Threatened Species Recovery Hub

National Environmental Science Programme

Christmas Island Spatial Conservation Planning Analysis: Final Report

Katherine Selwood, Heini Kujala & Brendan Wintle

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CHRISTMAS ISLAND NATIONAL PARK

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Front cover: Lookout between Lily Beach and Ethel Beach, Christmas Island. Photo: Katherine Selwood

Contents

Ethel Beach, Christmas Island. Photo: Katherine Selwood

Executive Summary

Christmas Island is a site of international conservation significance and home to many endemic and threatened species. In this work we used spatial prioritisation tools to build an understanding of how biodiversity values on Christmas Island are distributed. The aims of this were to evaluate the current protection of priority species and habitats within the National Park, to identify key areas of priority within the National Park, and to identify important areas for biodiversity that are not currently protected.

The spatial prioritisation tool hierarchically ranks each 100 square-metre location on Christmas Island based on its biodiversity value, using information on the mapped distributions of priority species and habitats. The top ranked sites together represent the core habitats of all included species. The highly ranked sites are also those most irreplaceable, as there are few or no locations with same biodiversity values. It is important to note that the spatial prioritisation process ranks all areas within a set study area (i.e. Christmas Island). It does not represent an absolute rating of the conservation value of any individual location but a relative value between locations within the study area. That is, areas in the top and bottom 10% ranked priorities each represent exactly 10% of the study area, and so their rankings need to be considered holistically across the study area. Lower ranked areas may still be of high conservation value for the species and habitats assessed.

We found the highest ranked areas on Christmas Island to be mostly located on the western coast and south-west point, the eastern end of the north coast, and the central-east coast. On average, the National Park currenly protects 69% of species island-wide habitats, although there is high variation in protection between species. We ranked areas outside of the National Park according to their complementarity to biodiversity already protected in the park, and found that many of the high ranked areas are located within the boundaries of proposed National Park additions (on unallocated crown land). These proposed additions would increase the area of protection for all focal species.

Red crab and robber crab, Christmas Island. Photo: Katherine Selwood

Background

Christmas Island is a site of international conservation significance. The island supports 32 taxa that are threatened under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), including 19 terrestrial species (plants and animals), 13 marine species, and many others that are protected under international agreements. Christmas Island provides nesting habitat for several species of seabirds, including the endemic and threatened Abbott's booby (*Papasula abbotti*) and Christmas Island frigatebird (*Fregata andrewsi*). Many of Christmas Island's species are endemic to the island, including several forest birds (e.g. the Christmas Island goshawk, Christmas Island hawk-owl, Christmas Island imperial pigeon, Christmas Island emerald dove, Christmas Island thrush, Christmas Island white-eye, Christmas Island swiftlet), reptiles (e.g. Lister's gecko, Blue-tailed skink, Giant gecko), numerous plants (18 species) and a multitude of invertebrates (e.g. crabs and insects). Two of the island's wetland ecosystems are listed under the Ramsar Convention (The Dales and Hosnies Springs).

Despite the conservation value of Christmas Island, the island's biodiversity is under substantial pressure from a number of threats, including introduced species (such as yellow crazy ants *Anoplolepis gracilipes*, feral cats, rats, wolf snakes, centipedes and weeds), and direct human impacts such as clearing and fragmentation of native vegetation and impacts from road vehicles. Since permanent human settlement in the late 1880s, several endemic species have gone extinct in the wild, some as recently as 2010. A large proportion of (c. 63%) Christmas Island is reserved and protected by a National Park, but many threatened and significant species occur in other areas of the island, most of which is Crown Land. Unallocated Crown Land (UCL, otherwise known as Vacant Crown Land) accounts for just under 25% of the island, and most of the remainder is currently allocated to mining lease. Unreserved parts of the island may be subject to proposals for various types of development.

A comprehensive understanding of the relative biodiversity values across Christmas Island, within and outside the National Park, will assist with integrated land-use planning on the island to maximise outcomes for both conservation and human land-use. In this project we document and geographically circumscribe the biodiversity values of Christmas Island based on the habitat of priority species. We assess and rank the relative biodiversity value of land within the National Park. We also assess the relative importance for biodiversity of land across the whole island, and specifically identify areas that, if protected, would best complement the biodiversity already protected within the National Park system.

Rainforest floor with strangler fig buttress roots (Ficus microcarpa) in foreground. Photo: Katherine Selwood

Approach

Systematic conservation planning and spatial prioritisation

Systematic conservation planning was conceived as a framework for reserve design, with the goal of achieving adequate protection of a representative portion of biodiversity, rather than the potentially biased representation of biodiversity protected in traditional National Park networks. The approach is based on the use of clearly defined objectives and information on biodiversity across an entire region to systematically identify a network of locations that provide complementary and comprehensive protection for key biodiversity components, incorporating areas with a high degree of irreplaceability. Today, the field of systematic conservation planning has expanded to encompass a multitude of conservation challenges, such as restoration, management and threat abatement.

An important step in systematic conservation planning is the biogeographical identification of priority locations for conservation actions, called spatial prioritisation. Several spatial prioritisation methods have been developed for identifying an optimal network of conservation areas and holistically assessing the potential impacts of land-use scenarios. These methods apply the principles of biodiversity comprehensiveness, complementarity and irreplaceability to prioritise the focal region or candidate locations according to biodiversity representativeness, by simultaneously assessing the landscape value of multiple mapped biodiversity components (e.g. species).

We use the spatial prioritisation tool Zonation (Moilanen et al. 2014, Lehtomäki and Moilanen 2013) to identify areas of conservation priority across Christmas Island. Zonation evaluates the biodiversity value of all sites simultaneously to develop a hierarchical (0 - 100) ranking of the region based on areas that maximise the representation of suitable habitat for multiple species. We used Zonation to build an understanding of how biodiversity values on Christmas Island are distributed, to assess how priority species are currently protected and to identify potential priority areas for future conservation action both within and outside of the National Park. Specifically, our key goals were to:

1. Understand how biodiversity values on Christmas Island are distributed;
2. Identify the top areas of biodiversity value within the National Park; and
3. Identify the top priorities for biodiversity representativeness outside of the National Park.

It is important to note that the spatial prioritisation process using Zonation ranks all areas within a set study area (i.e. Christmas Island). It does not represent an absolute rating of the conservation value of any individual location but a relative value between locations within the study area. That is, areas in the top and bottom 10% priority ranks each represent exactly 10% of the study area, and so their rankings need to be considered holistically across the study area. Lower ranked areas may still be of high conservation value in absolute terms.

Biodiversity components

A total of 32 spatial maps of species and other important biodiversity features were used in the prioritisation. We included species that were identified as 'significant' in the draft Christmas Island Biodiversity Plan (Director of National Parks, 2014; Table 1). These include species that are (1) listed, or considered for listing as threatened under the EPBC Act, (2) play an important or 'keystone' role in maintaining the island's ecology or characterise a significant ecosystem, (3) are of conservation concern (those that have declined substantially on Christmas Island) but not listed as threatened, (4) are endemic vertebrates, and/or, (5) are of international conservation significance with strong community support for conservation.

The Christmas Island pipistrelle (*Pipistrellus murrayi*), Christmas Island shrew (*Crocidura trichura*), coastal skink (*Emoia atrocostata*) and forest skink (*Emoia nativitatis*) are presumed extinct and were excluded from the prioritisation. Despite being extinct in the wild, the blue-tailed skink and Lister's gecko were included because they persist in captive populations and could be reintroduced at some point in the future. The robber crab (*Birgus latro*) was excluded from the analysis because they roam widely and there was not adequate information available on their burrow locations.

In addition to 'significant' species, we also included in the prioritisation records of rare plants that are considered to be of conservation concern (*Cycas rumphii*, and rare plant records from Holmes and Holmes (2002), and Du Puy (1988)), and distribution maps of the red-footed booby and brown booby (which have significant breeding colonies on the island). Priority habitats included in the prioritisation were (1) primary rainforest, and (2) landscape wet refuges.

Tall evergreen primary rainforest is particularly rich in biodiversity, including many protected and endemic species such as epiphytic orchids, lichens, mosses, insects and other invertebrates. It also displays high structural complexity and provides food, resources and habitat for a high proportion of Christmas Island's species. Perennially wet locations (wet refuges) in the landscape are important safe havens for crabs and other animal species, especially during dry times.

Of the 32 biodiversity and conservation features included in the prioritisation model, nine are flora/vegetation related, and 23 are fauna/animal related.

Species data

All data on species occurrences and habitat were provided by Christmas Island National Park (CINP) and associated researchers. Much of the species data came from the Island Wide Survey (IWS) program (2001 - 2015), which has been conducted biennially since 2001 and consists of a regular survey grid of approximately 1000 points across Christmas Island (excluding inaccessible areas such as active mine leases and the detention centre) (Director of National Parks, 2013). Several significant species are targeted in these surveys (i.e., presence and absence data are collected) and incidental observations ('transit data') of non-target species are also recorded (presence-only) (Table 1). Several sources of presence-only species data were also provided by CINP, including targeted surveys for frigatebirds, and species-specific databases recording all known occurrences of reptiles and rare/threatened plant species (Table 1). We used unpublished data on foraging and roosting locations of the Christmas Island flying fox collected by researcher Chris Todd from the University of Western Sydney. For the Christmas Island hawk-owl, we used density estimates recorded by Morcombe (2016). Data from a survey program ('drive survey') targeting the Christmas Island flying-fox and Christmas Island hawk-owl was provided by CINP, but observations were made at varying distances from the recorded waypoints, and so the data was not spatially explicit enough to use for distribution modelling/mapping.

Mapping species distributions

Species distribution maps for species with <20 data points were compiled from the point locations of observations with a 50 m buffer. The same procedure was applied for rare plant species records from Holmes & Holmes (2002) and Du Puy (1988). Polygons of the Christmas Island frigatebird colonies were provided by CINP and extended to include additional observations that were recorded in the IWS (with a 50 m buffer). A polygon of the Hosnies Spring wetland was provided by CINP and was combined with vegetation information from the Christmas Island vegetation map (Geosciene Australia 2014) to map the distribution of the two mangrove species (*Bruguiera* spp.). For the hawkowl, we mapped predicted densities in each vegetation type as estimated by Morcombe (2016). The vegetation type 'primary rainforest' was defined as closed canopy evergreen forest (as classified by Geoscience Australia 2014) and was mapped as the percentage tree cover (of trees >10 m tall, in 50 m radius). Landscape wet refuges were mapped as polygons by CINP.

We built species distribution models for species with >20 records. We used boosted regression trees (Elith et al., 2008) for species with presence-absence or count data and Maxent for species with presence-only data (Jurka and Tsuruoka, 2013) (Table 1, detailed methods in Appendix 1). Species distributions were analysed at a resolution of 10 x 10 m. Along with species distribution models, we used additional habitat information for five species. For the Christmas Island swiftlet, we mapped known nesting caves, and for the Christmas Island flying fox we mapped the main roosting sites, each with a 100 m radius buffer. We modelled the occurrence of *Tectaria devexa var. minor*, but because there are a small number of known locations of this species we wanted to ensure that these known locations were ranked of highest importance, so also included a map of known locations, weighted by the size of the population in each location (buffer = 50 m). Similarly, for *Cycas rumphii*, we used both the modelled distribution map and a map of known occurrences (buffer = 50 m). These additional layers were all included as individual layers in the prioritisation process (weighting equivalent to all other species layers). The blue crab is known only to occur on the eastern and western coastlines of Christmas Island, so we cropped the modelled distribution map with polygons that map the species maximum distribution extent.

Syzygium nervosum tree in closed canopy evergreen forest. Photo: Katherine Selwood

Table 1: Biodiversity features included in the spatial planning analysis. Common name; scientific name; Thr. = listed as threatened under the EPBC Act, 'MM' = listed as migratory or marine under international agreements, 'Model' = type of model used to map species distribution (BRT = boosted regression trees for presence-absence or count data, Maxent for presence-only data), 'Data' = main data source, 'IWS' = island wide survey (Director of National Parks 2013). Additional information on data sources and modelling for each species is provided in Appendix 2.

Biodiversity features		Thr./MM	Model	Data
Crabs				
Red crab	*Gecarcoidea natalis*		BRT for total burrow size (number of burrows * average burrow size)	IWS
Blue crab	*Discoplax celeste*		Maxent, cropped by max. distribution	IWS; CINP shapefile of habitat
Seabirds				
Golden bosun / white-tailed tropicbird	*Phaethon lepturus fulvus*		Interpolated reporting rates	IWS
Abbott's booby	*Papasula abbotti*	Thr.	BRT	IWS
Christmas Island frigatebird	*Fregata andrewsi*	Thr., MM	Polygon colony	Frigatebird survey database; IWS
Red-footed booby	*Sula sula*	MM	BRT	IWS
Brown booby	*Sula sula*	MM	Point locations with 50 m buffer	IWS (survey and transit)
Land birds				
Christmas Island hawk-owl	*Ninox natalis*	Thr.	Density estimates by veg. type	Morcombe 2016; Geoscience Australia 2014
Christmas Island Emerald dove	*Chalcophaps indica natalis*	Thr.	BRT	IWS
Christmas Island goshawk	*Accipiter hiogaster natalis*	Thr., MM	BRT	IWS
Christmas Island thrush	*Turdus poliocephalus erythropleurus*	Thr.	BRT	IWS
Christmas Island imperial pigeon	*Ducula whartoni*		BRT	IWS
Christmas Island white-eye	*Zosterops natalis*		BRT	IWS
Christmas Island swiftlet	*Collocalia linchi natalis*		BRT	IWS
Christmas Island swiftlet - breeding caves			Point locations with 100 m buffer	CINP Cave database

Biodiversity features		Thr./MM	Model	Data
Reptiles				
Christmas Island blind snake	*Ramphotyphlops exocoeti*	Thr.	Point locations (2) with 50 m buffer	CINP reptile database
Blue-tailed skink	*Cryptoblepharus egeriae*	Thr.	Maxent	CINP reptile database
Lister's gecko	*Lepidodactylus listeri*	Thr.	Maxent	CINP reptile database
Giant gecko	*Cyrtodactylus sadleiri*	Thr.	Maxent	CINP reptile database
Mammals				
Christmas Island flying fox - roosting	*Pteporus natalis*	Thr.	Maxent	IWS survey and transit, C.Todd unpublished data
Christmas Island flying fox - major roosts			Point locations with 100 m buffer	CINP Flying fox database
Christmas Island flying fox - foraging			Maxent	C. Todd unpublished data
Plants				
a fern	*Tectaria devexa var. minor*	Thr.	Maxent model, plus point locations of populations with 50 m buffer (value = population size)	CINP species database
mangrove	*Bruguiera gymnorhiza & B. sexangula*		Polygon	Polygon of wetland; CI veg. map mangrove distribution
Christmas Island spleenwort	*Asplenium listeri*	Thr.	Point locations with 50 m buffer	CINP species database
a fern	*Pneumatopteris truncata*	Thr.	Point location with 50 m buffer	CINP species database
Cycad	*Cycas rumphii*		Maxent model, plus point locations with 50 m buffer (value = 1)	CINP species database
Primary rainforest cover			Percentage cover of trees (>10 m) within 50 m radius (moving window)	Canopy Height Model 2011 (Geoscience Australia 2012); Geosciences Australia (2014);
Wet refuges			Polygons of perennially wet locations	CINP polygons

Zonation specifications

We used Zonation to build an understanding of how biodiversity values are distributed across Christmas Island, to assess how priority species and habitats (Table 1) are currently protected and to identify potential priority areas for future conservation action. We included the entire Christmas Island land mass in the prioritisation process, except for built up areas (including towns, north-west point, and the airstrip). We assessed the following scenarios:

1. **Whole Island prioritisation** In this scenario, the entire island was ranked hierarchically according to the biodiversity value of each location (grid cell). The aim of this was to map the relative importance of all land areas on Christmas Island for the conservation of the priority species, regardless of land tenure or future development plans.
2. **National Park prioritisation** The objective of this scenario was to map the location of the top biodiversity values within the National Park (regardless of where species occur outside of the park) in order to identify the most 'irreplaceable' areas for biodiversity within the park, to inform management planning. We also assessed the proportions of species distributions that are protected in the current National Park using the species distribution maps.
3. **Areas of high biodiversity value outside of the National Park** The objective of this scenario was to identify areas outside the current National Park system that are most complementary to the biodiversity within the National Park. We overlaid the boundaries of proposed National Park extensions as submitted by CINP to the Crown Land Development plan (Department of Infrastructure and Regional Development 2017). We also assessed the proportions of species distributions that would be protected if the National Park were to be extended to the proposed parcels.

Zonation settings

Zonation conducts a hierarchical ranking of the sites through a removal process, where the software starts by assuming that all sites (grid cells) in the landscape are protected. It then proceeds by progressively removing cells that cause the smallest marginal loss in biodiversity value, producing a ranking based on the biodiversity value of each site.
To run scenarios 2 and 3 we used hierarchical masks (Cabeza and Moilanen, 2006), which constrain Zonation to remove grid cells from certain areas first or to retain cells until the very end (e.g. existing protected areas), regardless of their biodiversity value. To assess scenarios 2 and 3 we applied a hierarchical mask so that all areas within the National Park were removed last in the cell removal process (hierarchical mask value for National Park = 2, rest of island = 1).

In each Zonation scenario, we used the core area function to rank the island, the warp factor was set to 10, and edge removal was implemented. We included the distribution maps for all species and habitats listed in Table 1, weighted equally, at a 10 x 10 m resolution. A 'condition layer' was applied to the prioritisation (all species and habitats). All areas identified as 'uncleared' in the CI Vegetation and Clearing Map (Geoscience Australia, 2014) were considered intact (condition value = 1), while all areas identified as 'cleared' were discounted (multiplied) in the prioritisation process according to vegetation height, e.g. regrowth consisting of tall trees was considered more ecologically valuable than low fern/weed cover. Condition in cleared areas was rated according to vegetation height in each cell (from Lidar canopy height data), relative to 25 m (height / 25 m); a conservative estimate of the original vegetation height on the plateau/upper terrace, where most of the cleared areas are located (A. Grigg, pers. comm.).
For example, the mean condition value for areas classified as rehabilitated areas was 0.32 (sd = 0.18), average regrowth: 0.48 (sd = 0.23) and weed dominated regrowth: 0.10 (sd = 0.12).

Juvenille brown booby (Sula leucogaster)
Photo: Katherine Selwood

Findings

Species distribution maps

Species distribution maps are presented in Appendix 2, including the fit of each model (AUC).

Spatial conservation prioritisation

Biodiversity rankings across Christmas Island

The whole island spatial prioritisation highlighted a number of important areas distributed across Christmas Island (Figure 1). The highest ranked areas were mostly located on the western coast and south-west point, the eastern end of the north coast, and the central-east coast. The lowest ranked areas (bottom 10%, purple areas in Figure 1) were predominantly located inland in the north east and inland at north-west point and around currently developed and populated parts of the island.

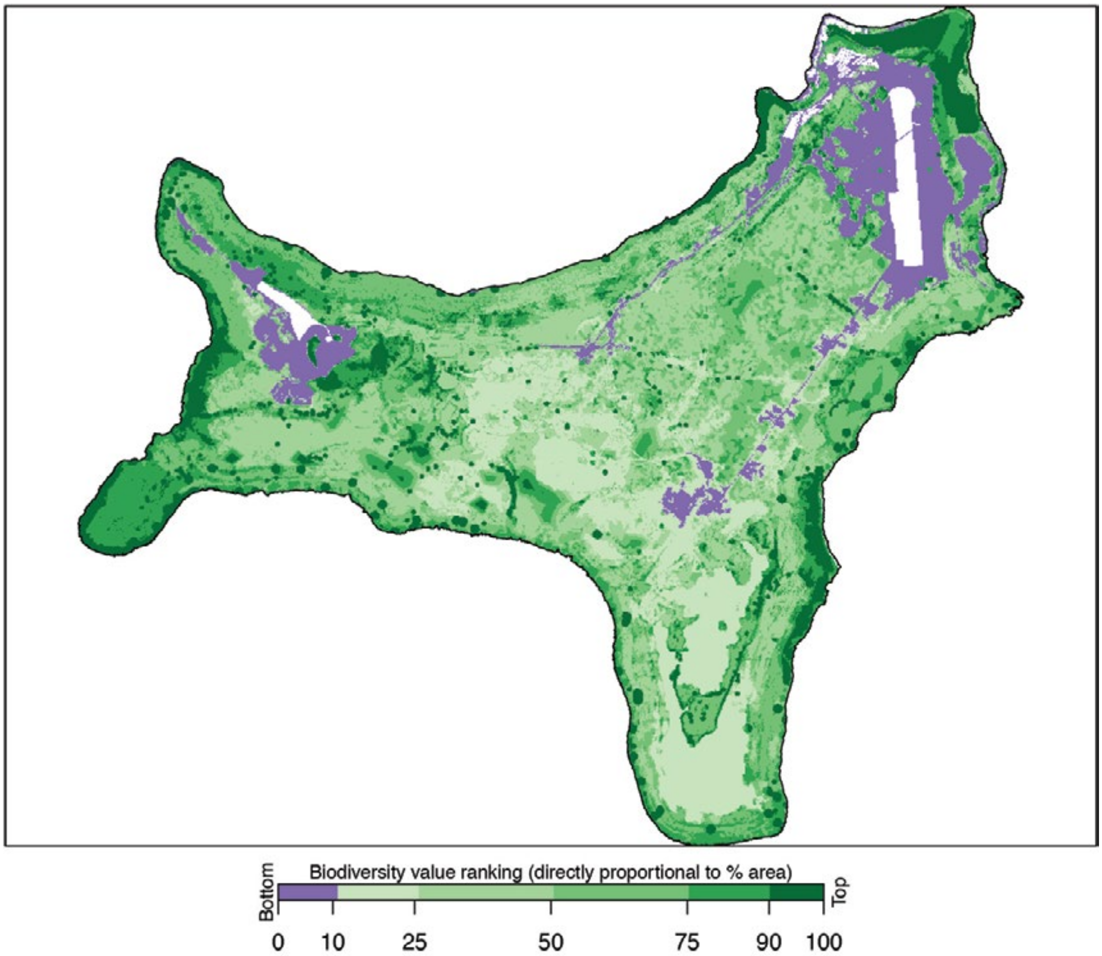

Figure 1: Whole island conservation spatial prioritisation of Christmas Island based on the 32 included biodiversity features and ignoring current land tenure. Mapped values represent a relative ranking between locations within the study area and do not represent an absolute rating of the conservation value of any individual location. Areas in the top and bottom 10% each represent exactly 10% of the study area, and so their rankings need to be considered holistically across the study area. Lower ranked areas may still be of high conservation value in absolute terms. White areas on the island indicate built-up locations that were not considered in the prioritisations.

National Park conservation priorities

The top priority areas within the National Park, based on biodiversity rankings, are mapped in Figure 2. This prioritisation ranking disregards the representativeness of biodiversity outside the National Park, to highlight the areas within the National Park that are most irreplaceable. Although the relative rankings appear mostly similar to the whole-island prioritisation (Figure 1), there are some small differences in the top ranked areas, e.g. near the detention centre and on the south-west tip. On average, the National Park currently protects 69% of species island-wise habitats, although there is high variation in protection between species (Figure 5). In particular, *Asplenium listeri*, the known major roost sites of the Christmas Island flying fox, and the habitat and breeding caves of the Christmas Island swiftlet seem to be somewhat underrepresented, and none of the known locations of the Christmas Island blind snake are currently protected by the National Park.

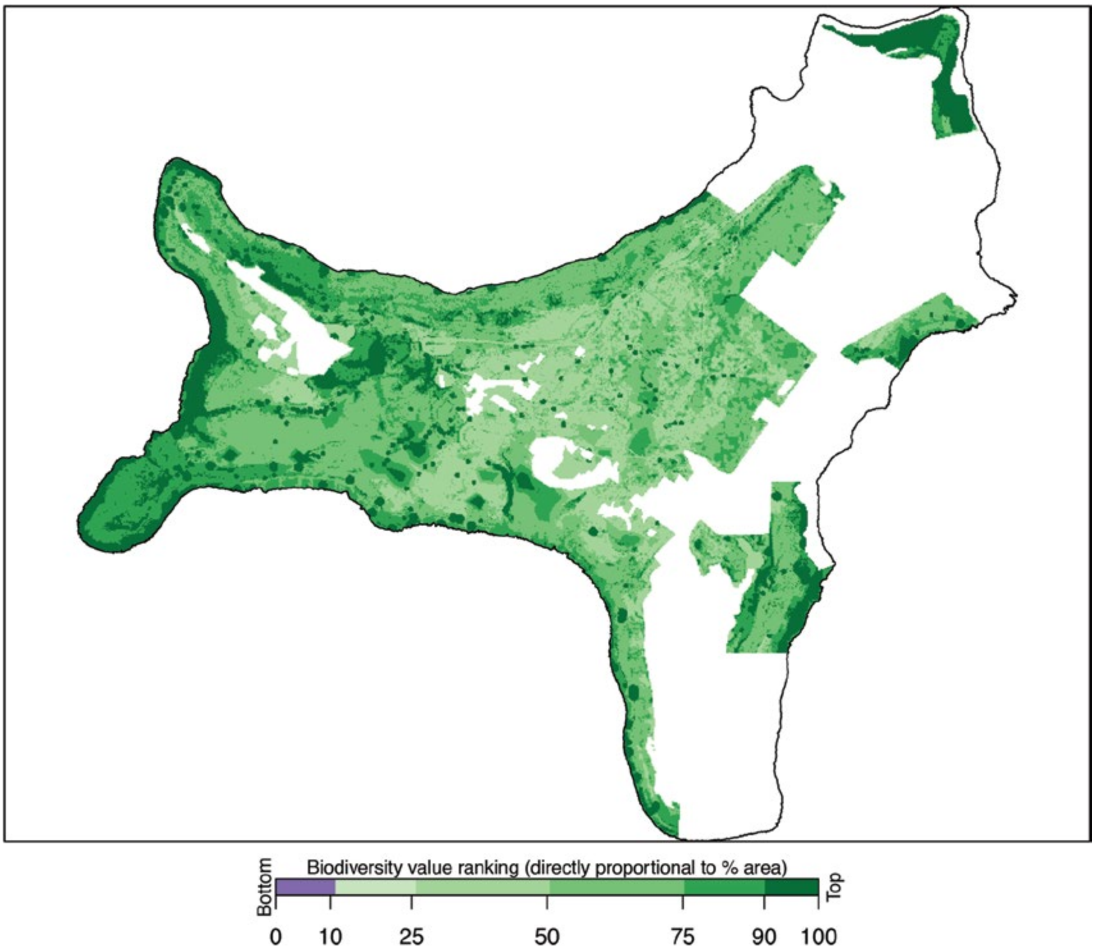

Figure 2: Biodiversity rankings within the current National Park system. This prioritisation ranking disregards the representativeness of biodiversity outside the National Park, to highlight the areas within the National Park that are most irreplaceable. Mapped values represent a relative ranking between locations within the study area and do not represent an absolute rating of the conservation value of any individual location. Areas in the top and bottom 10% each represent exactly 10% of the study area, and so their rankings need to be considered holistically across the study area. Lower ranked areas may still be of high conservation value in absolute terms.

Areas of biodiversity value outside of the National Park

Figure 3 shows the relative conservation importance of areas outside of the current National Park boundaries (predominantly, unallocated crown land). The areas ranked highest on the rank scale of the map are those areas that would add most value to the current reserve system, considering the proportion of species distributions that are already protected within the National Park. Most of the higher ranked areas are located within parcels recommended for protection in a reserve (e.g. 'high priority' and 'very high priority' for National Park, Figure 4) in the Christmas Island National Park submission to the Crown Land Registration of Interest (ROI) process (Figure 4).

If the National Park were to be extended to include the proposed National Park additions, the estimated level of protection for all species habitats would increase (Figure 5). The average increase in the level of protection for each species is 14.7%. These extensions would deliver the largest additional benefits to the protection of *Asplenium listeri* (19% increase), the blue crab (25% increase), flying fox roost sites (27% increase), swiflet breeding caves (27%) and Christmas Island blind snake observed locations (49%).

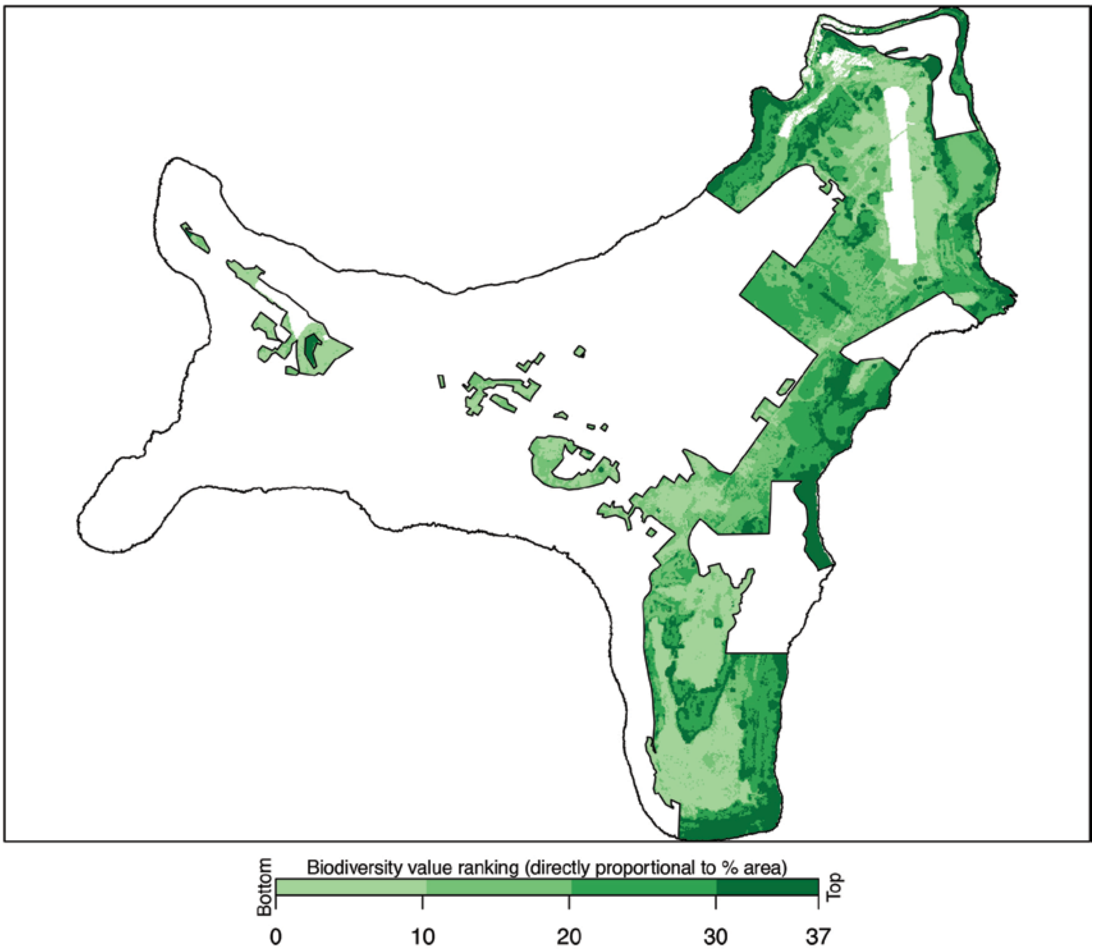

Figure 3. Biodiversity ranking of land outside of the current National Park in relation to its complementarity to the current National Park. If protected, the top ranked sites on this map would add the most value to the current National Park. Mapped values represent a relative ranking between locations within the study area and do not represent an absolute rating of the conservation value of any individual location. Areas in the top and bottom 10% each represent exactly 10% of the study area, and so their rankings need to be considered holistically across the study area. Lower ranked areas may still be of high conservation value in absolute terms.

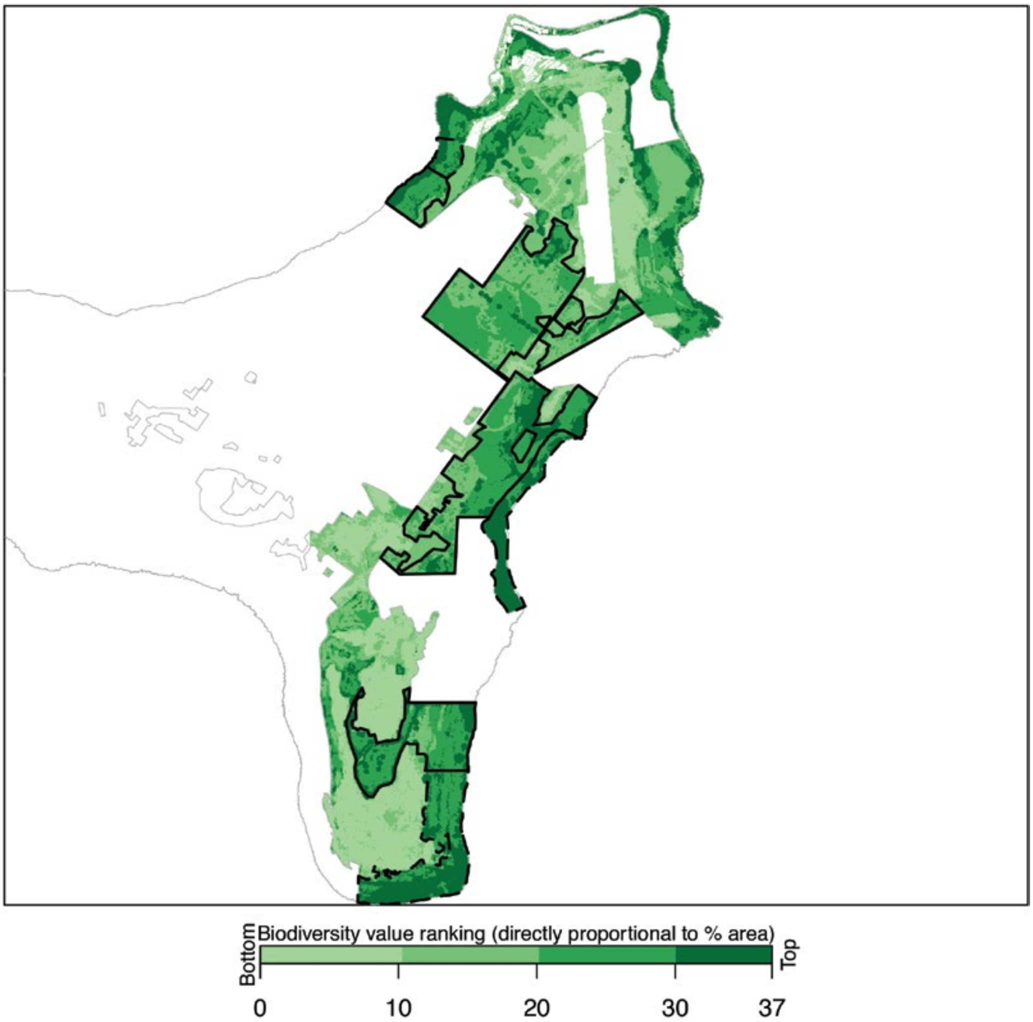

Figure 4. Biodiversity ranking of land outside of the current National Park in relation to its complementarity to the current National Park, highlighting proposed National Park additions. If protected, the top ranked sites on this map would add the most value to the current National Park. Solid lines are those areas that have been identified as 'very high priority' by CINP, dashed lines are areas identified as 'high priority'. Mapped values represent a relative ranking between locations within the study area and do not represent an absolute rating of the conservation value of any individual location. Areas in the top and bottom 10% each represent exactly 10% of the study area, and so their rankings need to be considered holistically across the study area. Lower ranked areas may still be of high conservation value in absolute terms.

Ryan Hill, Christmas Island. Photo: Katherine Selwood

Figure 5. Percentage of species island-wide distributions protected (blue) in current National Park compared to an extended National Park system, with the addition of land parcels of unallocated crown land that have been proposed by CINP.

Discussion

The spatial prioritisation process highlighted a number of areas within the National Park, and on unallocated crown land with highly ranked biodiversity values. From a whole-island perspective, the highest ranked areas were mostly located on the western coast and south-west point, the eastern end of the north coast, and the central-east coast. The lowest ranked areas were located in the inland in the north east and inland at north-west point and around currently developed and populated parts of the island. The distribution of rankings within the National Park was reflective of the whole-island rankings, with the most irreplaceable parts of the park being located along the east-coast, in the central-eastern section of the main parcel, and in the smaller parcels on the west, particularly near the coast.

The most highly ranked areas represent core habitats for the priority species, and encompass a high proportion of the distributions of rare species. As such, the biodiversity rankings of the National Park may be used to help prioritise conservation actions within the National Park, in order to maximise the number of species benefiting from management activities. In developing the approach for this project, there was a question of whether to include the distribution of yellow crazy ant (YCA) super colonies in the prioritisation process, for example, as a condition or cost layer, so as to avoid giving high priority to areas with YCA supercolonies currently present. It was decided that it would be undesirable to penalise areas that currently have YCA supercolonies, because many of these areas still have high value habitat for many species, the colonies are dynamic and it is hoped that they will be significantly reduced or eradicated once the biological control program reaches full saturation. Given that YCA supercolonies were not explicitly included in this prioritisation process, the results from this prioritisation may be used independently to inform the targeting of actions for yellow crazy ant control, e.g. locations to bait or use biocontrol.

We identified areas outside the National Park, on unallocated crown land, that would be most complementary to the biodiversity already protected within the National Park. There was a high degree of overlap between the highest ranked areas and those that have been recommended for protection by the Christmas Island National Park as part of the Crown Land ROI process. If added to the National Park, these parcels would increase the level of protection of habitat for all species and biodiversity components included in this prioritisation. The proposed parcels would also connect the isolated parcels of National Park on the east coast that have high biodiversity rankings.

Limitations

The spatial prioritisation rankings indicate local habitat quality for the included biodiversity features and 'irreplaceability' of areas, in relation to the representativeness of mapped species habitats elsewhere on the island. The most highly ranked areas represent the 'core' habitat for included species, and so present a starting point for targeting conservation actions on an island-wide, or National Park-wide level. It is important to note that the spatial prioritisation process ranks all areas within a set study area (i.e. Christmas Island). It does not represent an absolute rating of the conservation value of any individual location but a relative value between locations within the study area. That is, areas in the top and bottom 10% each represent exactly 10% of the study area, and so their rankings need to be considered holistically across the study area. Lower ranked areas may still be of high conservation value. Furthermore, many of the most highly ranked areas (e.g. top 10%) have a relatively disparate distribution across the island, and so if protected in isolation, would be unlikely to support viable populations.

Red crabs. Photo: Katherine Selwood

Static distribution maps of species and habitats were the basis of our prioritisation and so the proportion of area that is needed to secure the long-term viability of any individual species or habitat cannot be determined from our analyses. Furthermore, the rankings do not take into account species-specific connectivity or habitat cohesiveness, and so this prioritisation is not suitable for holistically informing targeted conservation actions or impact assessments for individual species. Tools such as spatial population viability analyses, when accompanied with sufficient information on species life histories, are likely to be useful for assessing the the location, extent and configuration of habitat needed to protect the viability of individual species. However, maintaining healthy ecosystems starts by securing the presence of their biodiversity components. The findings of this report provide valuable information on the critical habitat needed to halt further biodiversity loss on Christmas Island.

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Appendix 1

Species distribution modelling methods

For species that were monitored in the IWS surveys (i.e. species with both presence and absence information), we modelled distributions using using boosted regression trees (BRT, Ridgeway, 2017), and for all other species, we used 'Maxent' (Jurka and Tsuruoka, 2013). We conducted all modelling with the 'dismo' package (Hijmans et al. 2016) in the statistical program R (R Core Team, 2017). Environmental predictors used in the modelling process were vegetation structure (canopy height, variation in canopy height), geology, topography (slope, elevation, aspect, topographic wetness index) and landscape context (distance to nearest valley, distance to nearest coast, distance to cleared areas). Elevation and distance to coast were highly correlated (r>0.7), and so we used elevation for all species models, except the crab species, for which we used distance to coast.

BRT is a flexible regression modelling technique for selecting relevant variables, fitting accurate functions and automatically identifying and modelling interactions (Elith et al., 2008). All BRT models used ten-fold cross validation, with bag fraction = 0.75, tree complexity = 5 and learning rate = 0.005 (golden bosun model learning rate = 0.001). We used the gbm.step function to select the optimal number of trees for inclusion in each model. Species with presence-absence data were modelled with Bernoulli error distributions. Red crab burrow size was modelled with a Gaussian error distribution. Species with presence-only observations (6 species, Table 1) were modelled using Maxent in the dismo package in R, enabling all feature classes. Ten-fold cross validation was used to measure the predictive performance of the model. Final models included all observation data. Predicted distributions for species modelled with Maxent consist of the logistic output from Maxent, which is indicative of the probability of occurrence.

The model for the golden bosun had poor fit (AUC = 0.55), and so we used raw reporting rates from the IWS, interpolated to create a continuous map of estimated reporting rates (number of observations at a location divided by the number of surveys) in QGIS. Five bird species had models with only moderately good fit (AUC 0.6 - <0.7, Christmas Island thrush, Christmas Island emerald dove, Christmas Island imperial pigeon, Christmas Island swiftlet, Christmas Island white-eye), but were considered by CINP staff to be representative of species distributions, and so these models were retained. These models predicted the species to be distributed relatively evenly across the inland terrace, which is consistent with the general understanding of the species' ecology. All other models had good fit (AUC>0.7) and were retained, except for the brown booby. While the model had apparently good fit (AUC = 0.94), it predicted a relatively high probability of the species occurring inland, whereas it is known to only occur on the coast. Instead of this model we mapped observed nesting locations with a 50 m buffer.

We assessed whether to include maps of yellow crazy ant (YCA) supercolony presence as an environmental predictor in species distribution modelling in order to account for potential impacts of the YCA on species presences. The probability of presence of yellow crazy ant supercolonies was highly correlated with elevation (r> 0.7), so both variables could not be included in any one species model. We compared species models for all modelled species with YCA included as a predictor (E. van Burm, in prep.), however all models had either lower, or almost equivalent model fit (AUC) than when elevation was included.

Predictor variables used for species distribution models

Variable	Layer name	Description	Level	Source
Mean canopy height	*canopymean*	Mean canopy height within 50 m radius	NA	Derived from Canopy Height Model 2011 (CHM) (Geoscience Australia 2012)
Canopy	*canopy_cv*	Coefficient of variation for canopy height	NA	Derived from CHM
Elevation	*elevation*	Elevation (m), from sea level	NA	2011 Digital Elevation Model (DEM) (Geoscience Australia 2012)
Aspect	*aspect*	Aspect, ranging from 0 to 360 degrees	NA	Derived from DEM
Slope	*slope*	Angle of slope (degrees)	NA	Derived from DEM
Topographic wetness index	*twi*	RSAGA Topographic Wetness Index	NA	Derived from DEM
Distance to valley	*distvalley*	Distance to nearest valley	NA	Derived from Valley Networks (Geoscience Australia 2012)

Variable	Layer name	Description	Level	Source
Distance to coast	*distcoast*	Distance to nearest coastline	NA	Derived from 1:250000 Topography (Geoscience Australia 2012)
Distance to cleared areas	*distcleared*	Distance to cleared areas	NA	Derived from Geoscience Australia (2014)
Vegetation type	*vegtype*	Level 2 vegetation categories	NA	Geoscience Australia 2014
	vegtype	Bare ground	1	
	vegtype	*Bruguiera gymnorhiza* dominant	2	
	vegtype	Closed canopy evergreen forest (moderate)	3	
	vegtype	Closed canopy evergreen forest (tall)	4	
	vegtype	Coastal herbland	5	
	vegtype	Coastal pinnacles/sand	6	
	vegtype	Coastal shrubland	7	
	vegtype	Fern field	8	
	vegtype	*Hibiscus tilaeus* dominant	9	
	vegtype	Infrastructure	10	
	vegtype	*Incocarpus facifer* dominant	11	
	vegtype	*Leaucanea leucocephala* dominant	12	
	vegtype	Mining	13	
	vegtype	Mixed weed and pioneer species	14	
	vegtype	Regrowth	15	
	vegtype	Rehabilitation	16	
	vegtype	Residential	17	
	vegtype	Semi-deciduous forest	18	
	vegtype	Semi-deciduous scrub	19	
Geology	*geology.r*	(LITH_DESC)	NA	Geology Map of Christmas Island 1966 (Geoscience Australia 2012)
	geology.r	Limestone	1	
	geology.r	Limestone - undifferentiated	2	
	geology.r	Limestone/Talus	3	
	geology.r	Pellet limestone, contains pellets and pebbles of phosphate rock	4	
	geology.r	Phosphate rock - massive, boulder, and pebble deposits	5	
	geology.r	Phosphatised volcanics	6	
	geology.r	Pinnacles of limestone with variable amounts of unconsolidated material (Czp)	7	
	geology.r	Unconsolidated material - mostly phosphatic soil containing >20% P2O5	8	
	geology.r	Volcanics - mostly bassalt, some tuff, scoria - undifferentiated	9	

Appendix 2: Species distribution maps

Distribution maps are presented for each species, in alphabetical order of common names. For species with modelled distributions, mapped distributions are model predictions, with the scale ranging from from 0 to 1, indicating the probability of occurrence for Boosted Regression Tree (BRT) models and relative likelihood for Maxent models (unless otherwise indicated).

Abbott's Booby

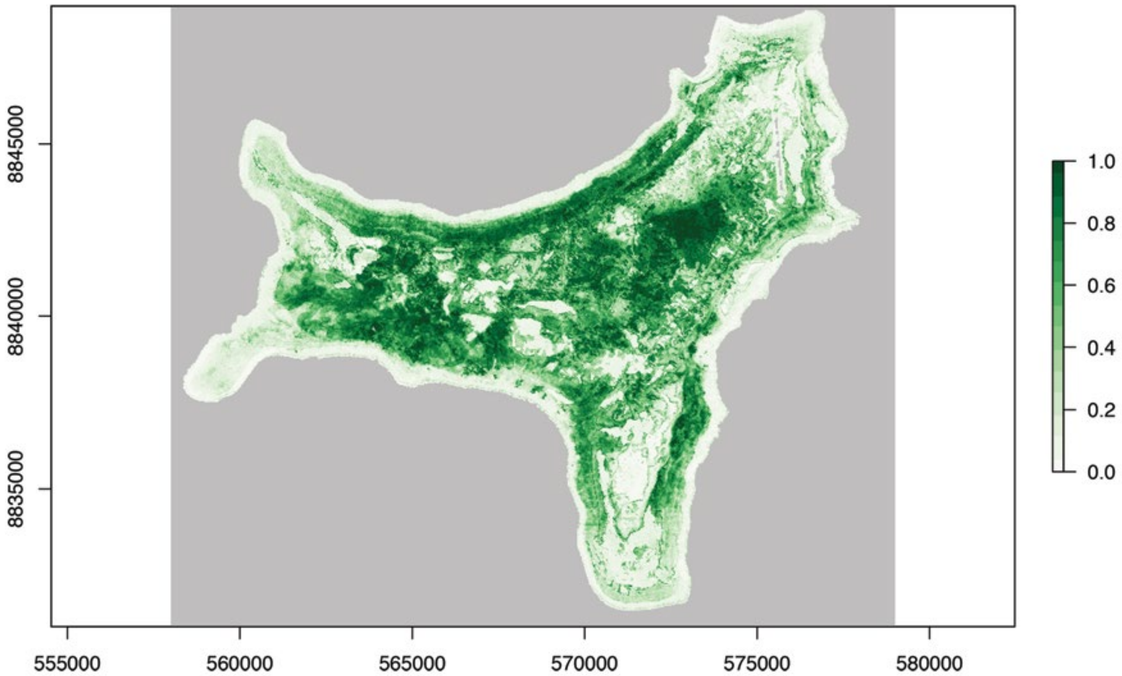

Figure 1. Abbott's booby distribution model. Modelled with BRT, 10-fold cross validation AUC = 0.853

Blue crab

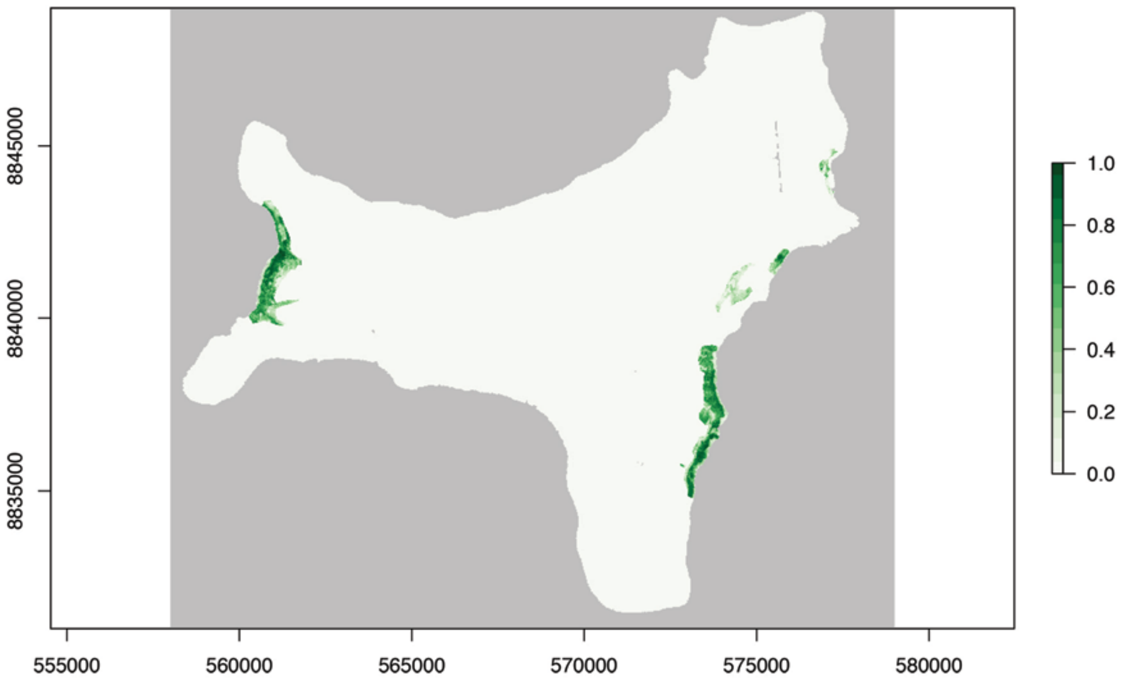

Figure 2. Blue crab distribution model modelled with Maxent and cropped to extent of maximum distribution, 10-fold cross validation AUC = 0.900.

Blue-tailed skink

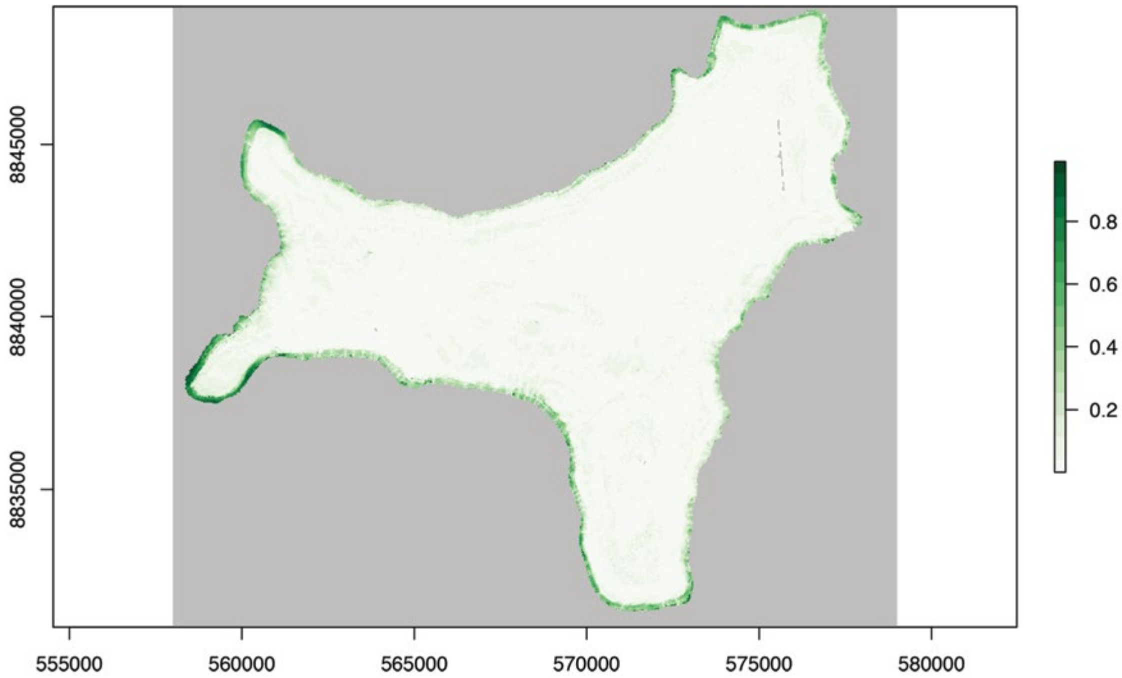

Figure 3. Blue-tailed skink distribution model modelled with Maxent, 10-fold cross validation AUC = 0.902

Brown booby

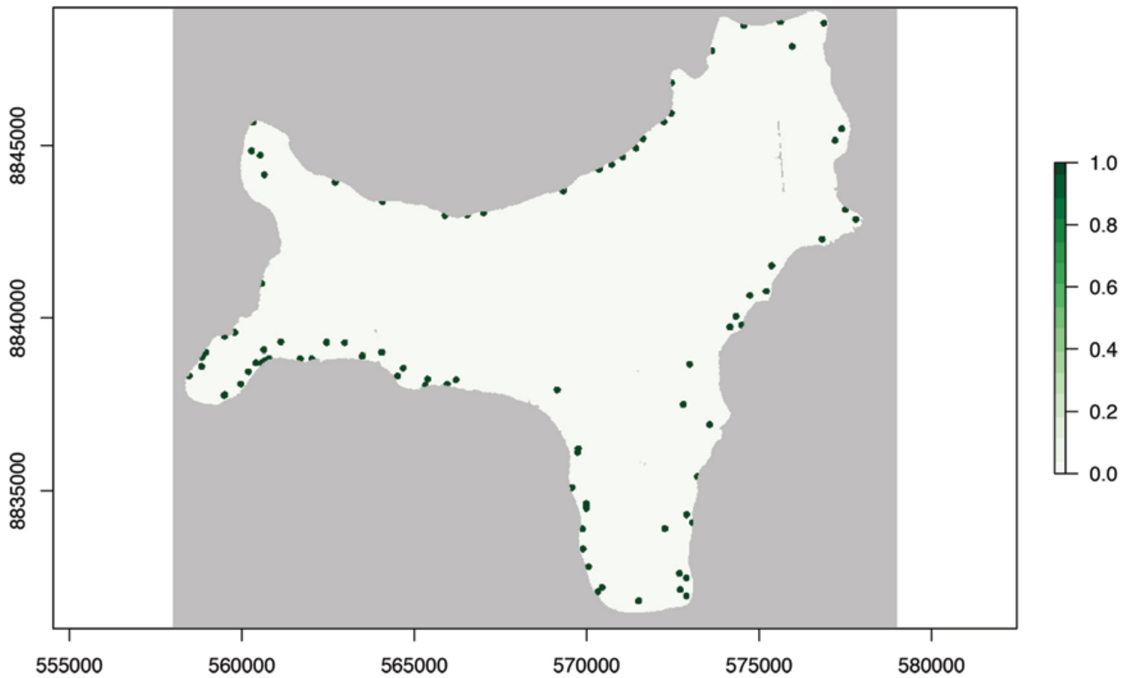

Figure 4. Brown booby 50 m buffered point locations

Bruguiera gymnorhiza and *Bruguiera sexangula*

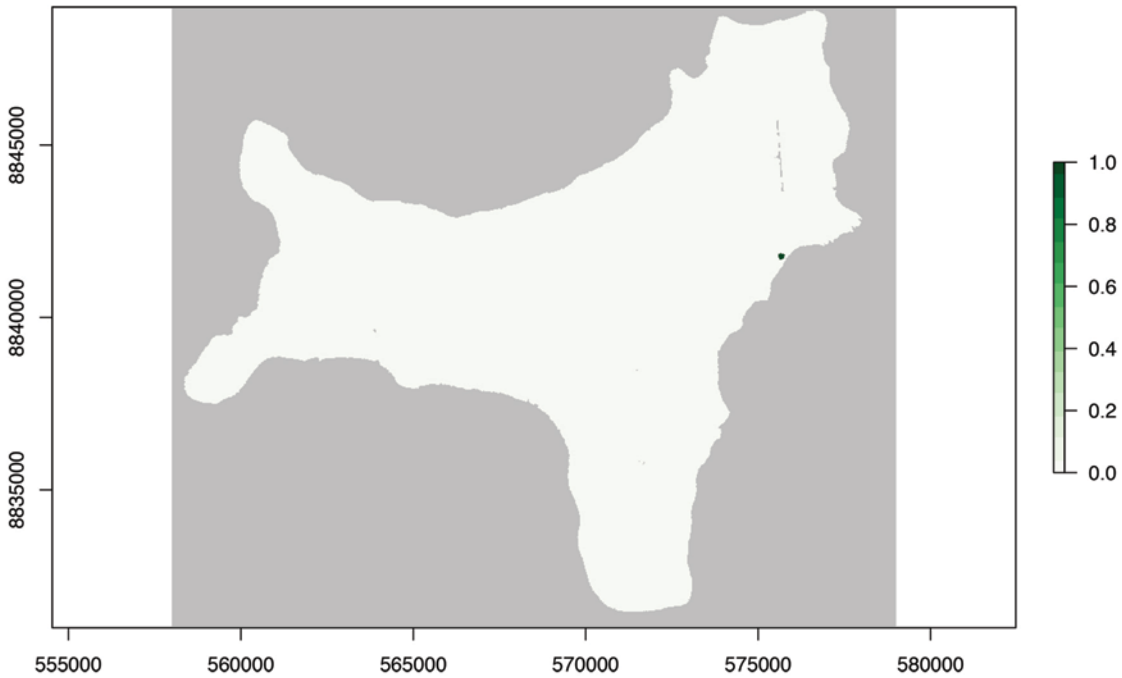

Figure 5. Distribution map of Bruguiera spp.

Christmas Island blind snake

Figure 6. Point locations of Christmas Island blind snake with 50 m buffer

Christmas Island flying fox

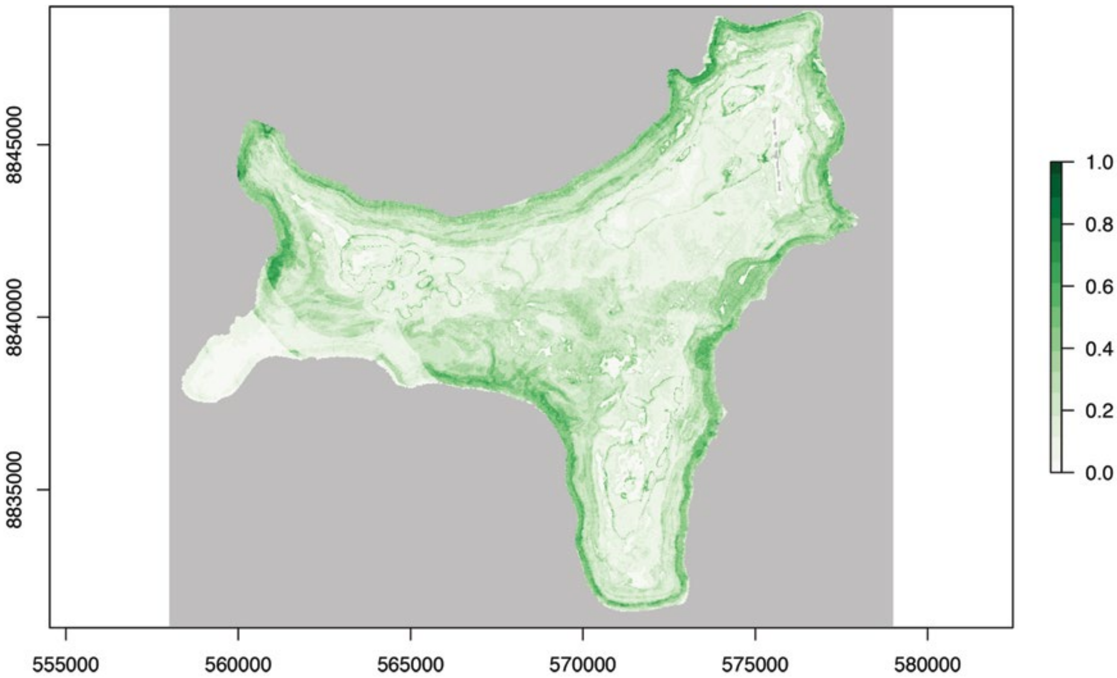

Figure 7. Christmas Island flying fox distribution model of foraging habitat modelled with Maxent, 10-fold cross validation AUC = 0.783

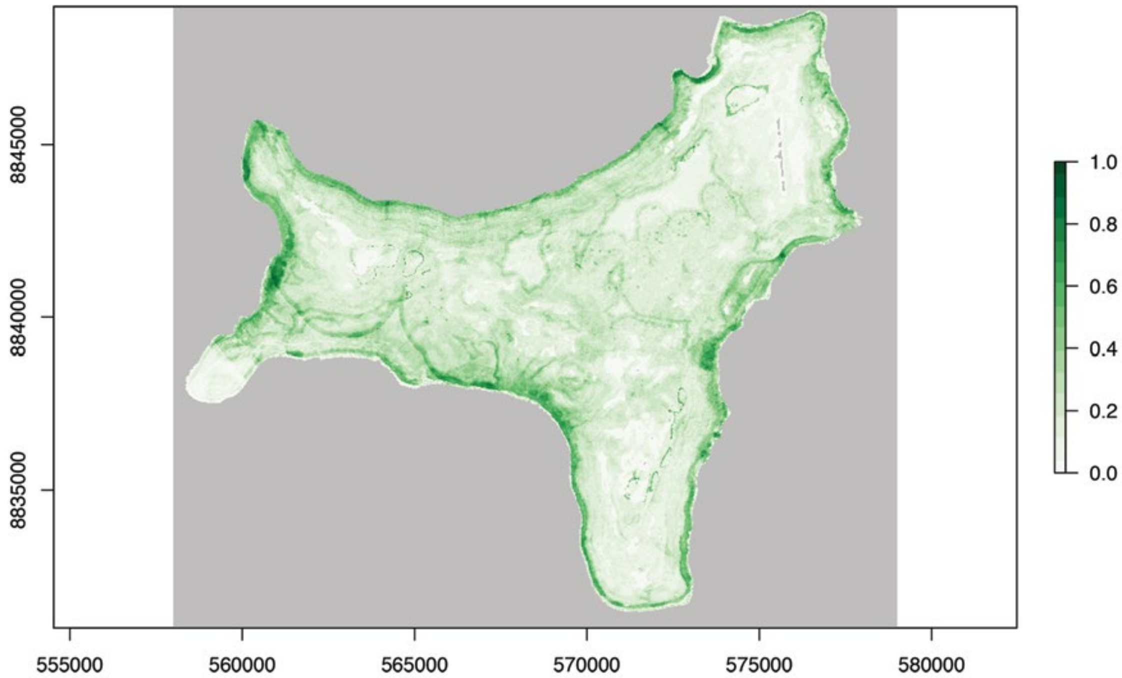

Figure 8. Christmas Island flying fox distribution model of roosting habitat modelled with Maxent, 10-fold cross validation AUC = 0.806

Figure 9. Christmas Island flying fox major roosting sites with 100 m buffer

Christmas Island frigatebird

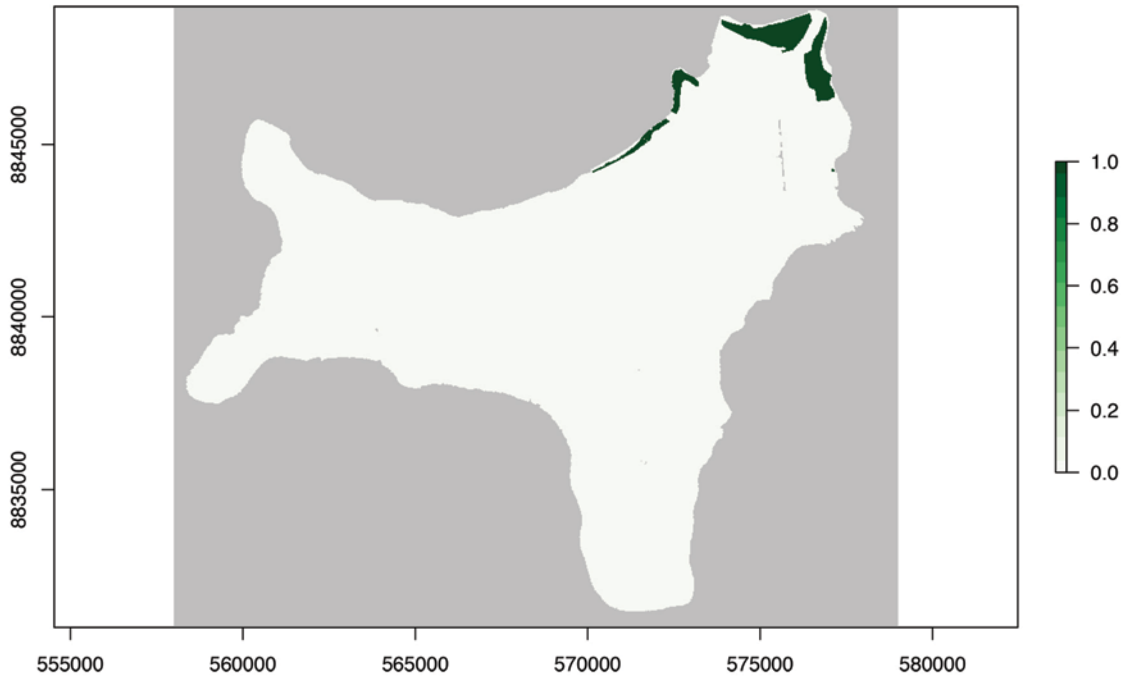

Figure 10. Polygons of Christmas Island frigatebird nesting colonies

Christmas Island goshawk

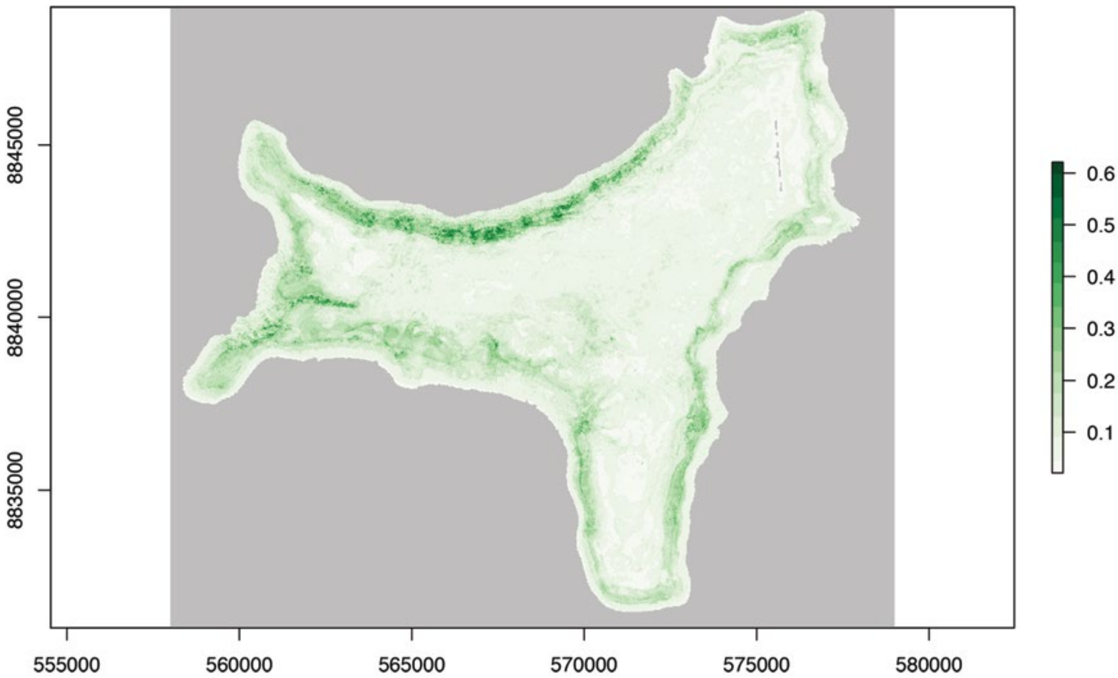

Figure 11. Goshawk distribution model modelled with BRT, 10-fold cross validation AUC = 0.736

Christmas Island hawk-owl

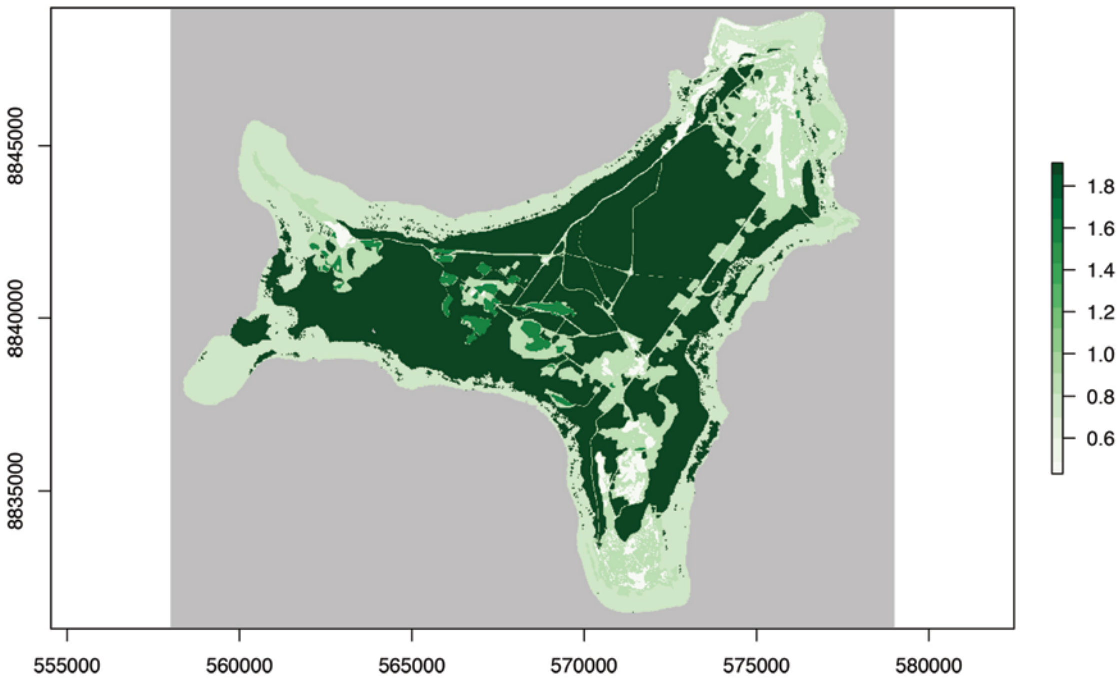

Figure 12. Hawk-owl distribution density estimates from Morcombe (2016)

Christmas Island spleenwort *(Asplenium listeri)*

Figure 13. Point locations of Asplenium listeri with 50 m buffer

Greater frigatebird (Fregata minor) . Photo: Katherine Selwood

Christmas Island swiftlet

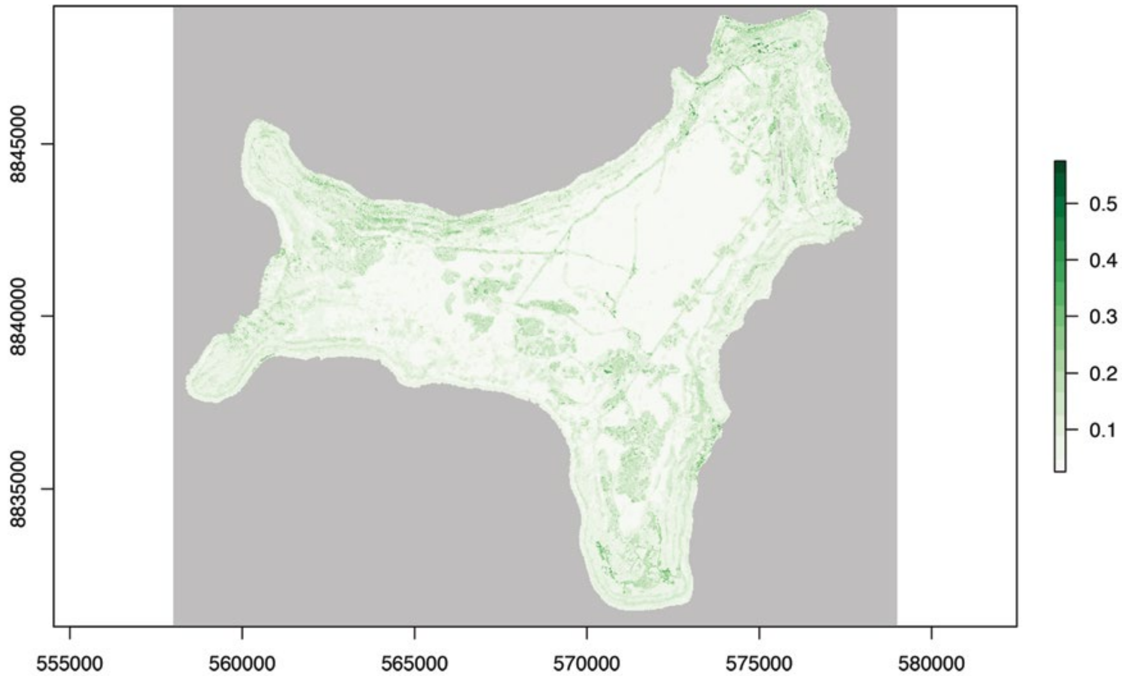

Figure 14. Christmas Island swiftlet distribution model modelled with BRT, 10-fold cross validation AUC = 0.674

Figure 15. Christmas Island swiftlet breeding caves with 100 m buffer

Christmas Island thrush

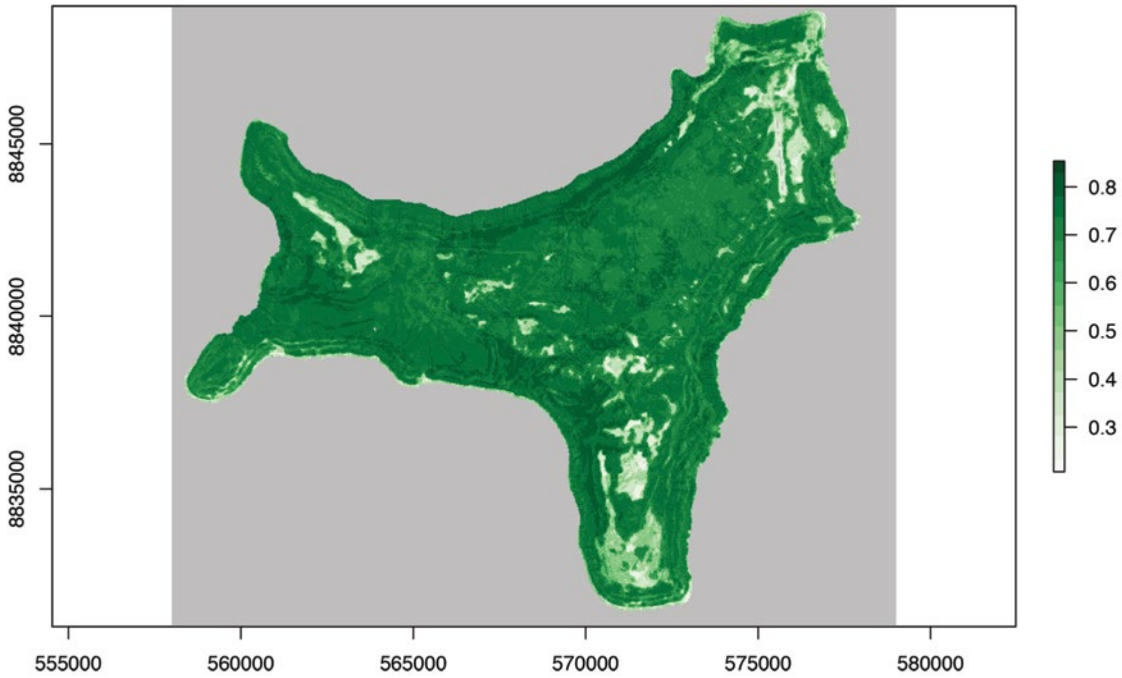

Figure 16. Christmas Island thrush distribution model modelled with BRT, 10-fold cross validation AUC = 0.622.

Christmas Island white-eye

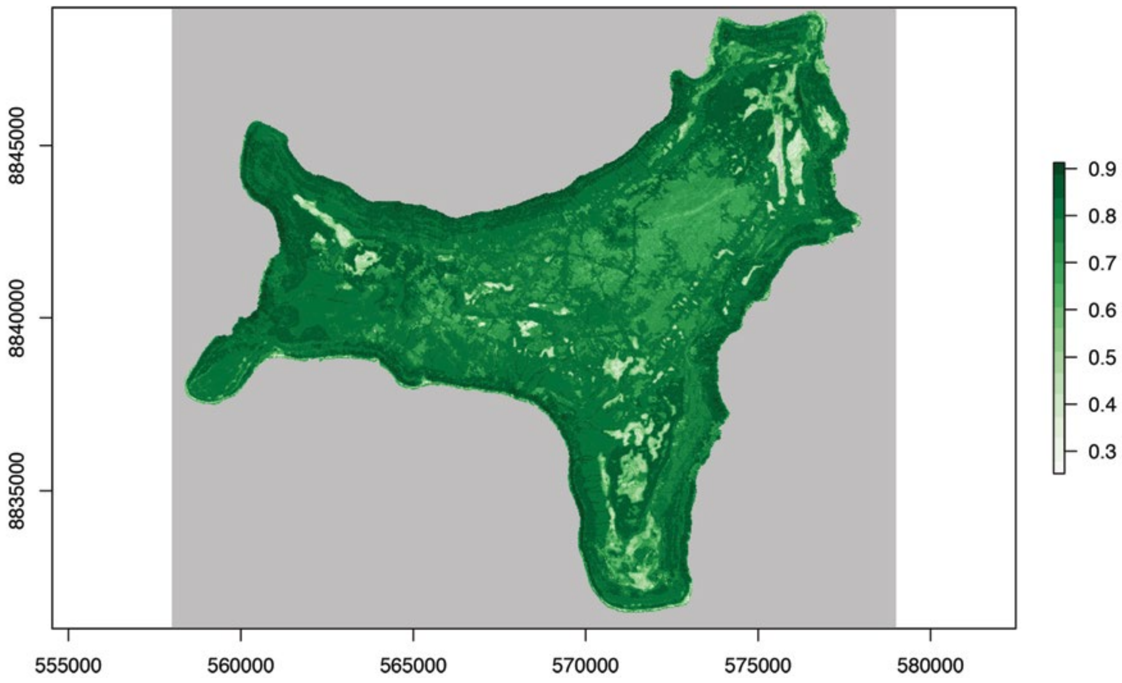

Figure 17. Christmas Island white-eye distribution model modelled with BRT, 10-fold CV AUC = 0.638

Cycas rumphii

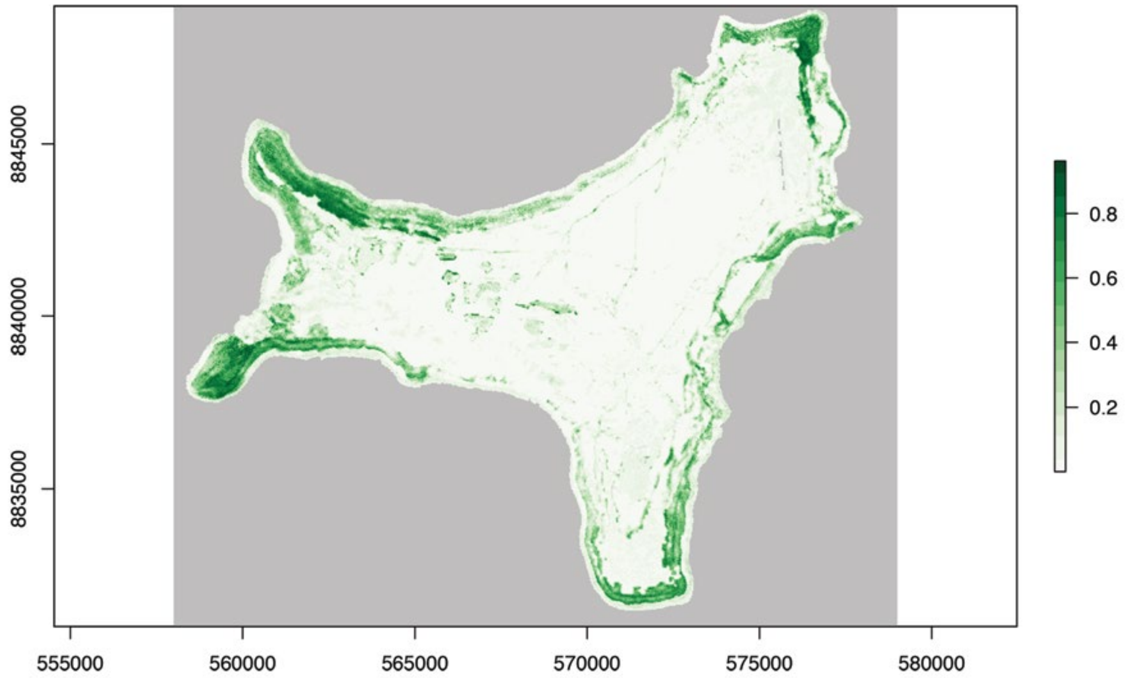

Figure 18. Cycas rumphii distribution model modelled with Maxent, 10-fold CV AUC = 0.912

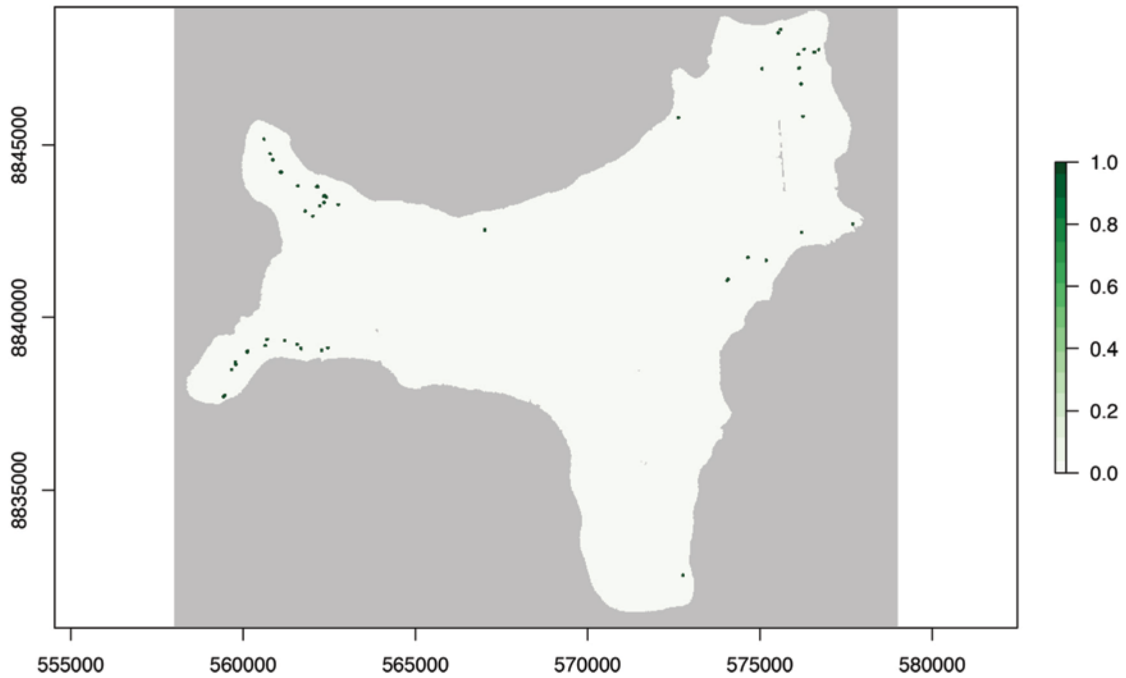

Figure 19. Cycas rumphii point locations with 50 m buffer

Christmas Island emerald dove

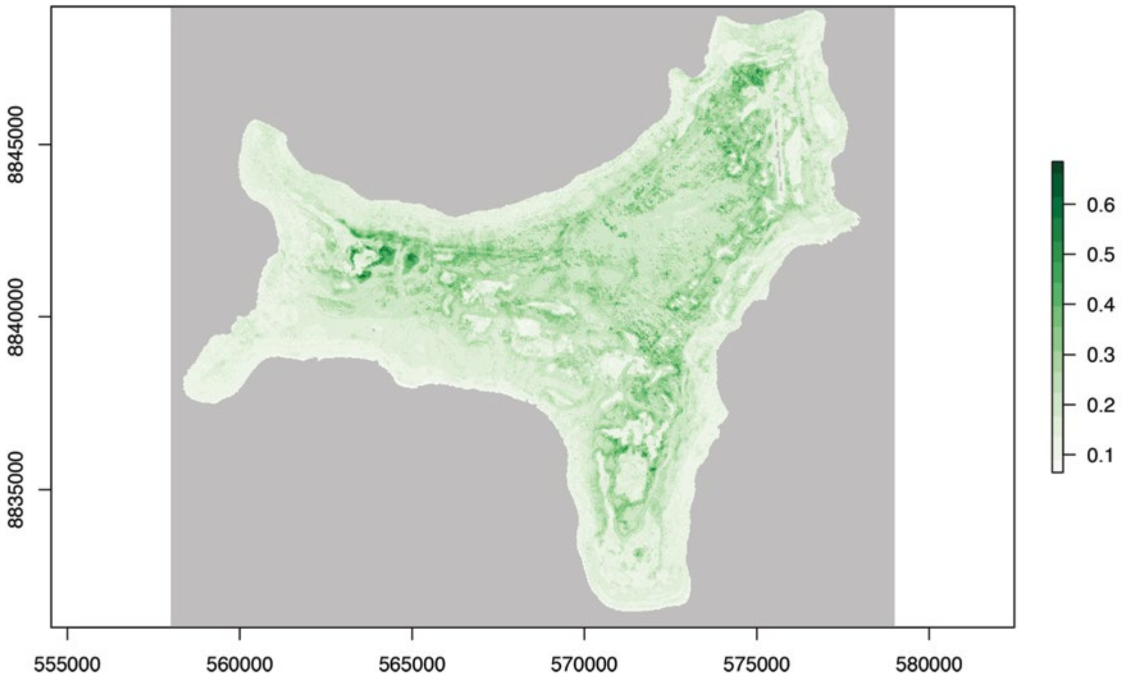

Figure 20. Christmas Island emerald dove distribution model modelled with BRT, 10-fold cross validation AUC = 0.627

Giant gecko

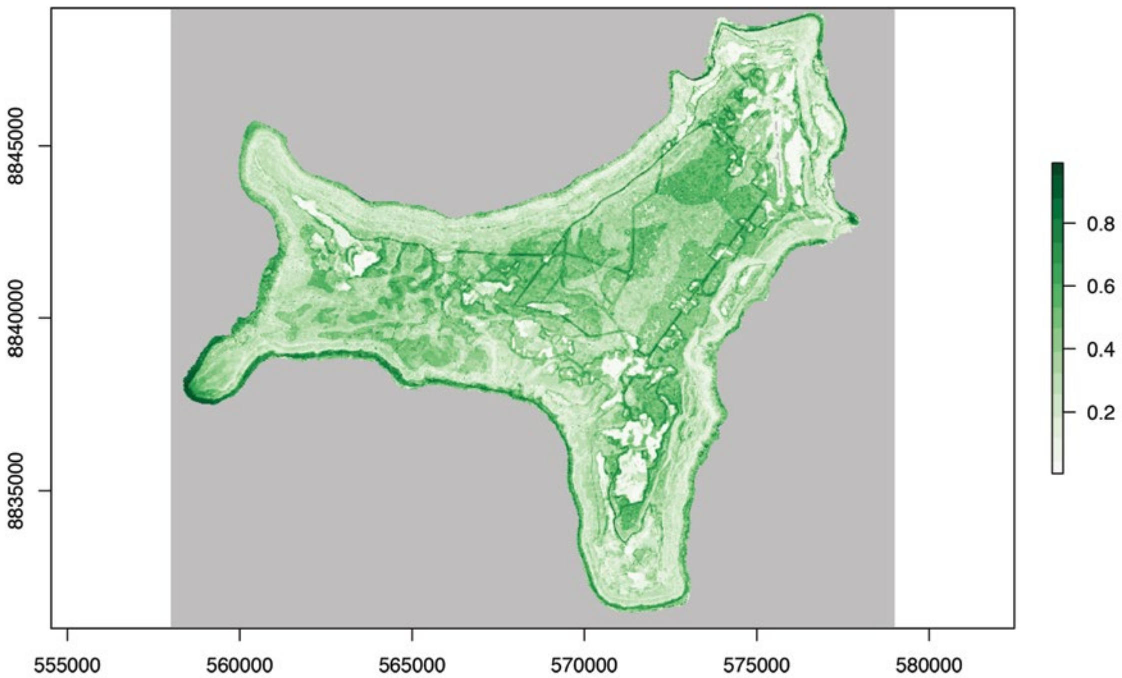

Figure 21. Giant gecko distribution model modelled with Maxent, 10-fold cross validation AUC = 0.730

Golden bosun

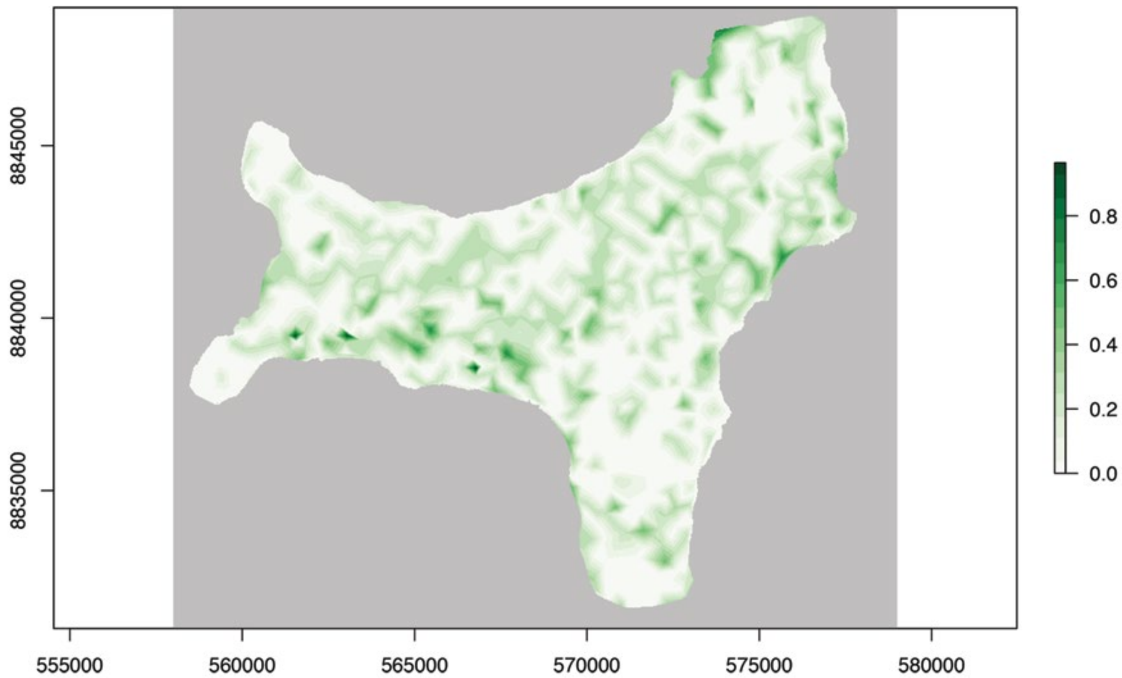

Figure 22. Golden bosun distribution map created by interpolating reporting rates between IWS survey locations

Christmas Island imperial pigeon

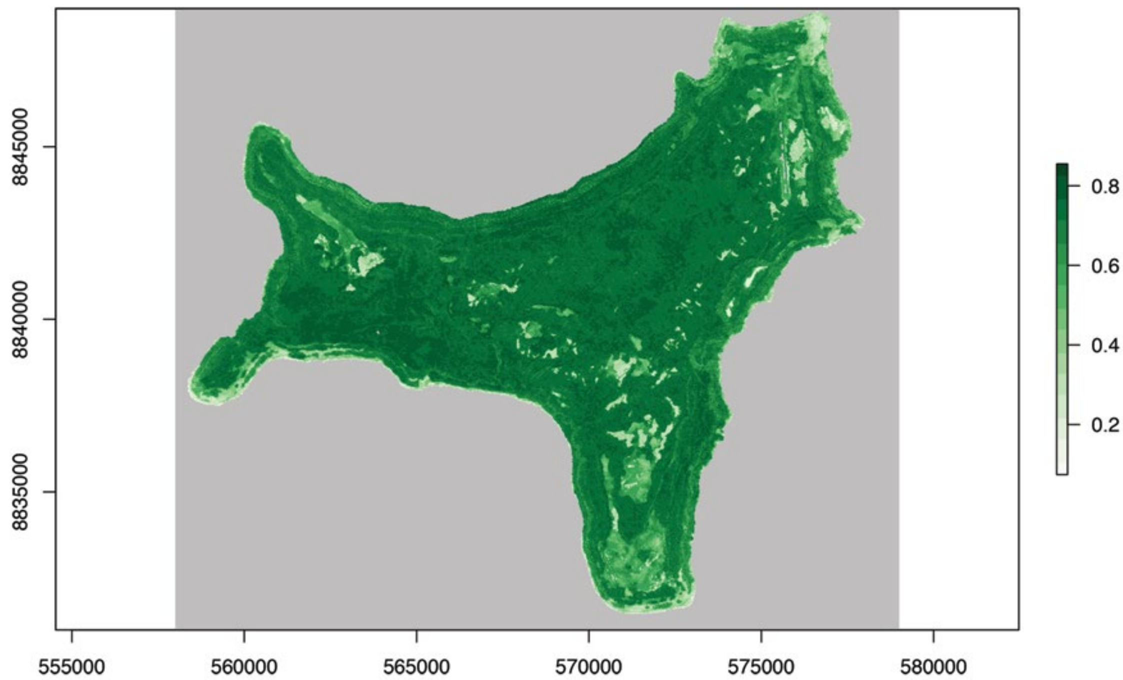

Figure 23. Christmas Island imperial pigeon distribution model modelled with BRT, 10-fold cross validation AUC = 0.621

Landscape wet refuges

Figure 24. Landscape wet refuges, as mapped by Christmas Island National Park

Lister's gecko

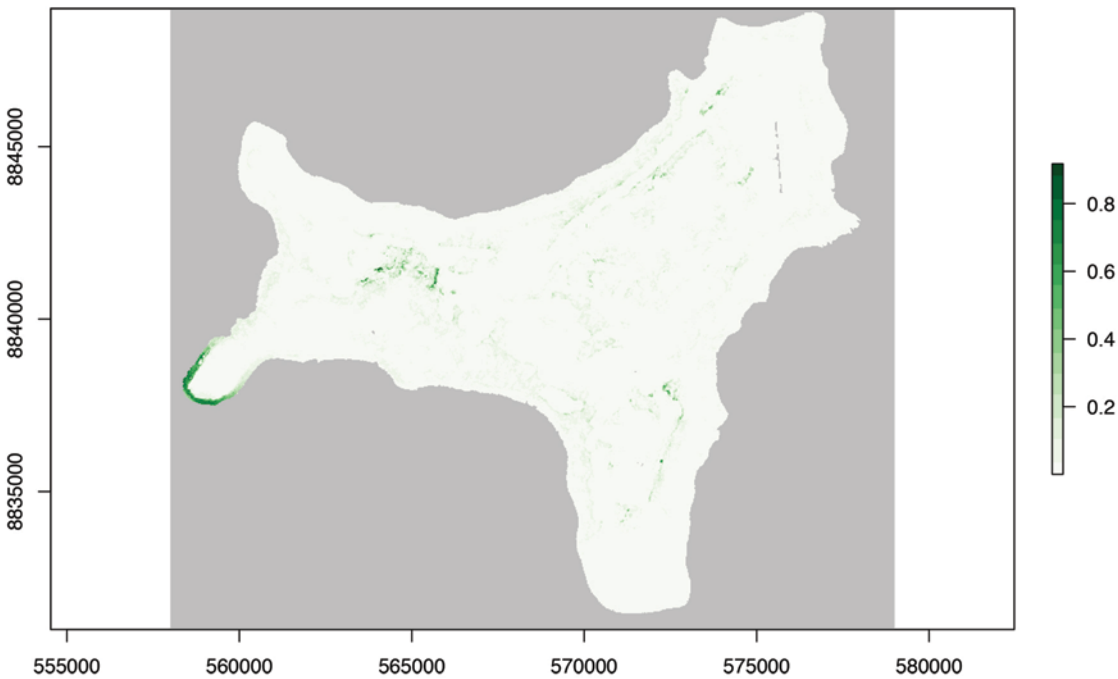

Figure 25. Lister's gecko distribution model modelled with Maxent, 10-fold cross validation AUC = 0.976

Pneumatopteris truncata

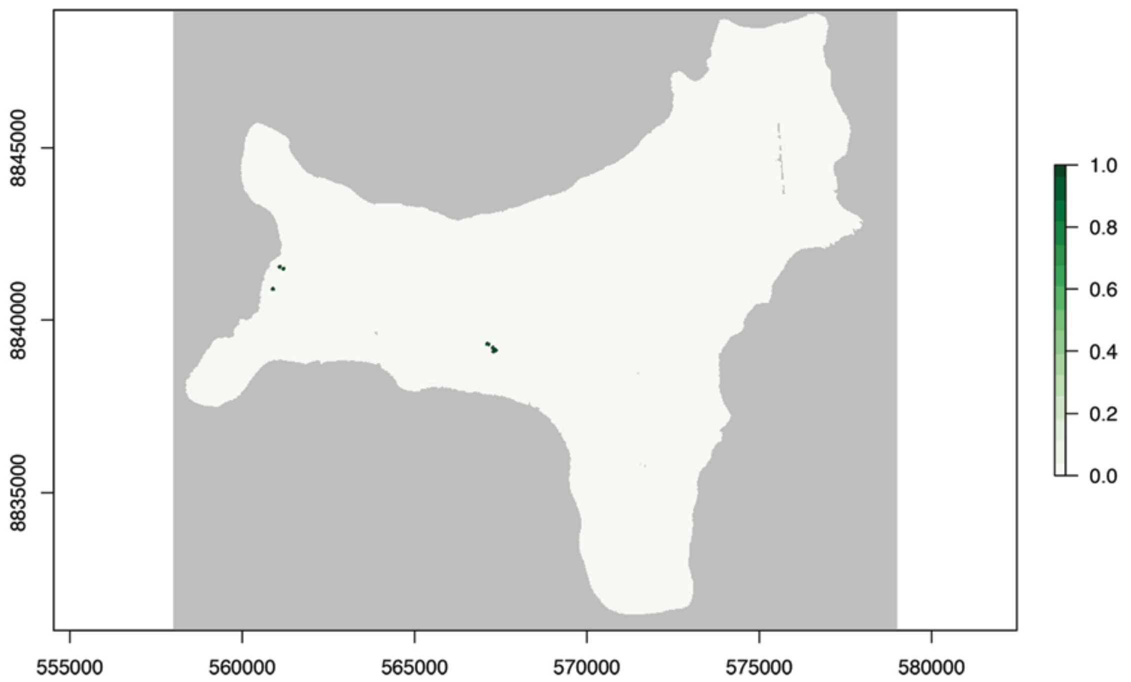

Figure 26. Point locations of Pneumatopteris truncata with 50 m buffer

Primary rainforest

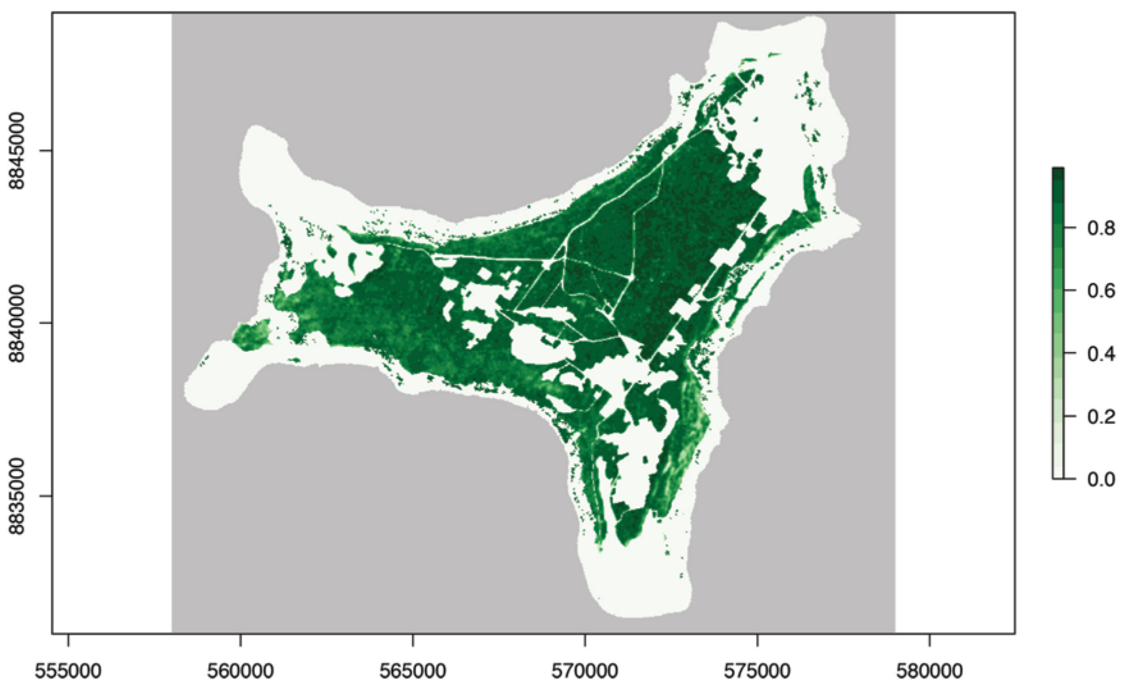

Figure 27. Primary rainforest tree cover (closed canopy evergreen forest, cover is moving window of percentage cover in 50 m radius of trees that are >10 m high)

Red crab (total burrow area)

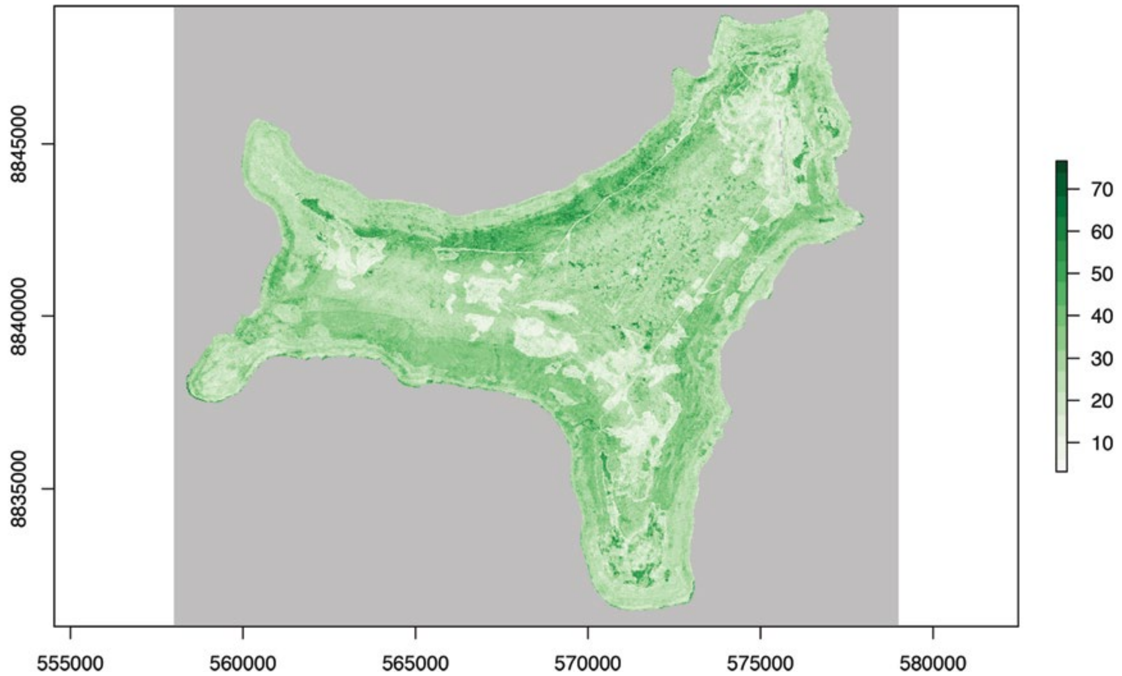

Figure 28. Model of red crab total burrow area (cumulative sum of area of all burrow openings in 50 square metre transect, cm-squared)

Red-footed booby

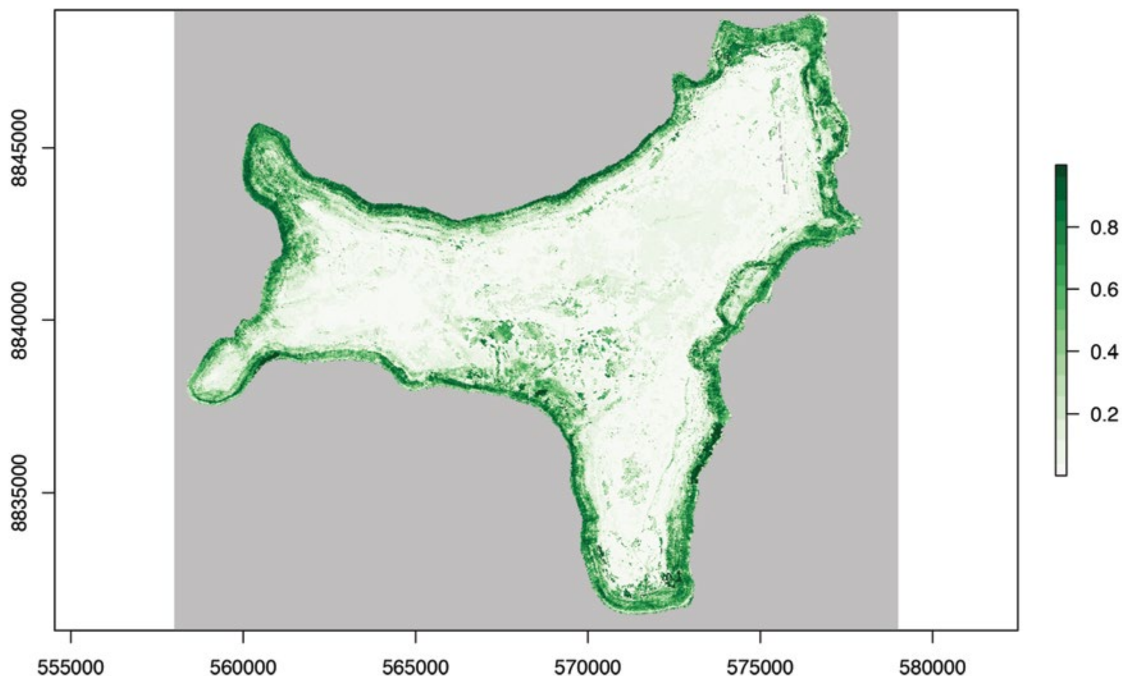

Figure 29. Red-footed booby model modelled with BRT, 10-fold cross validation AUC = 0.752

Tectaria devexa var. minor

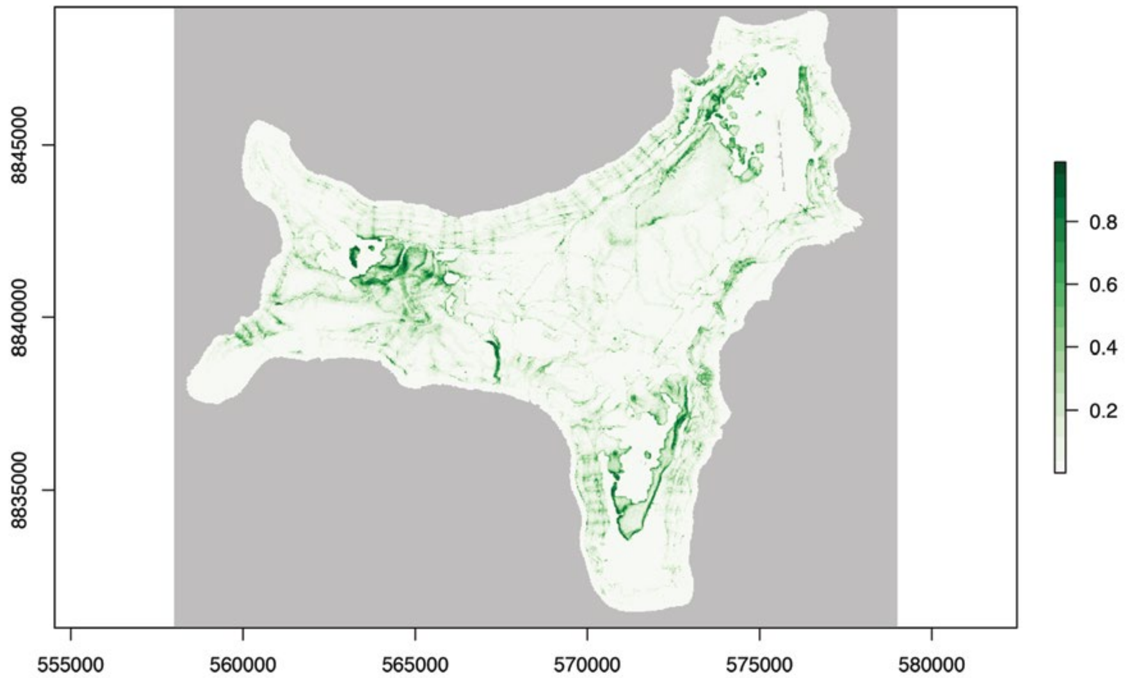

Figure 30. Tectaria devexa var. minor distribution model modelled with Maxent, 10-fold cross validation AUC = 0.922.

Figure 31. Tectaria devexa var. minor population locations with 50 m buffer, weighted by population size

Further information:

http://www.nespthreatenedspecies.edu.au/

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Threatened Species Recovery Hub

National Environmental Science Programme