Geographic Information Systems in wildlife management

A case study using yellow-eyed penguin nest site data

Ryan D. Clark, Renaud Mathieu and Philip J. Seddon

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ABSTRACT

This report provides a comprehensive yet simple guide to the construction and use of a Geographic Information System (GIS) for collating, analysing, updating and managing data in wildlife management or research projects. The spatial analysis of yellow-eyed penguin (hoiho, *Megadyptes antipodes*) nest site data from Boulder Beach, Otago Peninsula, is used as an example. The report describes the key components used in the construction of the GIS, which included aerial photography, a digital elevation model and habitat map of the study area, and nest site data collected at Boulder Beach between 1982 and 1996. The procedures for estimating the geographic locations of nest sites using historical hand-drawn sketch maps are also described, demonstrating the potential for incorporating and analysing historical datasets in this type of GIS. The resulting GIS was used to conduct simple spatial analyses of some of the characteristics of yellow-eyed penguin nesting habitat selection, as well as the densities of nest sites in each type of nesting habitat at Boulder Beach. The sources of error, uncertainty and other limitations of this and other GIS are described, along with procedures and steps to minimise and avoid them. The yellow-eyed penguin GIS described in this report provides an example of the potential utility of GIS in ecological research and management of both yellow-eyed penguins and many other species.

Keywords: Geographic Information Systems (GIS), yellow-eyed penguin, hoiho, *Megadyptes antipodes*, wildlife management, habitat map, spatial analysis, spatial ecology, New Zealand

1. Introduction

Spatial ecology is the study of patterns and processes occurring in a geographic space or landscape that influence characteristics of plant and animal populations such as densities, distributions and movements. In recent years, there has been an increased awareness of the importance of incorporating spatial ecology into wildlife management. However, the analysis of spatial (or geographical) patterns and processes can require time and resources that are typically not available. Fortunately, there is a fast-growing repertoire of computer-based tools available to assist with complex spatial analyses.

1.1   GEOGRAPHIC INFORMATION SYSTEMS (GIS)

Geographic Information Systems (GIS) are some of the most important of these computer-based tools, and have rapidly become highly valuable—if not essential—to wildlife managers and researchers. A GIS generally consists of a computer-based program designed for organising, integrating, storing, analysing and creating visual representations (e.g. maps) of information about features of a particular geographic area or landscape. Data incorporated into a GIS usually have (or are given) a spatial reference. This reference links the data to the features they describe in a particular geographic 'space'. A common format of a GIS is a digital, interactive map of an area or location (typically) on the Earth's surface, which is linked to a database containing tables or spreadsheets of data (i.e. feature datasets) associated with some or all of the features displayed on the map (e.g. roads, water bodies, patches of vegetation and/or the locations of wildlife). This configuration enables relatively quick and easy visual assessment of spatial patterns and relationships in the data, as well as the ability to efficiently edit, update, analyse and create displays of potentially very large quantities of data. There are many different types, brands and configurations of GIS available, and most of these are capable of conducting a wide variety of analyses, both statistical and spatial (i.e. an analysis of how features are related to each other in the 'space' represented on a map).

In most GIS, feature datasets can be configured and displayed in the digital map space in raster or vector format. The raster format is generally used for datasets that describe continuous features (i.e. features that occur across the entire landscape, such as elevation or slope), while the vector format is used for discrete features (e.g. water bodies, roads and trees). Raster datasets are displayed as a sheet or grid of equal-sized square or rectangular cells, while vector datasets are displayed as points, lines or polygons. For example, the discrete features (i.e. nest sites) in the nest site dataset used in this study (described in section 2.2.4) were represented as points on the map. Other discrete features can be represented by lines (e.g. roads and rivers) or polygons (e.g. an area covered by a certain type of vegetation). When displayed in the digital map space, each raster or vector dataset represents an individual 'layer' of data, such that when several feature datasets are displayed they are stacked in overlapping layers.

Each type of data in a feature dataset is an attribute (i.e. qualitative or quantitative characteristic) of the feature it is linked or related to in the geographic space represented on the digital map. Spatial or geographic attributes contain data that specifically describe the geographic (or spatial) location and extent of features (e.g. the x and y coordinates or latitude and longitude, and area on the map where a feature occurs). All other attributes (e.g. names, nest site numbers, or virtually any other qualitative or quantitative data) are considered non-spatial because they do not contain inherent spatial information (i.e. they cannot be linked to a 'space' on the map without being paired with associated spatial attributes). The data for each type of feature (i.e. raster or vector dataset) are organised into spreadsheets or tables, where each row in a table represents a single cell in a raster dataset or an individual feature in a vector dataset, and each column represents a different attribute in the dataset.

As with most types of computer-based programs or systems, in GIS there is a unique set of terminology, or jargon, used for referring to common components, features and processes. In addition, despite having similar components and processes, this unique terminology can also vary between different GIS packages or brands (i.e. developed by different vendors). For example, in the ArcGIS® software developed by the Environmental Systems Research Institute (ESRI), vector data are typically stored in 'shapefiles'. Definitions of GIS-related terminology used in this report are listed in the Glossary. A thorough introduction to GIS and their utility in science can be found in Longley et al. (2005).

1.2 THE UTILITY OF GIS IN WILDLIFE MANAGEMENT

In the context of wildlife management, a GIS enables wildlife distributions, movements and habitat use patterns and processes to be mapped and analysed, which can provide valuable information for the development of management strategies (for examples see Lawler & Edwards 2002; Harvey & Hill 2003; Fornes 2004; Gibson et al. 2004; Greaves et al. 2006; Shanahan et al. 2007). Recently, the rapid development and technological improvements in GIS, as well as in remote sensing techniques and global positioning systems (GPS), have significantly increased their availability and utility in ecological management and research (Guisan & Zimmermann 2000). Subsequently, the use of GIS for mapping, monitoring, analysing and modelling the nesting behaviour and habitats of wildlife populations has become increasingly widespread. For example, studies have used GIS to determine the distributions and extents of habitats selected by nesting animals (McLennan 1998; Maktav et al. 2000; Sims & Smith 2003; Fornes 2004; Smith et al. 2004; Beggs 2005; Urios & Martínez-Abraín 2006), and to identify nesting habitats that are potentially available (Lawler & Edwards 2002; Harvey & Hill 2003; Gibson et al. 2004; Clement 2005; Mathieu et al. 2006).

1.3 YELLOW-EYED PENGUIN MANAGEMENT

The yellow-eyed penguin or hoiho (*Megadyptes antipodes*) is a nationally vulnerable (Hitchmough et al. 2007) and globally endangered (Birdlife International 2007) species that is endemic to New Zealand (Marchant & Higgins 1990; Williams 1995). It breeds in coastal habitats along the eastern and southern coasts of the South Island, and on Stewart Island/Rakiura, Codfish Island (Whenuahou), the Auckland Islands, and Campbell Island/Motu Ihupuku (Marchant & Higgins 1990; Williams 1995). Yellow-eyed penguins are the least colonial of all penguin species (Richdale 1957; Jouventin 1982; Darby & Seddon 1990). Breeding pairs commonly select well-concealed nest sites that are spaced relatively far apart and up to 1 km inland (Seddon & Davis 1989; Darby & Seddon 1990).

The importance of the yellow-eyed penguin population to New Zealand's tourism industry, its threatened status, and a general increase in public awareness of the species has increased attention to its conservation (Wright 1998; McKinlay 2001; Ellenberg et al. 2007). Since the 1970s, many penguins have been banded to assist with data collection for biological and ecological studies, as well as population monitoring (Efford et al. 1996). Several studies have sought to provide an improved scientific basis for yellow-eyed penguin management. These studies have resulted in a large collection of data and information about the growth, feeding, breeding success and nesting habits of individual penguins and their offspring (e.g. Darby 1985; Lalas 1985; Seddon & Davis 1989; Darby & Seddon 1990; van Heezik 1990; van Heezik & Davis 1990; Alterio 1994; Moller et al. 1995; Efford et al. 1996; Ratz 2000; Ellenberg et al. 2007). However, although different management strategies have been tested, there has so far been little effort to incorporate the spatial patterns and processes that could be assessed from the large amount of data now available.

1.4 OBJECTIVES

This report describes the construction and basic functionality of an updatable GIS of yellow-eyed penguin nest site data that managers and researchers could use to assist in the development of conservation strategies for the species, and could expand and modify as necessary.

Data collection, field surveys and initial GIS setup were completed in 2005 by Justin Poole for a Bachelor of Science Honours project (Poole 2005). The data and methods used in the construction of the GIS are outlined in section 2 of this report. Section 3 provides examples of analyses using the GIS, plus suggestions for additional uses in ecological research and management of yellow-eyed penguin and other species. The error and uncertainty in the yellow-eyed penguin GIS and some general limitations of GIS are then addressed (section 4), followed by a summary of the main capabilities of the GIS described in this report and recommendations for future studies (section 5).
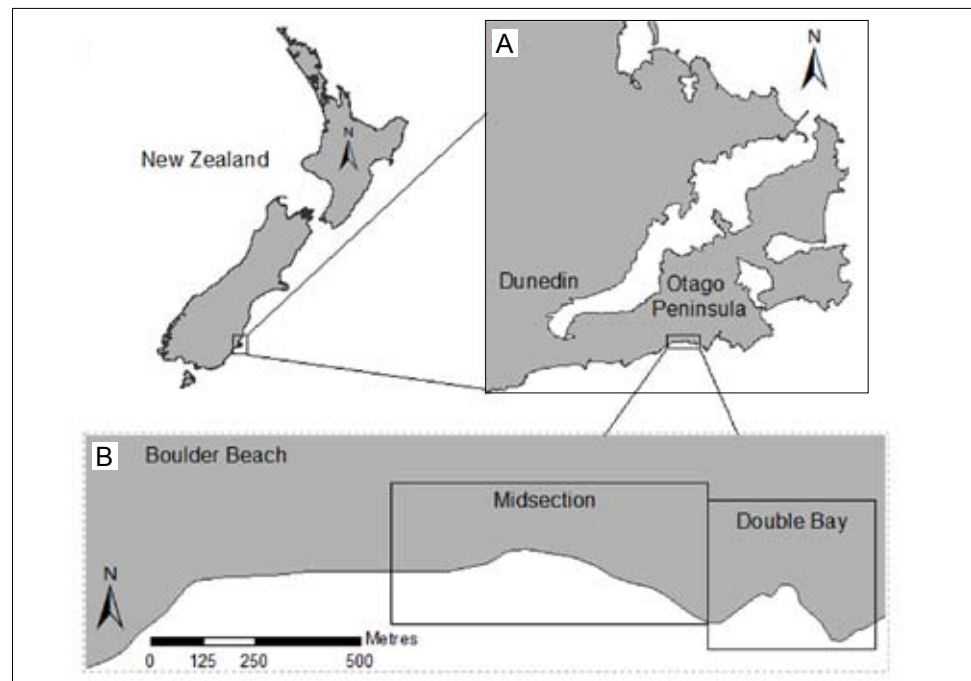
2. Configuration and construction of the yellow-eyed penguin GIS

2.1 STUDY AREA

Boulder Beach, located at 45°53′S, 170°37′E on the southern coast of the Otago Peninsula (Fig. 1), was selected as the study area for demonstrating the capabilities of a GIS database in yellow-eyed penguin management. Boulder Beach contains one of the largest breeding populations of yellow-eyed penguins on the South Island of New Zealand and is a protected reserve owned by WWF and administered by the New Zealand Department of Conservation (DOC). It is considered to be one of the most important, and is one of the most intensely studied, of all yellow-eyed penguin breeding areas (Darby 1985; Seddon et al. 1989; Efford et al. 1996). An extensive range of data has been collected from the breeding yellow-eyed penguin population at Boulder Beach for more than 25 years.

The Boulder Beach area consists of two main sections, which are usually managed and studied separately: Midsection and Double Bay (see Fig. 1). Vegetation cover at both sections consists of dense stands of flax (*Phormium tenax*) interspersed with open areas of bare ground and/or grass, as well as patches of coastal scrub composed primarily of *Hebe elliptica, Lupinus arboreus, Myoporum laetum* and *Ulex europaeus*.

Figure 1. Map of New Zealand showing A. the location of the Otago Peninsula and B. the location and extent of the yellow-eyed penguin (*Megadyptes antipodes*) nesting areas at Midsection and Double Bay at Boulder Beach on the southern coast of the Otago Peninsula.

2.2   GIS CONSTRUCTION

As described previously, a common GIS configuration is essentially a digital, interactive map linked to a database that contains several datasets related to features in the map space. The yellow-eyed penguin GIS follows this general configuration, and was constructed using ArcGIS® 9.1 (ESRI).

For the construction of the yellow-eyed penguin GIS, four key feature datasets, or data layers, were required for the Boulder Beach study area: base map imagery, elevation data, habitat data and nest site data. The procedures for acquiring, collating, deriving and implementing these datasets into the GIS are described below.

2.2.1   Base map imagery

A base map is often an important data layer in many GIS. It provides fundamental information that can be used for the extraction of data for geographic features (e.g. the extent of different types of land cover or habitats), and as a reference for localising or overlaying other feature datasets (e.g. the locations of nest sites).

A base map often consists of one or more aerial photography or satellite imagery raster datasets. When selecting the imagery for the base map of Boulder Beach, it was important to consider the resolution or pixel size (i.e. the detail to which the location and shape of geographic features were depicted) and scale (i.e. the size of objects or features in the imagery relative to their actual size) required, as these would influence the accuracy of subsequent analyses, and the interpretation and classification of features (Burrough & McDonnell 1998; Henderson 1998). For example, it would have been difficult to distinguish small patches of vegetation with small-scale (i.e. where objects or features were very small relative to their actual size) and/or low-resolution (i.e. large pixel size) imagery.

The imagery acquired for the yellow-eyed penguin GIS was a stereopair of colour aerial photographs of Boulder Beach (Fig. 2) taken in 1997 by Air Logistics (now GeoSmart© Ltd). Amongst the different sets of imagery available, the 1997 stereopair provided the most suitable resolution (scanned pixel size = 0.5 m) for the interpretation, classification and extraction of habitat data, and estimation of the geographic locations of nest sites (described in sections 2.2.3 and 2.2.4, respectively).

Figure 2.   The raw (i.e. un-orthorectified) stereopair of aerial photographs of Boulder Beach used to create the orthorectified base map image in the yellow-eyed penguin (*Megadyptes antipodes*) GIS. These are black and white images of the original colour photographs taken in 1997 by Air Logistics (now GeoSmart© Ltd).
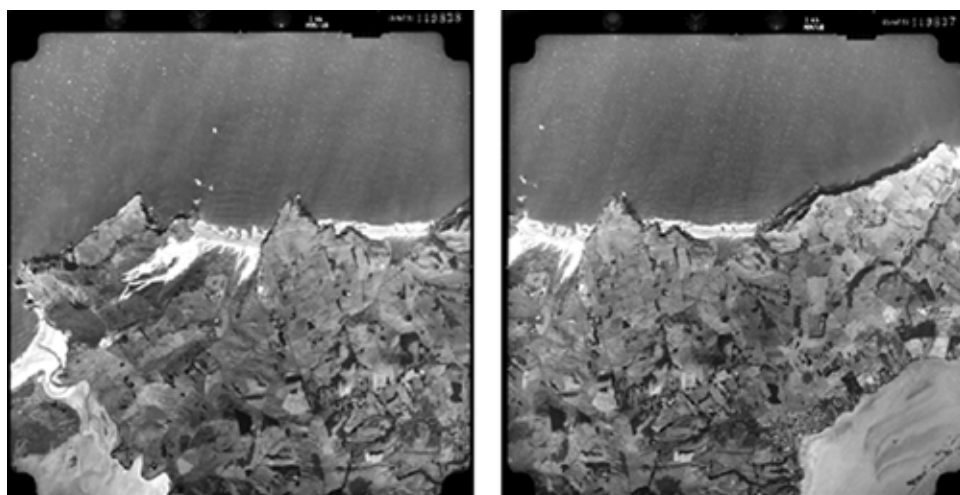
2.2.2 Elevation data

Before the 1997 aerial photography of Boulder Beach could be used for analysis, interpretation or extraction of other data layers, the imagery needed to be registered to a projection coordinate system. Measurements made from raw aerial photography or satellite imagery are generally not reliable due to geometric distortions caused by camera or sensor orientation, terrain relief, curvature of the Earth, film and/or scanning distortion, and/or measurement errors (Thomas 1966; Wolf 1983; Jensen 1996). Therefore, photogrammetric modelling is used to remove these errors through the process of orthorectification, which generates planimetrically true images that have the geometric characteristics of a topographic map combined with the visual quality of a high-resolution photograph.

Several software programs are available for relatively easy and rapid orthorectification of digital or scanned aerial photographs. The Leica Photogrammetry Suite (LPS) V8.6 (Leica Geosystems 2003) software package was used to orthorectify the scanned 1997 stereopair of aerial photographs of Boulder Beach. This process consisted of the following steps: collection of ground control points, definition of the interior and exterior orientation parameters, extraction of a digital elevation model, and image resampling (Li et al. 2002).

Ground control points

Ground control points (GCPs) are accurate coordinates for specific and distinct positions that appear in the imagery to be orthorectified. GCPs are collected to provide a reference for registering imagery to a projection coordinate system via a process called georeferencing. When collecting GCPs for the Boulder Beach imagery, the following methodology was followed to ensure accurate and effective orthorectification:

- The GCPs were collected with a GPS device capable of obtaining a relatively high level of positional accuracy (i.e. a GIS or mapping-grade GPS capable of obtaining positions with less than ± 5 m error).

- A sufficient number and spatial coverage (both horizontal and vertical) of GCPs were collected to adequately represent the geographic area and type of terrain depicted in the imagery.

- The GCPs were collected at distinct features or locations that were easily identifiable in the imagery (e.g. road or track intersections, the corners of distinct buildings or fence lines, and/or the centre of large solitary boulders or trees).

For the orthorectification of the Boulder Beach imagery, 12 GCPs were collected with a Trimble® GeoExplorer3™ GPS receiver. The specified accuracy of the receiver was ± 1–5 m after post-collection processing of the data with GPS Pathfinder® Office 3.0 software. The post-collection processing involved differential correction using data collected at the Trimble 4000SSE permanent reference station on the roof of the University of Otago's School of Surveying building, which is c. 9 km (along a straight line) from the Boulder Beach study area. Following post-collection processing, the GCPs were projected in the New Zealand Transverse Mercator (NZTM) coordinate system, which is the most current and accurate of the nationally accepted projected coordinate systems for New Zealand.

Interior/exterior orientation

Interior orientation refers to the internal geometry of the camera or sensor used to capture the imagery. Defining the interior orientation of an image identifies and corrects distortions that arise from the curvature of the sensor lens, the focal length and perspective effects (Leica Geosystems 2003). The procedure involves the establishment of the position (i.e. the 'x' and 'y' image coordinates) of the principal point of an image with respect to the fiducial (i.e. standard reference) marks of the sensor frame. The information required to define the interior orientation of an image is generally obtained through the process of camera calibration. The interior orientation parameters for the 1997 imagery of Boulder Beach were obtained from a camera calibration report provided by Air Logistics, the supplier of the aerial photographs.

The exterior orientation parameters of an image define the position and angular orientation of the camera or, more specifically, the perspective centre of the film or sensor, at the time of image capture. Due to the constant movement and positional changes that occur during the process of capturing aerial photographs, the exterior orientation parameters are different for each image. The process of defining the exterior orientation of an image involves a transformation from the image coordinate system (i.e. 'x' and 'y') to a projection coordinate system (i.e. easting and northing) (Leica Geosystems 2003). This results in the imagery being projected in the same NZTM coordinate system that was used for the GCPs.

A handful of methods are available for computing the exterior orientation parameters of imagery. In this study, we used the LPS software package, which uses the space resection by collinearity technique (Leica Geosystems 2003). After manually identifying the locations and registering the projected coordinates (i.e. easting, northing and height (elevation) in metres) of the 12 GCPs on the stereopair imagery of Boulder Beach, the LPS software automatically computed the exterior orientation parameters for both images using triangulation. The accuracy of the triangulation was indicated by the root mean square error (RMSE) of the residuals of the GCPs (see Appendix 1). These values equated to c. ± 0.22 m on the ground, which was adequate for the accuracy requirements of the yellow-eyed penguin GIS.

Digital elevation model extraction

With the interior and exterior orientation parameters defined, the stereopair of aerial photographs of Boulder Beach could be viewed as a single image in three dimensions with an appropriate stereo-viewing device. However, for use in a GIS, it was necessary to generate an orthorectified image, which is a two-dimensional image (i.e. visible in the 'x' (easting) and 'y' (northing) plane) that is adjusted to account for terrain or relief distortion (i.e. distortion in the 'z' (height or elevation) plane). Orthorectification required the extraction of height or elevation data from the stereopair of aerial photographs. This was achieved using the principle of parallax, which refers to the apparent shift in the position of an object or feature when viewed from two different angles. For the Boulder Beach imagery, the two different angles were determined by the height and perspective centre (see previous section) of the camera sensor for each of the two photographs in the stereopair. Triangulation was then used to estimate the

distance of different objects or positions in the imagery from the camera sensor. Smaller distances of objects or positions equated to higher elevation values, while larger distances equated to lower elevation values.

The elevation data required for the orthorectification of the Boulder Beach imagery was automatically extracted using the LPS software. The output of the extraction provided a digital elevation model (DEM) of Boulder Beach. Aside from its utility in image orthorectification, a DEM is often a very useful raster data layer from which other datasets related to topography can be derived (e.g. aspect, slope). After extraction, some manual editing of the Boulder Beach DEM was required to correct failed or incorrect elevation values, and to smooth out irregularities. For example, water features (i.e. the ocean) were given a constant elevation value of zero (i.e. sea level), and anomalies such as sudden dips or rises in elevation were smoothed over using a nearest neighbour method (a type of averaging).

Image resampling

The final step in the orthorectification process involved the resampling of the Boulder Beach imagery with the edited DEM. The resampling procedure involved the use of a nearest neighbour technique in LPS, which matched the position of each pixel of the DEM with its equivalent position in the imagery (Leica Geosystems 2003). This process is the actual orthorectification of the imagery. A portion of the resulting orthorectified image of Boulder Beach as of 1997 is displayed in Fig. 3.

Figure 3. A portion of the orthorectified 1997 image of Boulder Beach, Otago Peninsula. This image was used as the base map in the yellow-eyed penguin (*Megadyptes antipodes*) GIS (described in section 2.2.
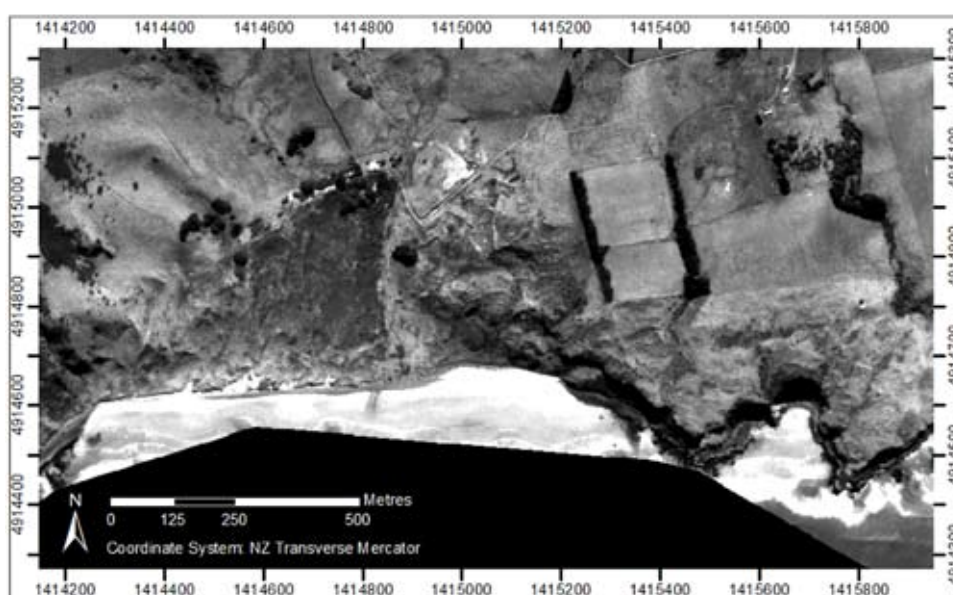
2.2.3 Habitat data

The next step in the construction of the yellow-eyed penguin GIS was the extraction of land cover data from the orthorectified image of Boulder Beach to create a habitat map data layer. This data layer was required to analyse the effects of habitat type on yellow-eyed penguin nest site selection and density at Boulder Beach. The creation of the habitat map consisted of the following two steps: defining a set of land cover classes (hereafter termed 'habitat classes') known to exist in the study area, and then using a remote sensing technique to classify the orthorectified imagery based on the pre-defined set of classes.

Five broad habitat classes were defined for the habitat map of Boulder Beach:

1. Dense scrub: patches greater than $100 \, \text{m}^2$ that contained dense coverage of primarily mature *Phormium tenax* and/or *Hebe elliptica*.

2. Sparse scrub: loosely dispersed, younger *P. tenax* and *H. elliptica* mixed with other species (e.g. *Cortaderia* sp., *Meuhlenbeckia australis, Myoporum laetum,* and *Pteridium* sp.).

3. Tree: primarily exotic *Macrocarpa* species.

4. Bare ground–grassland: all remaining types of land cover other than water, e.g. sand, boulders, and native and exotic grass covered areas.

5. Water: the ocean.

There were a variety of remote sensing techniques to choose from for classifying the orthorectified image of Boulder Beach, each with a different level of complexity and accuracy. The simplest technique may have been to manually draw polygons for each habitat class in ArcGIS® 9. However, the accuracy of this technique was subject to a potentially high level of observer bias and error. Therefore, a semi-automated, object-oriented technique was employed using the eCognition™ software program (Definiens® Imaging 2004). Rather than analysing individual pixels, the object-oriented technique identified groups of similar pixels as distinct objects in the image (e.g. buildings, patches of distinct vegetation and water bodies) based on several spectral and spatial parameters (Mathieu et al. 2007).

The classification process in eCognition™ consisted of three steps. Initially, the Boulder Beach image was automatically segmented into objects based on a combination of four pre-defined factors: scale, colour, smoothness and compactness (Mathieu et al. 2007). The software then needed to be 'trained' to classify the image objects into the five pre-defined habitat classes. This is known as a supervised classification and it required habitat information that was collected during a preliminary field survey of Boulder Beach. Information from photographs and written descriptions of distinct patches of each habitat class that were easily visible in the imagery were used as references for classifying the image objects. Samples of manually classified objects were then used by eCognition™ to calculate statistics (e.g. mean and standard deviation) of spectral (e.g. brightness and colour) and spatial (e.g. distribution and scale) parameters for each habitat class. These statistics were used to automatically classify the remaining objects in the image. The output of the classification was manually checked and edited where obvious errors occurred. The final classification dataset, hereafter termed the 'habitat map data layer', was then imported into ArcGIS® 9 as a polygon shapefile. Figure 4 displays the habitat map for the Midsection and Double Bay areas.

Figure 4. A habitat map of the Midsection and Double Bay yellow-eyed penguin (*Megadyptes antipodes*) nesting areas at Boulder Beach. Four of the five broad classes of the habitat map are overlaid on the orthorectified 1997 imagery of Boulder Beach from which the map was derived (as described in section 2.3.3); water is excluded.
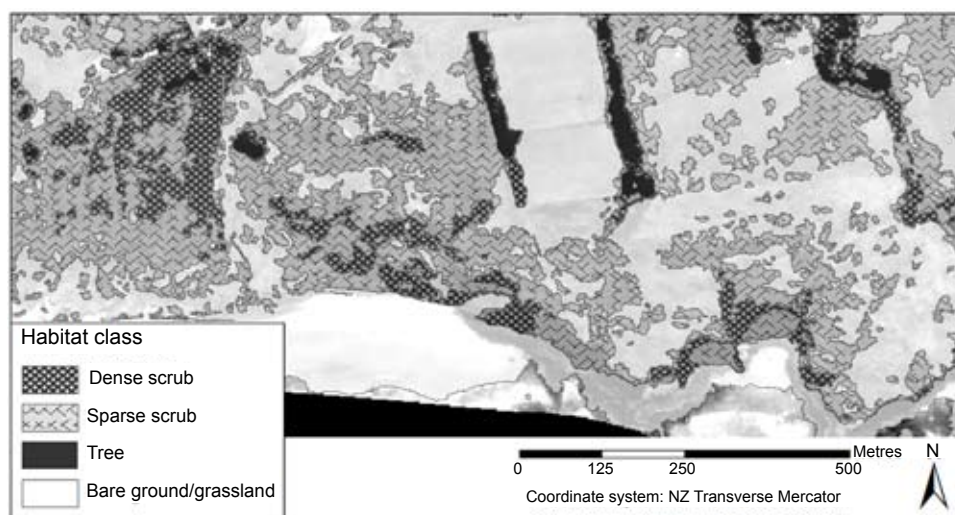

2.2.4 Nest site data

To demonstrate how historical data (i.e. data collected before GIS, GPS and related technologies were in use) could be incorporated and analysed in a GIS, yellow-eyed penguin nest site data that had been collected at Midsection and Double Bay from 1982 to 1996[1] were obtained from DOC in an Excel® spreadsheet. This nest site dataset contained information about several attributes of nest sites, including nest site identification codes, band numbers of nest-attending adults, types of nest site vegetation cover, and nest fate and fledging information (see Appendix 2 for a complete list of attributes in the yellow-eyed penguin nest site dataset).

Since it was already in a spreadsheet format, the nest site dataset could be easily imported into ArcGIS® 9. However, the dataset did not contain spatial attributes (i.e. data on specific geographic locations of nest sites), which were necessary for displaying the locations of nest sites on the digital base map and for completing any spatial analyses on the nest site data. The only information about the geographic locations of the nest sites were a collection of sketch (i.e. hand-drawn) maps of Midsection and Double Bay compiled by John Darby while working at the Department of Zoology, University of Otago. These sketch maps were originally designed to assist with nest site surveys in subsequent years and were drawn by different field surveyors, so there was variation in map scale and style between years.

On the sketch maps, the location of a nest site was indicated by either the nest site number alone or both the nest site number and a cross or point (see Fig. 5 and Appendix 3 for examples). To convert this information into spatial features that could be added to the nest site dataset, the sketch maps first needed to be incorporated into the GIS, and then georeferenced and overlaid on the orthorectified image of Boulder Beach. This was achieved by importing digitally scanned versions of the sketch maps into ArcGIS® 9, and then using the georeferencing tool in ArcMap™ (part of ArcGIS® 9) to manually connect and overlay distinct features in the sketch maps with their equivalent positions that

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[1]   The locations of nest sites in more recent years have primarily been recorded using GPS technology.

Figure 5. An example of a hand-drawn sketch map of historical yellow-eyed penguin (*Megadyptes antipodes*) nest site locations at the Midsection area of Boulder Beach, Otago Peninsula (see Appendix 2 for additional examples).
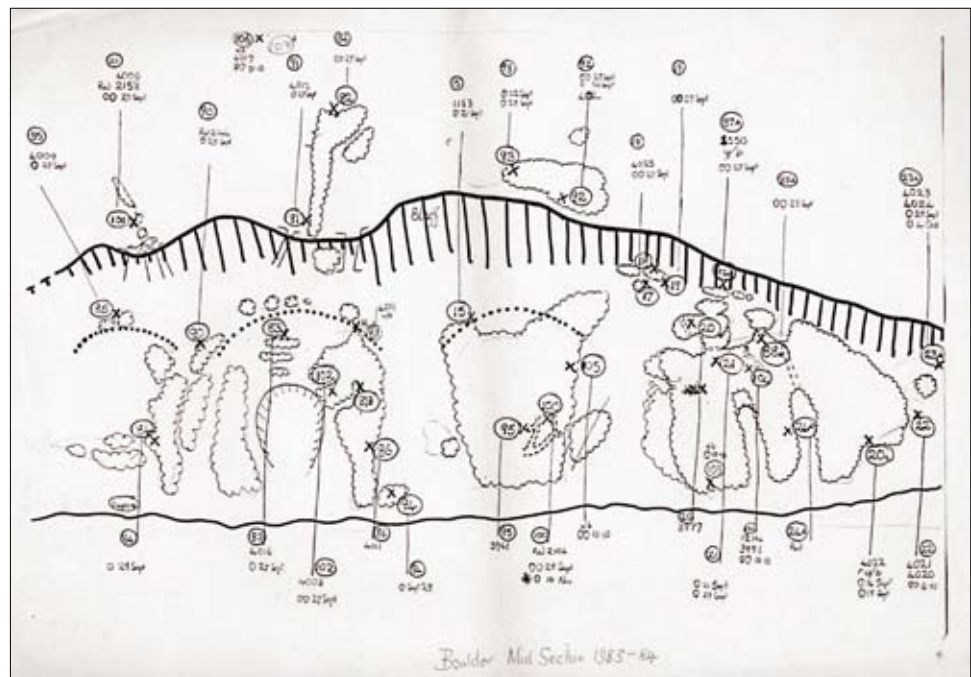
were clearly visible in the Boulder Beach image. Georeferencing was concentrated on the features in the sketch maps that were closely associated with nest site locations. An acceptable level of accuracy of georeferencing could be obtained only for the features in the sketch maps that were most easily recognisable in the Boulder Beach image. In this case, the accuracy of the georeferencing was indicated by an average residual RMSE of less than 7 m.

To obtain the specific geographic locations (i.e. projected in NZTM coordinates) of the historical nest sites, printed copies of the georeferenced sketch maps and the orthorectified Boulder Beach image were used, along with the assistance of John Darby, in a field survey of Midsection and Double Bay. During the field survey, the Trimble® GeoExplorer3™ GPS receiver was used to record the NZTM coordinates (i.e. easting and northing) of nest site locations on the sketch maps that were positively identified in the field. Where a nest site was listed in the DOC dataset but not in the sketch map for a particular year, it was only recorded if a nest site location for the same yellow-eyed penguin breeding pair was noted in a sketch map from the previous or subsequent year. Where nest site locations could not be positively identified in the field, the NZTM coordinates of the nearest locations that contained the densest vegetation were recorded. This tended to occur in areas where there was not a good match between vegetation patches on the sketch maps and the Boulder Beach image, which was a result of changes in vegetation cover (i.e. growth or removal) between the years when the sketch maps were drawn and when the aerial photographs were taken (a period ranging from 3 to 14 years).

NZTM coordinates were recorded for approximately 90% of the nest sites in the DOC dataset, for the years 1983–96 for Midsection and 1982–96 for Double Bay (see Fig. 6). This information was added to the DOC nest site spreadsheet, which was subsequently imported into ArcGIS® 9 and then converted to a point shapefile data layer. This data layer displayed the locations of the nest sites as points on the habitat map and the base map, and completed the construction of the yellow-eyed penguin GIS.

Figure 6. The estimated geographic locations (recorded in the NZTM geographic coordinate system) of yellow-eyed penguin (*Megadyptes antipodes*) nest sites (triangles) for the years 1983–1996 at A. the Midsection nesting area and B. the Double Bay nesting area of Boulder Beach, Otago Peninsula. The nest site locations are overlaid on the dense and sparse scrub habitat classes, which were the only two classes of the habitat map that nest sites were found to occur in. Some of the nest site locations are not visible because of overlap between nest sites that occurred in the same location in two or more years.
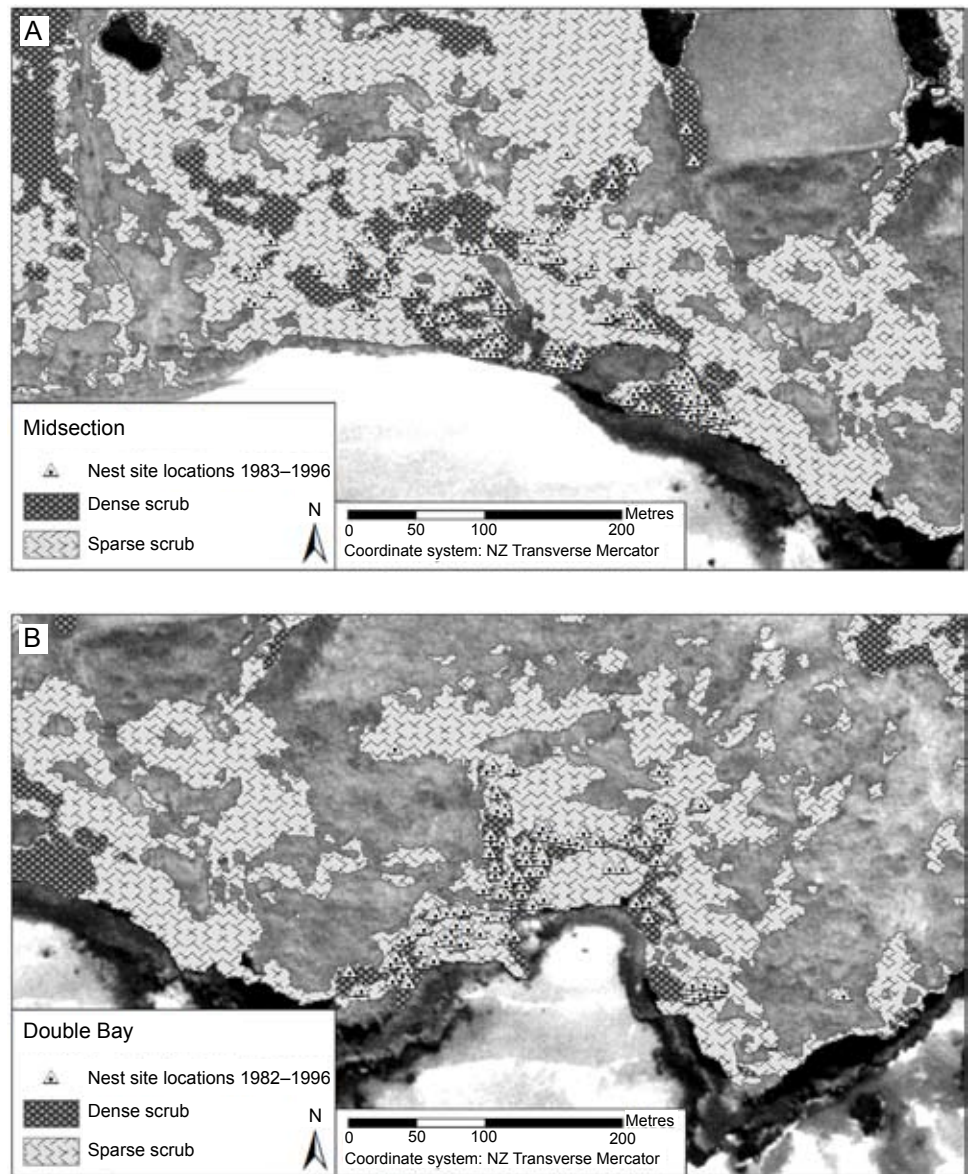
2.3 UPDATING THE YELLOW-EYED PENGUIN GIS

A secondary objective in the construction of the yellow-eyed penguin GIS was to make it possible to update the nest site shapefile dataset with a minimal amount of effort and error. This required the creation of a simple interface data entry form that would standardise the process of entering new data and remove the need to directly access the nest site shapefile.

The interface form was created using Visual Basic for Applications (VBA), which is an embedded programming environment in ArcGIS® 9 used for automating, customising and extending applications. The structure of the interface was designed to follow the format of the current DOC yellow-eyed penguin nest site field data collection form. With this structure, data from the DOC form could be transferred (i.e. typed) directly into the interface without the need to first organise and/or convert the data in a separate spreadsheet. As part of creating a standardised data entry process, combination boxes, or pick-lists, were used

for some fields of the interface to provide guided input when entering data. For example, the choices for nest site vegetation cover were presented in a drop-down pick-list to ensure that spelling mistakes and inconsistencies were minimised. In addition, as a form of quality control, some data restriction (e.g. date format, and a maximum number of eggs and chicks) and validation are allowed before updating the nest site shapefile. The final interface form is presented in Fig. 7.

Figure 7. The graphical interface form for entering new data into the nest site shapefile in the yellow-eyed penguin (*Megadyptes antipodes*) GIS (described in section 2.4).

3. Uses of the yellow-eyed penguin GIS

3.1 SPATIAL ANALYSIS

A GIS designed for ecological research or wildlife management purposes is often used to quantify habitat selection and use (Manly et al. 2002). Such analyses generally involve the computation of statistics describing different landscape features that exist at recorded geographic locations of individual animals or related biological/ecological units (e.g. nest sites). For example, the mean elevation of nest sites at Midsection and Double Bay between 1982 and 1996 was 35 m and 43 m, respectively; and the mean slope was 27° and 31°, respectively. While these figures suggest that yellow-eyed penguins may not be averse to nesting well above sea level or on steep slopes, it is likely that there are other landscape features that impose a greater influence on nest site selection.

By overlaying the nest site shapefile on the habitat map, the relationship between nest site locations and habitat classes became clearly visible (see Fig. 6), and it appeared that nest sites occurred more often in dense scrub than in the other habitat classes. To confirm and quantify this relationship, a process called a 'spatial join' in ArcMap™ was used to incorporate data from the habitat map into the attribute table of the nest site shapefile. This process added a field to the nest site attribute table that defined the habitat class that each nest site was placed in for each year (i.e. 1983–96 for Midsection and 1982–96 for Double Bay). Summary statistics of the updated nest site data were then computed, revealing that nest sites were found only in either dense or sparse scrub habitat. This summary information was then entered into an Excel® spreadsheet to run a statistical test that compared the average number of nest sites in dense v. sparse scrub habitat for the years 1983–96. A simple one-way ANOVA revealed that, for the years 1983–96, the average number of breeding yellow-eyed penguins selecting dense scrub was significantly greater than those selecting sparse scrub for the placement of nest sites in both Midsection ($F = 41.79$, $P < 0.01$) and Double Bay ($F = 41.59$, $P < 0.01$) (Fig. 8).

Figure 8. The annual mean number of yellow-eyed penguin (*Megadyptes antipodes*) nest site locations that occurred in dense scrub and sparse scrub habitat at the Midsection and Double Bay nesting areas of Boulder Beach, Otago Peninsula. The mean was calculated for nest site records from 1983–96. Error bars represent ± 1 standard error of the mean.
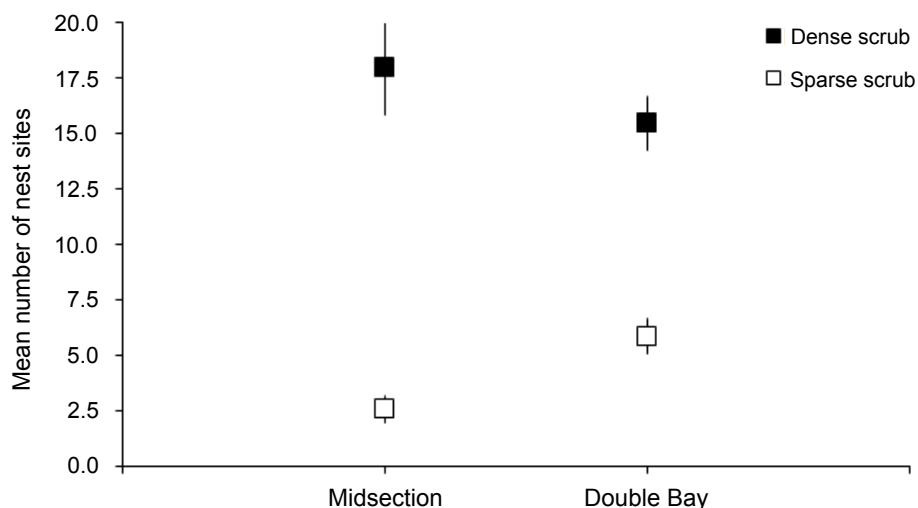
The tendency for yellow-eyed penguins to select well-concealed nest sites in dense vegetation has long been observed throughout much of their breeding range (Richdale 1957; Darby 1985; Lalas 1985; Seddon & Davis 1989; Moore 1992). In addition, higher nest densities have been observed in habitat patches that contain greater densities of vegetation (e.g. Seddon & Davis 1989; Moore 1992). The density of individuals and/or nest sites in relation to different habitat classes, or to other landscape features, is often an important measure in the analysis and monitoring of a species' habitat use and population trends. Population and/or nest site densities can easily be calculated and spatially represented in a GIS.

The density of yellow-eyed penguin nests in dense scrub was compared with that in sparse scrub between the years 1994 and 1996. These years were selected for analysis because the vegetation cover present at that time was likely to have been similar to that represented in the 1997 Boulder Beach image. The areal extent (in m^2) of each habitat class in Midsection and Double Bay was easily calculated in ArcMap™ and, not surprisingly, the density of nests in dense scrub was found to be significantly greater than in sparse scrub for both areas (Midsection: $F = 9.14$, $P < 0.05$; Double Bay: $F = 18.56$, $P < 0.01$; Fig. 9). However, due to natural changes in the extent of vegetation cover over time, the error associated with these trends may have increased with each year prior to 1997 (i.e. the amount of error may have been greatest for the 1994 nest sites).

Figure 9. The annual mean density of yellow-eyed penguin (*Megadyptes antipodes*) nest sites that occurred in dense scrub and sparse scrub habitats at the Midsection and Double Bay nesting areas of Boulder Beach, Otago Peninsula. The mean density was calculated for the years 1994–96. Error bars represent ± 1 standard error of the mean.
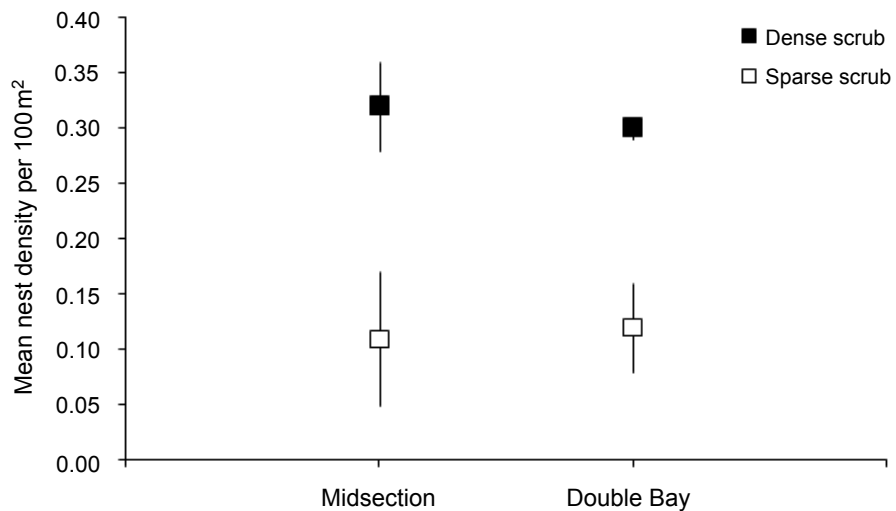
3.2 OTHER POTENTIAL USES

The analyses described above are just the 'tip of the iceberg' of ways in which a GIS could be used to examine the relationship between yellow-eyed penguins and their habitat. Given the variety of attributes collected for each nest site (see Appendix 2), many different analyses, both spatial and non-spatial, are possible. Some examples include tracking the movements of breeding adults to different nest sites or nesting locations between years; linking trends in egg laying, hatching or chick fledging dates to geographic patterns; and examining geographic trends in nest success (i.e. the average number of chicks per nest that successfully fledged). Analyses like these could help determine the extent and pinpoint the source of problems such as disease outbreaks, predation or effects of human disturbance. Expanding on these examples, one possible use of the GIS for management purposes could be to determine the sections of yellow-eyed penguin breeding areas that are most affected by predation, and to use this information to design a predator control strategy.

A GIS could also be useful for yellow-eyed penguin habitat restoration and tourism management. This report has described how the preferred vegetation cover for nest sites can be easily determined with a GIS. This information could be valuable for determining the type, amount and spatial layout (i.e. distribution and density) of vegetation that should be used in habitat restoration programmes, as well as for predicting the potential placement or distribution of nest sites for a given year in a breeding area given the habitat types available (along with other topographical parameters) (Clark 2008). By comparing the sections of a nesting habitat used by yellow-eyed penguins with those visited by tourists and other users, public access could be managed in ways that minimise disturbance to breeding birds. Lastly, a GIS could be used to monitor and evaluate the spatial consequences of virtually any management intervention, such as changes in the locations of nest sites or nest site densities in response to the erection of fencing or signage, or the effects of habitat protection or restoration work, which could be used to help adapt and improve management strategies.

3.3 BEYOND YELLOW-EYED PENGUINS

The type of GIS described in this report could easily be applied to many other types of ecological or wildlife management and research. There is a broad range of examples, both in New Zealand and other countries, where GIS similar to that presented here for the yellow-eyed penguin have been used to predict species distributions and/or the availability of suitable habitat for different plant and animal species (e.g. McLennan 1998; Guisan & Zimmerman 2000; Greaves et al. 2006; Mathieu et al. 2006). Some studies have also shown how this type of GIS may be valuable for predicting habitat use by reintroduced or translocated species (e.g. Michel 2006). Aside from being helpful in the analysis of habitat use and in designing conservation strategies for threatened species and habitats, the type of GIS outlined in this report can also be used to track and analyse the movements of introduced predators, which can be useful in the development of effective predator control programmes (Shanahan et al. 2007). Thus, there is great potential for GIS in virtually any aspect of wildlife research and management.

4. Error and uncertainty

For any project that involves data collection, analysis and interpretation, there exists some amount of error and uncertainty. These terms can be considered synonymous (i.e. a large amount of error can be seen as a large amount of uncertainty); however, in this report uncertainty is defined as any amount of error that cannot be quantified or accounted for. Generally, error and uncertainty can increase proportionally with the amount and variety of data collected, as well as with the types of analyses used (Stine & Hunsaker 2001). In a GIS, it is possible to produce additional error and uncertainty through processes such as the derivation of new data layers from pre-existing datasets (e.g. the extraction of the DEM of Boulder Beach from the 1997 imagery). Consequently, it is imperative that, wherever possible, all potential sources of error and uncertainty are accounted for and minimised, if not eliminated.

Among the potential sources of error and uncertainty in the yellow-eyed penguin GIS, the most significant were the sketch maps of historical nest site locations at Midsection and Double Bay. Because of the inconsistent scale and detail of these hand-drawn maps, and the fact that they were not originally intended for the purpose for which they were used in this study, they were not an ideal source for determining the accurate geographic locations of the historical nest sites. Nevertheless, these sketch maps were the only source of information available for estimating the historical nest site locations. Every effort was taken to minimise the amount of error associated with the georeferencing of the sketch maps and the collection of NZTM coordinates of nest site locations in the field. However, since there were no references available other than the sketch maps, it was not possible to check the accuracy of the estimated geographic locations of the nest sites against an independent source. Therefore, the error associated with the nest site locations was based primarily on the accuracy of the georeferencing of the sketch maps, which meant that nest site locations were estimated to within ± 5–30 m of their correct position.

Another primary source of error and uncertainty was the creation of the habitat map. Uncertainty is inherent in thematic mapping techniques such as object-oriented classification, where class definitions must be discrete (i.e. there cannot be overlap between classes). This means that local (i.e. within class) habitat variation or detail can be lost. In addition, the process of defining the different habitat classes is at least partially subjective, which can result in inaccurate representations of the true landscape. However, these issues are irrelevant if, as in this study, local habitat variation is not important and class definitions are thorough and distinct. Uncertainty in the classification of land cover data extracted from imagery can also arise from natural topographical variation, which can produce shadows that are captured in the imagery, as well as areas of the same type of land cover that have different reflectance intensities, both of which may result in misclassification. The uncertainty present in the habitat map derived from the 1997 Boulder Beach imagery was primarily due to the number of shadowed areas. This was particularly relevant to Double Bay, where some steep cliffs exist. The habitat map was corrected as much as possible

with manual editing, which was supported by other aerial photographs of Boulder Beach, and with photographs taken on the ground during a field survey. Since the habitat map was not validated with an independent set of field data, it was not possible to quantify the amount of error in the map. However, although the accuracy of the final habitat map was ultimately uncertain, it was still considered suitable for use in the analyses in this project.

A GIS can be a powerful tool for producing useful information for management purposes, but it can also produce misleading information (Monmonier 1991). The ability to use a GIS to produce visually appealing outputs can mislead users into believing that the GIS is more accurate than the data it represents (Bailey 1988). Ultimately, the errors, uncertainties and potential for misleading information associated with GIS emphasise the importance of carefully collecting appropriate data that meet the accuracy and quality required for the intended purpose, and for designing quality control protocols. Unfortunately, these aspects of GIS are often not considered because addressing them may require additional costs and resources.

5. Conclusions and recommendations

When used appropriately, a GIS can be a valuable tool for ecological or wildlife management and research. However, when constructing and using a GIS, the potential for error and other limitations must be clearly addressed and minimised. The yellow-eyed penguin GIS described in this report has demonstrated three main capabilities of GIS that could be beneficial for the management of virtually any plant or animal species or habitat.

The first and foremost capability of GIS is the broad scope provided for organising and storing a variety of potentially large datasets, and for comprehensive and efficient spatial and temporal analyses. While the accuracy of some of the derived data layers and associated analyses of the yellow-eyed penguin GIS were unknown (as described in section 4), the methods used to achieve them were robust. Furthermore, given that GPS and remote sensing technologies are improving and becoming more available and commonly used to collect data on nest site locations and other habitat features, the accuracy of future analyses based on up-to-date data will undoubtedly be much improved.

The second capability of the GIS described in this report is the ability to incorporate historical data for spatial analysis and interpretation. Wildlife researchers and managers should take care when working with historical data, as the level of accuracy, or amount of error, can be indeterminable. Nevertheless, with improvement, the methods outlined in this report for incorporating historical data can be quite useful, especially for comparing spatial patterns in historical data with current data to reveal changes and trends that have occurred over time.

Finally, the third main capability of GIS, as demonstrated in the construction of the yellow-eyed penguin GIS, is the creation of a simple, easy-to-use interface form that provides a standardised protocol for updating datasets such as the nest site shapefile. The main benefits of using a protocol such as this for entering data are that errors and inconsistencies can be minimised and routine manipulation of data should be easily understood and completed in a consistent format. In addition, a standardised procedure that is well designed and easy to use can help to overcome some of the difficulties associated with integrating ecological knowledge and technical GIS expertise.

The primary intention of this report was to provide a comprehensive yet simple guide to the construction and use of a GIS for collating, analysing, updating and managing data in wildlife management or research projects, using the spatial analysis of yellow-eyed penguin nest site data as an example. Wildlife managers, researchers and other users are encouraged to modify and update the structure of the GIS described in this report as necessary, and it is recommended that future studies incorporate current data as much as possible to ensure improved accuracy in analyses and other GIS output. Ultimately, as GIS technology improves, so will its effectiveness and value as a management and research tool.

6. Acknowledgements

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8. Glossary

The following definitions have been taken from the Environmental Systems Research Institute's (ESRI) Support website: http://support.esri.com (viewed 3 August 2008). Definitions of additional terminology relating to GIS can also be obtained from this site.

Aspect   The compass direction that a topographic slope faces, usually measured in degrees from north.

Attribute   Information about a geographic feature in a GIS that is usually stored in a table and linked to the feature by a unique identifier. See 'non-spatial attribute data' and 'spatial attribute data'.

Base map   A map depicting background reference information such as landforms, roads, landmarks and political boundaries, onto which other thematic information is placed.

Classification   The process of sorting or arranging entities (or data) into groups or categories.

Data layer (or layer)   The visual representation of a geographic dataset in any digital map environment. Conceptually, a layer is a slice or stratum of the geographic reality in a particular area, and is more or less equivalent to a legend item on a paper map. On a road map, for example, roads, national parks, political boundaries and rivers might be considered different layers.

Database (or geodatabase)   One or more structured sets of persistent data, managed and stored as a unit and generally associated with software to update and query the data. A simple database might be a single file with many records, each of which references the same set of fields. A GIS database includes data about the spatial locations and shapes of geographic features recorded as points, lines, areas, pixels or grid cells, as well as their attributes.

Differential correction   A technique for increasing the accuracy of GPS measurements by comparing the readings to two receivers, one roving and the other a fixed base station.

Digital elevation model (DEM)   The representation of continuous elevation values over a topographic surface by a regular array of z-values, referenced to a common datum. DEMs are typically used to represent terrain relief.

Feature   A representation of a real-world object on a map.

Feature class   In ArcGIS®, a collection of geographic features with the same geometry type (such as point, line or polygon), the same attributes and the same spatial reference. For example, highways, primary roads and secondary roads can be grouped into a line feature class named 'roads'.

Geographic coordinate system   A reference system that uses latitude and longitude to define the locations of points on the surface of a sphere or spheroid (which represents the surface of the Earth). A geographic coordinate system definition includes a datum, prime meridian and angular unit.

Geographic Information System (GIS) An integrated collection of computer software and data used to view and manage information about geographic places, analyse spatial relationships and model spatial processes. A GIS provides a framework for gathering and organising spatial data and related information so that it can be displayed and analysed.

Georeferencing Aligning geographic data to a known coordinate system so it can be viewed, queried and analysed with other geographic data. Georeferencing may involve shifting, rotating, scaling, skewing, and in some cases warping, rubber sheeting or orthorectifying the data.

Global Positioning System (GPS) A system of radio-emitting and -receiving satellites used for determining positions on the Earth. The orbiting satellites transmit signals that allow a GPS receiver anywhere on Earth to calculate its own location through trilateration.

Image/imagery A representation or description of a scene, typically produced by an optical or electronic device, such as a camera or a scanning radiometer. Common examples include remotely sensed data (e.g. satellite data), scanned data and photographs.

Land cover The classification of land according to the vegetation or material that covers most of its surface, e.g. pine forest, grassland, ice, water or sand.

Nearest neighbour A technique for resampling raster data whereby the value of each cell in an output raster is calculated using the value of the nearest cell in an input raster. Nearest neighbour assignment does not change any of the values of cells from the input layer; for this reason, it is often used to resample categorical or integer data (e.g. land use, soil or forest type), or radiometric values, such as those from remotely sensed images.

Non-spatial attribute data Non-spatial information about a geographic feature in a GIS usually stored in a table and linked to the feature by a unique identifier. For example, attributes of a river might include its name, length and sediment load at a gauging station.

Orthorectification The process of correcting the geometry of an image so that it appears as though each pixel was acquired from directly overhead. Orthorectification uses elevation data to correct terrain distortion in aerial or satellite imagery.

Parallax The apparent shift in an object's position when it is viewed from two different angles.

Photogrammetry The science of making reliable measurements of physical objects and the environment by measuring and plotting electromagnetic radiation data from aerial photographs and remote-sensing systems against land features identified in ground control surveys, generally in order to produce planimetric, topographic and contour maps.

Pixel The smallest unit of information in an image or raster map, usually square or rectangular. Often used synonymously with cell. In remote sensing, the fundamental unit of data collection. In a remotely sensed image, a pixel is represented as a cell in an array of data values.

Planimetric   Two-dimensional; showing no relief. A two-dimensional map that serves as a guide for contour mapping, usually prepared from aerial photographs.

Polygon   On a map, a closed shape defined by a connected sequence of x and y coordinate pairs, where the first and last coordinate pairs are the same and all other pairs are unique.

Projected coordinate system   A reference system used to locate x, y and z positions of point, line and area features in two or three dimensions. A projected coordinate system is defined by a geographic coordinate system, a map projection, any parameters needed by the map projection, and a linear unit of measure.

Projection   A method by which the curved surface of the Earth is portrayed on a flat surface. This generally requires a systematic mathematical transformation of the Earth's graticule of lines of longitude and latitude onto a plane.

Raster data   A spatial data model that defines space as an array of equally sized cells arranged in rows and columns, and composed of single or multiple bands. Each cell contains an attribute value and location coordinates.

Relief   Elevations and depressions of the Earth's surface, including those of the ocean floor. Relief can be represented on maps by contours, shading, hypsometric tints, digital terrain modelling or spot elevations.

Remote sensing   Collecting and interpreting information about the environment and the surface of the Earth from a distance, primarily by sensing radiation that is naturally emitted or reflected by the Earth's surface or from the atmosphere, or by sensing signals transmitted from a device and reflected back to it. Examples of remote-sensing methods include aerial photography, radar and satellite imaging.

Resolution   The detail with which a map depicts the location and shape of geographic features. The larger the map scale, the higher the possible resolution. As scale decreases, resolution diminishes and feature boundaries must be smoothed, simplified or not shown at all; for example, small areas may have to be represented as points. Also defined as the dimensions represented by each cell or pixel in a raster.

Resampling   The process of interpolating new cell values when transforming rasters to a new coordinate space or cell size.

Root mean square error (RMSE)   A measure of the difference between locations that are known and locations that have been interpolated or digitised. RMSE is derived by squaring the differences between known and unknown points, adding those together, dividing that by the number of test points, and then taking the square root of that result.

Scale   The ratio or relationship between a distance or area on a map and the corresponding distance or area on the ground, commonly expressed as a fraction or ratio. For example, a map scale of 1/100 000 or 1:100 000 means that one unit of measure on the map equals 100 000 of the same unit on the Earth.

Shapefile   In ArcGIS®, a vector data storage format for storing the location, shape and attributes of geographic features. A shapefile is stored in a set of related files and contains one feature class.

Slope   The incline, or steepness, of a surface. Slope can be measured in degrees from horizontal (0–90) or percent slope (the rise divided by the run, multiplied by 100). The slope for a cell in a raster is the steepest slope of a plane defined by the cell and its eight surrounding neighbours.

Spatial analysis   The process of examining the locations, attributes and relationships of features in spatial data through overlay and other analytical techniques in order to address a question or gain useful knowledge. Spatial analysis extracts or creates new information from spatial data.

Spatial attribute data   Information about the locations and shapes of geographic features and the relationships between them, usually stored as coordinates and topology.

Spatial join   A type of table join operation in which fields from one layer's attribute table are appended to another layer's attribute table based on the relative locations of the features in the two layers.

Stereopair   Two aerial photographs of the same area taken from slightly different angles that produce a three-dimensional image when viewed together through a stereoscope.

Thematic data/map   Features of one type that are generally placed together in a single layer. A map designed to convey information about a single topic or theme, such as population density or geology.

Topography/topographic map   The study and mapping of land surfaces, including relief (relative positions and elevations) and the position of natural and constructed features. A map that represents the vertical and horizontal positions of features, showing relief in some measurable form, such as contour lines, hypsometric tints and relief shading.

Transformation   The process of converting the coordinates of a map or an image from one system to another, typically by shifting, rotating, scaling, skewing or projecting them.

Triangulation   Locating positions on the Earth's surface using the principle that if the measures of one side and the two adjacent angles of a triangle are known, the other dimensions of the triangle can be determined.

Uncertainty   The degree to which the measured value of some quantity is estimated to vary from the true value. Uncertainty can arise from a variety of sources, including limitations on the precision or accuracy of a measuring instrument or system; measurement error; the integration of data that use different scales or that describe phenomena differently; conflicting representations of the same phenomena; the variable, unquantifiable or indefinite nature of the phenomena being measured; or the limits of human knowledge. Uncertainty is often used to describe the degree of accuracy of a measurement.

Vector data   A coordinate-based data model that represents geographic features as points, lines and polygons. Each point feature is represented as a single coordinate pair, while line and polygon features are represented as ordered lists of vertices. Attributes are associated with each vector feature, as opposed to a raster data model, which associates attributes with grid cells.

Appendix 1

As described in section 2.2.2, the exterior orientation parameters of the stereopair of aerial photographs of Boulder Beach taken in 1997 were calculated using the space resection by collinearity technique in Leica Photogrammetry Suite V8.7 software program. Details about this technique and the procedures utilised in the software program are outlined in Leica Geosystems (2003). Using least squares adjustment techniques, the six exterior orientation parameters associated with each image were automatically calculated by the software program. The accuracy of these parameters is listed below. The summary of the root mean square error (RMSE) of the GCPs on the ground and in the two images are also listed.

Exterior orientation parameters

```
Image ID     X       Y       Z     OMEGA    PHI    KAPPA
       1   0.0677  0.0178  0.4073  0.0672  0.2023  0.0599
       2   0.0176  0.0113  0.0936  0.1677  0.1780  0.0600
```

Summary RMSE (in metres) for GCPs on ground (number of observations in parentheses)

```
Ground X: 0.1859 (12)
Ground Y: 0.1157 (12)
Ground Z: 0.1593 (12)
```

Summary RMSE (in pixels) for GCPs on image (number of observations in parentheses)

```
Image X: 0.3449 (12)
Image Y: 0.2147 (12)
```

Appendix 2

ATTRIBUTE	DESCRIPTION	EXAMPLE
Nest year	Year of the particular breeding or nesting season.	1996
Location	Name of the breeding area.	Double Bay
Locode	Two-letter code for location name.	DB
Site	Specific code or ID for each nest site.	10
Nestid	Full nest site ID. Includes Nestyear and Locode.	1996DB10
P1	Band or ID number of first parent observed at nest. Left empty if number is never read or parent is unbanded.	10094
P1id	Same as P1, except for the few cases where old band numbers are replaced.	10094
P2	Band or ID number of second parent observed at nest. Left empty if number is never read or parent is unbanded.	9914
P2id	Same as P2, except for the few cases where old band numbers are replaced.	9914
Vegetation	Primary type of vegetation immediately surrounding nest site.	Flax
Cover	Whether nest site is covered or not (i.e. closed or open).	Closed
Date found	Date the nest site was first found.	9/25/1996
Nest status	Whether nest site is active (i.e. eggs laid or not).	Eggs laid
Treatment	Any actions taken by DOC personnel or researchers.	Chick taken into captivity
Lay date e1	Estimated lay date of the first egg.	10/1/1996
Lay error e1	Estimated error of Lay date e1.	3
Lay date e2	Estimated lay date of the second egg.	10/5/1996
Lay error e2	Estimated error of Lay date e2.	3
Hatch date e1	Estimated hatch date of the first egg.	11/15/1996
Hatch error e1	Estimated error of Hatch date e1.	2
Hatch date e2	Estimated hatch date of the second egg.	11/15/1996
Hatch error e2	Estimated error of Hatch date e2.	2
Incub span e1	Estimated number of days of incubation of the first egg.	46
Incub error e1	Estimated error of Incub span e1.	0
Incub span e2	Estimated number of days of incubation of the second egg.	42
Incub error e2	Estimated error of Incub span e2.	0
Nlaid	Number of eggs laid.	2
Nhatched	Number of eggs hatched.	2
Nfledged	Number of chicks fledged.	1
Fate egg1	Fate of the first egg (fledged, predated, etc.).	Fledged
Fate egg2	Fate of the second egg.	Hypothermia
Nest memo	Comments, memos or notes of interest about the nest site.	
Easting*	Easting coordinate of nest site in NZTM.	4914556.76
Northing*	Northing coordinate of nest site in NZTM.	1415518.42
Who	Surname of person who found nest site.	Clark
C1kg	Weight of first chick prior to fledging.	5.5
C2kg	Weight of second chick prior to fledging.	
VegClass*	For Midsection and Double Bay, the habitat class that a nest site was located in based on the habitat map derived from 1997 imagery of Boulder Beach.	Dense Scrub

*   These attributes were added to the dataset when constructing the GIS as described in this report.

Appendix 3

SKETCH MAPS OF YELLOW-EYED PENGUIN
NESTING HABITAT AREAS

Additional examples of the sketch maps of the Midsection and Double Bay yellow-eyed penguin (*Megadyptes antipodes*) nesting habitat areas at Boulder Beach, Otago Peninsula.

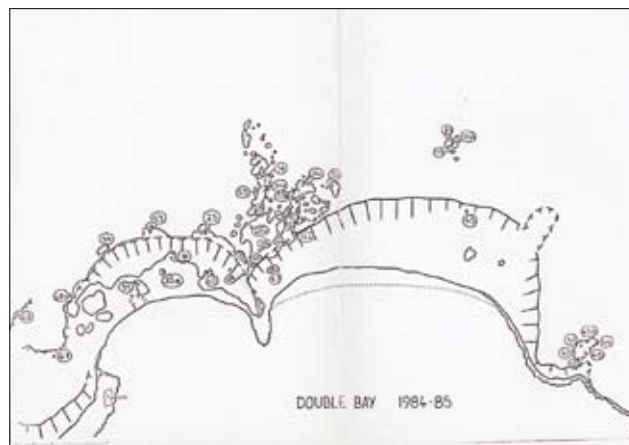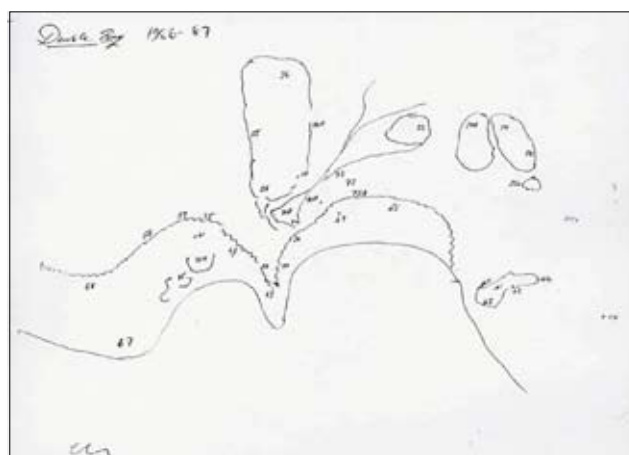Figure A3.1. Midsection 1984–85.

Figure A3.2. Double Bay 1984–85.

Figure A3.3. Double Bay 1986–87.

New Zealand Government