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GIS-based multi-criteria analysis of breeding habitats for recolonising species: New Zealand sea lions

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A B S T R A C T

The New Zealand sea lion (*Phocarctos hookeri*) is a threatened endemic species, with only three breeding colonies in the sub-Antarctic islands. Since 1993, there has been evidence for recolonisation of mainland New Zealand. Yet the coast that the sea lion has returned to only has fragmented and unevenly distributed potential habitats due to coastal urbanisation and development. Therefore, the need to identify and protect potential breeding habitats for recolonisation is a priority for management.

A GIS-based multi-criteria analysis was used to identify potential suitable habitats for a 1600 km length of the NZ South Island coast based on distance to anthropogenic disturbance (urban areas, roads), distance to desirable environmental features (beaches, estuaries) and presence of suitable habitat/land access. From this model, we identified preliminary suitable habitat for breeding sites on the Otago Peninsula (east coast) and Catlins Coast (south). We independently detected some of the current dominant areas used by recolonising sea lions as well as identifying some promising new sites.

We discuss the limitation of the results of this case study and the need for further data to be added to the model in the face of limited data availability. Overcoming this data limitation will meet an increasing need for a New Zealand-wide study for determining potential habitat for NZ sea lions. The results of such a study would identify areas to allow real-world management (protection or restoration) of the limited potential breeding sites for New Zealand sea lions. This new method could also be used for other recolonising species and encourage management of areas most likely to be recolonized by them.

1. Introduction

1.1. The New Zealand sea lion

The New Zealand sea lion (*Phocarctos hookeri*) is a threatened species, the only pinniped species endemic to New Zealand (Gales and Fletcher, 1999). Due to a limited geographic distribution and a declining population, *P. hookeri* (previously known as the Hooker's sea lion) has been identified as a conservation priority for the New Zealand Department of Conservation (DOC) (Baker et al., 2010). Only three breeding colonies exist, two in the Auckland Islands, where 73% of pups are born each season (Robertson and Chilvers, 2011), and the other on Campbell Island (Maloney et al., 2012) (Fig. 1). Archaeological evidence shows that *P. hookeri* once bred around the north and east coasts of the North Island, South Island and Stewart Island before extirpation in the 1830s, primarily by Maori, then by European sealers (Childerhouse and Gales, 1998).

A natural recolonisation of the New Zealand mainland by New Zealand sea lions has now slowly started on the Otago Peninsula (Fig. 1). In 1993, a female New Zealand sea lion (born in the Auckland Islands) gave birth to a pup on the Otago coast, the first New Zealand sea lion birth on the New Zealand mainland in over a century (McConkey et al., 2002). As of 2013, this animal and her female offspring have bred on the Otago coast, producing 60 pups (New Zealand Sea Lion Trust, 2014). Further natural recolonisation events are likely to occur on the New Zealand mainland in the future. For instance, another female from the Auckland Islands has

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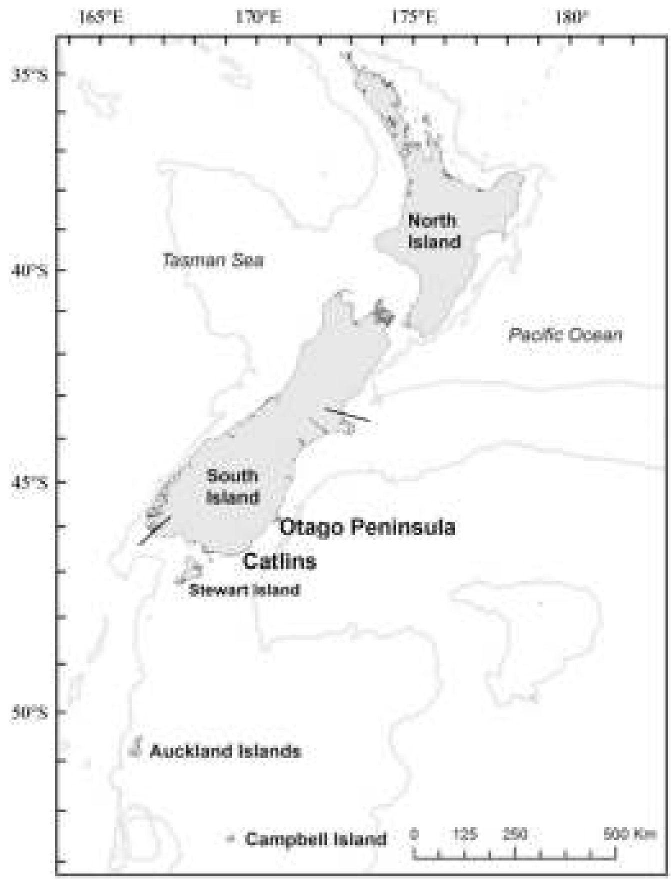

Fig. 1. Breeding colonies (Auckland and Campbell Islands) and recolonisation sites (Catlins and Otago Peninsula) of the New Zealand sea lion, *Phocarctos hookeri*. Historical range includes North, South and Stewart Islands. The study area is the SE coastline between the two black lines on the South and East coasts of the South Island.

started breeding in the Catlins as of 2006 (Fig. 1; New Zealand Sea Lion Trust, 2014). Protecting sites where New Zealand sea lions are likely to breed and establish colonies will be a critical factor for recolonisation success. A new mainland breeding colony would increase the likelihood of the species being removed from their current "threatened" classification, one of the key objectives in the New Zealand Sea Lion Species Management Plan 2009–2014.

1.2. Potential sea lion habitat

However, the coastal environment of the New Zealand mainland has undergone significant change since the complete extirpation of *P. hookeri*. Hilton et al. (2000) reported a 70% reduction in the area of active duneland of the three major New Zealand islands since the 1940s due to planting to stabilise dunes. Fleet (1986) noted that human settlements have reduced the indigenous forest of New Zealand to only 23% of its pristine area, with coastal forest being the most reduced. Coastal areas have long been targets for urbanisation and transport; today most major New Zealand urban settlements and many roads (including highways) are located close to the shoreline. This anthropogenic modification of the coast means that the potential mainland breeding habitats that sea lions are returning to is extremely reduced in area and unequally distributed.

Identification of suitable breeding habitat sites requires knowledge of both the attribute and spatial parameters within an area. Augé et al. (2012) studied the terrestrial habitat use and preferences of female New Zealand sea lions at one of the breeding colonies at Sandy Bay, Enderby Island, Auckland Islands (Fig. 1). The results of this study provides the sole terrestrial habitat preference knowledge for the species along with some anecdotal references that can also be found in other publications (Marlow, 1975; Chilvers and Wilkinson, 2008; Maloney et al., 2012). These results provide a the best available details on the types of habitat features that New Zealand sea lions require to form a breeding colony at a particular site. The terrestrial breeding system of *P. hookeri* consists of a breeding phase (a concentration of breeding females) and a dispersion phase (Augé et al., 2012). The breeding phase occurs close to shore on flat sandy beaches, avoiding rock substrates (Augé et al., 2012). After the mating season, *P. hookeri* female-pup pairs disperse inland for the dispersion phase, during which their habitat preferences change progressively to coastal forests (up to 1000 m inland from the breeding beach and on slopes of less than 30°), an unusual preferred habitat for marine mammal species.

1.3. Aims of the study

This study primarily aims to apply a method to identify suitable New Zealand sea lion terrestrial breeding habitat sites for recolonisation of the South Island using Multi Criteria Analysis (MCA), which has been adapted for GIS. MCA synthesises data representing the major factors known to affect habitat suitability, to produce a habitat suitability map of the entire study area. As there are only two known breeding locations on the New Zealand mainland, this study relies heavily on current literature concerning breeding habitat in the sub-Antarctic Islands and the expert knowledge of researchers and scientists involved in the management of *P. hookeri* in New Zealand. The ability to identify suitable recolonisation sites for breeding *P. hookeri* should give managers an advantage in management of sites from adverse human interactions and facilitate possible site enhancement such as re-vegetation. Methods of habitat modelling such as the Mahalanobis distance statistic (Clark et al., 1993), artificial neural network model (Özesmi et al., 2006) or logistic multiple regression (Pereira and Itami, 1991) often require the target species to already be present within the study habitat. In the case of *P. hookeri*, there is currently no breeding colony on the New Zealand mainland. Breeding colonies occur when a threshold number of females gather to breed at a site and form a breeding aggregation on the beach where males come to mate. At the moment, in the area currently being recolonized in the southern part of the South Island, this does not occur as the number of breeding females is too low. However, it is expected that breeding aggregations will develop in the future as the numbers increase. A habitat preference study at one of the current sub-Antarctic breeding colonies and experts' knowledge are consequently used in this study. A suitable method for model development therefore needs to be able to accept expert knowledge in lieu of sighting data, a condition that is matched by MCA.

1.4. Multi-criteria analysis (MCA)

GIS-based MCA is a process which integrates and transforms layers of co-located spatial data (normally raster data) and value judgements (based on the decision maker's preferences and uncertainties) into an overall assessment of decision alternatives relative to an overall goal and associated objectives (Malczewski and Rinner, 2015). This allows for multiple criteria (each criterion being equivalent to an attribute and linked to a data layer), grouped by objective, to be combined and the alternatives ranked based on their suitability when compared to the preferences of the decision maker. The degree of suitability is indicated using an index that is mapped by raster pixel. Pixels that contain a value above a suitability threshold represent optimal locations.

GIS-based MCA has been applied to a number of land use suitability mapping applications, for example in land allocation for planning (Hanink and Cromley, 1998), natural wastewater treatment (Anagnostopoulos et al., 2009), bicycle facility planning (Rybarczyk and Wu, 2010) and conservation effects on urban land-use planning (Çelik and Türk, 2011). Other biological examples include evaluation of land suitability for giant prawn farming (*Macrobrachium rosenbergii* - Hossain and Das, 2010), planning for biodiversity assets (Geneletti, 2008) the identification of suitable habitat for the old-forest polypore (*Skeletocutis odora* - Store and Kangas, 2001), or for black bear (*Ursus americanus*) habitat (Clevenger et al., 2002).

Boroushaki and Malczewski (2008) developed a plug-in for ArcGIS 9.3.1 which implements GIS-based MCA (specifically the method used in this study – the Analytical Hierarchical Process: MCA-AHP). This method is capable of integrating expert knowledge and spatial data to model the relationship between *P. hookeri* habitat suitability and the spatial features and attributes on the New Zealand mainland coast. The method does not require *a priori* sea lion breeding sites to be identified within the study area. The method featured in this paper is therefore a significant addition to the toolset addressing the challenge of modelling and identifying areas of breeding habitat where no *a priori* data exists.

2. Materials and methods

The habitat suitability modelling method consists of the following steps: (1) Assessment of suitability structure, including choosing the habitat factors and determining their importance and how they affect the habitat suitability; (2) Production of appropriate map layers, entailing possible raw data acquisition and subsequent data management in a GIS; (3) Spatial analysis, that is using MCA-AHP to combine the habitat factors to produce an index of habitat suitability.

2.1. Study area

The area of interest for this study was the 1600 km stretch of coastline on the East and South coast of the South Island between Banks Peninsula, Canterbury and Puysegur Point, Fiordland as delimited in Fig. 1. The width of the study area strip was set at 2500 m from the coastline (Mean High Water), more than covering the maximum extent that a breeding sea lion could travel inland (McNally et al., 2001; Augé et al., 2009). This meant approximately a 4000 km^2 study area.

The study area is partially urbanised and 20% of roads are within 500 m of a beach. Coastal forest covers only 32% of the study area with 92% of this located within the Fiordland National Park in the southwest of the South Island.

2.2. Model structure designed to calculate habitat suitability

Determining the habitat factors is the first step in assessing the structure of the habitat suitability model. Here, judgements based on the scientific literature and expert knowledge can be applied (see section 2.4 for more detail). Using the breeding habitat preference characteristics used by *P. hookeri* at the Sandy Bay breeding site in the Auckland Islands (Augé et al., 2012) as a foundation, six criteria are included as part of the habitat suitability model in this case study: land cover and proximity to estuaries, beaches, urban areas, roads and cliffs. Other criteria such as vehicular access to beaches, presence of fences and public behaviour towards sea lions were considered but were not used as they can be managed via policies and laws. The hierarchical structure employed by the MCA-AHP method allows for the grouping of multiple attributes into objectives. Each objective is used to represent groups of attributes which are either similar in nature, or have similar effects on habitat suitability. Fig. 2 shows the three-tiered hierarchy structure chosen for this study. The two objectives occupying the middle tier are used to represent the main attribute themes which define habitat suitability, anthropogenic and environmental factors. This is a standard stage in MCA-AHP – for example, Geneletti (2008) uses six objectives (two species-related, four ecosystem-related), each with a number of criteria (e.g. his animal species objective has trophic level, habitat requirements, natural rarity, sensitivity and vulnerability criteria).

The purpose of the anthropogenic objective is to model the effect that humans have on the suitability of habitat for *P. hookeri* breeding. Augé et al. (2012) identified roads and urban areas as being the attributes most likely to affect habitat suitability. Urban areas are likely to cause high rates of unwanted interactions between sea lions and humans. Roads can act both as sources of disturbance and as barriers to the movement of sea lions. The environmental objective is designed to model the attributes and features of the landscape within the study area. Augé et al. (2012) described the preferential habitat features of the breeding habitat for New Zealand sea lions as areas within 1400 m of the nearest ocean access with a sandy beach backed by forest land cover and a slope of $<30°$. The sandy beaches and forest provide preferential land cover during the breeding and dispersion phases respectively, while the beaches themselves are the preferential ocean access points. The slope factor affects the ability of the sea lion to traverse the terrain; slopes which are too steep become impassable for sea lions. Sea lion pups in the Auckland Islands and on the Otago Peninsula have been observed swimming in the sheltered waters afforded by estuaries (personal observation), and as such are considered a positive attribute when determining site suitability.

2.3. Production of map layers

ESRI ArcGIS v9.3.1 (ArcGIS, ESRI, Redlands, CA, USA) was used for managing, producing, analysing, combining and displaying the required spatial data (Augé et al., 2012), as well as for compatibility with the MCA plug-in (Boroushaki and Malczewski, 2008). The spatial data required for this study was collected from government department geodatabases available to the public (Table 1). The use of the data is licensed under the Creative Commons Public License.

For the purpose of this study, Land Information New Zealand (LINZ) road data were split into two categories, sealed and unsealed. As data describing the volume of traffic each road receives was not available for most of the area under study, the type of road was used as a proxy, with sealed roads assumed to have a greater volume of traffic than unsealed roads. For the unsealed roads a 100 m buffer was placed on either side of the road, while for sealed roads the buffer size was 200 m. The buffer zones are used to represent the influence roads have on the space surrounding them, in that sea lions are highly unlikely to find the habitat in these areas suitable.

Land cover classes were reclassified from the NZ Land Cover Database v.2 (LCDB2) dataset into a raster format using a 10-point scale based on their suitability for sea lion breeding habitat. Inappropriate land covers such as urban areas and high-intensity farming were given lower values (1), low producing grassland and saline vegetation were given medium values (5,6) while the most suitable land covers like forests and beaches (sand and gravel) were given higher values (9). Areas of coastal sand and gravel were selected and extracted from LCDB2. Urban areas are classified from the LCDB2 as any central business district, suburban dwellings, commercial and industrial areas, or horticultural sites dominated

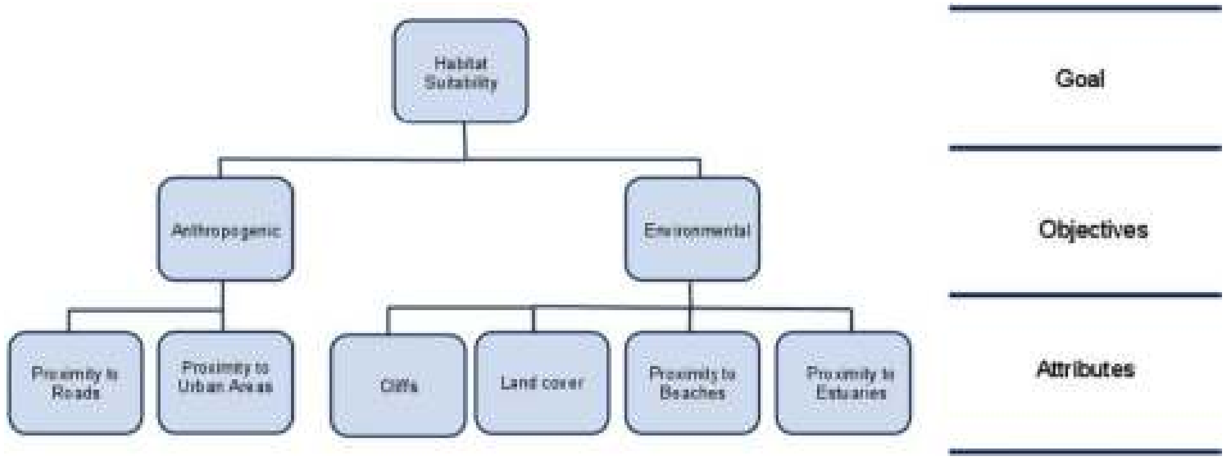

Fig. 2. Three tiered hierarchy structure designed to represent the breeding habitat requirements of *P. hookeri*.

Table 1
Source of datasets used for the MCA analysis.

Shapefile dataset & year	Source	Attributes to be utilised for the study	Notes
New Zealand Roads (2007)	Land information New Zealand	roads	All weather routes suitable for the passage of any vehicle; 1:50,000 topo; 22 m spatial accuracy
Land Cover Database Version 2 (2001/2) LCBD2	Ministry for the environment	Beaches, estuaries, urban areas, forests	43 land cover and land use classes derived from Landsat 7 ETM+; 15 m resolution
New Zealand Cliffs (2007)	Land information New Zealand	cliffs	Any high steep or overhanging rock or face; 1:50,000 topo; 22 m spatial accuracy
New Zealand Coastline (2007)	Land information New Zealand	context	Mean High Water line; 1:50,000 topo; 22 m spatial accuracy
DOC Public Conservation Land (2010)	Department of conservation	context	National Parks, Marine Reserves, Marine Mammal Reserves, Scenic Reserves

by structures and sealed surfaces.

The Euclidean distances to the road features, to the urban features and to the beaches were then calculated and stored as a raster data layer of 100 m resolution (all rasters in the study were produced at this resolution). Due to the importance of having an accurate representation of the location of beaches, the presence of beaches was checked against satellite imagery to improve the classification accuracy. Estuary classification areas were selected and extracted from LCDB2. Euclidean distance to estuaries was then calculated and stored as a raster data layer. As cliffs represent impassable terrain for sea lions, the area landward of cliffs needed to be identified within the model as being unsuitable due to its inaccessibility. This was achieved by placing a 1000 m buffer around cliff features derived from the LINZ 1:50,000 topo dataset and rasterised. Pixels were either classified as accessible (not within 1000 m of a cliff feature) or inaccessible (within 1000 m of a cliff feature). Fig. 3 shows the raw data maps for the six themes of data.

2.4. Expert knowledge

The expert knowledge needed for this study was elicited in 2010 from the marine mammal specialist leading the sea lion management programme for New Zealand's Department of Conservation (the 4th author of this paper), with 14 years of research experience on NZ sea lions and 15 international peer reviewed journal publications on NZ sea lions. The expert was asked to state the relative importance of attributes and objectives in a pairwise fashion. The structure used to express this knowledge is as follows. A scale (Table 2) with values ranging from 1 (equal importance, relative to another criterion) to 9 (extremely more important) was used to rate the relative preference of each attribute within an objective, and each objective within the goal (Fig. 2). The comparison matrix for the attributes within the anthropogenic objective is shown in Table 3. The matrix for the attributes comprising the environmental objective is in Table 4. The matrix for the hierarchy level of the two objectives (comprising the overall goal) is in Table 5.

Regarding the anthropogenic objective as an illustration, proximity to urban areas was estimated by the expert to be twice as important as proximity to roads (Table 3). Also based on this sea lion expert knowledge, the environmental objective was estimated to be twice as important as the anthropogenic objective (Table 5).

2.5. Spatial analysis

The AHP procedure is the initial stage of MCA (Siddiqui et al., 1996), which is the ranking of a set of alternatives with respect to the main goal desired by the decision maker. This main goal is the top level of a hierarchical structure, broken down into objectives representing the main groups of attribute criteria which comprise the main goal (Fig. 2). The use of the hierarchy allows the decision maker to combine a variety of different attributes in order to represent the problem (Saaty, 1980). Formally, for a goal G there is a set of p objectives O_j for $j = 1,2, \ldots, p$. For the p objectives there is a set of q criteria, A_k for $k = 1,2, \ldots,q$. Therefore, for the jth objective the set is $A_{l(j)}$ for $l = 1,2, \ldots,r$ where $r \leq q$. Two sets of weights are associated with the objectives and criteria, respectively (adapted from Boroushaki and Malczewski, 2008). Thus, in Fig. 2, there are $p = 2$ objectives and where $j = 1$, for example, objective O_1 (=anthropogenic) has $r = 2$ criteria $A_{l(1)}$, where $A_{1(1)}$ = proximity to

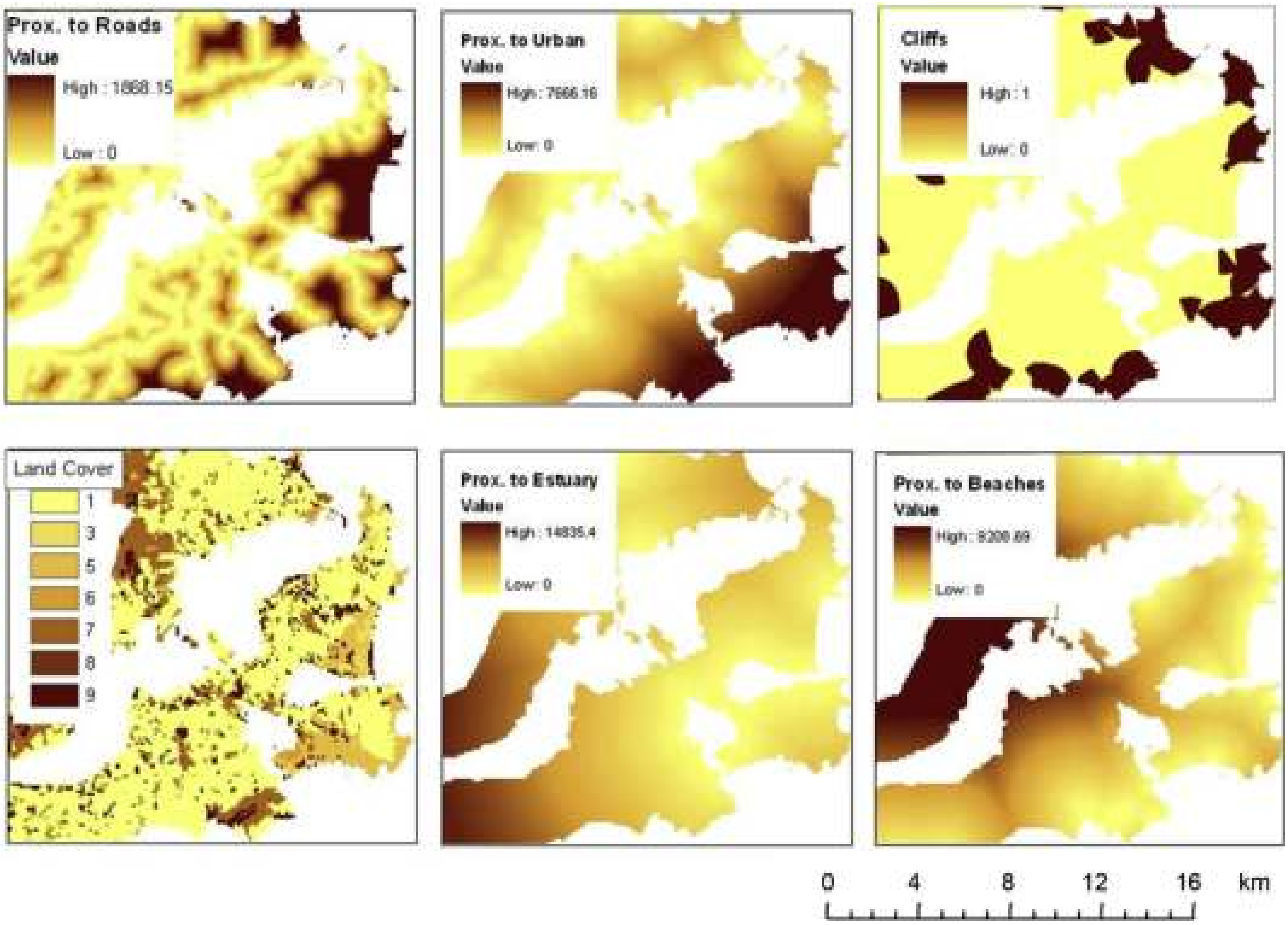

Fig. 3. Data layers representing the six different attributes which define habitat suitability (Otago Peninsula).

Table 2
Scales for pairwise comparisons (adapted from Saaty 1980).

Intensity of importance	Verbal judgement of preference
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values between adjacent scale values

Table 3
Importance rankings and criterion weights for the Anthropogenic attributes.

	Prox. To urban	Prox. To roads	Criterion weights
Prox. to urban	1	2	0.666
Prox. to roads	1/2	1	0.333

Table 5
Importance rankings and criterion weights at the objective level.

	Anthropogenic	Environmental	Criterion weights
Anthropogenic	1	1/2	0.333
Environmental	2	1	0.666

roads and $A_{2(1)}$ = proximity to urban areas. The pairwise comparison of criteria outlined in 2.4 is the basic method of measurement employed by the AHP method (Boroushaki and Malczewski, 2008).

Criterion weights are the result of the summarisation of the preferences of each attribute and objective from the pairwise matrices. Criterion weights are optimised using the eigenvalue method of ratio scale estimation (refer to Boroushaki and Malczewski, 2008; for more detail). Regarding the anthropogenic

Table 4
Importance rankings and criterion weights for the Environmental attributes.

	Landcover	Prox. To beaches	Cliffs	Prox. To estuaries	Criterion weights
Landcover	1	1	1	3	0.300
Prox. To Beaches	1	1	1	3	0.300
Cliffs	1	1	1	3	0.300
Prox. To Estuaries	1/3	1/3	1/3	1	0.100

objective as an illustration, proximity to urban areas was estimated by the expert to be twice as important as proximity to roads. As such, the criterion weight for the proximity to urban areas attribute was twice that of the proximity to roads attribute. Based on this sea lion expert knowledge, the environmental objective was estimated to be twice as important as the anthropogenic objective and was given twice the criterion weighting (Table 5).

The raster data layers derived in the previous section were then combined with the criterion weights in order to produce a habitat suitability index as a combination of single habitat features.

$$S_{ij} = \sum_{l=1}^{r} w_{ijl} A_{ijl} \forall i,j \quad (1)$$

where S_{ij} is the suitability index, w_{ijl} is the weight of the l th criterion for the j th objective for the i th pixel and A_{ijl} is the suitability value corresponding to that weight (adapted from Hanink and Cromley, 1998).

To facilitate combination, the attribute layers associated with the criteria were initially standardised to a scale from 0 to 1.

$$S'_{ij} = W_j \frac{S_{ij} - min_i S_{ij}}{max_i S_{ij} - min_{ij} S_{ij}} \quad (2)$$

(Hanink and Cromley, 1998).

To reduce the distortion caused by outlier pixels (i.e. grid cells with large distance values but small frequency counts) on the standardisation process, a maximum distance of 40 km was set for all Euclidean distance derived data layers. For example, the distance to, say, the nearest road can be calculated in all directions and can exceed 40 km (measured alongshore) in remote coastal areas without road access. A per-attribute suitability index was calculated by multiplying the standardised data layer pixel values by their corresponding criterion weights. Using an addition overlay operation on the weighted data layers, a habitat suitability index could be calculated. This produced a raster dataset with pixel values between 0 (not suitable) and 1 (most suitable) which represents the suitability of the habitat at that location with regards to *P. hookeri* breeding preferences (see Fig. 4 for an example). Spatially contiguous groups of similar pixels could now be grouped to identify areas with habitat suitable for *P. hookeri* breeding colonies.

The knowledge elicitation procedure through pairwise comparison is followed in Hanink and Cromley (1998), Clevenger et al. (2002), Hossain and Das (2010) and Çelik and Türk (2011) and subsequent suitability mapping is a stage shared by all of the stated examples. Clevenger et al. (2002) developed an expert-based model (using 2 experts) and a literature-based model, with the latter found to be the closest estimate to an empirical model that the authors had developed. Hossain and Das (2010) had one author estimate the pairwise weightings, with the values subsequently verified and consensus reached by the local community. Although the other examples cited used several experts in the knowledge elicitation phase, the use of one expert here is justified as domain knowledge for this species of sea lion is rare and there is literature backup (Augé et al., 2012).

3. Results

The habitat suitability map for the Otago Peninsula is shown in Fig. 4. As it contains the most used breeding site by recolonising *P. hookeri* females within the study area (Victory Beach on the North East side of the peninsula), the suitability index threshold was estimated from the index values at this site. Any pixel with a value that is less than this threshold was deemed suitable for sea lion habitat. The extents from several suitability thresholds were mapped against the Victory Beach habitat. Fig. 5 shows the size of suitable habitat area at Victory Beach at three different suitability thresholds, 0.1, 0.2 and 0.3. This relates the habitat suitability to underlying habitat more effectively than the continuous habitat scale in Fig. 4. It was found that a suitability threshold value of 0.2 best represents the area of Victory Beach that is currently used by *P. hookeri* for breeding (0.1 threshold classified land that was too far inland, while the 0.3 threshold missed the land to the south of Victory Beach where sealions have been regularly observed) and was therefore used for all other areas.

Six suitable areas were identified by the MCA within the study area, based on the 0.2 threshold defined at Victory Beach. They are all located in the Catlins and Otago Peninsula areas, with one exception (in Fiordland). Fig. 6 illustrates the location of three of the areas classified as the most suitable breeding habitat areas identified by the MCA.

For both Figs. 5 and 6, "Open Land" within the buffer zone is a mixture of land cover classes, such as low producing grassland, mixed exotic shrubland, saline vegetation, coastal sand and gravel. The forest category is a mix of both exotic and indigenous forest (LCDB).

4. Discussion

4.1. GIS-based MCA for habitat suitability model of *P. hookeri*

In this research we show that GIS-based MCA can successfully be applied to identifying *P. hookeri* breeding habitat using habitat preference information from another region (Sandy Bay, Auckland Islands) and experts' knowledge. The output model of habitat suitability captured some of the sites currently used by recolonising *P. hookeri*, an independent verification. Only six suitable areas along the 1600 km long coastline modelled were identified, which, given the satisfaction of various criteria needed for positive identification, is a reasonable result. Victory, Allans and Sandfly Beaches were clearly identified as the best breeding habitats on the Otago Peninsula in the model (see Figs. 4 and 6), currently the main areas used by *P. hookeri* females with pups (Augé et al., 2014). However, other sites currently used by these females were mis-identified as non-suitable in the model. For instance, the main beach used by the recolonising breeding female in the Catlins was not selected as a suitable site by the model due to the presence of a small gravel road on the opposite side of the inlet. Other sites that were selected were assessed as realistically unsuitable due to the steep slopes surrounding the sites, high exposure to storms, human activities and other factors that were not included in the model. These limitations were due to the non-availability of spatial data or the lack of previous research in coastal processes. Therefore this research can be considered a conservative estimate of areas that could be utilised by NZ sea lions for breeding. Our results demonstrate the usefulness of this GIS-based MCA for habitat suitability modelling approach and how relevant it can be for management. We think that further modelling and refinement, including extending the study area to the whole of the New Zealand coastline, incorporating more spatial data as described in the next section and refining some of the rules for suitability would be beneficial for the proactive management of NZ sea lions.

4.1.1. Victory Beach, Otago Peninsula

In particular, Victory Beach in Otago (Fig. 6) is a notable positive result for the use of MCA for identifying potential breeding habitat for *P. hookeri*. This beach is located in an isolated area. There is no significant urban or road development nearby, and as such the threat of human disturbance at the site is low. Victory Beach is also the main site chosen by females to nurse their pups in Otago and its

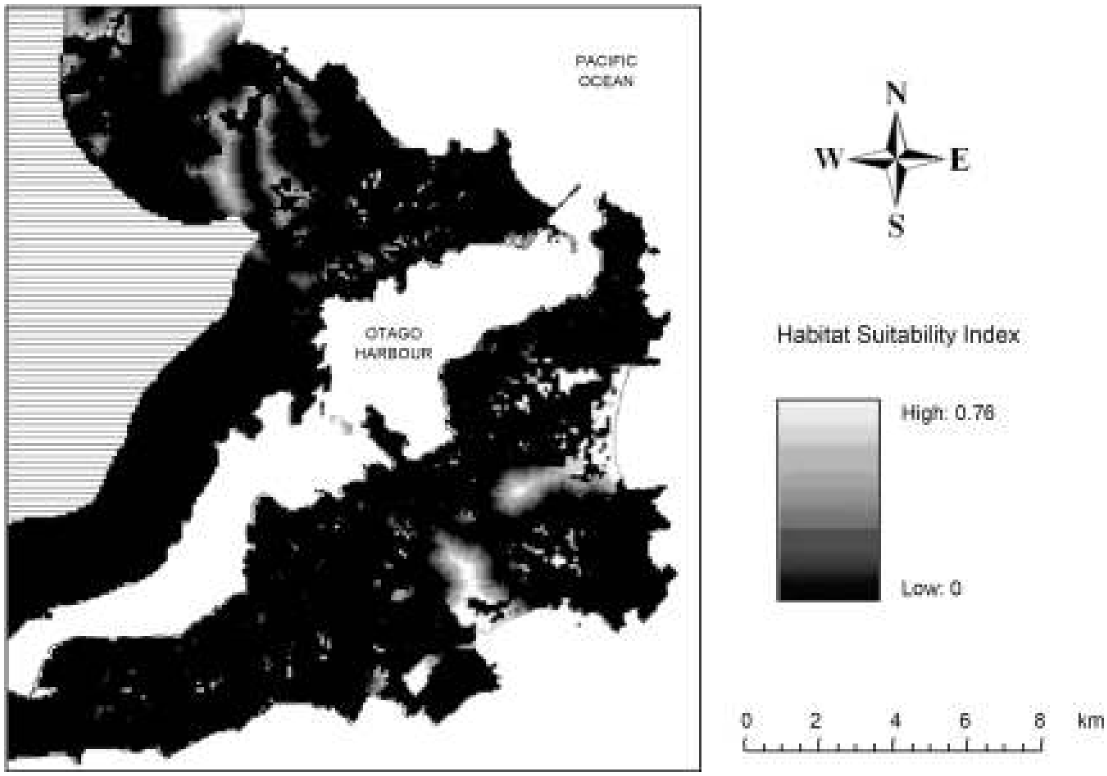

Fig. 4. Habitat suitability index generated from the GIS-based MCA for a subsection of the study area (Otago Peninsula).

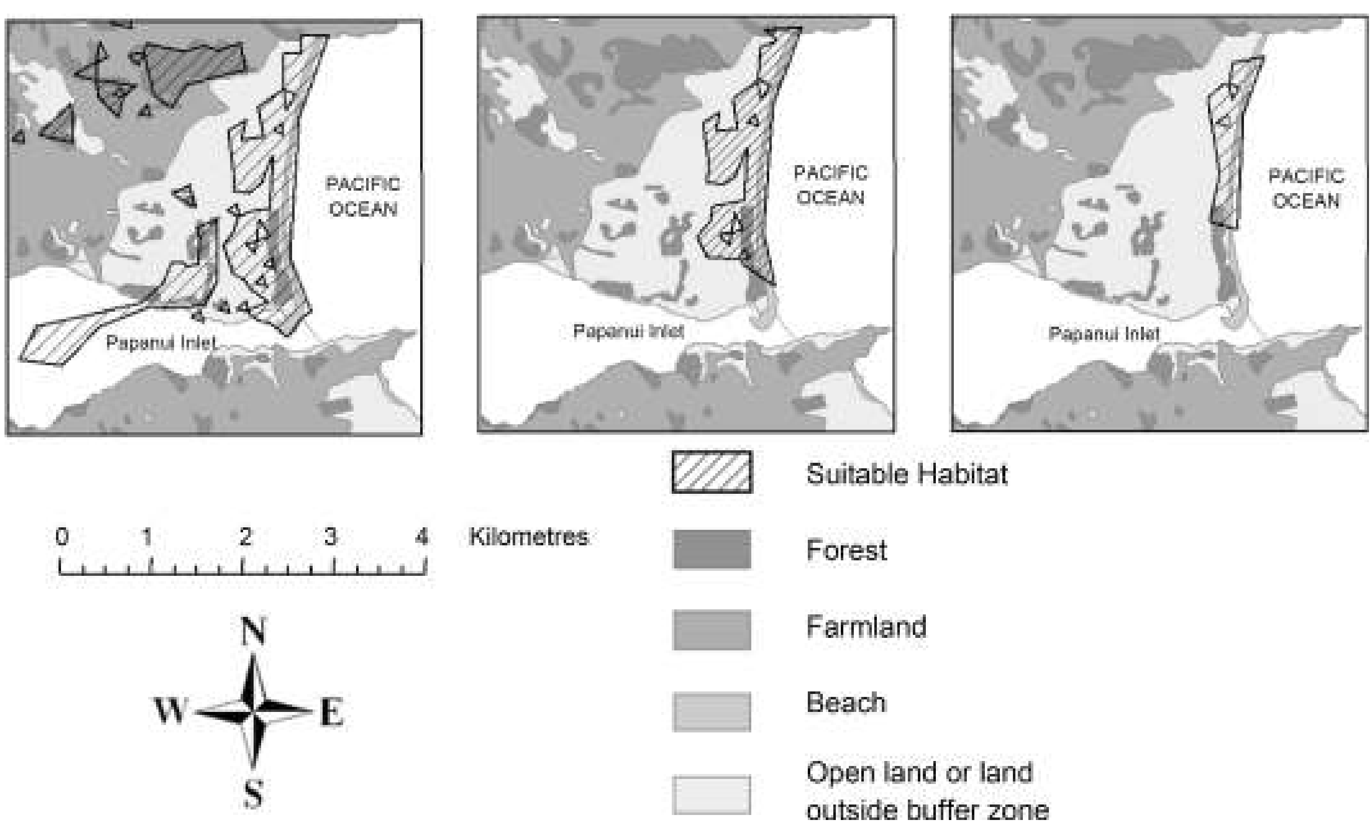

Fig. 5. Comparison of the extent of suitable habitat at Victory Beach (on the Otago Peninsula) based on three suitability thresholds: 0.1 (left), 0.2 (middle) and 0.3 (right).

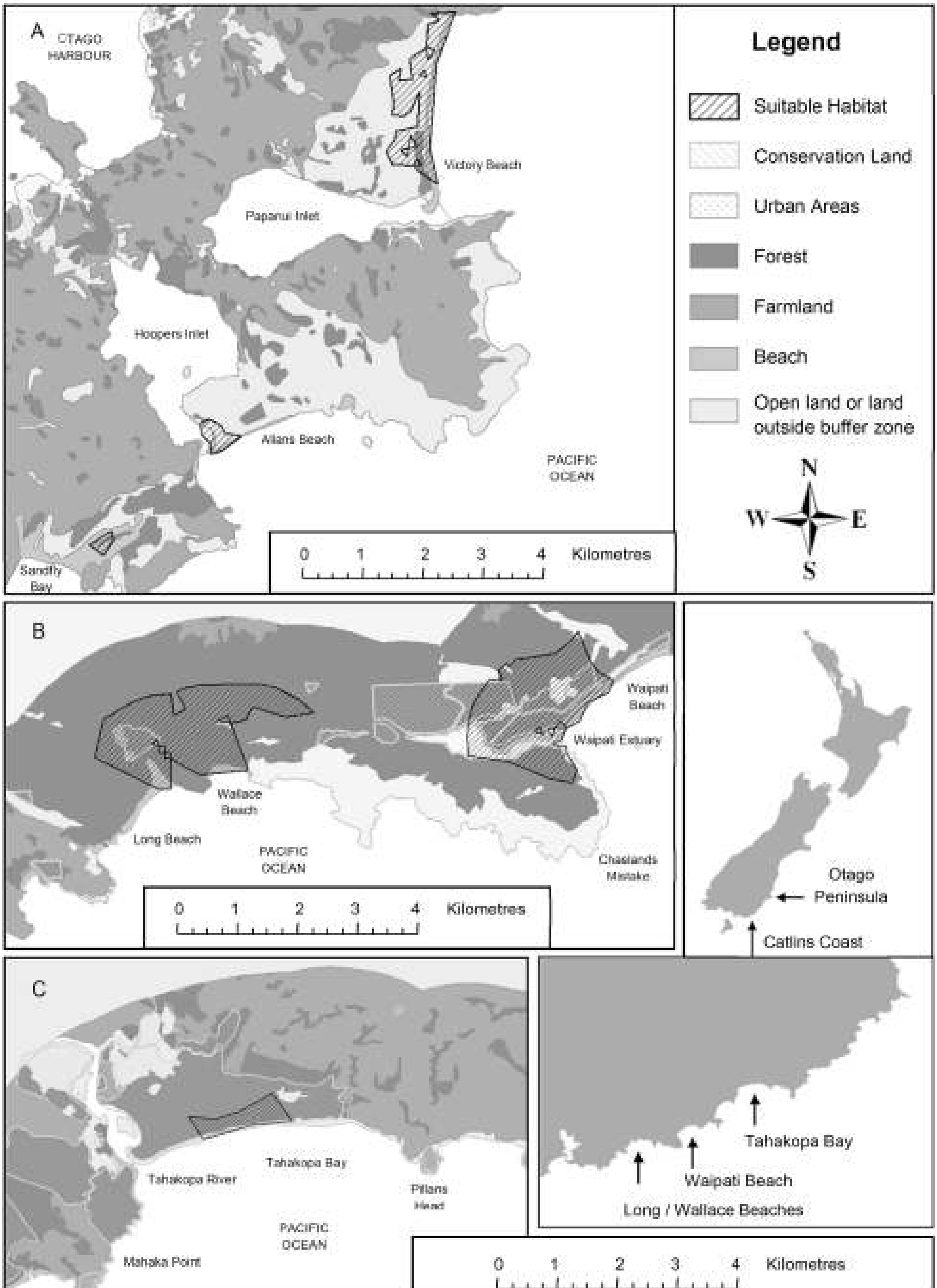

Fig. 6. Distribution of selected suitable habitat areas on the New Zealand mainland. From guide map, anti-clockwise (east to west): a) Victory Beach, Allans Beach and Sandfly Bay on the Otago Peninsula; b) Waipati Beach to the east and around Long/Wallace Beaches to the west (Catlins); c) Tahakopa Bay in the Catlins region of Otago.

habitat corresponds to the optimal terrestrial habitat for *P. hookeri* (Augé et al., 2012). Currently, females at Victory Beach only utilise a small part of the preferential habitat identified in this study, with females extending no further than 200 m inland. This is most likely caused by fences restricting sea lion movement, but also a lack of pressure to utilise more habitat due to the current small population of female *P. hookeri*. The size of the pine forest at Victory Beach is approximately 14 ha, and represents the most preferred land cover over the mixed exotic shrubland.

During the dispersion phase the use of terrestrial habitat by female *P. hookeri* becomes a lot more varied than sandy beaches and requires the maximum amount of space (Augé et al., 2009). At Sandy Bay (Enderby Island, Auckland Islands), females were observed forming into groups of 4–5 female-pup pairs and moving into the area behind the sand dunes. Female density during this phase decreased significantly to approximately one group of 5 female-pup pairs per hectare, mainly in forest habitat. This is the best indicator of habitat capacity of this habitat type and overall of the breeding site. Based on this density figure, the current 14 ha of pine forest found behind the sand dunes at Victory Beach would therefore be capable of supporting approximately 70 breeding females each season. Additional females would be forced to either occupy the less preferred mixed exotic shrub land surrounding the pine forest, or move to another location to nurse their pup.

There were smaller suitable areas identified at Allans Beach and Sandfly Bay to the south west of Victory. The latter area is some distance inland as there is access via an extensive dune system; the area next to the sea was not identified due to the presence of cliffs nearby.

4.1.2. Catlins Coast

In the Catlins, suitable habitat for breeding *P. hookeri* was identified at Tahakopa Bay and Waipati Bay (Fig. 6), each bay capable of supporting large breeding colonies as they have large areas of native forest in the vicinity (similar calculations as conducted for Victory Beach back this up). However, the habitat area at Tautuku Bay, one of the other sites identified, is not likely to be a suitable breeding habitat despite being identified as such from the MCA. This beach has vehicle access and is frequently used by cars to access Tautuku village. The resultant noise, disturbance and risk of death (Lalas, 2008) makes recolonisation unlikely here. Several other beaches in the Catlins that have potential suitable breeding habitat are currently used in the same manner as roads themselves, also rendering them unsuitable.

4.2. Limitations of the study

All spatial data are subject to temporal, spatial and attribute uncertainty (Zhang and Goodchild, 2002), which needs to be considered when interpreting these results. In terms of spatial uncertainty, the road, cliffs and coastline data sets all had a spatial accuracy of $\pm$22 m. The conversion to a raster format at 100 m spatial resolution (due to the computational limitations of the MCA plugin) would have added another source of error. A 100 m spatial resolution is suitable for a study aiming to identify breeding habitat at the beach level. This is equal to the minimum mapping unit used in the LCDB2, one of the main data sources in this study. The LCDB2 was also the source of the greatest temporal uncertainty, being derived from satellite data collected in 2001. The potential for land cover to have changed significantly (particularly pine forest intended for harvest) within this timeframe could have serious implications for the results of this study. Such temporal uncertainty impinges on attribute accuracy, where pixels close to the edge of a buffer could easily either be a danger zone or a safe zone for the sea lion.

The use of Euclidean distance to model proximity to different features is also problematic, as it assumes that the land is isotropic. Changes in slope, elevation and vegetation mean that movement effort is not equal in all directions. This has influence on the calculated importance of roads noted earlier, close in planar distance but separated by, for instance, estuaries, inlets or cliffs; this could be addressed by using some “spatial barriers” to movement in the model. These physical barriers should be factored in, for example masking out estuaries (a land cover class) so that a road on one bank of the estuary would have no influence across the estuary to the other bank.

Roads are important in the context of the study as the most influential anthropogenic factor affecting the suitability of breeding habitat. The method by which road traffic volume was modelled in this study is based on the assumptions that all sealed roads receive more traffic than unsealed roads, and that traffic volume is equal for all sealed roads, and equal for all unsealed roads. In many cases this assumption is not valid, especially when considering isolated rural roads. There are also issues with beaches used as roads in many parts of rural New Zealand. Such information is not contained in the Land Information New Zealand road dataset used as road layers in this study but should be added to improve the model results.

4.3. Future considerations

As a natural environmental issue, the introduced sand binder *Ammophila arenaria* is the dominant dune species through much of the sandy beaches in Otago, and has a significant effect on the morphology of the sand dunes in the area. *A arenaria* are highly effective in fostering the building of steep scarps at the foot of the sand dune that can act as a barrier impeding sea lion movement into the forest behind the dunes during the dispersion phase (Augé et al., 2012). Therefore, this is a significant threat to the sustainability of beaches as a potential breeding colony area. Consequently, detailed mapping of the distribution of this species would add more detail to habitat suitability.

Moving beyond this relatively small case study, there is the opportunity to develop country-wide models of the specific suitable habitat areas for breeding *P. hookeri* and other species so that results can be used for management (more spatially specific large scale models are possible too). Inclusion of further variables as mentioned earlier and factorisation of uncertainty in the model and its application to the entire New Zealand coastline should correctly identify potential suitable sites for breeding *P. hookeri*. With this more refined model, managers could then use the output to be site-specific in their advice. For example, spatial patterns describing how females and pups utilise the habitat during the dispersion phase (Augé et al., 2012), could be applied to the potential breeding sites so that managers can understand where actions such as protection or restoration would be necessary to keep or render the site fully suitable. This type of approach has been used for the protection of habitat for black bears (Clevenger et al., 2002) and old forest polypore (Store and Kangas, 2001).

5. Conclusions

In this study, we demonstrated that GIS-based MCA can be successfully applied to develop a habitat suitability model for recolonisation, using current published data and expert knowledge on the breeding habitat preference of a threatened species. This model can be used for management to identify suitable sites for future recolonisation. We identified a number of sites as suitable for breeding sea lions although these results should be interpreted as preliminary and conservative results. Several sites were correctly classified, but others were misidentified as either non-suitable or suitable, mainly due to the lack of data on slopes, beach-roads or specific vegetation types. The refinement and application of the MCA method to the whole New Zealand coastline should produce an even more efficient and effective tool for species management. The New Zealand Sea Lion Species Management Plan identifies the protection and propagation of sites of significance to *P. hookeri* as a key objective in successfully managing the species, monitoring sites for recolonisation and hopefully leading to new breeding colonies. Our case study points out that application of MCA with detailed improvements should allow significant identification of potential sites for recolonisation. We consequently illustrated that GIS-based MCA models are a useful tool for habitat suitability studies for new areas either for recolonisation or for reintroduction of threatened species.

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