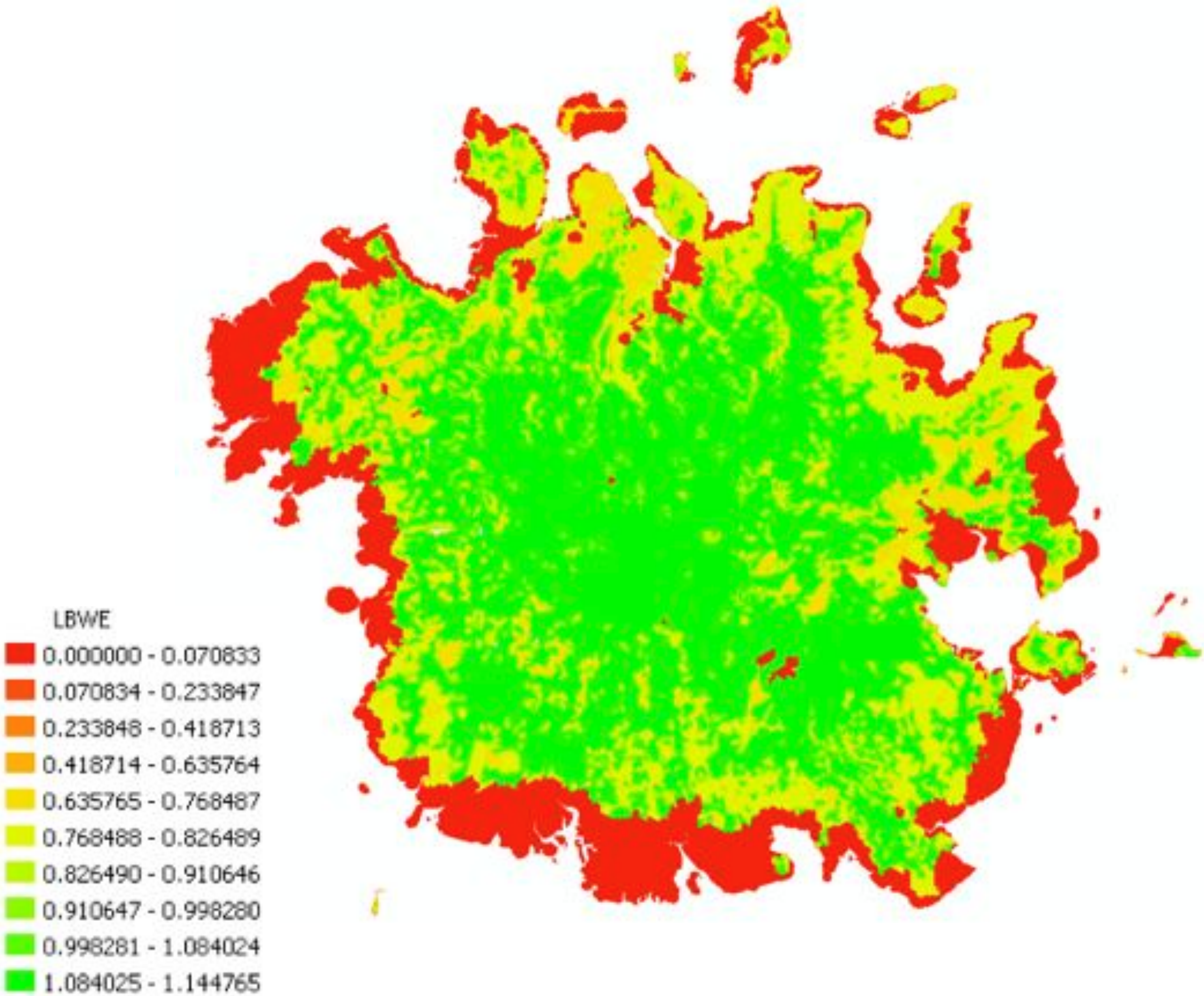











LBWE
0.000000 - 0.070833
0.070834 - 0.233847
0.233848 - 0.418713
0.418714 - 0.635764
0.635765 - 0.768487
0.768488 - 0.826489
0.826490 - 0.910646
0.910647 - 0.998280
0.998281 - 1.084024
1.084025 - 1.144765

Species Summary: Myzomela rubratra

Common name:
Micronesia Honeyeater (MIHO)

Estimated population:
Results from a comparison between previous surveys (Engbring et al 1990, Buden 2000) and detections from our 2012 surveys indicated a mean change in detection rates of -80% and -22%, respectively. Substantial declines were evident in all elevation zones when compared to previous studies, but birds were detected at higher rates above 600 m.

Significant occupancy features:
Occupancy results indicated that the probability *M. rubratra* occurred at stations was not significantly associated with any site variables.

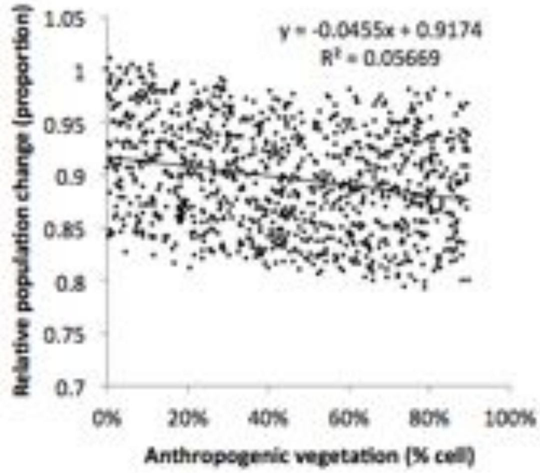
Significant features associated with density:
Results from density analysis indicated higher densities of *M. rubratra* at survey stations were positively associated with the undisturbed vegetation, mangrove and agroforest. Secondary vegetation was negatively associated.

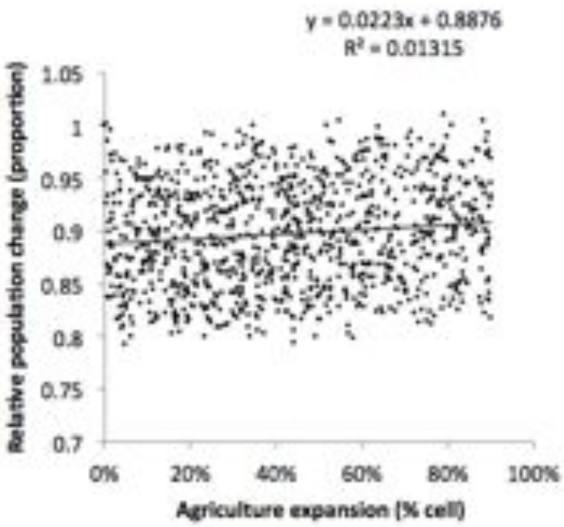
Population change under 1000 future landscape scenarios:
Spatially explicit habitat models linked to density functions for *M. rubratra* predicted a contemporary population of 302,955 birds on Pohnpei. When density models were applied to 1,000 potential future landscapes with habitat features perturbed by anthropogenic and climate-related factors, results indicated a mean population decline of 11% (SD 8%) in *M. rubratra* populations.

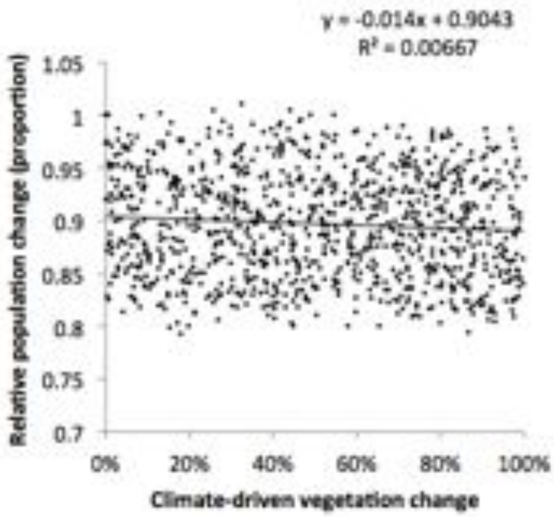
The factor most closely associated with population change in *M. rubratra* in the simulation analysis was mangrove loss by sea level rise ($r^2 = 0.92$).

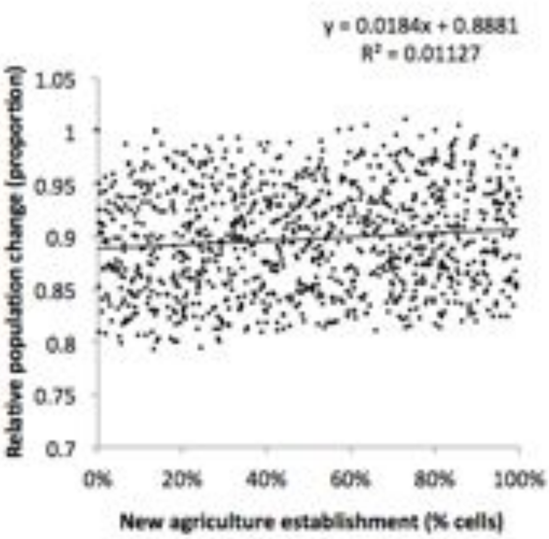
Management recommendations:
M. rubratra is the most common forest species throughout the island of Pohnpei and the contemporary population is large. Results illustrated that agroforest could provide habitat and food, however the population may also benefit from upland habitat and mangrove preservation. Minimizing the transformation of undisturbed habitat and established agroforest to secondary vegetation could help to maintain a healthy population. Sea level rise and the associated loss of mangrove are likely to impact the population.

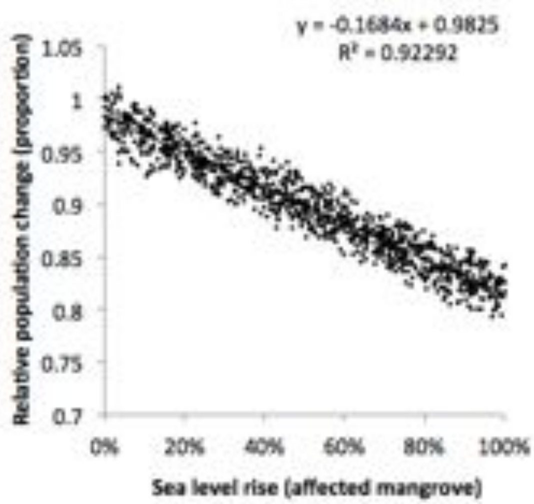
Species: MIHO

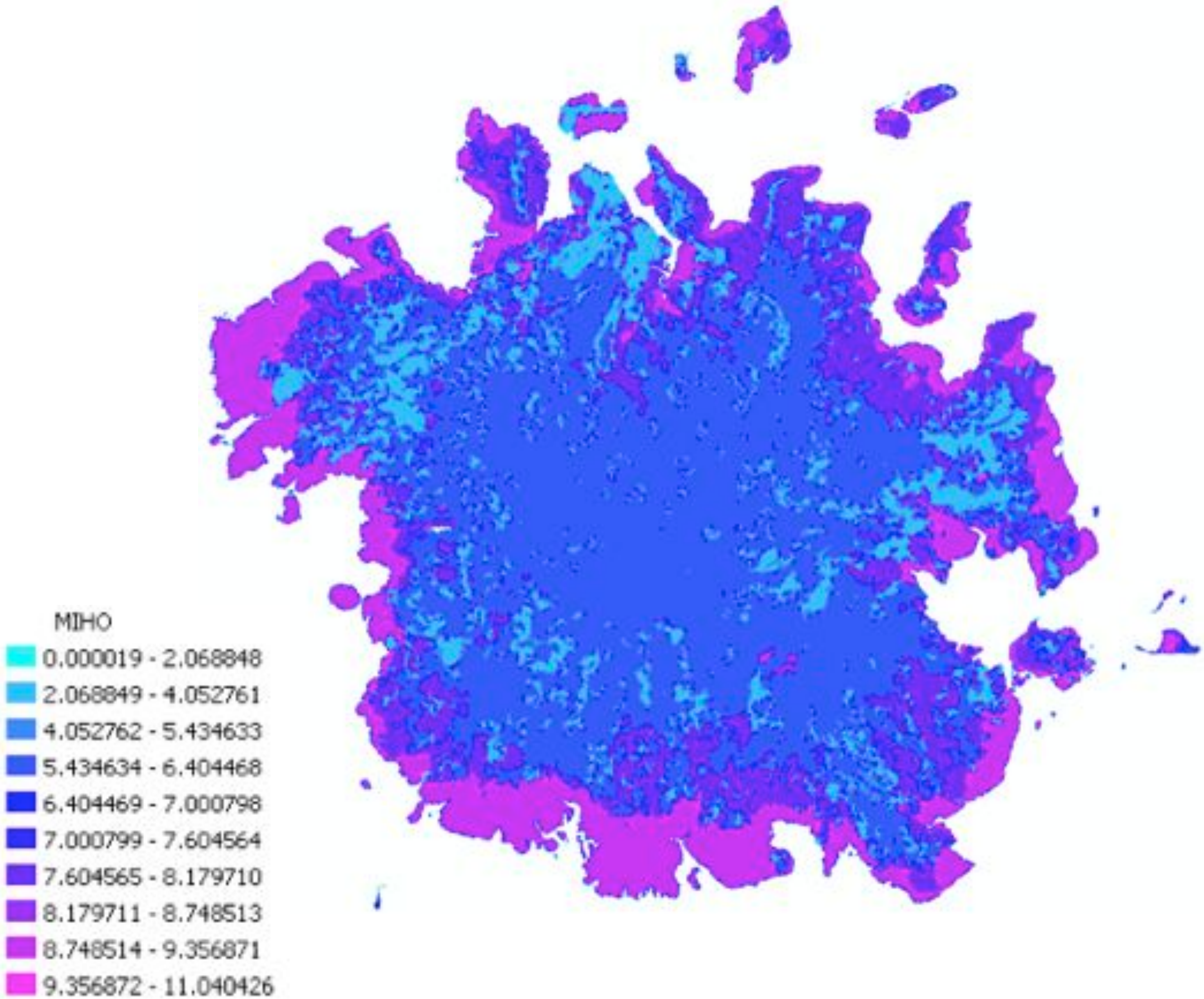











MIHO
0.000019 - 2.068848
2.068849 - 4.052761
4.052762 - 5.434633
5.434634 - 6.404468
6.404469 - 7.000798
7.000799 - 7.604564
7.604565 - 8.179710
8.179711 - 8.748513
8.748514 - 9.356871
9.356872 - 11.040426

Species Summary: Todiramphus reichenbachii (Endemic)

Common name:
Micronesia Kingfisher (MIKI)

Estimated population:
Results from a comparison between previous surveys (Engbring et al 1990, Buden 2000) and detections from our 2012 surveys indicated a mean change in detection rates of -73% and -16%, respectively. Substantial declines were evident in all elevation zones when compared to previous studies. However increasing detection rates were observed at mangroves and between 100 and 200m.

Significant occupancy features:
Results from occupancy analysis indicated that the probability *T. reichenbachii* occupied survey stations was positively and significantly associated with canopy height, and negatively associated with tree stocking rate, after accounting for confounding factors that could affect detection.

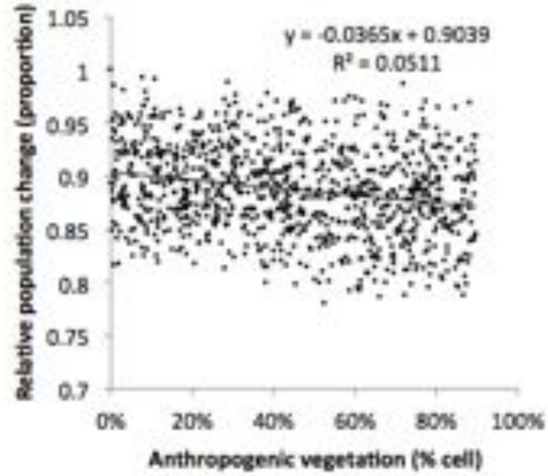
Significant features associated with density:
Results from density analysis indicated that densities of *T. reichenbachii* at survey stations were negatively associated with number of habitat patches in the survey area.

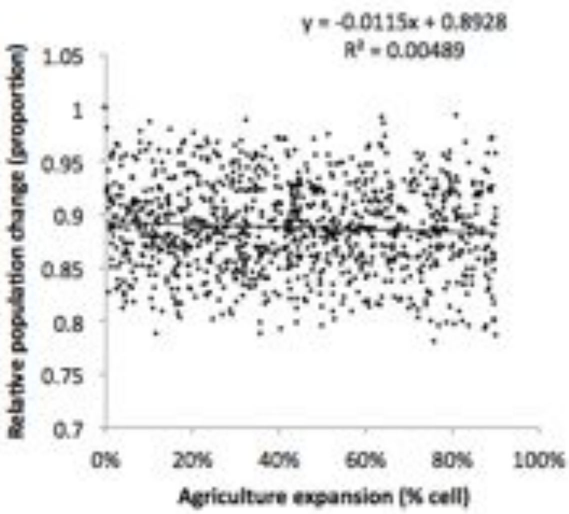
Population change under 1000 future landscape scenarios:
Spatially explicit habitat models linked to density functions for *T. reichenbachii* predicted a contemporary population of 17,375 birds on Pohnpei. When density models were applied to 1,000 potential future landscapes with habitat features perturbed by anthropogenic and climate-related factors, results indicated a mean population decline of 12% (SD 7%) in *T. reichenbachii* populations.

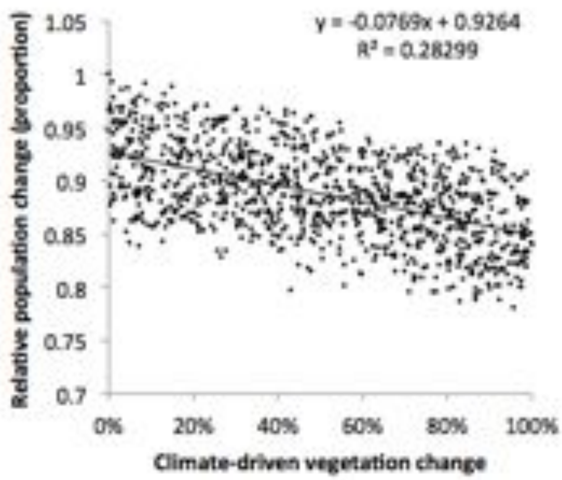
The factor most closely associated with population change in *T. reichenbachii* in the simulation analysis was mangrove loss by sea level rise (r^2 = 0.62).

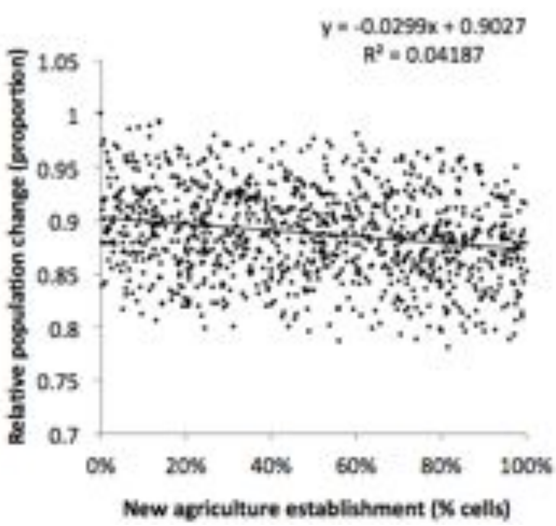
Management recommendations:
T. reichenbachii is the second least common species on Pohnpei (of the 10 with density models). Results illustrated that agroforest could provide habitat and food, however the population may benefit from upland habitat and mangrove preservation. Sea level rise and the associated loss of mangrove are likely to impact the population.

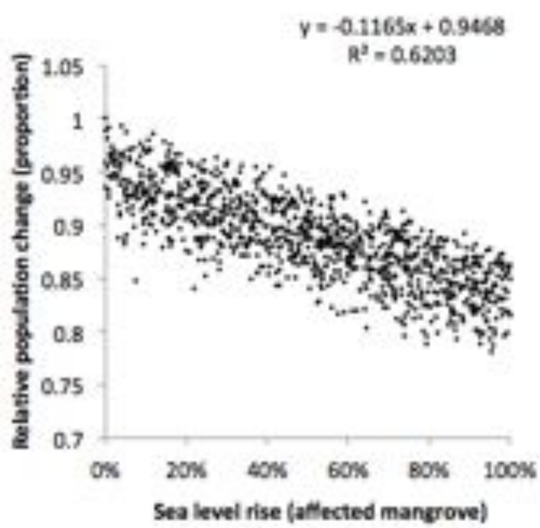
Species: MIKI

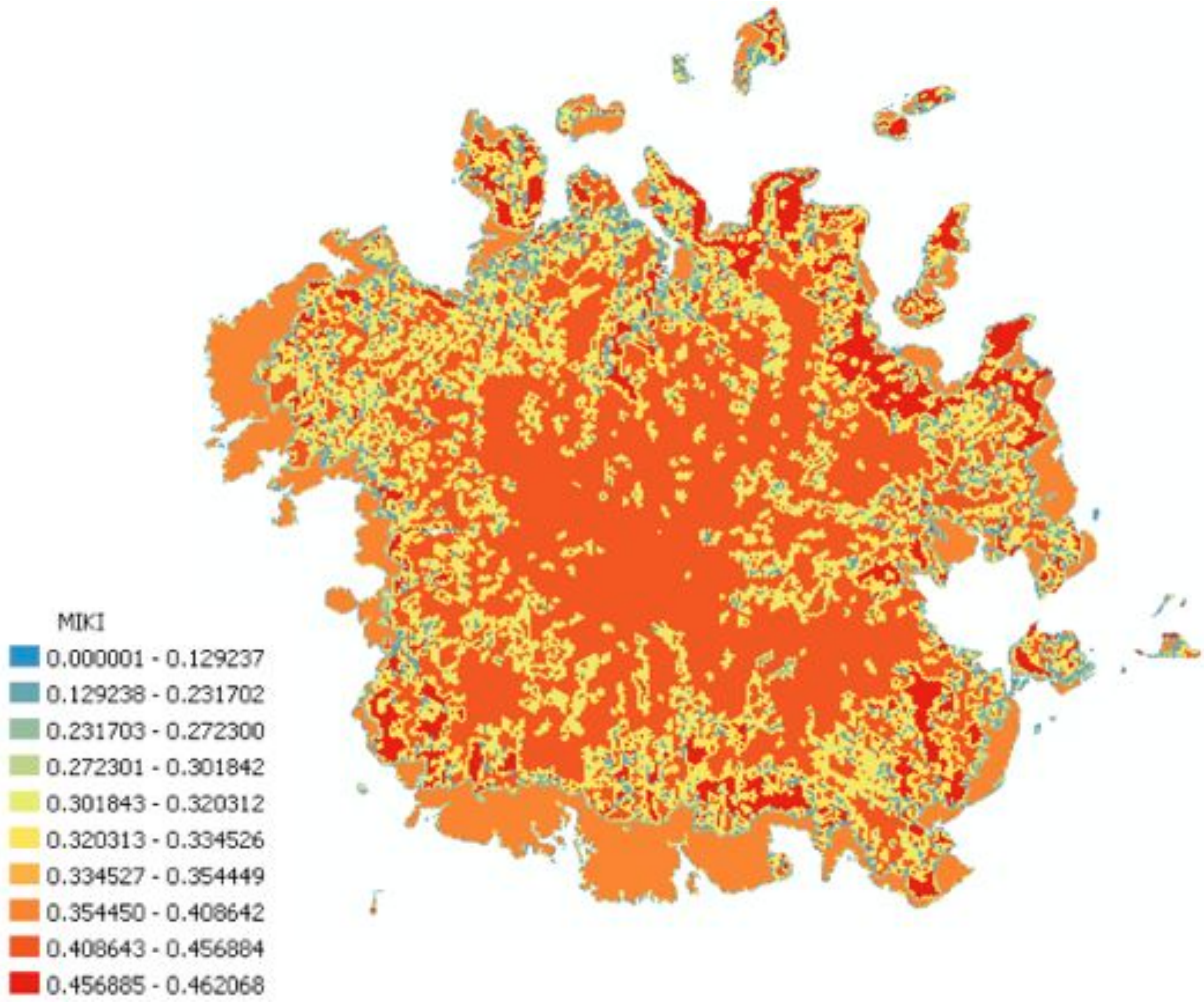











MIKI
0.000001 - 0.129237
0.129238 - 0.231702
0.231703 - 0.272300
0.272301 - 0.301842
0.301843 - 0.320312
0.320313 - 0.334526
0.334527 - 0.354449
0.354450 - 0.408642
0.408643 - 0.456884
0.456885 - 0.462068

Species Summary: Ducula oceanica

Common name:
Micronesia Pigeon (MIPI)

Estimated population:
Results from a comparison between previous surveys (Engbring et al 1990, Buden 2000) and detections in our 2012 survey indicated a mean change in detection rates of -15% and +220% respectively. When compared to Buden (2000), increasing detection rates were evident in all elevation zones except between 0-200 m (~ 14%). *D. oceanica* was detected in areas >600 m in 2012.

Significant occupancy features:
Results from occupancy analyses indicated that the probability *D. oceanica* occupied survey stations was negatively and significantly associated with undisturbed habitat, and positively associated with forest canopy height.

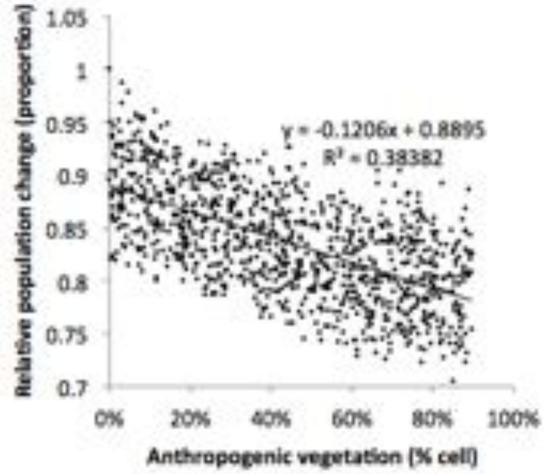
Significant features associated with density:
Results from density analyses indicated that densities of *D. oceanica* at survey stations were negatively associated with the presence of agroforest and undisturbed habitat.

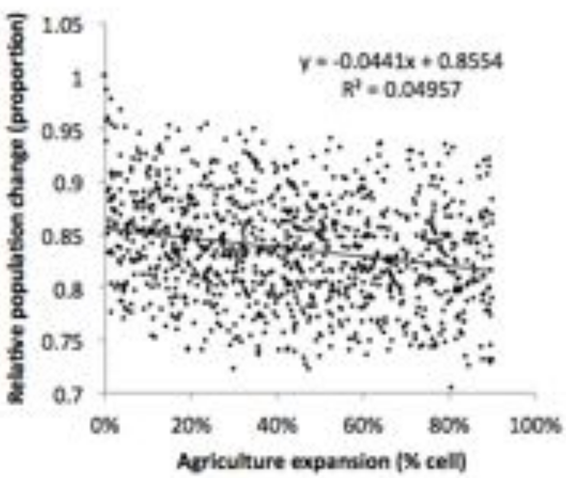
Population change under 1000 future landscape scenarios:
Spatially explicit habitat models linked to density functions for *D. oceanica* predicted a contemporary population of 5,025 birds on Pohnpei. When density models were applied to 1,000 potential future landscapes with habitat features perturbed by anthropogenic and climate-related factors, results indicated a mean population decline of 12% (SD 8%) in *D. oceanica* populations.

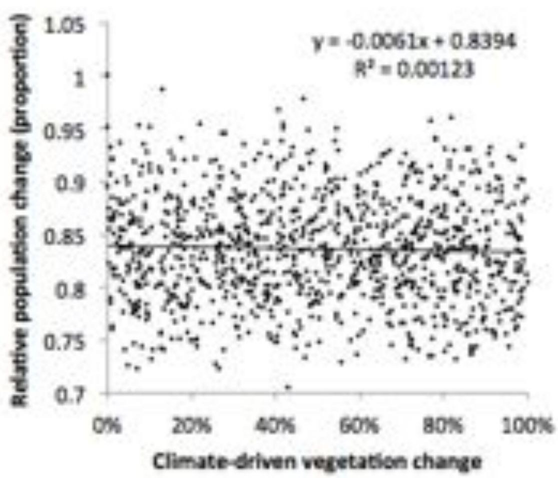
The factor most closely associated with population change in *D. oceanica* in the simulation analysis was mangrove loss by sea level rise ($r^2 = 0.55$), followed by anthropogenic vegetation ($r^2 = 0.38$).

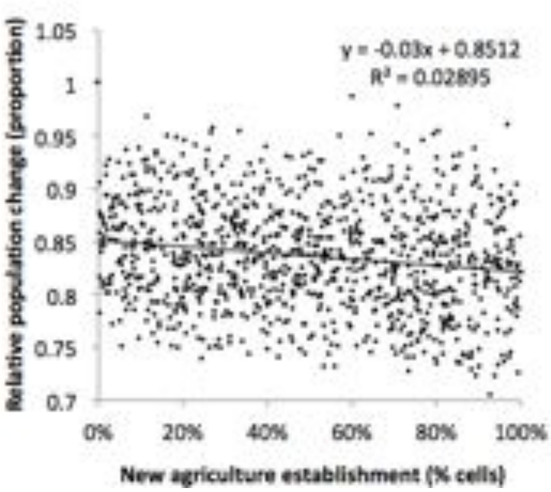
Management recommendations:
D. oceanica is a shy species that avoids human interaction. The bird is found throughout the island of Pohnpei and the contemporary population appears to have increased since Engbring et al. (1990). Results illustrated that mangrove loss and anthropogenic vegetation expansion could greatly affect the population. Minimizing mangrove alteration and setting aside reserve areas could aid in maintaining a stable population.

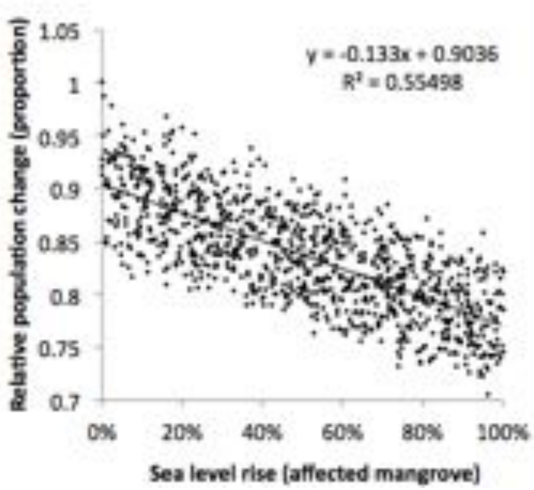
Species: MIPI

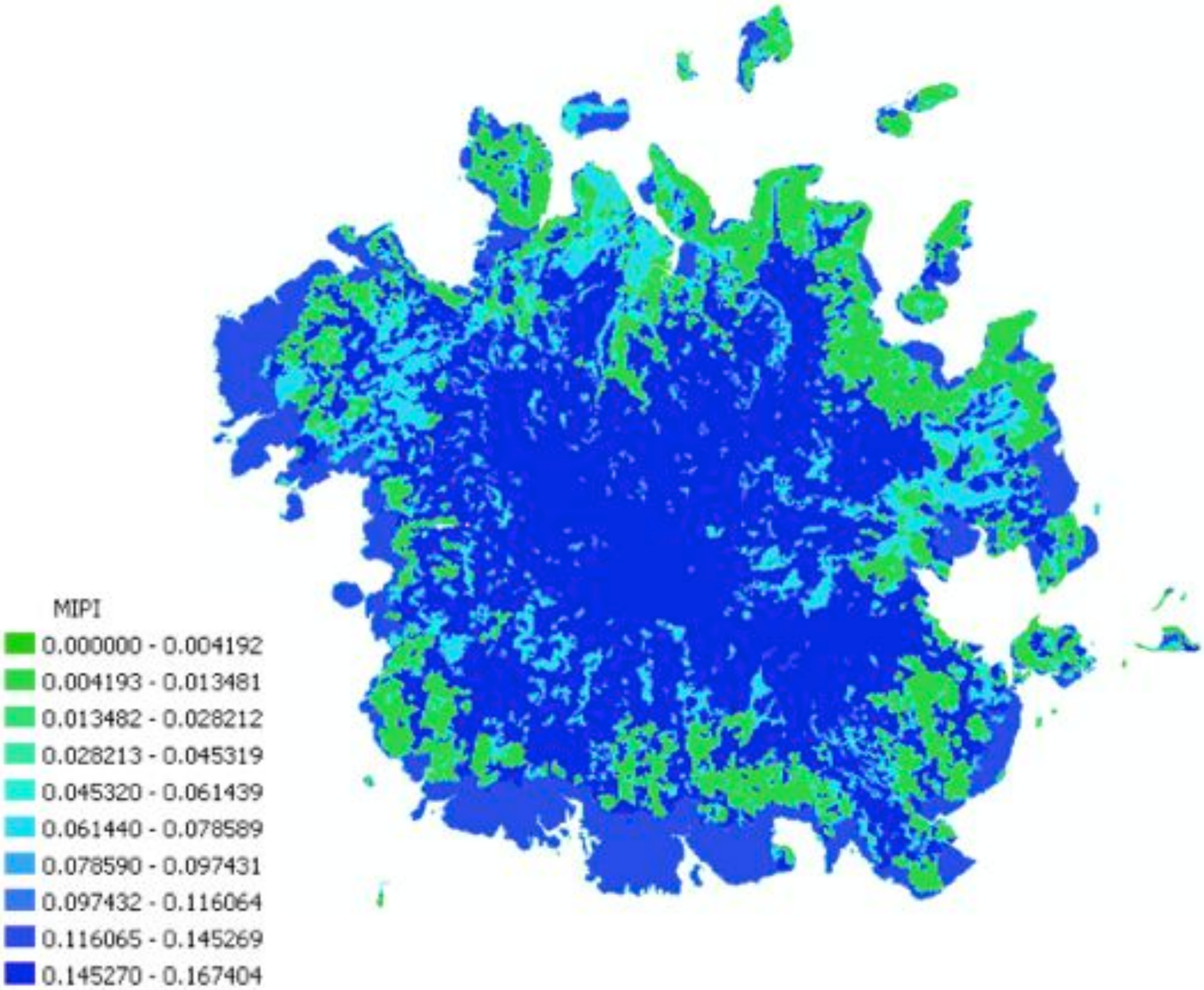











MIPI
0.000000 - 0.004192
0.004193 - 0.013481
0.013482 - 0.028212
0.028213 - 0.045319
0.045320 - 0.061439
0.061440 - 0.078589
0.078590 - 0.097431
0.097432 - 0.116064
0.116065 - 0.145269
0.145270 - 0.167404

Species Summary: Aplonis opaca

Common name:
Micronesia Starling (MIST)

Estimated population:
Results from a comparison between previous surveys (Engbring et al 1990, Buden 2000) and detections in our 2012 surveys indicated a mean change in detection rates of -81% and -22% respectively. When compared to Buden (2000) increases were evident at > 600 m in elevation (23%).

Significant occupancy features:
After accounting for confounding factors that could affect detection, results from occupancy analyses indicated that the probability *A. opaca* occupied survey stations was not significantly associated with any of our site variables. Similar to *M. rubrata, A. opaca* was widely detected.

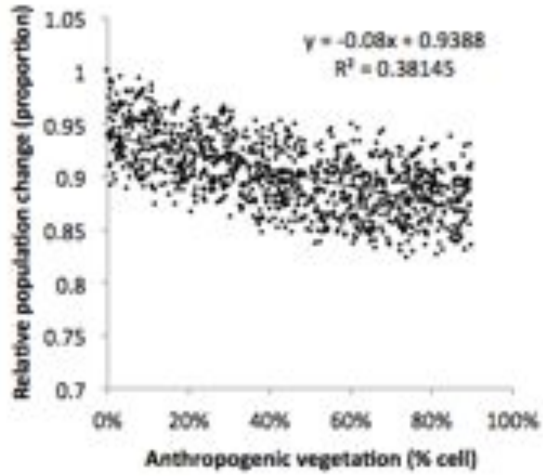
Significant features associated with density:
Results from density analyses indicated that densities of *A. opaca* at survey stations were positively associated with undisturbed vegetation and negatively associated with the presence of secondary vegetation and mangroves.

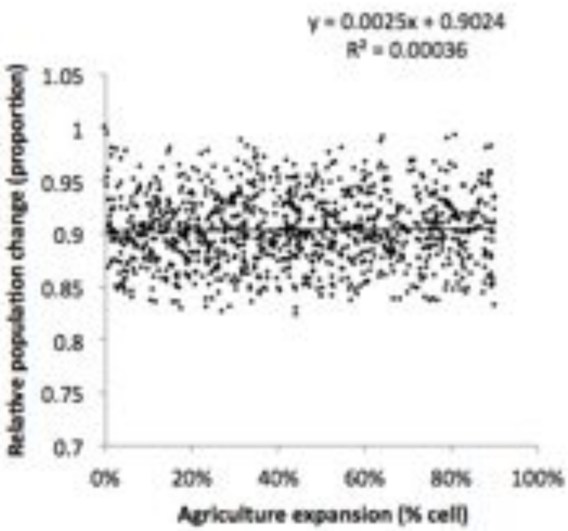
Population change under 1000 future landscape scenarios:
Spatially explicit habitat models linked to density functions for *A. opaca* predicted a contemporary population of 115,587 birds on Pohnpei. When density models were applied to 1,000 potential future landscapes with habitat features perturbed by anthropogenic and climate-related factors, results indicated a mean population decline of 11% (SD 7%) in *A. opaca* populations.

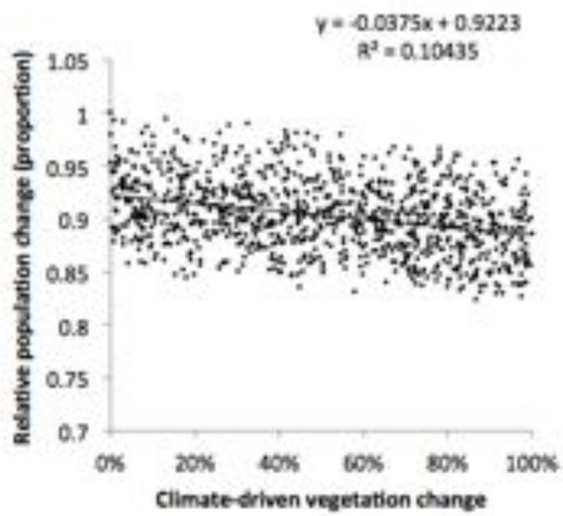
The factor most closely associated with population change in *A. opaca* in the simulation analysis was mangrove loss from sea level rise ($r^2 = 0.52$).

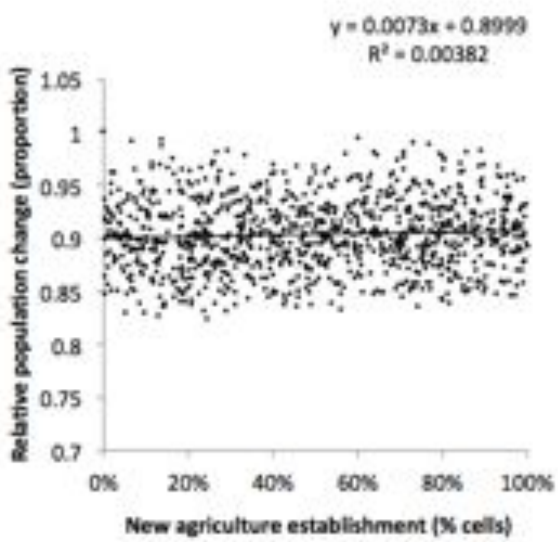
Management recommendations:
A. opaca is a common species on Pohnpei and the contemporary population is large. Results illustrated that mangrove loss and anthropogenic vegetation could greatly affect the population. Similar to *D. oceanica,* minimizing mangrove alteration and anthropogenic vegetation establishment could aid to maintain a stable population.

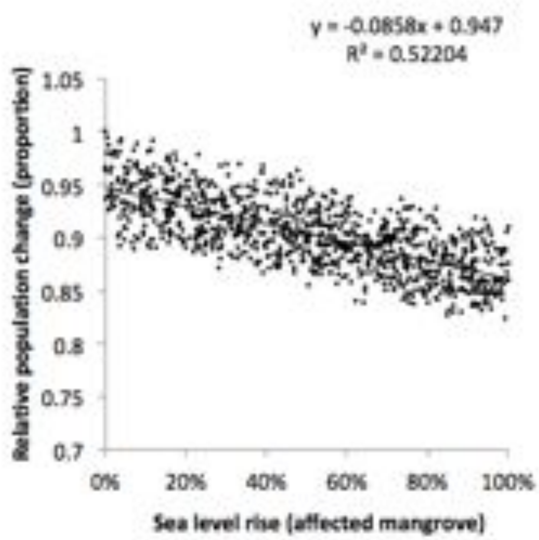
Species: MIST

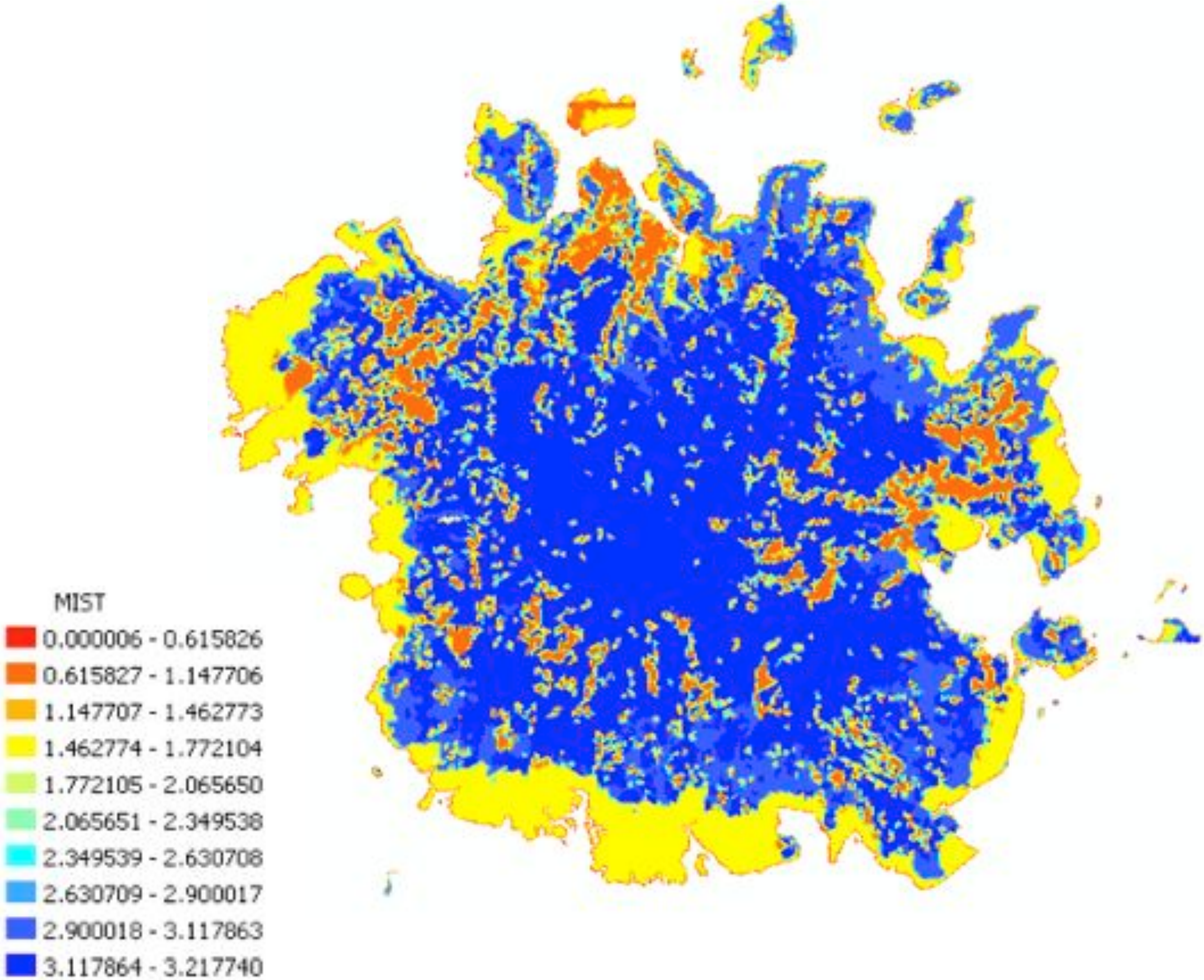











MIST
0.000006 - 0.615826
0.615827 - 1.147706
1.147707 - 1.462773
1.462774 - 1.772104
1.772105 - 2.065650
2.065651 - 2.349538
2.349539 - 2.630708
2.630709 - 2.900017
2.900018 - 3.117863
3.117864 - 3.217740

Species Summary: Ptilinopus porphyraceus

Common name:
Purple-capped Fruit-Dove (PCFD)

Estimated population:
A comparison between previous surveys (Engbring et al 1990, Buden 2000) and detections from our 2012 surveys indicated a mean change in detection rates of -74% and + 60% respectively. When compared to Buden (2000) increases were evident in mangroves and at > 600 m (220%).

Significant occupancy features:
After accounting for confounding factors that could affect detection, results from occupancy analyses indicated that the probability *P. porphyraceus* occupied survey stations was positively and significantly associated with undisturbed habitat.

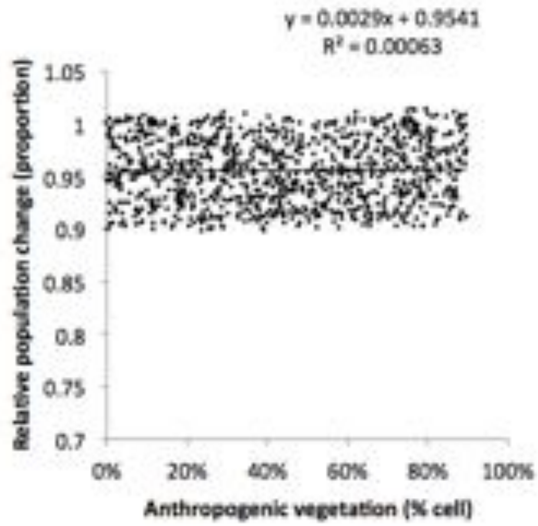
Significant features associated with density:
Density analysis differed from occupancy, in that it indicated that densities of *P. porphyraceus* at survey stations were negatively associated with undisturbed vegetation.

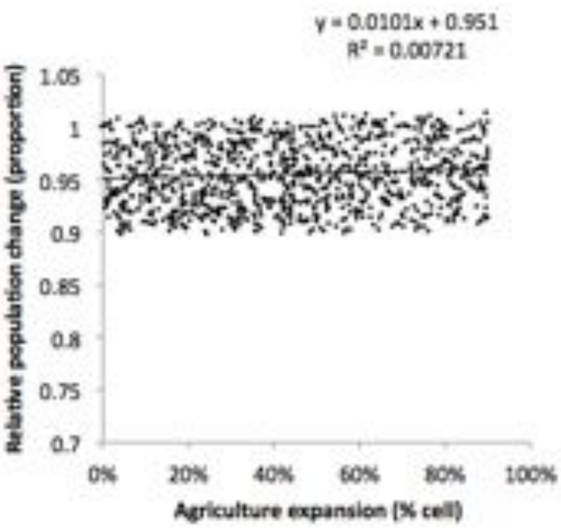
Population change under 1000 future landscape scenarios:
Spatially explicit habitat models linked to density functions for *P. porphyraceus* predicted a contemporary population of 18,784 birds on Pohnpei. When density models were applied to 1,000 potential future landscapes with habitat features perturbed by anthropogenic and climate-related factors, results indicated a mean population decline of 5% (SD 7%) in *P. porphyraceus* populations.

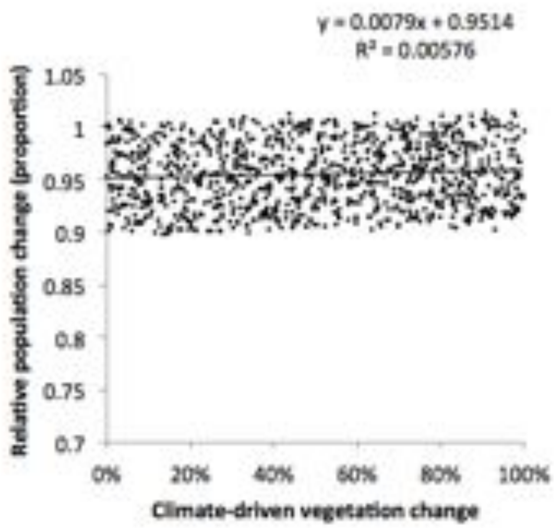
The factor most closely associated with population change in *P. porphyraceus* in the simulation analysis was mangrove loss by sea level rise (r^2 = 0.98).

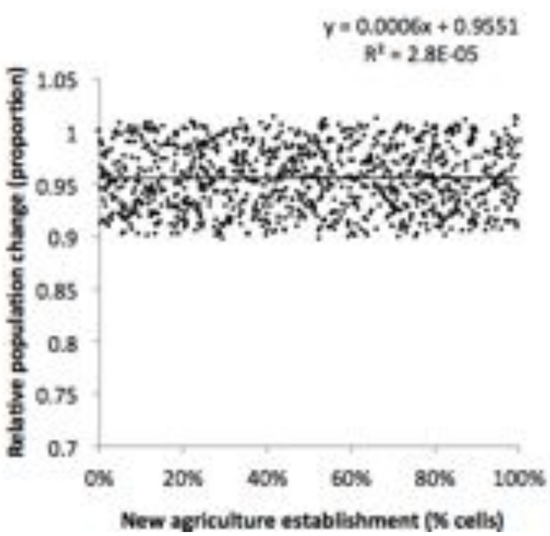
Management recommendations:
P. porphyraceus is a very common species capable of adapting to several habitats. The contemporary Pohnpei population continues to decline however. Results illustrated that mangrove loss could greatly affect the population. Maintenance of undisturbed forest and mangroves are recommended to maintain the population.

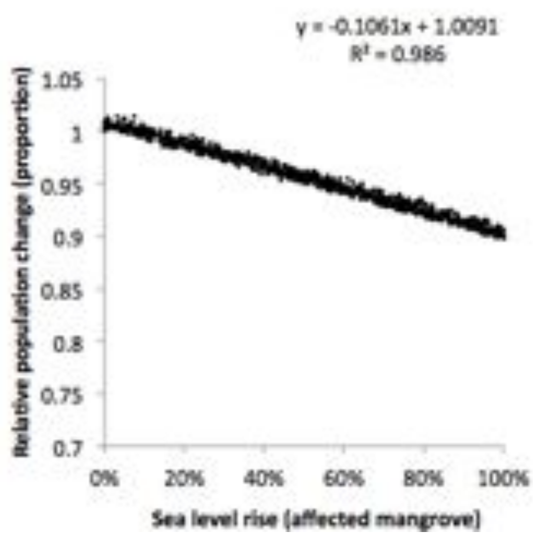
Species: PCFD

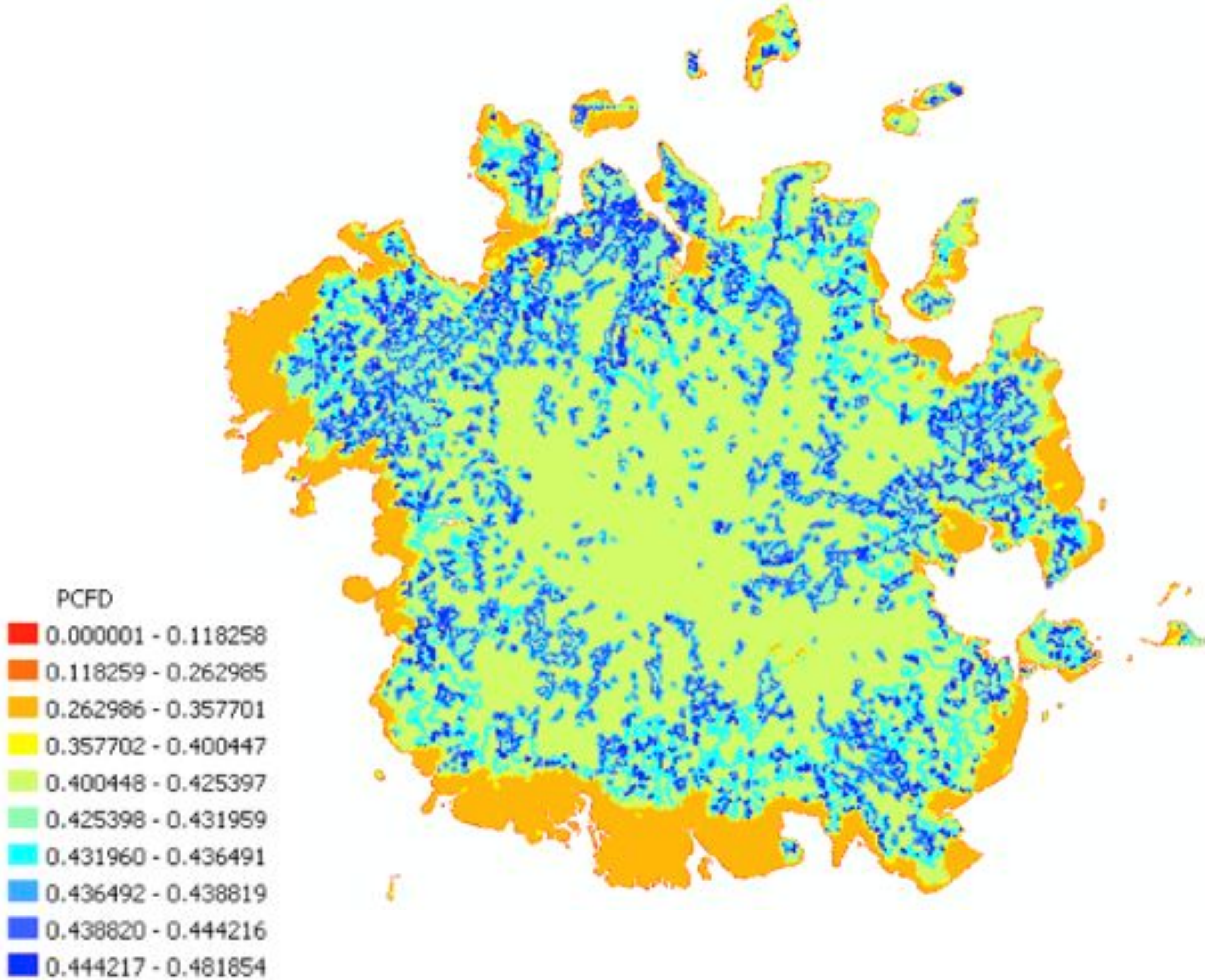











PCFD
0.000001 - 0.118258
0.118259 - 0.262985
0.262986 - 0.357701
0.357702 - 0.400447
0.400448 - 0.425397
0.425398 - 0.431959
0.431960 - 0.436491
0.436492 - 0.438819
0.438820 - 0.444216
0.444217 - 0.481854

Species Summary: Rhipidura kubaryi (Endemic)

Common name:
Pohnpei Fantail (POFA)

Estimated population:
Results from a comparison between previous surveys (Engbring et al 1990, Buden 2000) and detections from our 2012 surveys indicated a mean change in detection rates of -67% and 10% respectively. When compared to Buden (2000) the largest increase was evident at > 600 m (47%).

Significant occupancy features:
After accounting for confounding factors that could affect detection, results from occupancy analysis indicated that the probability *R. kubaryi* occupied a survey station was significantly associated with undisturbed vegetation, canopy height and the habitat edge. Mangrove was negatively associated with this species.

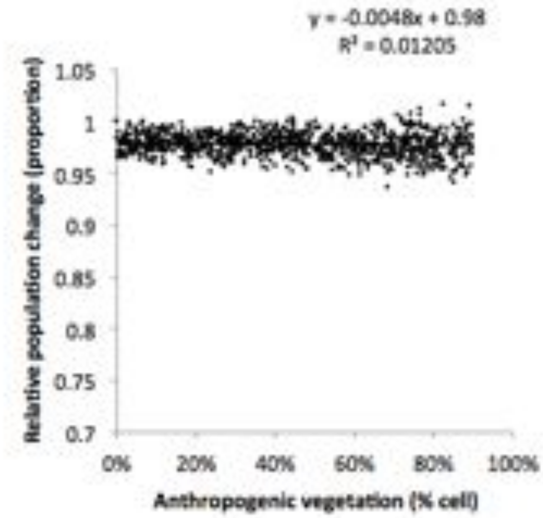
Significant features associated with density:
Results from density analysis indicated that densities of *R. kubaryi* at survey stations were negatively affected by agroforest and mangrove presence.

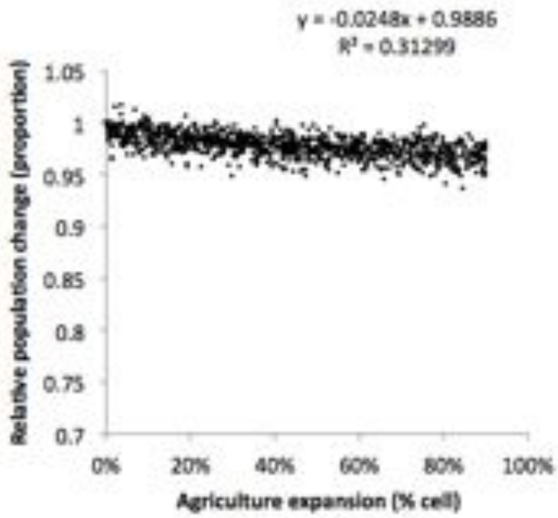
Population change under 1000 future landscape scenarios:
Spatially explicit habitat models linked to density functions for *R. kubaryi* predicted a contemporary population of 22,263 birds on Pohnpei. When density models were applied to 1,000 potential future landscapes with habitat features perturbed by anthropogenic and climate-related factors, results indicated a mean population decline of 2.7% (SD 7%) in *R. kubaryi*.

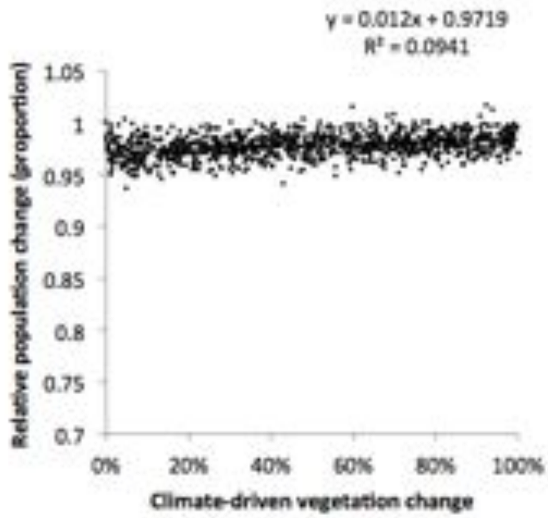
The factor most closely associated with population change in *R. kubaryi* in the simulation analyses was new agroforest establishment across the island ($r^2 = 0.37$).

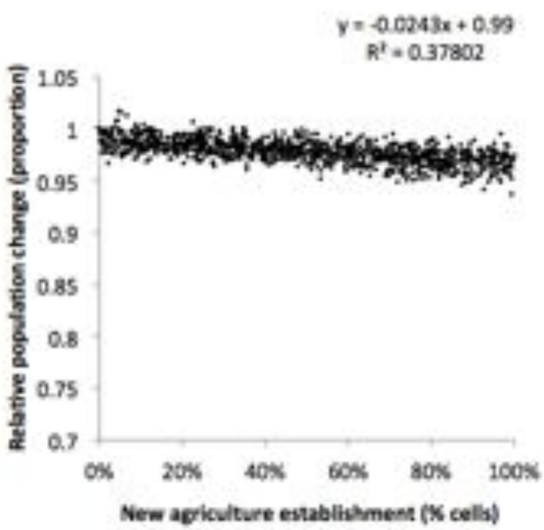
Management recommendations:
R. kubaryi is a common species found through out the island of Pohnpei. Its population has declined since 1983. Results illustrated that anthropogenic vegetation could underpin this pattern. Occupancy analyses indicated that patch specifics (e.g., canopy height, habitat edge and undisturbed habitats) have positive associations with populations. Preventing the establishment of homogeneous patches of agroforest could aid to maintaining the population

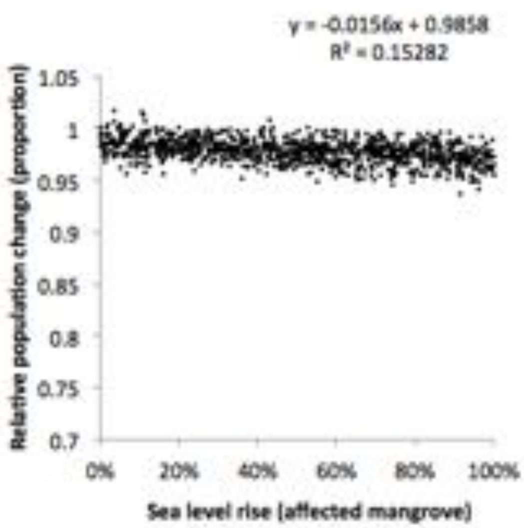
Species: POFA

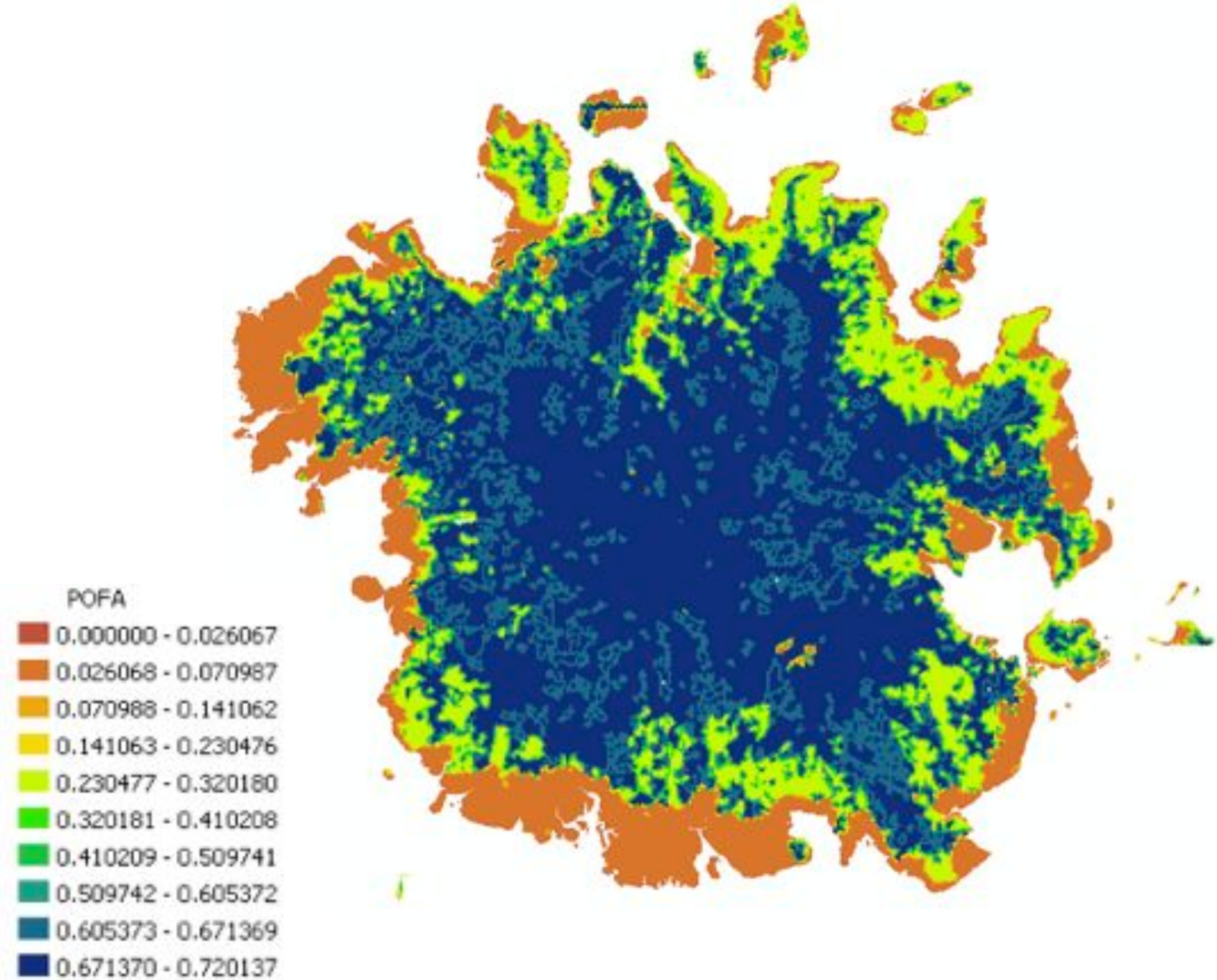











POFA
0.000000 - 0.026067
0.026068 - 0.070987
0.070988 - 0.141062
0.141063 - 0.230476
0.230477 - 0.320180
0.320181 - 0.410208
0.410209 - 0.509741
0.509742 - 0.605372
0.605373 - 0.671369
0.671370 - 0.720137

Species Summary: Myiagra pluto (Endemic)

Common name:
Pohnpei Flycatcher (POFL)

Estimated population:
Results from a comparison between previous surveys (Engbring et al 1990, Buden 2000) and detections from our 2012 surveys indicated a mean change in detection rates of -70% and -19% respectively. When compared to Buden (2000) declining detection rates occur at all elevation zones and the declining rate decreased as elevation increased.

Significant occupancy features:
After accounting for confounding factors that could affect detection, results from occupancy analysis indicated that the probability *M. pluto* occupied survey stations was positively associated with undisturbed vegetation, tree stocking rate and canopy height, and was negatively associated with crown cover and agroforest. However none of these relationships were significant.

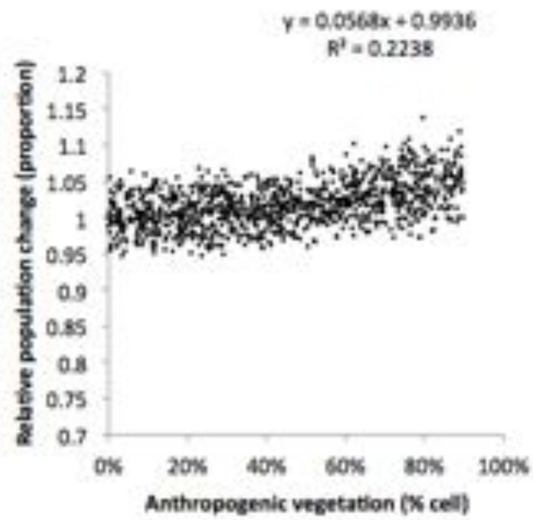
Significant features associated with density:
Results from density analysis indicated that densities of *M. pluto* at survey stations were significantly and negatively affected by mangrove, and positively associated with the intercept (undisturbed vegetation).

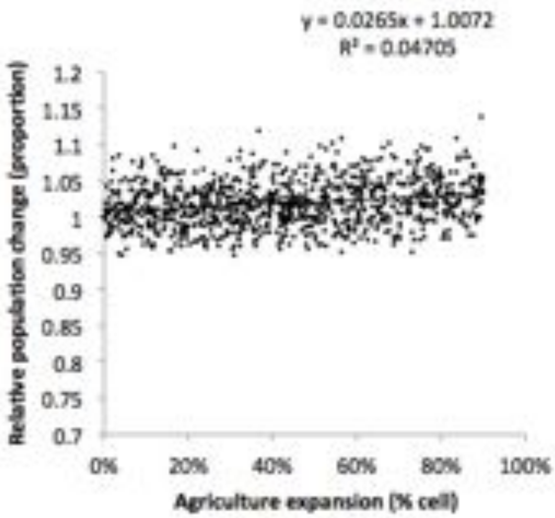
Population change under 1000 future landscape scenarios:
Spatially explicit habitat models linked to density functions for *M. pluto* predicted a contemporary population of 87,242 birds on Pohnpei. When density models were applied to 1,000 potential future landscapes with habitat features perturbed by anthropogenic and climate-related factors, results indicated a mean population increase of 1.01% (SD 7%) in *M. pluto* populations.

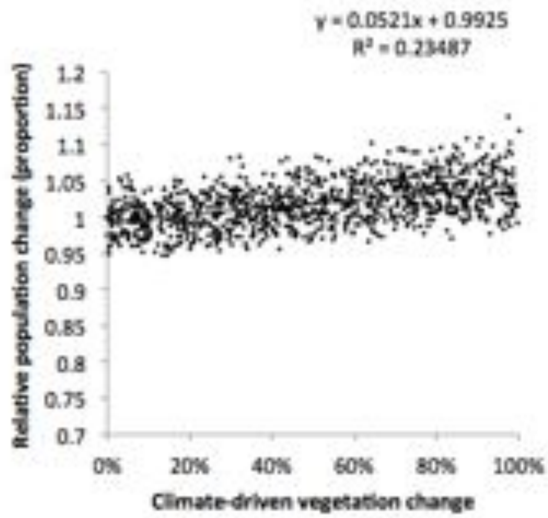
Four of five factors affecting *M. pluto* showed positive associations with population numbers. However, the loss of mangrove habitat had the largest, and most negative effect (r^2 = 0.41).

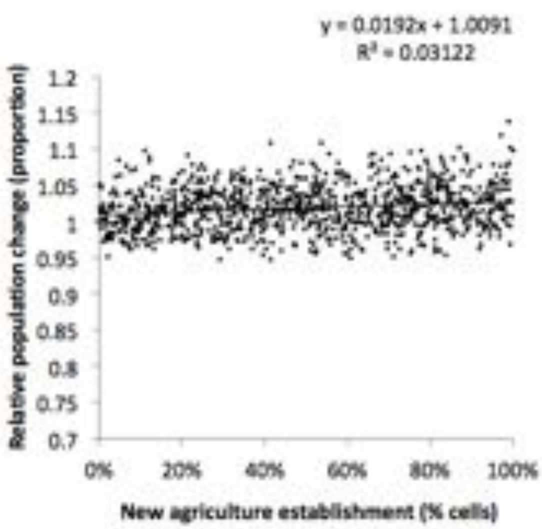
Management recommendations:
M. pluto is a common species found throughout the island of Pohnpei. Its population has declined drastically in since 1983. Occupancy and density analyses indicated *M. pluto* was negatively associated with agroforest. Controlling transformation of undisturbed forest into agroforest could aid to maintain the population. Sea level rise and the associated loss of mangrove are likely to impact the birds.

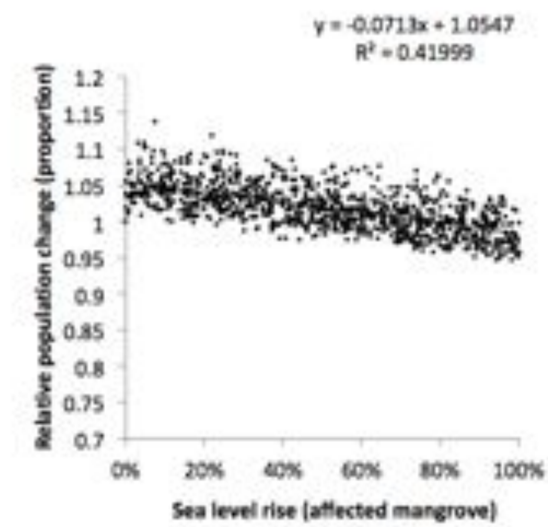
Species: POFL

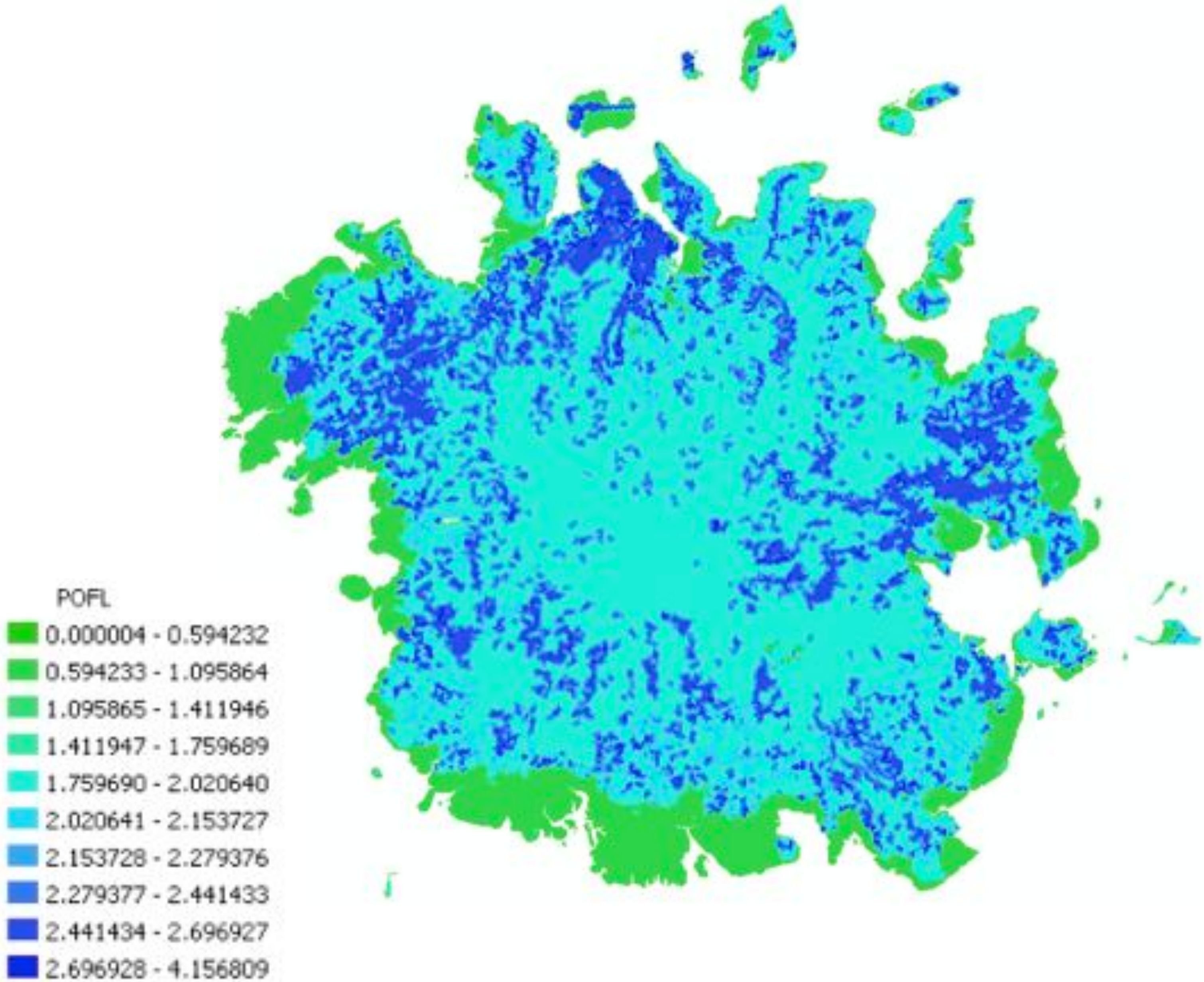











POFL
0.000004 - 0.594232
0.594233 - 1.095864
1.095865 - 1.411946
1.411947 - 1.759689
1.759690 - 2.020640
2.020641 - 2.153727
2.153728 - 2.279376
2.279377 - 2.441433
2.441434 - 2.696927
2.696928 - 4.156809

Species Summary: Trichoglossus rubiginosus (Endemic)

Common name:
Pohnpei Lorikeet (POLO)

Estimated population:
Results from a comparison between previous surveys (Engbring et al 1990, Buden 2000) and detections from our 2012 surveys indicated a mean change in detection rates of -70% and -20% respectively. When compared to Buden (2000), declining detection rates occur at all elevation zones and increased as elevation increased. Nonetheless in 2012 detections in mangroves exhibited increases (67%).

Significant occupancy features:
After accounting for confounding factors that could affect detection, results from occupancy analysis indicated that the probability *T. rubiginosus* occupied survey stations was negatively and significantly associated with areas with higher tree stocking rates, and that it was positively associated with canopy height. Both higher stocking and canopy are associated with undisturbed vegetation.

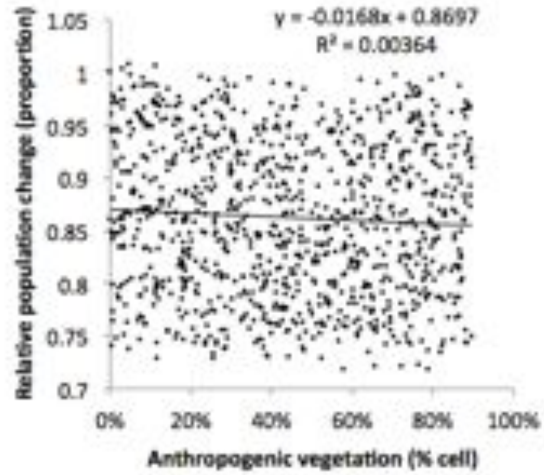
Significant features associated with density:
Results from density analyses indicated that densities of *T. rubiginosus* at survey stations were positively associated with the intercept (undisturbed vegetation) and mangroves.

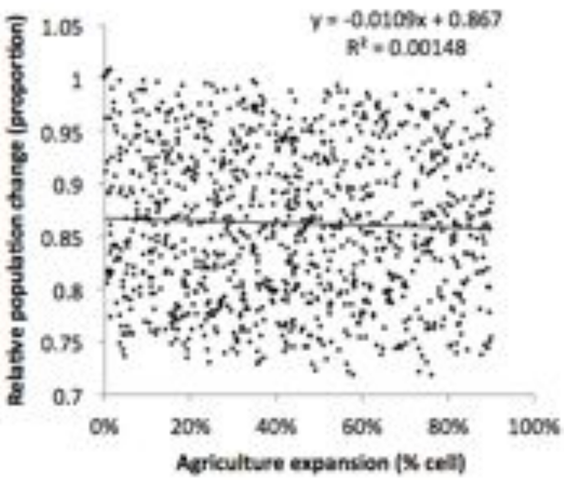
Population change under 1000 future landscape scenarios:
Spatially explicit habitat models linked to density functions for *T. rubiginosus* predicted a contemporary population of 100,803 birds on Pohnpei. When density models were applied to 1,000 potential future landscapes with habitat features perturbed by anthropogenic and climate-related factors, results indicated a mean population increase of 15 % (SD 9.6%) in *T. rubiginosus* populations.

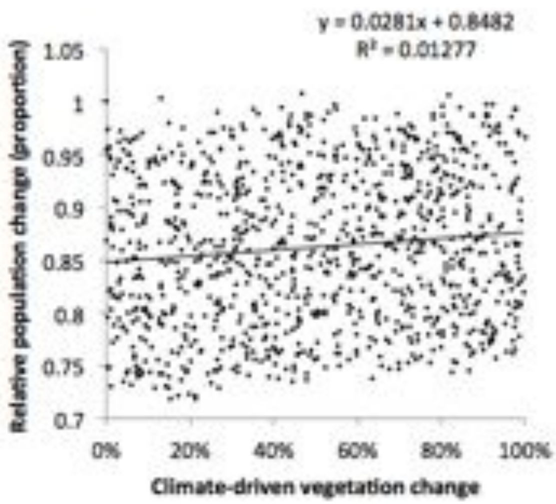
Four of five factors affecting *T. rubiginosus* showed very low population change associations, however the lost of mangrove as habitat surface has the largest negative effect ($r^2 = 0.97$).

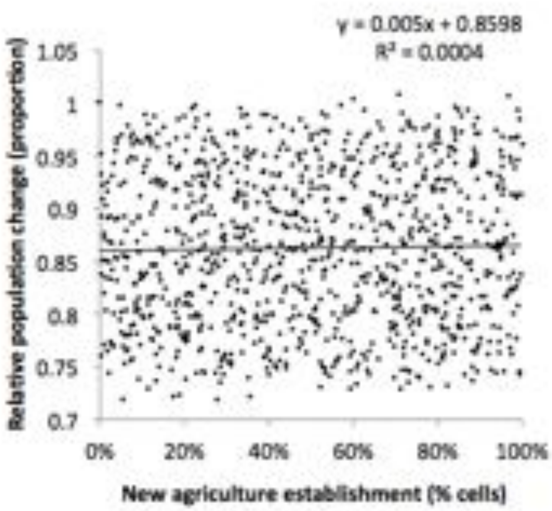
Management recommendations:
T. rubiginosus is a common species found throughout the island of Pohnpei. Its population has declined drastically in since 1983. Occupancy and density analysis indicated agroforest was negatively associations with *T. rubiginosus*. Controlling the transformation of undisturbed forest to agroforest could help maintain the population, and sea level rise is likely to impact the birds through loss of mangrove.

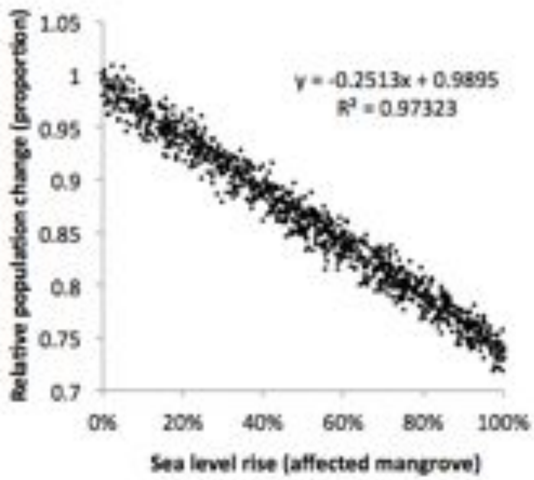
Species: POLO

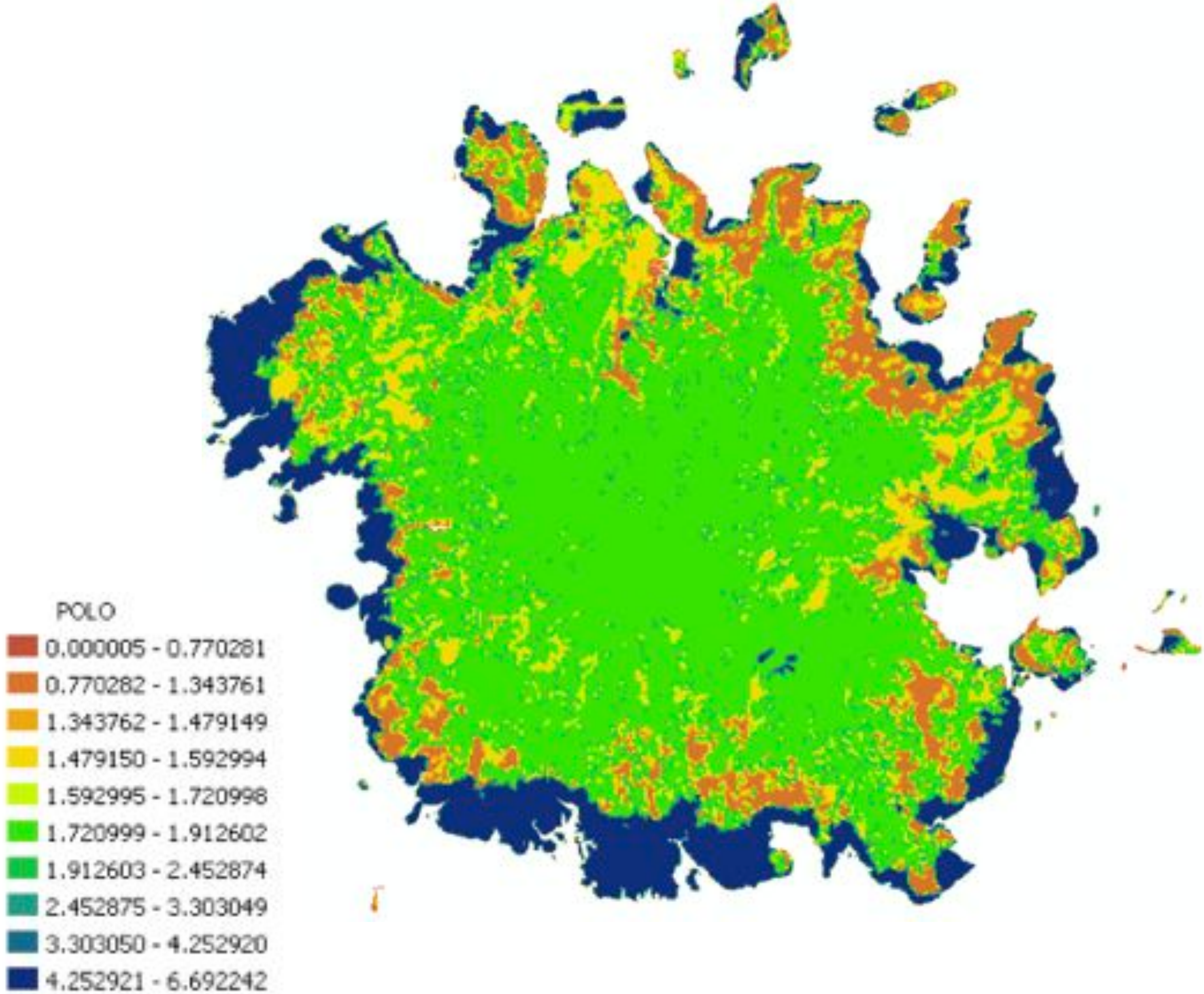











POLO
0.000005 - 0.770281
0.770282 - 1.343761
1.343762 - 1.479149
1.479150 - 1.592994
1.592995 - 1.720998
1.720999 - 1.912602
1.912603 - 2.452874
2.452875 - 3.303049
3.303050 - 4.252920
4.252921 - 6.692242