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TROPICAL ECOSYSTEMS hub

Final Report

Prioritising Management Actions for Great Barrier Reef Islands

Bob Pressey and Amelia Wenger

Australian Government
Department of the Environment

Reef & Rainforest RESEARCH CENTRE

Prioritising Management Actions for Great Barrier Reef Islands

Bob Pressey[1] and Amelia Wenger[1]

[1] ARC Centre of Excellence for Coral Reef Studies, James Cook University

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This report is available for download from the NERP Tropical Ecosystems Hub website
http://www.nerptropical.edu.au/research

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Acronyms Used In This Report

ABHA............ African Big Headed Ants
CPT................ Conditional Probability Tables
EM .... Expectation Maximization
EPBC............. Environment Protection and Conservation Biodiversity
IUCN............. International Union for Conservation of Nature
GBR............... Great Barrier Reef
GBRMPA....... Great Barrier Reef Marine Park Authority
NERP .... National Environmental Research Program
QPWS………. Queensland Parks and Wildife Services
RE.................. Regional Ecosystem

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Introduction

The anthropogenic domination of the planet has resulted in the loss of biodiversity at an alarming rate (Vitousek et al. 1997; Butchart et al. 2014). Among the culprits for this biodiversity loss, invasive species account for a large proportion of extinctions (Courchamp et al. 2003). Island ecosystems, which have a disproportionate share of global terrestrial biodiversity, have suffered heavily from invasive species introductions (Kier et al. 2009; Brooke et al. 2007; Medina et al. 2011). Importantly, islands host a high number of endemic species, meaning that threats to islands can have significant consequences for global biodiversity loss (Brooks 2000; Kier et al. 2009).

The isolated nature of islands makes them candidates for successful eradications, restoration, and protection from the arrival of threats (Towns and Ballantine 1993; Brooke et al. 2007). Indeed, worldwide there are several examples of successful invasive species eradications and subsequent native species recovery (Clout 2001; Courchamp et al. 2003). However, management actions to eradicate or control invasive species are expensive and logistically challenging undertakings (Myers et al. 2000; Courchamp et al. 2003). With limited resources for such types of activities, it is crucial to prioritize how the resources are spent to increase the probability of achieving conservation objectives (Pieterse et al. 2002; Brooke et al. 2007).

The Great Barrier Reef (GBR) islands face many pressures, including climate change, invasive species, fishing, industrial development, and tourism. In the face of these threats, environmental managers need an explicit framework with specific objectives and structured decision-making to guide their conservation investments.

Managers of the GBR's 900 islands face difficult decisions when it comes to investing in conservation management. With insufficient staff and funds to deal with all management problems, where should they invest limited resources to achieve the best outcomes? These conservation decisions must be made in the face of spatially heterogeneous and dynamic threats, including invasive plants and animals and inappropriate fire regimes, and within a constrained budget. A suite of actions can be applied to address conservation objectives, but they cost different amounts, contribute differently to goals, and can be applied on many different islands at different times. Furthermore, most decisions must be made under considerable uncertainty. This problem - complex, dynamic and multifaceted - describes the reality of much conservation decision-making, and defines the problem faced by managers of islands in the GBR World Heritage Area.

Project 9.3 aimed to address the problem faced by island managers by developing a decision-making framework for investing in management actions. Working closely with Great Barrier Reef Marine Park Authority (GBRMPA) and the Queensland Government, the project developed a cost-effective approach to prioritising management actions across GBR islands. More specifically, the goal was to maximize conservation outcomes, defined by specific objectives for diverse natural features (native plant and animal species, vegetation assemblages, breeding aggregations). A decision-support tool with GIS capability was developed as part of the project and will help managers to identify management priorities within and between islands. The project delivered results that are useful to a range of stakeholder organisations including State and Australian Government bodies, the tourism sector, and conservation planners and managers. Research-user organisations include the Queensland Government, the Australian Department of the Environment, and the Great Barrier Reef Marine Park Authority (GBRMPA).

The project covers both Queensland and Commonwealth islands in the southern sector of the GBR, from Mackay to Bundaberg (Fig.1). This region was chosen based on the national and international significance of these islands in relation to vulnerable and endangered species, tourism value, and the likely threats presented by expanding industrial development and recreational use.

Methodology

Study Region

This study was undertaken on the national parks islands of the Southern Great Barrier Reef (Figure 1). There are 206 islands in the study region, including continental or rocky islands and sand cays.

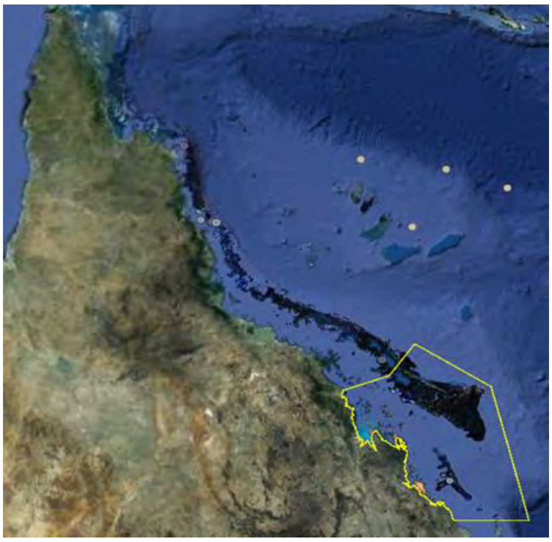

Figure 1: The study area – the southern sector of the Great Barrier Reef

Data compilation and selection

Survey data, published literature, and government reports and databases were collated over the course of several months in 2014 and 2015.

After several consultations with three senior natural resource managers, we derived a priority species list, given the likelihood of direct management intervention aimed at protecting the species. The list was based upon three criteria: 1) Islands are important for a species on the state, national, international level, 2) Occurrences are sufficiently predictable (e.g. not vagrant bird records) that they can form the basis of prioritization 3) Numbers sufficient, relative to the persistence needs of the species, to warrant management.

Publicly available habitat data

The Queensland Environmental Protection Agency has undertaken an extensive mapping exercise of regional ecosystems (REs) in the state (Sattler and Williams, 1999). The (REs) have been defined through a combination of three major attributes: 1) landscape patterns as described by bioregions and provinces, 2) geology, landform and soils, and 3) vegetation. For detailed information on the mapping of REs, see (Sattler and Williams, 1999). Regional ecosystems were originally defined by Sattler and Williams (1999) as vegetation communities in a bioregion that are consistently associated with a particular combination of geology, landform and soil. Descriptions presented in Sattler and Williams (1999) were derived from a broad range of existing information sources including land system, vegetation and geology mapping and reports. Maps were prepared at a scale of 1:100,000, using aerial photographs, satellite imagery, and digital elevation models. The maps were then validated through extensive field sampling and ground surveys.

A shapefile of the study region was sent to the Queensland Herbarium and the corresponding RE information was extracted from their database and a shapefile with the data was distributed to our project. The area of each RE on each island was calculated in Arc Map version.

High-resolution mapping

Over the course of this study, it was discovered that the current spatial data used by GBRMPA and QPWS was not spatially accurate, leading to mismatches in data. In order to improve the accuracy of the island spatial datasets, the project undertook extensive island mapping. Two ALOS PRISM panchromatic data mosaics were supplied by Geoscience Australia. Originally captured between 2007 and 2010, the single band images were ortho-rectified as UTM55S and UTM56S scenes using the WGS84 datum at 2.5m resolution. Root mean square horizontal error estimates of individual scenes were typically reported as 3 to 5 m, thereby providing a high confidence in the positional accuracy of these data mosaics. The ALOS PRISM mosaics were used to map main habitats found in islands and cays.

Mapping was done using contextual editing and manual delineation with the ArcGIS software (ESRI). Polygons were delineated based on the black and white ALOS PRISM image. A combination of three types of high-resolution multispectral imagery was used to improve the mapping and for validation: 1) when available, the imagery provided by ArcGIS Online World Imagery Basemap from ESRI's map service; 2) the imagery available through Queensland Globe (an interactive online tool that can be opened inside the Google Earth™); 3) the imagery freely available on Google™ Earth. For example, where a habitat boundary or class was unclear based solely on the ALOS PRISM image, the ArcGIS Online imagery was used for the delineation and to confirm the habitat class. If this imagery was not available for the area of interest, Queensland Globe or Google™ Earth image at the same location were used to confirm the habitat class. This method allowed for mapping a larger range of habitat types, minimizing map uncertainty and improving thematic accuracy.

The existing map provided by the GBRMPA was used in combination with data from the Queensland Globe to assign official names to newly mapped islands and cays.

Expert elicitation

Two 3-day expert elicitation workshops were conducted in February and August 2014. Two pilot workshops were conducted prior to the first elicitation workshop. These were conducted to trial the methodology and to uncover any additional data sources in order to focus the elicitation efforts on islands and species for which we did not have survey data. Each elicitation group consisted of six experts. The experts were chosen based on their experience with the islands and their knowledge of the species. Each participant was a male from the same government management agency. Their qualifications ranged from a boat driver to a senior regional manager. Prior to the commencement of the workshop, the managers were asked to correctly identify the priority species on which they were being asked questions, to ensure that they all recognized the species. Over the course of three days, the participants were asked to estimate the population size of each priority species on specific islands, using the Delphi method. Briefly, participants were asked to privately record their best guess for the population estimate of 1) breeding pairs of birds; 2) number of individual mammals; and 3) number of sea turtle nests laid on an island during the nesting season. Participants were also asked to record their lower and upper estimates for the population estimates. Finally, participants were asked to record their confidence that the true answer was somewhere between their lower and upper bounds. Once participants were finished, their answers were collated and discussed as a group the next day, keeping each answer anonymous. Following the discussion, participants were asked to repeat the exercise, keeping in mind any new information that was obtained from the group discussion. To avoid fatigue, experts were asked to engage in elicitation only for three hours, after which the workshop focused on other topics. Overall, population estimates for the priority species were collected for 58 islands.

In order to determine the reliability of the expert data, the experts were unknowingly asked questions about population estimates for which we had survey data. 232 questions with known answers were randomly distributed across islands and species, representing 17% of the questions asked to experts.

In the first workshop, a group discussion occurred to generate a list of relevant flora and fauna threats that the managers would actively manage on islands. Experts were then asked to privately fill in a spreadsheet about the presence or absence of each threat on each island. Group discussions occurred to reach consensus on the presence of a threat on an island and the native species that each threat would directly affect.

Validation of expert data and habitat proxy data

The information from the different species indicators (survey, expert elicitation and habitat proxies based on publicly available habitat mapping) was used to train a Naïve Bayes classifier, so that the predictive accuracy of the different data types could be reported. Only species for which there were at least 25 survey records were used. Figure 2 shows the classifier BN; the class variable (parent node) is the true species value, with the children being the different species indicators.

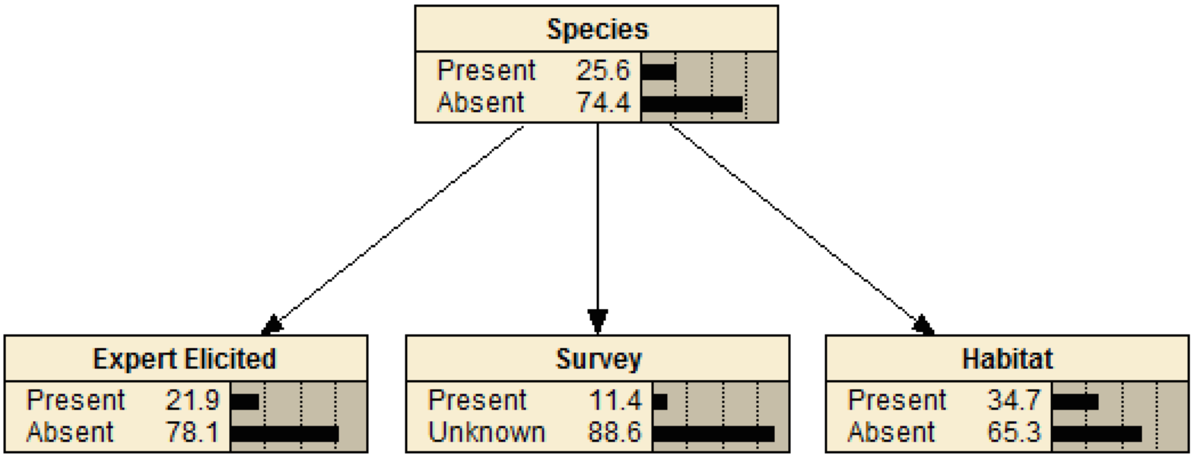

Figure 2: Naïve Bayes classifier of the predictive accuracy of the different data types: expert elicited, survey, and habitat mapping.

Naïve Bayes classifiers are used in supervised classification problems, where the class (e.g. species presence) is determined by a set of feature values. Naïve Bayes models are not causal: the class variable is always parent of its attributes, and attributes are treated as independent (i.e., no arcs are permitted between them). As such, Naïve Bayes models are extremely simple; in particular, as each feature node has only one parent, its conditional probability tables are minimal. Consequently, Naïve Bayes models, in contrast with other methods, are a simple way of dealing with missing data – however, to train a Naïve Bayes model, some data are needed for all variables.

Expert elicited values (for each species/island combination) either predicted the species presence or absence or were unknown (that is, not determined). If only one expert said a species was present and all others said the species was absent, the species was considered absent based on expert opinion. If all of the best guesses were zero but some had added an upper bound of some individuals, the species was considered absent. The habitat mapping values either predicted the habitat presence or absence or were unknown. Survey data can either report the species presence or be unknown.

There was no information on the true species value. However, some of the different indicators were reliable determinants. Survey data are reliable in determining the species presence, but there are no negative survey results (only unknown), so lack of records do not necessarily indicate species absence. Conversely, habitat mapping is a reliable indicator of species absence (if there is no habitat available, then the species will not be able to persist). However, the presence of habitat doesn't infer the presence of species (because the species may not have arrived, or the habitat definition might not be appropriately refined).

Using this information, a training data set was created, populating the true species values using the rule:

IF Survey is Present THEN Species is Present

ELSE IF Habitat is Absent THEN Species is Absent

ELSE Species is Unknown

Once the training data set was created it was used to train the BN - that is, generate conditional probability tables (CPTs) for the variables. This was done using the Expectation Maximization (EM) learning method, available the in the Netica BN tool. The EM algorithm works by finding the BN that is the most likely given the data: P(BN | Data).

Variations in predictions

Predictive accuracy was also be determined based on species/island attributes to determine if experts and habitat mapping were biased towards a particular type of data. This was done by adding a node for the attribute and making the classifier nodes conditional upon it.

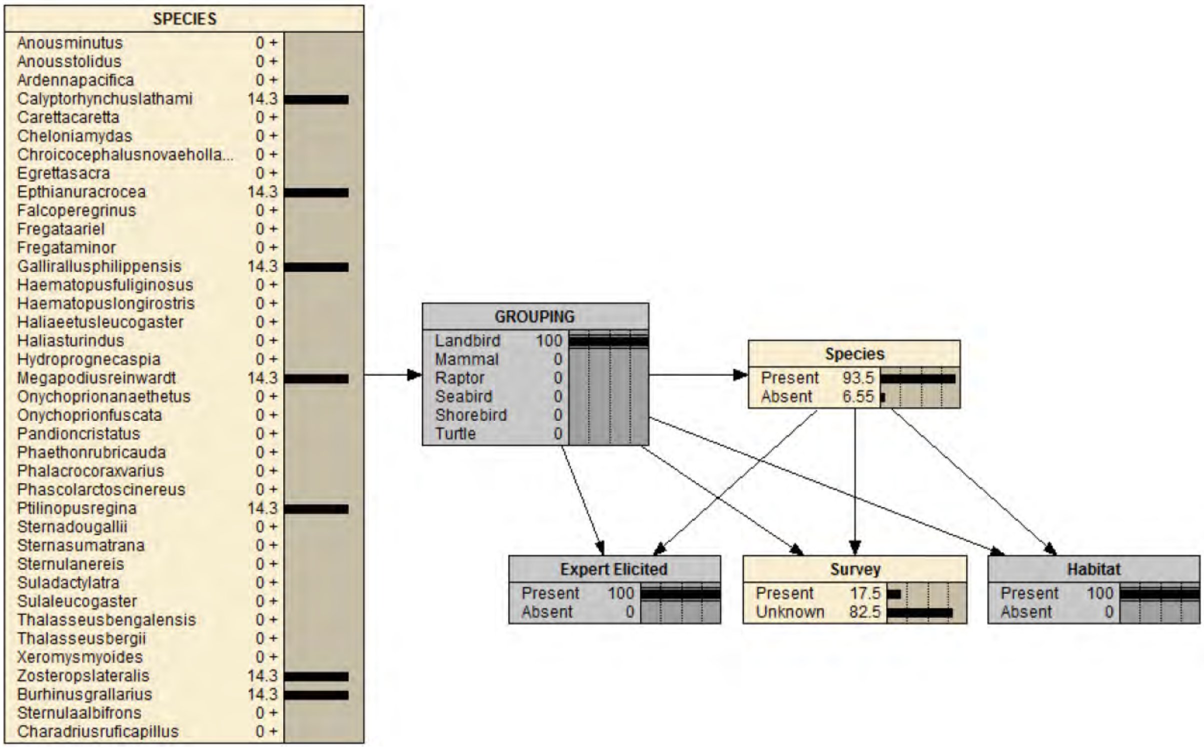

Figure 3: Predicting presence of species based on different attributes.

Predicting species distribution

The predictive accuracy of the models was used to assess how many additional islands currently without records of respective species could be said to have a species present, given only expert and habitat data were available. Predictions were made only for species that had at least 25 survey points and expert responses to train the BNs.

Actions and costs

A separate set of elication workshops and phone discussions occured in Septermber and October 2014 to generate information on management actions that would be required to mitigate island threats and the costs of each action. The aim of the elicitation was to understand the mechanisms behind the cost differences from island to island. Quantifying the mechanisms behind the costs allowed us to predict the costs of actions on islands for which the managers had no first-hand experience and it removed the need to ask identical sets of questions for each of hundreds of islands, which would have been infeasible.

Software development

The project, in conjunction with a similar one funded separately for the islands of the Pilbara coast, set out to produce a new decision-support tool for island managers. The main aims were to:

- Develop new software from scratch that would circumvent the limitations of existing tools for conservation planning

- Allow managers and scientists to address the full complexity of the decision problem, including temporally-explicit models of the effects of actions on invasive species and the effects of invasive species (or their reduction) on native species
- Link to a graphic user interface for ease of interpretation.

Results

Database

This dataset contains native and alien species records for islands in the southern GBR. Attributes for each record include information on abundance, life-history traits, habitat requirements, limitations of source (e.g. partial survey coverage of islands), and relevant species information from government bodies including EPBC and NCA listings. Basic interaction information among species (alien vs. native) is also recorded. This dataset also has basic information about each of the islands such as area, location, and regional ecosystem types. While focus has been on the National Parks in the southern GBR, data from other islands have been included.

Records include presence/absence data and, where possible, abundance, distribution, and on-island activity data for both native and non-native animals, and invasive plants. Currently, the database contains >31500 records from 183 sources (ranging in date from 1827 to present day) covering:

- 303 islands in total
- 147 National Park Islands and 4 Commonwealth Islands between Mackay and Bundaberg
- 695 unique species, consisting of
  - 564 native animal species
    (313 birds, 111 insects, 76 reptiles, 51 mammals, 10 amphibians, and 3 others)
  - 43 invasive animal species (12 Birds, 23 mammals, 5 insects, and 3 other),
  - 252 invasive plant species
  - 88 fungi

Additionally, the database contains information about the ecology (habitat, reproduction, migration/dispersal, etc.) and current status (vulnerable, near threatened, etc.) of native species and the ecology and impacts (economic, environmental, and social) of invasive species. Known direct interactions between invasive species and those native to the islands are also recorded.

Sources include:

- Peer-reviewed journal articles
- Reference books
- Government reports
- Datasets (e.g. from Wildnet, Wetlandinfo, Department of Environment, Queensland Parks and Wildlife Service, Queensland Museum, Queensland Herbarium, Atlas of Living Australia)
- Expert elicitation

The dataset contains two types of primary data: records data and attributes data. Records describe the observations made about the flora/fauna on the islands. For example, the presence of 1,000 Sooty Terns on Heron Island in the summer of 2003 is a record datum. For a given source, each species on each island, at a given time received a unique record. Records are structured within the database so that each record remains associated with its source, allowing revisitation to review records within their original context. Attribute data describe information relevant to objects in the records. For example, an attribute datum is that Sooty Terns are ground nesting seabirds that occur in tropical and subtropical seas, islands, and cays. Attributes were extracted from sources, including information on habitat requirements, life history traits, abundance, and source limitations. Additional attributes for each record were extracted from the Australian and Queensland Government websites, including information on EBPC and IUCN listings, and endemicity. Only one attribute row can occur for a combination of species/ island/ publication/etc., while multiple records can exist for a combination of species/ island/ publication/etc. Records and attributes are linked in the database through 'relationships', with the attribute table typically containing the primary keys (see Access help files for more information on relationships and primary keys).

Priority Species

The list was comprised of 37 species: two sea turtle species, two mammal species, and 33 bird species that breed within the system (Table 1). Although the database had thousands of records about species on islands, after discussions with managers, only survey data post 2005 were used for estimating abundances. Survey data from 1995 to 2005 were used as presence-only data.

Table 1: Priority species for GBR Islands

SPECIES	SURYEY RECORDS	GROUPING
Anous minutus	25	Seabird
Anous stolidus	17	Seabird
Ardenna pacifica	22	Seabird
Burhinus grallarius	3	Landbird
Calyptorhynchus lathami	0	Landbird
Caretta caretta	9	Turtle
Charadrius ruficapillus	4	Shorebird
Chelonia mydas	8	Turtle
Chroicocephalus novaehollandiae	35	Seabird
Egretta sacra	31	Shorebird
Falco peregrinus	7	Raptor
Fregata ariel	13	Seabird
Fregata minor	11	Seabird
Gallirallus philippensis	15	Landbird
Haematopus fuliginosus	36	Shorebird
Haematopus longirostris	29	Shorebird
Haliaeetus leucogaster	36	Raptor
Haliastur indus	14	Raptor
Hydroprogne caspia	7	Seabird
Megapodius reinwardt	7	Landbird
Onychoprion anaethetus	17	Seabird
Onychoprion fuscata	9	Seabird
Pandion cristatus	25	Raptor
Phaethon rubricauda	1	Seabird
Phalacrocorax varius	11	Seabird
Phascolarctos cinereus	0	Mammal
Ptilinopus regina	6	Landbird
Sterna dougallii	18	Seabird
Sterna sumatrana	21	Seabird
Sternula albifrons	18	Seabird

Sternula nereis	0	Seabird
Sula dactylatra	10	Seabird
Sula leucogaster	24	Seabird
Thalasseus bengalensis	24	Seabird
Thalasseus bergii	37	Seabird
Xeromys myoides	0	Mammal
Zosterops lateralis	16	Landbird

Publicy available habitat mapping

In total, there were 74 unique REs on 150 islands in our study region. The REs were then placed into broad categories to reflect the level of resolution of the habitat association data we had determined for each priority species. There were four categories for REs that existed only on rocky islands:
1) coast dunes and beaches;
2) dry forest;
3) wetlands, mangroves, marshes, and mudflats; and
4) moist forest.

There were also four categories for REs that existed only on cays:
1) coastal zone;
2) grassland/ shrubland/ herbland/ woodland;
3) Pisonia forest; and
4) moist forest.

Habitat association information was extracted from the collated sources and confirmed by two senior natural resource managers.

High resolution habitat mapping

The new map contains 275 National Park islands and cays in the Southern Great Barrier Reef region. Features were mapped at a 1:2,500 scale, which constitutes, by far, the highest existing spatial resolution map for these islands. The current habitat classification was constrained by the species for which broad habitat information was required (e.g. marine turtles, sea birds). It includes:

- Exposed fine sediments
- Vegetated
- Mangrove
- Shallow coral reef (only for coral cays)
- Other – bare rock
- Other – gravel, rocks
- Other – mud flat
- Other – shallow/intertidal envelope

Expert Elicitation

The project has elicited data on species occurrence on 58 National Park islands. We held an expert elicitation workshop over three days in Rockhampton in early August 2014. During that workshop, we elicited information on the abundance of native species on 43 islands and alien species occurrence, where known, on all National Park islands (206) in the study region. These data complement the existing monitoring records from 45 National Park islands. A two-day workshop was held in Gladstone in September 2014 to elicit data on the costs of individual management actions on islands.

A two-day workshop was held in Townsville in October 2014 to examine the habitat associations of native and invasive species. These data are being used to predict absence of species based on the absence of their associated habitat. This analysis was completed to assist QPWS in designing future monitoring programs. During this workshop, the relationship between invasive weeds and regional ecosystems they can invade was also determined. This information is essential for modelling the effects that weeds can have on regional ecosystems and associated species.

Through workshops and ongoing collaboration between managers and researchers, the relationship between the costs of management actions and the drivers of those costs, such as island characteristics, has been quantified. This new understanding of the effects of terrain, island size, and distance to management base on costs provides immediately-useful data for the prioritisation project, and additionally will be useful for conservation planning across the agency in future.

Validation of data

Overall, experts correctly predicted presence of species 75% of the time (Table 2). When both expert elicted data and habitat availability were used, the predictive accuracy was 95%. There was a high level of variation in the predictive accuracy of experts alone, ranging from 99% with tree nesting species to 49% with shorebirds. The predictive accuracy of habitat proxies was much lower than expert judgement, ranging from 83% for species that disperse regionally to 51% for dry forest species. However, when combined, there was very high predictive accuracy (Table 2).

Table 2: The likelihood that a group is present given what each data type says.

Species Category	Expert = present	Expert = absent	Habitat = present	Habitat = absent	Expert = present & Habitat = present
All data	0.746	0.110	0.670	0.027	0.947
Tree nesting	0.996	0.132	0.776	0.061	0.999
Grassland species	0.951	0.135	0.823	0.016	0.996
Raptor	0.989	0.160	0.706	0.085	0.996
Seabird	0.812	0.134	0.824	0.017	0.988
Regional dispersion	0.734	0.144	0.828	0.019	0.979
Unlisted	0.814	0.124	0.736	0.026	0.971
Coastal species	0.669	0.103	0.802	0.033	0.968
Ground nesting	0.709	0.138	0.791	0.021	0.965
Island resident	0.804	0.127	0.680	0.046	0.940
Land bird	0.842	0.063	0.581	0.007	0.939
Wet vegetation species	0.650	0.140	0.705	0.059	0.911
Dry forest species	0.846	0.143	0.511	0.037	0.905
Shorebird	0.492	0.108	0.648	0.079	0.832
Island Category					
Coral cay	0.923	0.355	0.851	0.123	0.979
Island	0.729	0.103	0.707	0.018	0.959

The ability to extrapolate species occurrence to other islands that do not currently have survey data for respective species but do have expert data and habitat data, is presented in table 3. Only 8 species had enough survey data to train the BN. The amount of additional islands where predictions could be made ranged from 0-10. For most species, predictive accuracy was very high.

Table 3: Predicting species presence on islands with only expert and habitat proxy data

Species	Islands with expert data and habitat data only	Predictive accuracy
Chroicocephalus novaehollandiae	3	95
Egretta sacra	7	99
Haematopus fuliginosus	7	65
Haematopus longirostris	0	75
Haliaeetus leucogaster	6	100
Pandion cristatus	6	99
Thalasseus bergii	5	86

Actions and costs

Through expert workshops and discussions, a list of 23 potential actions for eradicating or controlling invasive species was derived (Table 4).

Table 4: On-island actions to eradicate and control invasive species on islands.

On Island Actions
aerial baiting rats control
aerial baiting rats erradication
shooting possums control
culling cane toads
aerial baiting cats control
aerial baiting ants
aerial baiting ants control
aerial baiting foxes control
aerial baiting dogs control
aerial shooting goats control
aerial baiting mice control
aerial baiting mice erradication
aerial baiting sparrows control
aerial baiting sparrows erradication
aerial baiting grazers control
aerial baiting grazers erradication
culling gulls control
culling Scale
aerial baiting pigs control
aerial shooting cattle control
aerial shooting horses control
aerial shooting deers control
spraying bees control

Each action was then broken down into its different components so that cost data could be generated (Table 5).

Table 5: An extract of management action information for African Big Headed Ants (ABHA), rats, prickly pear, and lantana.

ABHA	ABHA
Amdro kg per ha	2
Amdro $ per kg	100
TTime (days per ha)	4.8
MTime (days per ha)	1.1
STime (days per island)	1
Erad Treatment years	3
Museum costs per island	2000
Treat freq (per year)	0.33
Team size	12
Number of Trips required	4

Rats	**Rats**
TTime (days per ha)	0.5
MTime (days per ha)	0.1
STime (days per island)	1
Erad Treatment years	1
Treat freq (per year)	3
Team size	NA
Control effort (prop of erad)	0.5
Consumables (bait per ha)	200
Helicopter $ per hr	1750
Number of Heli hours (per ha)	0.05

Prickly Pear	**Prickly Pear**
Herbicide drum per ha	0.33
Herbicide $ per drum	600
TTime (days per ha)	0.25
MTime (days per ha)	NA
STime (days per island)	NA
Erad Treatment years	3
Museum costs per island	NA
Treat freq (per year)	2
Team size	NA
Control effort (prop of erad)	0.33
Proportion of Island to be treated	0.1
Terrain 2 effect	1.4
Terrain 3 effect	2

Woody Spray (Lantana, Rubbervine)	**Woody Spray (Lantana, Rubbervine)**
Herbicide 200l drum per ha	0.12
Herbicide $ per drum	500
TTime (days per ha)	4
MTime (days per island)	1
STime (days per island)	1
Erad Treatment years	3
Museum costs per island	NA
Treat freq (per year)	1
Team size	NA
Control effort (prop of erad)	0.25
Terrain 2 effect	1.4
Terrain 3 effect	2
Proportion of Island to be treated	0.2

The overall formula for each action is generally similar and takes the form:

Eq1: Labour + Consumables + Transport + Equipment + Associated actions (e.g. monitoring, translocation)

Each of the components in Eq. 1 has its own calculation method detailed below. Not every action needs every component. These component calculations need tailoring for each individual action and are likely to have variable units.

Labour costs
Labour costs generally include staff (salary) multiplied by the amount of work to be done (area or amount to be treated) multiplied by the amount of time required per unit area or amount:

Eq2: Salary costs X Area to be treated X effort per unit of area

Required effort per unit area needs to be adjusted to suit the circumstances of the island (e.g. terrain roughness, access difficulty) following the feedback from the managers.

Consumables costs
Consumables cost is generally the purchase cost of the consumable multiplied by the rate of application rate (i.e. 1kg per ha) multiplied by the area to be treated. If the consumable is diluted this must be taken into account.

Eq3: Purchase price per unit X Application rate X Area to be treated

Transport costs
Transport costs for the GBR are the distance from the nominated boat ramp to the island (doubled) multiplied by the costs of boat per unit of distance multiplied by the number of trips required within a year. Distance was calculated as the straight-line distance between the island centroid and the lat long of the boat ramp. Costs of travel vary according to the boat type used. The number of trips required per year has been assumed to be one unless explicitly stated otherwise.

Eq4: (Distance to Travel*2) X Cost per unit of distance X Number of trips

Equipment costs
Equipment costs are the purchase cost of the item multiplied by the number of items and then annualised by the useful life of the equipment.

Eq5: (Item Cost X Number of Items) / Years

Table 6: An extract of costs for two fauna threats and two weed species

	ABHA	Rats/Mice	Prickly Pear	Woody Weed
Island Name	**Total $ Eradication**	**Total $ Eradication**	**Total $ Eradication**	**Total $ Eradication**
Anvil Island	9771	3581	2692	2524
Aquila Island	862284	132914	13129	155034
Aspatria Island	217772	39050	9796	75016
Bacchi Cay	43611	24841	21884	14365
Barren Island	84342	18384	7668	21818
Bell Cay	91557	28680	18472	21662
Bellows Island	11656	3973	2838	3017
Berwick Island	48677	12358	6515	12908
Beverlac Island	243952	47760	15633	62419
Blackcombe Island	25000	6088	3107	6309

Software development

A working prototype of the software, with functional graphical user interface, has been developed and demonstrated to island managers. The software combines information on native species, invasive species, actions, and costs to optimize the allocation of a limited management budget across a set of islands, in this case the Commonwealth and National Park islands of the southern GBR.

The prototype software has been described at three conferences on computational science, the latter two involving proceedings papers that describe the formulation and application to data on the GBR islands:

- International Conference on Computational Science, Cairns, June 2014. Contributed presentation: Towards a new software tool for conservation planning, by J. Brotánková, B. Pressey, I. Craigie, A. Wenger and M. Pergel.
- Australasian Conference on Artificial Life and Computational Intelligence, Newcastle, New South Wales, February 2015. Contributed presentation: A heuristic solver for pest management on islands, by J. Brotánková, M. Randall, A. Lewis, B. Pressey and A. Wenger.
- 24th International Joint Conference on Artificial Intelligence, Buenos Aires, August 2015. Contributed presentation: Planning habitat restoration with genetic algorithms, by J. Brotánková, P. Kilby and T. Urli.

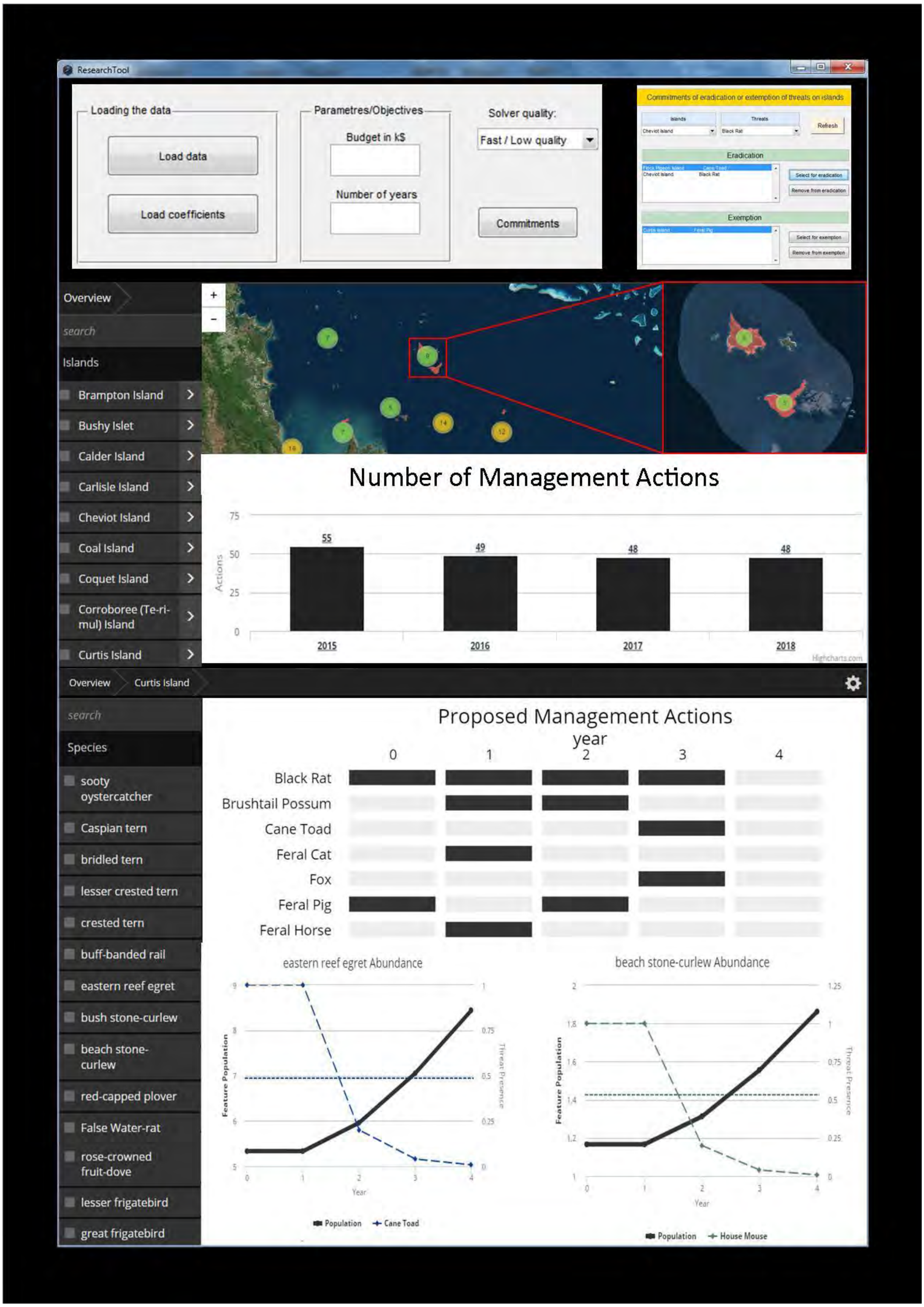

Figure 4: Screenshot of graphic user interface with an example of species responses to different management actions

Discussion

This project has highlighted the challenges in multi-objective decision making. Each island has a unique suite of native species and invasive species and the costs of effectively managing them will influence how decisions are made. Being explicit about uncertainty in data, necessary assumptions that need to be made, and the trade-offs of different management decisions is paramount to ensuring the persistence of species on islands in the Great Barrier Reef.

Although protection of biodiversity is often considered within the context of reserve design and creation, the main tenets hold true for the designation of resources for invasive species management. Specifically, when considering how to effectively protect a range of species, it is important to consider representativeness and complementarity (Vane-Wright et al. 1991; Margules and Pressey 2000). Other considerations that come into play are connectivity between areas, the human use of an area, and the cost of management (Pressey and Bottril 2009). All of these factors will contribute to the overall impact that management actions will have on improving the likelihood of the persistence of a species (Pressey et al., 2015). Determining the best way to balance competing forces is actively debated among conservation scientists, but all approaches have one aspect in common: it is critical to know where the species are that you want to protect.

Determining the location of species is often more challenging than realized, particularly in island ecosystems, which are inherently difficult to get to and are often remote. Spatially explicit data on biodiversity is one of the foundations of systematic conservation planning (Kirkpatrick et al. 1983). Local records are often spatially biased and related to access (Pressey 2004; Rondinini et al. 2006 and references within). Even systematic monitoring efforts will be spatially limited, and will either intentionally or unintentionally record a subset of species (May 2000; Pearce et al. 2001; Kadmon et al. 2004). However, locality records can greatly assist conservation planning by providing information on species occurrences and their ranges, and can act to ground-truth distribution and occurrence predictions on a broader spatial scale. In this project, we were able to collect a century's worth of data, but most of it had limited application to management.

Habitat maps and expert knowledge have both been shown to enhance field data (Culmsee et al. 2014; Schmidtlein et al. 2014) and have allowed for the scaling up of survey data (Elbroch et al. 2011). However, there has been little work done on how these alternatives perform at telling "the truth" about biodiversity (but see Raxworthy et al. 2003). The relationship between species' occurrence and landscape characteristics are often modelled so that habitat distributions can be used to predict potential species distribution in unsurveyed areas (Guisan and Thuiller 2005; Pettorelli et al. 2014). However, although there has been a lot of effort into ground-truthing remotely sensed landscape characteristics, there has been little work done on assessing the accuracy of these species predictions. Similarly, the ability of expert elicited information to accurately predict species occurrence has rarely been tested, as expert data is often collected in the absence of survey data (Jetz et al 2012). Intuitively, the use of data from habitat maps or expert knowledge to enhance field surveys to decide where to undertake additional surveys and where to invest management resources calls for testing the reliability of these different techniques at predicting species distributions. The development of a novel approach to test the accuracy of expert elicited data and habitat proxy data has enabled this project to be more transparent about assumptions and uncertainty that exist within the datasets used to make management decisions.

One of the foundations of conservation planning is relevant quality spatial datasets on the features to be protected and on their threats. Coast, islands, islets, exposed rocks and cays of Queensland as defined by the GBRMPA are currently mapped at 1:250,000 using Landsat imagery (30 m spatial resolution), and this map is used as the basis of many broad-scale conservation plans and studies. This project used habitat proxies based on publicly available data to ensure that future work undertaken in this study region would not be limited by data accessibility issues. However, with a very high proportion of small islands and cays, this coarse map conveys a high risk of missing features (false negatives), overestimating surface area, and poor positional accuracy, which can highly bias and affect planning and management. To help predict the occurrence of threatened and invasive species and improve the chances of adequately managing National Parks, an essential dataset is missing: an up-to-date, high spatial resolution, high positional accuracy, and high thematic accuracy map of these islands and their main habitats such as vegetation, beaches, rocks and mangroves, which this project aimed to develop. A map product should not be used for any purpose without an assessment of its accuracy. Positional accuracy is high with ALOS PRISM imagery. However, there is no information on how accurately the habitat classes represent habitats on the ground. Therefore, collecting ground truth information to measure thematic accuracy will be an essential step if the map is to be used for conservation planning and management. Because the Southern GBR islands and cays are numerous and remotely located, there are two ways to do this. First, a desktop-based method can be used with available archived aerial photographs (<50cm spatial resolution). Second, we propose a joint work with local rangers and managers who visit these islands on a day-to-day basis to collect field data. The information will consist in as many records as possible, as randomly located as possible, containing at the very least: 1) accurate GPS coordinates; and 2) a photograph or a set of photographs of the habitat at the location. Ideally, participants would use a camera with integrated GPS.

Generally where cost data are available in the literature the different cost components are not separated but instead are amalgamated into a single value for an action. The problem this presents is that it makes it difficult to transfer the information to different circumstances. This project has developed a transparent and transferable way to calculate management costs. The cost estimates gathered during elicitation will always have considerable uncertainty. This is fundamental to the type of questions being asked which often involve future scenarios for which the managers have little or no first hand experience. To combat this, we had multiple participants involved in generating the estimates and to ensure full participation. In some cases it was necessary to coach managers to have the confidence to provide estimates. The project team found it useful to ask the under-confident participants 'who should I ask instead?' They often struggled to name a good alternative that has more knowledge of the action or location being discussed, which increased their confidence and their participation level.

One of the challenges encountered throughout the project was how to incorporate costs through time in the models. Most actions take place over a number of years before being completed. The optimisation model runs over sequential years so requires a cost for each year. This can be produced by calculating the total costs of an action (e.g. a vertebrate eradication) over the whole treatment period (e.g. 5 years) and then dividing to produce a uniform annual cost. While simple, this method does not allow for inter-annual variations in costs for the same action, which are common in reality. The typical inter-annual cost change is a reduction in costs as actions taper in intensity over the treatment period, weed eradications typically have a season or two of intense work followed by less intensive mopping-up periods. GBR managers did not say there was a need to vary action costs over the treatment period. However, other island managers suggested it would be necessary.

It may be beneficial to adjust the cost estimates for inflation if the prioritisation model is run over a considerable number of years. This can be done most simply by assuming inflation affects all components of an action's costs equally, and increasing the annual costs of an action incrementally by a fixed percentage (i.e. 3%). The choice of percentage can be guided by the forecast consumer or wage price index published by the ABS. Adjusting for inflation in this way will make no difference to the outcome of the optimisation because all costs will inflate evenly. However, if one of the desired outputs of the model is an estimate of future budget requirements then it might be worth incorporating inflation.

Equipment and infrastructure costs that occur in a single year but provide benefits for a number of years require a framework to deal with them. The typical accountancy procedure is to depreciate the value of the asset by a regular amount every year over the useful life of the asset and treat this annual depreciation value as a cost. However, this level of complexity may not be required for the islands due to low importance of capital assets in the total costs. A simpler approach will be to annualise the costs of the infrastructure (e.g. visitor signage) by dividing the construction costs by the longevity of the infrastructure, or over run period of model. This annualised cost is then applied to every year in the model.

Prospects

Although NERP funding has now finished, aspects of the project will continue. The project has also been subsidised considerably (with cash totalling about $150,000, plus in-kind contributions). Several journal papers are in preparation, and discussions with GBR island managers are ongoing. Supported by funding from the project on the Pilbara Islands, the software is in continuous refinement, with recent workshops in July 2015 improving the approach to both analysing cost data and modelling the population dynamics of native and invasive species. Refined versions of the software will be made available to managers of GBR islands. Sources of further funding are being investigated.

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