Prioritising weed management activities in a data deficient environment: the Pilbara islands, Western Australia

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Abstract

Along the Pilbara coast of Western Australia (WA) there are approximately 598 islands with a total area of around 500 km^2. Budget limitations and logistical complexities mean the management of these islands tends to be opportunistic. Until now there has been no review of the establishment and impacts of weeds on Pilbara islands or any attempt to prioritise island weed management. In many instances only weed occurrence has been documented, creating a data deficient environment for management decision making. The purpose of this research was to develop a database of weed occurrences on WA islands and to create a prioritisation process that will generate a ranked list of island-weed combinations using currently available data. Here, we describe a model using the pairwise comparison formulae in the Analytical Hierarchy Process (AHP), four metrics describing the logistical difficulty of working on each island (island size, ruggedness, travel time, and tenure), and two well established measures of conservation value of an island (maximum representation and effective maximum rarity of eight features). We present the sensitivity of the island-weed rankings to changes in weights applied to each decision criteria using Kendall's tau statistics. We also present the top 20 ranked

island-weed combinations for four modelling scenarios. Many conservation prioritisation tools exist. However, many of these tools require extrapolation to fill data gaps and require specific management objectives and dedicated budgets. To our knowledge, this study is one of a few attempts to prioritise conservation actions using data that are currently available in an environment where management may be opportunistic and spasmodic due to budgetary restrictions.

Keywords: Environmental management, Decision analysis, Nature conservation, Invasive plant species, Landscape conservation

1. Introduction

1.1. Prioritising weed management activities

Broadly speaking, there are two types of prioritisation processes: scoring or ranking management options and systematic planning [1]. Scoring procedures rank management options in order of value or priority according to a combined score from a range of criteria such as diversity, rarity, size, and naturalness [1]. The criteria that may be used in a scoring procedure vary widely, as do the multi-criteria decision-making (MCDM) calculations that allow the user to determine the importance or influence of each criterion [2]. Where ranking typically involves a unidirectional and static calculation aimed at maximising the combined score of potentially competing criteria [3], systematic planning tools (e.g. MARXAN, C-PLAN) are dynamic, incorporate the complementarity and connectivity of adjacent areas and require the user to set quantitative conservation or budgetary goals [4]. Systematic conservation planning tools are frequently used to design conservation reserves [5,6]. These tools have also been used to identify priority areas for management activities [7] or to prioritise projects [8,9].

Despite their sophistication there are two impediments to the implementation of existing systematic conservation planning tools: one, they require a lot of detailed data describing the environment and the management problem, and two there is a gap between model generated conservation plans and the implementation of local conservation actions [10].

Data deficiency is a common problem [11], which many of us would attribute to developing nations. It is also a problem for under-studied and remote regions of the developed world, such as the north-west coast of Australia, particularly north-west islands [12]. Global research has shown that invasive species are less likely to be documented in data-deficient countries [13]. On the larger Pilbara islands, weed occurrence may have been documented, but the precise locality and abundance of the weed was not typically documented. Some researchers are addressing the problem of data deficiency through expert elicitation methods [14]. In this manuscript we combine data from an expert elicitation process with

basic but globally available spatial data to prioritise weed management in a data deficient environment.

Failure to implement management plans is also a common problem. For example, Knight et al. [15] reported that only 33% of outputs from conservation planning models were implemented; of those 19% were done so ineffectively. Indistinct assumptions contained within conservation planning models may cause some of the implementation gap. For example, systematic conservation plans may contain the implicit assumption that dedicated budgets and teams of managers are available for implementing a plan [7,9]. This assumption may prove false in many areas. In the absence of dedicated budgets, the implementation of conservation actions will compete with other tasks for a manager's time and resources and hence a conservation plan will be influenced by unanticipated factors over time and deviations from the original conservation plan may occur [10]. Currently available systematic conservation planning models can adjust to deviations from the original plan if specialised knowledge of the software, the model, and the original plan are retained and available to update input files. Unless model use and maintenance requires a minimal amount of time and skill on the part of the responsible land manager, conservation planning models once complete are likely to be left untouched until a new allocation of funds allows a planning specialist to commence work [16].

1.2. Weeds on islands

There are more than 3,700 islands along the Western Australian (WA) coast, ranging in size from small rocky outcrops to Dirk Hartog Island, the largest at 50,640 hectares. As with many other islands and archipelagoes around the world, many of the WA islands are the last refuge for threatened and endemic species against the numerous threatening processes present on the mainland [17,18,19]. Unfortunately, many of these isolated and mostly uninhabited islands have been invaded by multiple introduced species.

The Western Australian Department of Parks and Wildlife (hereafter Parks and Wildlife) oversees the management of natural ecosystems in Western Australia and is directly responsible for managing the conservation estate. In the Pilbara Region, Parks and Wildlife are responsible for managing approximately 598 islands (defined as above the high water mark) with a cumulative area of approximately 500 km^2. Of these, 383 are at least partial nature reserves (unpublished data). The median size of the remaining 215 islands is 2.8 ha. These islands are spread over 33,000 km^2 and range from mangrove-covered mudflats near the coastline, to sand cays 20 km or more from the mainland, to tightly clustered archipelagos of limestone-based islands. With so many islands and a limited budget for management, prioritising management actions,

including which weeds or other pests are targeted for control or eradication activities is essential.

There have been no previous reviews of the establishment and impacts of weeds on Pilbara islands [20], and no attempts to prioritise island weed management. Additionally, there is no state-wide biosecurity surveillance system for island conservation reserves. Visits to Pilbara islands by Parks and Wildlife staff tend to be opportunistic or for purposes other than detecting exotic organisms [20].

There are hundreds of discrete weed populations on islands in the Pilbara region (hereafter island-weed combinations). This, combined with the opportunistic nature of island management, suggests a need for a tool that can quickly generate a ranked list of island-weed combinations in universally available and understood software (e.g. Microsoft Office) to facilitate more efficient and effective management of introduced plants. The purpose of this research was three-fold: 1) to develop a database of weeds on WA islands, 2) to extend an expert elicitation process used to prioritise weed species state-wide [21] to create a ranked list of island-weed combinations, and 3) create a prioritisation process that uses currently available data and may be readily updated with limited input from modellers.

2. Methods

2.1. Island-weed database

Between 2012 and 2014 a database of weed occurrences on WA islands was compiled [22]. This database includes current scientific and common names, date and location of a record, size and density of the weed infestation if available, and information on the status of a weed species on lists such as the Western Australian Organism List (WAOL) [23], the IUCN's World's 100 Worst Invasive Species list [24], Weeds of National Significance [25], and The National Environmental Alert List [26]. Published lists and those found in proposed development projects were entered into the database as were unpublished lists held in Departmental archives. All records were cross-referenced with FloraBase [27], the Australian Plant Name Index [28], and local expertise to validate the non-native status of weeds recorded in the database. Cross-referencing records allowed us to minimise the possibility of false positives in the database and identify probable identification errors and errors related to changes in taxonomy.

2.2. Weed prioritisation

A weed risk assessment has been completed individually for each Parks and Wildlife administration regions (Fig. 1; [21]). Initial weed lists for Parks and
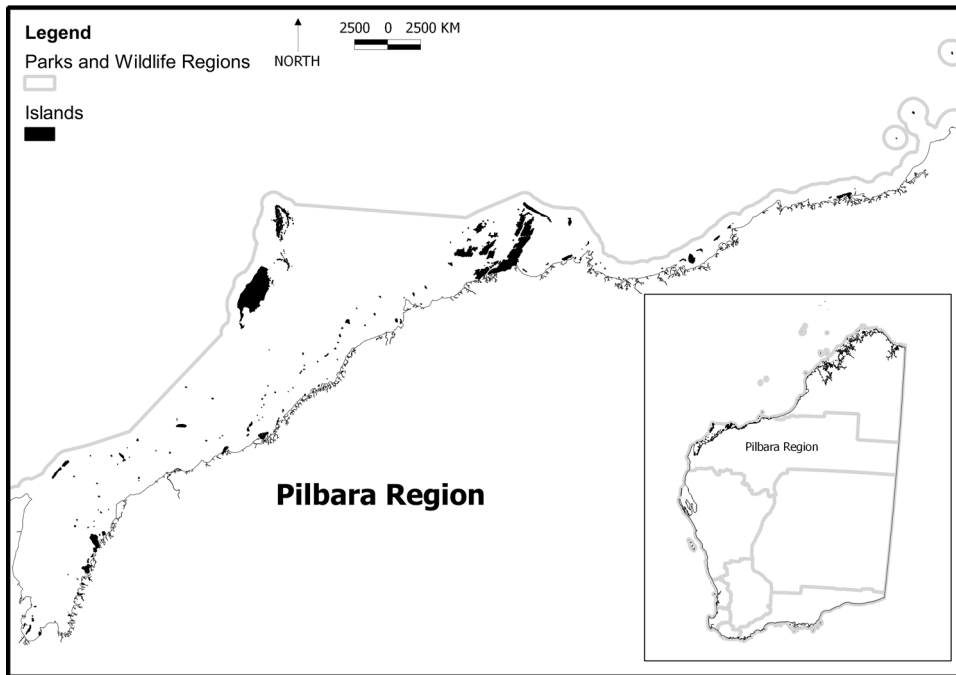
Fig. 1. Map of the Pilbara islands with an overview map of the Western Australia Parks and Wildlife regions.

Wildlife regions were based on data published in Keighery and Longman (2004) [29], Peltzer (2008) [30], Bettink and Keighery (2008) [31], and FloraBase [27]. Facilitated expert elicitation workshops involving Parks and Wildlife staff were used to supply additional data regarding the current and potential distribution, ecological impact, invasiveness, and feasibility of controlling each weed listed in a region (Table S1). These workshops also provided information regarding a weed's listing elsewhere and any knowledge gaps. In some regions, external stakeholders were consulted to provide further information on weed occurrences and impacts on Parks and Wildlife managed estate. The data were provided on a region-wide scale by experts with experience working in each of the Parks and Wildlife regions and variation within each region was ignored. Huber et al. (2010) [32] established that the results of any conservation planning effort are influenced by the geographic scale of data inputs. To tailor these assessments specifically to the Pilbara islands, inputs associated with weed characteristics were modified by Parks and Wildlife weed experts to ensure local applicability.

The weed prioritisation process (Fig. 2) involved a series of matrices in which pairs of metrics were cross-referenced (Table 1). The categorical results generated by this process included five possible weed rankings (*Wr*): very high (VH) priority, high (H) priority, medium (M) priority, low (L) priority, and negligible (N) priority. Weed species were allocated to each category. Given the extensive elicitation effort used to create the weed prioritisation, we did not alter
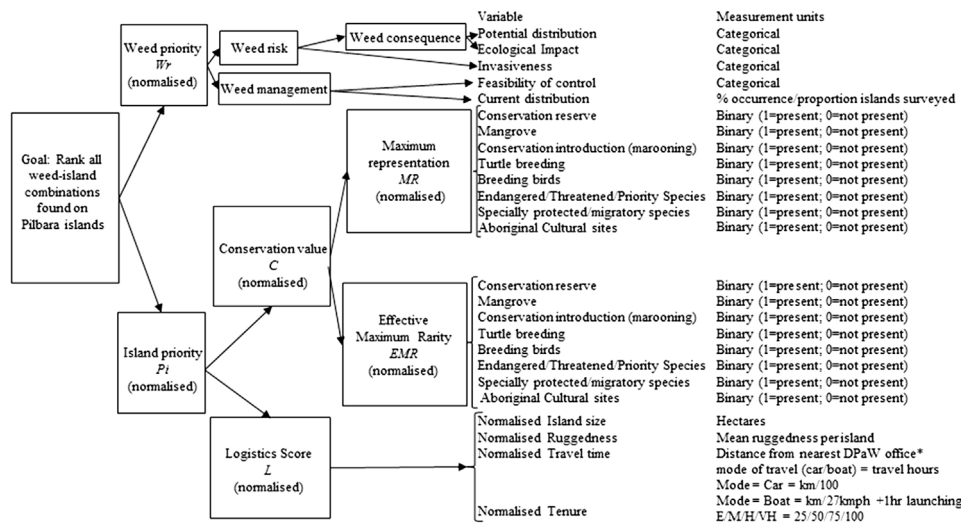
Fig. 2. List of decision criteria and sub-criteria used for ranking island-weed combinations. Scores were normalised to range between 0-100 to ensure that any two summed metrics carried equal weight in subsequent calculations unless AHP weights differed from a 1/1 ratio. Tenure categories are: E = easy = Conservation reserves; M = Medium = Unallocated Crown Land or single lease; H = Hard = mixed tenure; VH = Very hard = reserved for specific complicated cases.

the weights or relationships between sub-criteria used to determine weed priority. We did, however, alter the Pilbara-wide distribution data to weed occurrence data contained within our island-weed database, divided by the proportion of islands that have been surveyed for flora (only 14% at the time of writing). The final categorical results of the modified weed prioritisation process were assigned a numerical value ranging between 100 and 0 (VH = 100; H = 75; M = 50; L = 25; N = 0) so that weed priorities could be combined with island priorities to extend the capabilities of the model.

2.3. Island-weed prioritisation

Here, we describe a model built using a modified version of the Analytical Hierarchy Process (AHP) [33] with the goal of generating a complete ranking of all island-weed combinations in the Pilbara region (Fig. 2). The model was built in Microsoft Excel®. AHP involves setting a goal, breaking the goal down into its constituent decision-criteria and then assigning weights to each of these criteria via pairwise comparisons. Typically, all of the management options – in this case, island-weed combinations – form the bottom level of the hierarchy. AHP has been widely used for numerous purposes [34] including identifying priority areas for conservation management [35,36].

The strength of AHP is its use of pair-wise comparisons of decision criteria to derive accurate ratio-scale weights, as opposed to the traditional approach of assigning single weights [33,37]. The use of pair-wise comparisons exposes

Table 1. Matrices used to calculate weed priority during Parks and Wildlife weed prioritisation process.

STEP 1: WEED CONSEQUENCE[a]

		ECOLOGICAL IMPACT			
		High (H)	**Medium (M)**	**Low (L)**	**Unknown (U)**
POTENTIAL DISTRIBUTION	Extensive (E) >80% management area	VH	H	M	M
	High (H) 40–80% management area	H	M	L	L
	Medium (M) 10–40% management area	M	M	L	L
	Low (L) <10% management area	M	L	N	L
	Unknown (U)	M	L	L	FAR

STEP 2: WEED RISK[b]

		STEP 1: WEED CONSEQUENCE				
		Very High (VH)	**High (H)**	**Medium (M)**	**Low (L)**	**Negligible (N)**
INVASIVENESS	Rapid (R)	VH	H	M	M	L
	Moderate (M)	H	M	L	L	N
	Slow (S)	M	L	L	N	N
	Unknown (U)	M	L	L	L	L

STEP 3: FEASIBILITY OF CONTROL[c]

		FEASIBILITY			
		High (H)	**Medium (M)**	**Low (L)**	**Unknown (U)**
CURRENT DISTRIBUTION	Low (L) <10% of surveyed islands	VH	H	M	VH
	Medium (M) 10–40% of surveyed islands	H	M	L	H
	High (H) 40–80% of surveyed islands	M	L	L	M
	Extensive (E) >80% of surveyed islands	L	L	N	L
	Unknown (U)	M	L	L	FAR

STEP 4: WEED SPECIES RANKING[d]

		STEP 2: WEED RISK				
		Very high (VH)	**High (H)**	**Medium (M)**	**Low (L)**	**Negligible (N)**
STEP 3: FEASIBILITY OF CONTROL	Very high (VH)	VH	H	M	L	N
	High (H)	H	H	M	L	N
	Medium (M)	M	M	L	L	N
	Low (L)	L	L	L	N	N
	Negligible (N)	L	L	N	N	N

[a] Results: VH–very high; H–high; M–medium; L–low; N–negligible; FAR–further assessment required and species will not proceed through ranking process, however this species may require ongoing monitoring in the field.

[b] Results: VH–very high; H–high; M–medium; L–low; N–negligible.

[c] Results: VH–very high; H–high; M–medium; L–low; N–negligible; FAR–further assessment required and species will not proceed through ranking process, however this species may require ongoing monitoring in the field.

[d] Results: VH–very high = 100; H–high = 75; M–medium = 50; L–low = 25; N–negligible = 0.

and limits inconsistencies in decision-makers weights. In a typical AHP, each management option is compared to every other management option in terms of

lowest level decision criterion. The number of pair-wise comparisons (*pwc*) that must be made escalates rapidly against the number of decision criteria or management options (*n*) that must be compared (*pwc* = $0.5n^2$-*n*/2). As there are hundreds of island-weed combinations in the Pilbara region, the number of pair-wise comparisons that must be made prohibits the use of traditional AHP.

Previous studies have demonstrated that quantitative biological data can be used to link AHP weighted decision criteria to management options to greatly limit the number of pair-wise comparisons that must be completed [3,37]. Similarly, we modified the traditional AHP by using currently available datasets to provide values for each weed priority; the logistics score (L_i) and the conservation value (C_i) of each island. The data sets used in this research are available as Supplemental data files.

The conservation value ($C_i = wEMR_i + wMR_i$) of an island (*i*) was a combined score of maximum representation ($MR_i = \left(\frac{n_f}{\Sigma f_i}\right) * 100$) and effective maximum rarity ($EMR_i = 100/frequency_{rarest\ feature}$) of eight desirable features (*f*; Fig. 2; Table 2) *EMR* is calculated iteratively with the frequency of the rarest feature used to calculated the *EMR* of any islands where that feature is present [38]. The conservation value of an island is calculated independently of any feature-threat interactions because this information is largely unavailable. *MR* and *EMR* are two criteria for measuring conservation value [1]. The conservation features listed for Western Australia's islands are similar to those listed in the Conservation Commission of Western Australia's status performance assessment [20].

A logistics score ($L_i = w$Area$_i$+ wRuggedness$_i$+ $w$travel$_i$+ $w$tenure$_i$) was calculated from four weighted (*w*) metrics that can be readily obtained from spatial datasets and land tenure records (Fig. 2,Table 2). The conservation value of an island was attenuated by its logistics score to create an island priority ($P_i = wC_i - wL_i$). Ultimately, island priority was combined with weed rank (*Wr*) to calculate island-weed score (*IWS* = $P_i + Wr$).

We used pair-wise comparisons to apply weights (*w*) to four sets of decision criteria: weed rank (*Wr*), versus island priority (P_i), logistics score (L_i) versus conservation value (C_i), *EMR* versus *MR*, and island area versus ruggedness versus travel versus tenure (Fig. 2). The subjective weights generated by AHP are not the focus of this paper as they are liable to change between stakeholders or decision makers. Typically, the AHP weights reported in articles are not transferable in time or space. Rather we present the sensitivity of the rankings to changes in weights applied to each decision criterion. We used Kendall's tau statistics to determine if weights assigned to child-variables influence the rankings assigned to parent-variables. We present the results of four decision-making scenarios.

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Table 2. The conservation and logistics metrics included in the AHP and the source of the data.

Metric	Description	Source
Conservation reserve	Any islands that are at least partially listed as a conservation reserve by Conservation Commission of WA	Parks and Wildlife tenure data
Mangrove	Extant mangrove patches	Parks and Wildlife mangrove maps
Conservation introduction	Extant population of fauna introduced for the purposes of conserving the species	Literature
Turtle breeding	Beaches with observed turtle breeding activity	Parks and Wildlife Marine Conservation Science database and literature
Breeding birds	Terrestrial and marine birds that have been observed breeding on an island	Burbidge et al. seabird breeding database and literature
Endangered, Threatened or Priority species	Schedule 1 fauna under Wildlife Conservation Act 1950, fauna listed as endangered, threatened or vulnerable by IUCN and Priority Flora taxa listed in WA Herbarium's database 'FloraBase'	IUCN Red List and Parks and Wildlife databases
Specially protected Migratory species	Species listed as Schedule 3 or 4 under Wildlife Conservation Act 1950 Species listed as migratory under Environment Protection and Biodiversity Conservation Act 1999	EPBC Species Profile and Threats database
Aboriginal cultural sites	Sites registered by the Department of Aboriginal Affairs	Department of Aboriginal Affairs
Island area	Island area provides a measure of the area to be searched for a weed	Parks and Wildlife island shapefile
Ruggedness	Island ruggedness provides a relative measure of the difficulty of searching for weeds and implementing control methods	Parks and Wildlife island shapefile and coastal SPOT DEM
Travel time	Travel time provides a proxy for the cost of moving resources to an island	Parks and Wildlife spatial data and island shapefile
Tenure	Tenure provides a proxy for the time that may be spent negotiating/designing management actions (Conservation reserves = easy; Unallocated Crown Land or single lease = medium as depends on provisions of lease etc; mixed tenure = hard; Very hard = reserved for specific cases e.g. Barrow island).	Parks and Wildlife tenure data

Scenario 1: All comparable weights are equal.

Scenario 2: Islands are ranked for general weed management by summing all island-weed scores for each island.

Scenario 3: Travel given high priority with $w = 0.9$, all other logistics $w = 0.1$.

Scenario 4: Conservation value of an island given high priority with $wC_i = 0.9$ and $wL_i = 0.1$.

Under Scenario 2 we summed the final island-weed scores for each island. This scenario identifies islands with numerous high priority weed species and hence ranks islands by the suite of weeds present, the individual weed priorities, and island priorities. Travel to the Pilbara islands is an expensive and hence a severely limiting factor for island management actions. When travel opportunities to the islands become available it can be argued that it may be more cost-effective to manage multiple weed species simultaneously. Alternatively, Scenario 3 applies priority to travel time over all other decision criteria.

3. Results

There are 196 island-weed combinations in the Pilbara region (Table S2). Five weed species currently listed as declared plants (C3) by the Department of Agriculture and Food Western Australia (*Datura leichhardtii*, *Emex australis*, *Opuntia stricta*, *Parkinsonia aculeatea*, and *Tamarix aphylla*) formed a total of nine of the island-weed combinations. Some of the records of declared plants on Pilbara islands may no longer be relevant. *Opuntia stricta* for example has been the subject of several eradication attempts through the use of Cochineal insects (*Dactylopius* spp.) and herbicide [39,40]. Whether the eradication attempts were successful has not been confirmed. In other cases, a weed was recorded as present on an island when the only known example of the weed was collected as a specimen (e.g. we presumed *Papaver somniferum* on Barrow Island, to be eradicated because the only recorded individual was collected as a herbarium specimen).

Weights assigned to variables used to measure conservation value, *EMR* and *MR* had the least influence on the ranking of islands as measured by their conservation value only. Approximately 40% of the islands would change rank if weights were pushed to scale extremes (Table 3). Kendall's tau results (tau > 0.95) revealed that when a few islands changed rank, the remaining islands were simply shunted down the list and hence the rank assigned to the majority of islands remained proportional (Fig. 3). Weights assigned to the four logistic metrics had a greater influence on island rank with more than 97% of islands changing rank. Kendall's tau results (0.56–0.68) revealed that island rank

Table 3. Influence of maximum weight variation on ranks assigned to islands or island-weed combinations as measured by Kendall's rank correlation.

Ranked variable		Weighted variable	Assigned weight	% changed rank	tau	z	p-value
	Scenario 1	Equal weight for all decision criteria	0.5	–	–	–	–
Conservation value		Δ Scenario 1 to		38.6	0.95	34.7	<0.001
		Maximum representation	0.1				
		Effective maximum rarity	0.9				
		Δ Scenario 1 to		40.3	0.98	35.8	<0.001
		Maximum representation	0.9				
		Effective maximum rarity	0.1				
Logistics score		Δ Scenario 1 to		97.9	0.68	24.8	<0.001
		Island area	0.9				
		Ruggedness	0.1				
		Travel	0.1				
		Tenure	0.1				
		Δ Scenario 1 to		99.3	0.56	20.5	<0.001
		Island area	0.1				
		Ruggedness	0.9				
		Travel	0.1				
		Tenure	0.1				
	Scenario 3	Δ Scenario 1 to		98.5	0.6	21.8	<0.001
		Island area	0.1				
		Ruggedness	0.1				
		Travel	0.9				
		Tenure	0.1				
		Δ Scenario 1 to		99.3	0.62	22.7	<0.001
		Island area	0.1				
		Ruggedness	0.1				
		Travel	0.1				
		Tenure	0.9				

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Table 3. (*Continued*)

Ranked variable	Weighted variable		Assigned weight	% changed rank	tau	z	p-value
Island Rank	Scenario 4	Δ Scenario 1 to		98.5	0.64	23.4	<0.001
		Conservation value	0.9				
		Logistics Score	0.1				
		Δ Scenario 1 to		100	0.49	17.8	<0.001
		Conservation value	0.1				
		Logistics Score	0.9				
Ranked island-weed combinations		Δ Scenario 1 to		80.6	0.94	19.6	<0.001
		Island	0.1				
		Weed	0.9				
		Δ Scenario 1 to		99.5	0.68	14.3	<0.001
		Island	0.9				
		Weed	0.1				
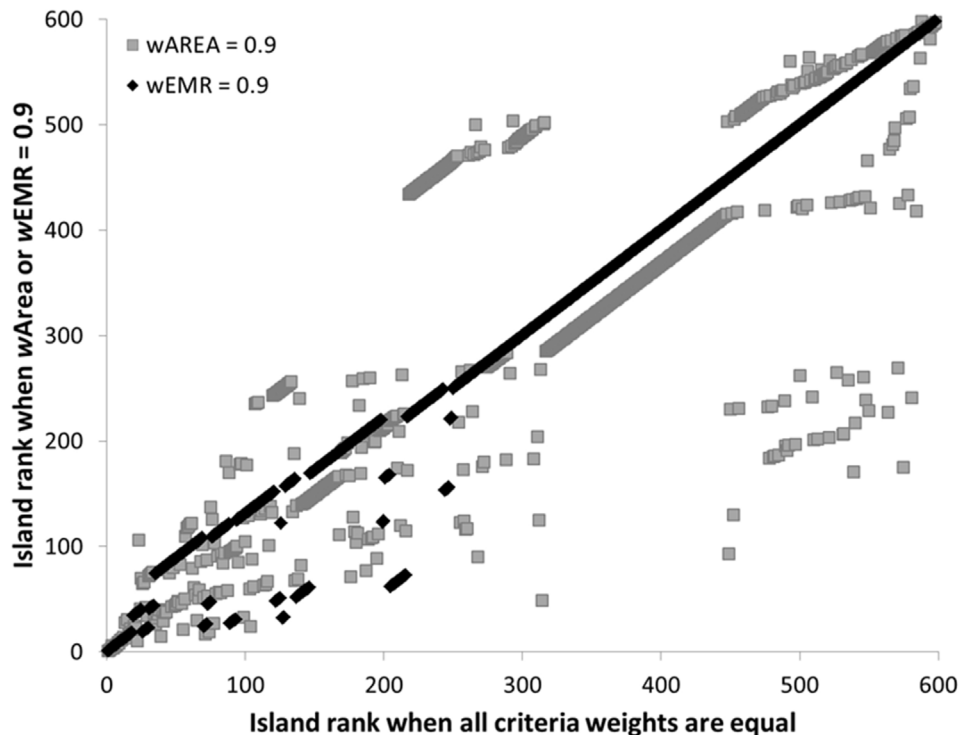
Fig. 3. Change in island rank when weights applied to decision criteria move from all being equal to maximum weight is applied to island area or *EMR*. In either scenario, weights applied to all other decision criteria is 0.1.

was largely re-ordered and did not remain proportional for the majority of islands when weights applied to logistics metrics changed (Fig. 3). Similarly, weights assigned to higher level decision criteria (Conservation value, Logistics score, Island rank, and Weed Priority) had greater influence, altering the rank of 80–100% of islands or island-weed combinations.

We present the top 20 ranked island-weed combinations for four decision scenarios (Table 4). Comparing Scenario 1 with Scenario 3, we can see that the island order changed with islands that are closer to the mainland (e.g. Dixon <1 km from mainland) replacing islands from the Montebello archipelago (e.g. Hermite >70 km), but *Aerva javanica* remained the highest ranked weed species. Scenario 2 places emphasis on islands with multiple high priority weed species. Barrow Island has 16 weed species but only one of those species is ranked as high priority and five are ranked as negligible priority. Thevenard Island has 13 weed species, three of which are ranked as high priority species and two ranked as negligible priority. Scenario 4 highlighted the conservation value of West Lewis, East Lewis, Hermite, Serrurier, Doole, North West, Trimouille, Alpha, and Boodie Island. Each of these islands have become home to a translocated or marooned mammal species. Previous investment in

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Table 4. Top 20 ranked island-weed combinations for decision scenarios 1–4.

Rank	Scenario 1–Equal weight	Scenario 2–Sum	Scenario 3–Travel	Scenario 4–Conservation value
1	West Lewis South - *Aerva javanica*	Thevenard	West Lewis South - *Aerva javanica*	West Lewis South - *Aerva javanica*
2	West Lewis South - *Opuntia stricta*	West Lewis South	West Lewis South - *Opuntia stricta*	West Lewis South - *Opuntia stricta*
3	East Lewis - *Aerva javanica*	Varanus	East Lewis - *Aerva javanica*	West Lewis South - *Cenchrus ciliaris*
4	East Lewis - *Opuntia stricta*	Angel	East Lewis - *Opuntia stricta*	West Lewis South - *Flaveria trinervia*
5	Doole - *Aerva javanica*	Rosemary	Doole - *Aerva javanica*	West Lewis South - *Malvastrum americanum*
6	Hermite - *Aerva javanica*	Legendre	Dolphin - *Aerva javanica*	East Lewis - *Aerva javanica*
7	Alpha - *Aerva javanica*	Hermite	Enderby - *Aerva javanica*	East Lewis - *Opuntia stricta*
8	Enderby - *Aerva javanica*	East Lewis	Dixon - *Aerva javanica*	East Lewis - *Cenchrus ciliaris*
9	Dolphin - *Aerva javanica*	Barrow	Angel - *Aerva javanica*	Hermite - *Aerva javanica*
10	Delambre - *Aerva javanica*	North Muiron	Angel - *Passiflora foetida*	Serrurier - *Cenchrus ciliaris*
11	Potter - *Aerva javanica*	South Muiron	Hermite - *Aerva javanica*	Serrurier - *Flaveria trinervia*
12	Gidley - *Aerva javanica*	Dolphin	Delambre - *Aerva javanica*	Doole - *Aerva javanica*
13	Rosemary - *Phoenix dactylifera*	Jarman	Gidley - *Aerva javanica*	North West - *Flaveria trinervia*
14	Rosemary - *Tamarix aphylla*	Enderby	Rosemary - *Phoenix dactylifera*	Trimouille - *Flaveria trinervia*
15	Angel - *Aerva javanica*	Boodie	Rosemary - *Tamarix aphylla*	Hermite - *Cenchrus ciliaris*
16	Angel - *Passiflora foetida*	Airlie	Alpha - *Aerva javanica*	Hermite - *Flaveria trinervia*
17	Dixon - *Aerva javanica*	Alpha	Malus Large - *Aerva javanica*	Hermite - *Malvastrum americanum*
18	Malus Large - *Aerva javanica*	West Moore	Finucane - *Aerva javanica*	Alpha - *Aerva javanica*
19	Finucane - *Aerva javanica*	Serrurier	Potter - *Aerva javanica*	Boodie - *Cenchrus ciliaris*
20	Fortescue - *Aerva javanica*	Potter	Legendre - *Aerva javanica*	Boodie - *Malvastrum americanum*

conservation on these islands raised their conservation value above that of other islands (Lohr unpublished data). Prioritising the conservation value of islands added *Flaveria trinervia* and *Malvastrum americanum* to the top 20 weed populations on Pilbara islands.

4. Discussion

As a result of this study, we produced two resources that will aid weed management on islands. Firstly, we developed a database of weeds on WA islands, and secondly, we created an island-weed prioritisation model that uses readily accessible data and may be quickly updated and managed by users. Given the uncomplicated nature of the data used, the model framework could be applied to any series of discrete management parcels including areas where data deficiency is a problem.

Usually, effective prioritisation and implementation of weed management activities requires knowledge of current weed locations [37,41]. When the precise location of a weed population is unknown then the prioritisation process must account for time spent searching for a weed as this component may consume significant resources depending on the size of the area to be searched [42]. In our model we used island size as a proxy for the area that managers would need to search for weeds. If a precise location of weeds was known then users can use portions of islands (or mainland areas) as discrete management units to be prioritised.

In many survey reports, absence of a species is implied. Implied information however is not always transferred to biological databases and is essentially lost to future users of the data. *Papaver somniferum* for example is listed as present on Barrow Island in The Atlas of Living Australia, a nationwide biological database that is the online source of museum records (www.ala.org.au). While there are statistical methods of using occurrence data rather than presence-absence data when building species distribution models [43,44] the value of explicit absence data cannot be underestimated when prioritising management activities. For example, our model prioritises the management of *Opuntia stricta* on West Lewis and East Lewis Islands, islands where the effectiveness of past management activities has not to our knowledge been confirmed. It is our experience that several weeds could be 'eradicated' through data quality control. The quality of data transferred from the field to biological databases could be improved by including explicit information on survey methodology and absence of any species previously recorded in the area, particularly introduced species. Similarly, information on weed extent and density would be useful as these are primary attributes taken into consideration when identifying stands of weeds that can be managed [7,37].

Two strengths of this model are 1) that it was built and can be maintained in universally available and understood software, and 2) model maintenance only requires users edit a single matrix of management unit by weed presence, increased model precision can be created by splitting management units into subunits, and 3) it generates a complete ranking of all the island-weed combinations. The purchase, training of personnel, model use, and data maintenance requirements of specialist software is a limiting factor against the use of more sophisticated conservation planning tools.

The ranking of island-weed combinations provides a management schedule. In reality, managers are unlikely to be able to target island-weed combinations in the exact order they are ranked. However, managers can readily sort the ranked options to find the highest priority for management in an area scheduled to be visited for other reasons. Managers can also readily monitor the total number of island-weed combinations to be addressed and identify cases where the success or failure of previous management regimes needs to be confirmed. Maximizing management outcomes in this manner is important in an environment where allocation of resources is increasingly dependent on sporadic funding.

The primary weakness of using AHP to prioritise environmental management decisions is that a hierarchy does not allow for dynamic interactions between criteria. For example, in our model the effectiveness of a weed management regime does not influence the cost of management on a particular island. Other attempts to rank species management actions have encountered similar problems [45,46]. Our results also do not address spatial variation in the intensity of the threat posed by each weed. These data are largely unavailable. Other authors have dealt with this problem by incorporating species distribution models in the prioritisation process [7,47]. We avoided species distribution models because we set out to create a model that does not require specialist training to manage.

Future attempts to prioritise weeds or other pests should consider prioritising weeds using ordinal categories with known intervals, discretised ranges or normalised numeric scales. This prioritisation process involved combining or comparing disparate metrics which may be weighted by the decision maker. Care must be taken during the prioritisation process to ensure that metrics are on the same scale; otherwise in an unweighted process, priority is automatically placed upon the metric with the broader scale. Polasky (2008) [48] described several conservation planning projects whose priorities were relatively insensitive to biodiversity data because costs were measured on a broader scale. For example, in this study, prior to normalizing all criteria used in our model, island-weed rankings were not sensitive to changes in weights applied to *EMR*. At this point, the scale for *EMR* ranged from 0 to 11, whereas the scale for *MR* ranged from 0 to 100, giving greater weight to *MR* in calculations. By

converting all metrics to numeric scales and normalising data we were able to ensure that all decision-criteria carried the same weight, unless criteria weights were intentionally altered by the decision-maker.

Here, we describe an example of a prioritisation process that can be applied to day-to-day decision making even with a lack of dedicated management funds or quantitatively defined objectives. Other authors have demonstrated that budgets can be allocated more efficiently if objectives are defined quantitatively [8,9,46]. However, that ideal scenario (i.e. a dedicated budget) is not always available. To address the disconnect between conservation planning process and the implementation of conservation actions, conservation planners do need to address scenarios that involve opportunistic management under non-dedicated budgets and competing tasks.

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Author contribution statement

Competing interest statement

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