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Mapping the stray domestic cat (*Felis catus*) population in New Zealand: Species distribution modelling with a climate change scenario and implications for protected areas

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ABSTRACT

Species distribution models of stray cats were developed using two types of occurrence data: (i) a combined dataset of stray cats and cat colonies in Auckland and projected to the wider New Zealand area; and (ii) population density as an analogue for country-wide stray cat occurrence. These occurrence data, together with sets of environmental variables were used as input to the Maxent modelling tool to produce maps of suitability for the species. Environmental variables used in the models consist of current bioclimatic conditions, and a future climate scenario (RCP8.5 for year 2070 CCSM model). Commonly occurring bias in the modelling process due to latitude, the area for selecting background points in model evaluation, inherent spatial autocorrelation of occurrence points, and correlated bioclimatic variables were explicitly addressed. Results show that the North Island consistently provide more suitable areas for stray cats with increased suitability in a high emission climate change condition. Key protected areas at risk from the increased suitability to stray cats are also presented.

1. Introduction

The cat (*Felis catus*) has been identified as one of the world's most invasive species (Duffy & Capece, 2012; Lowe, Browne, Boudjelas, & De Poorter, 2000). Yet it is also the most common companion animal in many countries including New Zealand (Argante, 2008; MacKay and NZCAC, 2011) and as a consequence populations of cats (either as pets or un-owned) are in general associated spatially with human populations (Ferreira, Leitão, Santos-Reis, & Revilla, 2011). The population densities of urban free-living, un-owned cats (also known as 'stray cats'; see Farnworth, Campbell, & Adams, 2010) have been demonstrated to be closely linked to human population density (Aguilar & Farnworth, 2012; 2013). The management of populations of un-owned individuals, including cat colonies (Sparkes et al., 2013) that typically loosely aggregate around *ad hoc* provision of food and shelter is considered to be challenging. Reasons for this challenge include the emotional connection evident in those who care for un-owned animals, perception as a public nuisance (Ash, Adams, Ash, & Adams, 2003), predation of native fauna (Baker, Bentley, Ansell, & Harris, 2005; Dickman, Denny, & Buckmaster, 2010; Gillies & Clout, 2003; Van Heezik, Smyth, Adams, & Gordon, 2010; Woods, McDonald, & Harris, 2003), and potential for acting as vectors of pathogens and diseases (Levinthal, 2010; Simking, Wongnakphet, Stich, & Jittapalapong, 2010).

Decisions regarding the management of un-owned cat populations must therefore take into account a wide range of perspectives (Jarvis, 1990) that span animal (and human) welfare considerations, as well as environmental issues that focus on ecology and the conservation of biodiversity (Loss, Will, & Marra, 2013; Marston & Bennett, 2009; Van Heezik et al., 2010). The multifaceted human–cat relationship which is dominated by emotional attachments to domestic cats or their perceived prey are therefore considered when management strategies are developed (Clarke & Pacin, 2002). An essential step towards developing effective management strategies is to understand the spatial and temporal distributions of cats: Thomas, Fellowes, and Baker (2012), for example, demonstrated that predation of native birds by urban domestic cats was mediated by both spatial and temporal

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processes.

Management strategies such as 'Trap-Neuter-Return' (TNR), 'capture and rehoming' and euthanasia seek to address the growth of stray cat populations in a humane way (Farnworth, Campbell, & Adams, 2011, 2013). Despite these measures, there is no clear evidence that the management of urban cat populations has been effective. In Melbourne, Australia Marston and Bennett (2009) have shown that the main driver for the growth of the urban cat population is through reproduction of un-sterilised and un-owned cats. Within New Zealand, studies show that the sterilisation rate of owned cats is approximately 90% (Farnworth et al., 2010; McKay, Farnworth, & Waran, 2009), yet un-owned cat populations are seemingly growing (Aguilar & Farnworth, 2012).

A growing un-owned cat population is of concern, particularly with respect to their impact on native fauna (Calver, Grayson, Lilith, & Dickman, 2011; Fitzgerald, 1990). For example, un-owned cats that live in a wild state distant from human populations (Schmidt, Lopez, & Collier, 2007) are considered to be responsible for at least 14% of extinctions of birds, mammals and reptiles globally in island environments (Medina et al., 2011). Additionally, urban un-owned cat populations may act as a source of animals that turn feral and colonise adjacent rural or semi-urban areas that may be of high conservation value (Ferreira et al., 2011) and protected in law (Van Heezik et al., 2010). Pet cats tend to have a limited home range and reduced likelihood of dispersal as their territory is centred around food and shelter provided by the owner (Kays and DeWan, 2004), whilst un-owned cats often experience significant pressure to disperse (Liberg, Sandell, Pontier, & Natoli, 2000) primarily due to food availability. In spatial terms, urban environments may therefore act as a source (i.e. centres of dispersal) for cat dispersal.

Spatial and temporal distribution of cat populations are amenable to investigation using GIS and species distribution mapping techniques. Such analyses can: (i) evaluate and assess current un-owned cat distributions; (ii) identify natural areas that are proximal to urban areas to evaluate colonisation risk; and (iii) build future scenarios using climate models. Species distribution modelling generates maps showing the suitability of areas for a particular species and is a widely used approach, with a rapidly growing volume of work utilising improved algorithms and software tools. Scenarios can be modelled for species of interest over a range of geographic and temporal scales, using a variety of environmental, socio-economic and non-biological information layers (Booth, Nix, Busby, & Hutchinson, 2014; Guisan et al., 2013; Sherrouse, Semmens, & Clement, 2014). Models describing the range or distribution of species from future climate scenarios contribute to the growing work on the effects of climate change, and provide information that can be used in preparing strategic or regional management plans (Bertelsmeier, Luque, & Courchamp, 2013; Hellman et al., 2008). The need to provide attention on the relationship between climate change, biodiversity and important species is well-documented (Bellard, Bertelsmeier, Leadley, Thuiller, & Courchamp, 2012; De Souza, Lorini, Alves, Cordeiro, & Vale, 2011; Irlich et al., 2014; Thomas, Franco, & Hill, 2006; Yates et al., 2009). Specifically, observations by Huyser, Ryan, and Cooper (2000) on changes in the use of habitats and population of an endemic bird, the lesser sheathbills (*Chionis minor*) of the sub-Antartic Marion Island brought about by the interactions of feral cats, mice and observed warming over the 20 year comparison period of the study suggests the need for further investigations on implications of climate change.

In this study, we used species distribution modelling to describe the current distribution of un-owned cats, and investigated the potential impacts of climate change on future distributions.

2. Methodology

ArcGIS and Maxent v3.3.3k (Phillips, Anderson, & Schapire, 2006) were used for processing un-owned cat data available from previous studies (Aguilar & Farnworth, 2012, 2013). Maxent has been used to model and predict the distribution of invasive species (De Queiroz et al., 2013; Domíguez-Vega, Monroy-Vilchis, Balderas-Valdivia, Gienger, & Ariano-Sánchez, 2012; Elith et al., 2006), endangered and threatened flora and fauna (Shochat et al., 2010), organisms of economic significance (Blanchard, O'Farrell, & Richardson, 2014) and ancient species (Connolly, Manning, Colledge, Dobney, & Shennan, 2012). Based on the maximum entropy algorithm that tries to determine the probability distribution that is the most spread out or close to uniform based on constraints dictated by available data, Maxent models the distribution of a species over a defined area using the location of each sample and a set of environmental variables of the area (Phillips et al., 2006). The result is a 'suitability map' depicting the probability of occurrence of the species at each raster cell of the area covered.

Maxent is widely used (Fourcade, Engler, Rödder, & Secondi, 2014) and found to provide better performance when compared to other approaches (Elith et al., 2006). Techniques addressing model validity and robustness such as spatial autocorrelation, background data bias, environmental heterogeneity and latitudinal bias were also utilised during data processing (Brown, 2014; Elith et al., 2011; Phillips & Dudik, 2008).

We used un-owned cat data (stray and colony) sourced from animal welfare organisations and reported in previous papers (Aguilar & Farnworth, 2012, 2013) as the basis for running two models. Model A was based solely from actual data modelled in Auckland and projected to the entire country. Model B used human population data as an analogue for un-owned cat presence data.

Model A (Auckland un-owned cat data) was run with the highest resolution (30 arc-second) Bioclim environmental layers downloaded from the Worldclim database (Hijmans, Cameron, Parra, Jones, & Jarvis, 2005). Bioclim is a dataset consisting of 19 climatic variables, eleven of which are measures of temperature and eight of precipitation. The variables represent annual trends, seasonality and environmental parameters that limit or describe extreme climatic conditions. These sets of variables are considered to be more informative for modelling than simple measures such as monthly temperature and precipitation averages. Bioclim is used widely for species distribution modelling (Guisan & Thuiller, 2005; Wakie, Evangelista, Jarnevich, & Laituri.M, 2014; Wasowicz,

Table 1
Land cover classification from based on distances from Land Cover Database of New Zealand grouped into favourable environments for un-owned cats.

Land class name	Group
Urban Parkland/Open Space, Transport Infrastructure Built-up Area (settlement).	5
Orchard, Vineyard or Other Perennial Crop Indigenous Forest, High Producing Exotic Grassland.	4
Tall Tussock Grassland, Manuka and/or Kanuka, Low Producing grassland, Exotic Forest, Deciduous Hardwoods, Broadleaved Indigenous Hardwoods.	3
Short-rotation Cropland, Mixed Exotic Shrubland, Gorse and/or Broom, Forest – Harvested, Flaxland, Fernland, Depleted Grassland	2
Surface Mine or Dump, Sub Alpine Shrubland, Sand or Gravel River, Permanent Snow and Ice Matagouri or Grey Scrub, Mangrove, Landslide, Lake or Pond, Herbaceous Saline, Vegetation, Herbaceous Freshwater Vegetation, Gravel or Rock, Estuarine Open Water, Alpine Grass/Herbfield	1