Conservation ecology of the Cape clawless otter, *Aonyx capensis*, in an urban environment.

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ABSTRACT

Coastal cities have impacted negatively on freshwater and marine ecosystems - primarily through habitat loss, fragmentation and pollution. Globally, it has been found that otter's dependence on these ecosystems exposes them to a myriad of threats, including loss of habitat, human-wildlife conflict and the bioaccumulation of toxic pollutants. The Cape clawless otter, *Aonyx capensis,* is the most widely distributed otter species in southern Africa and persists in human-modified habitats, including large cities. The Cape Peninsula provides a unique opportunity to study the impacts of urbanisation on otters as it presents a gradient from densely populated urban areas in the north (City of Cape Town) to sparsely populated areas interspersed with large expanses of natural habitat (Table Mountain National Park) in the south. In this thesis, I investigate the distribution, diet and threats to otters living on the Cape Peninsula. I use sign-based occupancy surveys to determine both broad and fine scale drivers of otter presence within the Peninsula's river systems and predicted that otters would avoid densely populated urban areas and rivers or sections thereof that are heavily transformed and polluted. I collected spraint from living otters and vibrissae from dead otters to investigate their diet. I predicted that otters would show an increased reliance on marine foods in areas where freshwater habitats were degraded in addition to seasonal variation in diet associated with the marked seasonal variation in rainfall and primary productivity typical of temperate Mediterranean ecosystems. I explored both immediate and long-term threats to otters by collating all records of conflict, injury and mortality reported over 5 years in addition to determining PCB levels from road-killed otters. Contrary to my predictions, otters did not avoid urban areas, and were more frequently detected in transformed lowland freshwater river systems close to Marine Protected Areas (MPA). Within rivers otters avoided the relatively pristine, yet unproductive, upper reaches of rivers as well as canalised sections and those with consistently high *E.coli* counts. I found that otters were feeding on both marine and freshwater prey in both polluted and non-polluted systems. Where large, transformed lowland wetlands were in close proximity to MPAs, otter diet consisted largely of a combination of freshwater crabs and exotic fish from the polluted systems as well as marine fish and rock lobster from the relatively unpolluted MPA. Isotope results complemented the faecal analyses and confirmed that otters show significant variation in diet between seasons, sites and individuals, suggesting an opportunistic and generalist foraging strategy. Importantly, the dietary results reinforce the distribution model that otters rely heavily on the interface between coastal and lowland wetland and river ecosystems close to the MPA, for both foraging and breeding habitat. However, these are the areas that are transformed and heavily impacted by urban development, and therefore the area where otters would most likely be at risk. I developed a hotspot map of otter conflict across the Peninsula and found that the Peninsula otter population experiences low to moderate levels of conflict throughout most of their current range. High conflict areas are associated with optimal habitat that has been fragmented by canalisation and urban development. Road-killed otters showed signs of accumulation of PCBs in liver tissue suggesting that despite otters being adaptable generalists, their dependence on polluted freshwater systems may have long-term health impacts. Mitigating these threats is possible with improved urban planning, waste water treatment and education of the public. However the success of these approaches requires long-term monitoring which is unlikely to be prioritised by resource constrained conservation authorities. I thus explored whether the large citizen science community in Cape Town can be used to monitor the population. I used Maxent to model otter distribution using citizen reported sightings over 5 years and compared the results with the occupancy model outputs. The predicted Maxent distribution mirrored that provided by occupancy models, and highlighted further areas of suitable otter habitat and routes for dispersal. Together my findings suggest that Cape clawless otters, like many other meso-carnivores in South Africa and globally, display a remarkable ability to adapt to human-modified environments using the interface between degraded freshwater systems and the inshore region to feed on a diverse range of prey. Of concern are the moderate to high levels of conflict with people and dogs, vehicle accidents and the accumulation of toxins. Long-term monitoring of the population and the effect of proposed interventions can be achieved by creating a platform for citizen sightings to be recorded in perpetuity at low cost. This platform can also serve as tool for educating the public on the global challenges of conserving biodiversity within and adjacent to large cities.

DEDICATION

I would like to dedicate this work to the original N.C. Okes, my grandmother Nancy, who introduced me to the otters living in front of her house when I was very young. She sparked my lifelong fascination with these magical creatures, and through our regular dog walks on Kommetjie beach, encouraged my curiosity and love for the ocean.

PLAGIARISM DECLARATION

This thesis/dissertation has been submitted to the Turnitin module and I confirm that my supervisor has seen my report and any concerns revealed by such have been resolved with my supervisor.

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Date: 13 March 2017

This research complied with protocols approved by the ethics committees of the University of Cape Town and South African National Parks and adhered to South African legal requirements. All research methods were approved and conducted with permission and relvant permits from CapeNature (permit 056-AAA041-0086), City of Cape Town and South African National Parks.

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It has always been a dream of mine to study otters, and I am profoundly grateful to those who have allowed me to make this a reality. The otter’s shy, elusive nature meant that studying them was always going to be an enormous task, and I would not have been able to conduct this research without the support of a large number of people.

I acknowledge the South African National Parks and CapeNature for permission to conduct the research and for access to field sites. In particular thank you to Gavin Bell, Jacqueline Smith and Justin Buchman of Table Mountain National Park (TMNP), and Coral Birss from CapeNature. I am particularly grateful to the TMNP Silvermine Division, whose environmental monitors regularly accompanied me into the wetlands and surrounds to ensure I was able to collect sufficient samples. Thank you to the City of Cape Town for permission and access to data. In particular, thank you to Joshua Gericke and his team for assistance in collecting samples. Thank you to the volunteers who assisted with fieldwork, specifically Fongo, Sean Marr and Irfan Nurfoo. The spatial analysis side of the PhD would have been an overwhelming task if it were not for Nicholas Lindenberg and Thomas Slingsby at the UCT Geographical Information Systems Lab at UCT. Thank you not only for the hours of advice and teaching, but also for providing a fun space to enthuse over otters and science fiction.

Thank you to the inspiring group of scientists that I have had the privilege of spending the last few years with. Lab 3.20 – in particular Marine, Marion, Leigh, Tammy, Nikki, Storme, Zoë, Gareth, Guy, Ross, Matty, Rogan, Vince and Vinny – I will forever be grateful for your friendship and help with various statistical challenges. Thank you for not only welcoming me, but also Graeme, into the lab. Thank you for always providing a shoulder to punch and for not only tolerating, but also partaking in, the early morning ‘crazy’. I will especially miss our bizarre lunch conversations and stress-relieving runs and hikes on the slopes of Table Mountain.

Thank you to my family. You know better than anyone that I can never get the words right, but here goes. To my parents, thank you for the all-round support you provided during the PhD, from logistics, company on otter trips; for being available for 4am “are you awake?” texts; for listening; for spelling out o-t-t-e-r when I was too overwhelmed to even hear the

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I am deeply grateful to my husband, Graeme. Graeme, thank you for understanding my commitment to this project and for sharing my passion for data, science and wildlife. Thank you for the late nights accompanying me on otter-tracking trips around the Peninsula; for fixing crab traps at 3am; for collecting road-kills in your lunch hour; for being equally ecstatic about finding otter poo; for your limitless humour that kept me laughing when things got tough. Thank you for Pete, Hannah and perspective – the list is endless. I am especially grateful for your patience, untiring optimism and love over the last five years. This PhD couldn’t have been done without you.

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CHAPTER 1: INTRODUCTION

General Introduction

An expanding human population and increasing pressure for resources has resulted in landscape changes worldwide (Foley et al., 2005; Meyer and Turner, 1992). These changes are most evident at the confluence of protected coastal areas and large freshwater ecosystems (Vitousek et al., 1997) which facilitate access to ocean trade routes while providing access to both freshwater and marine resources (Neumann et al., 2015). Currently over half of the world's settlements occur within 100km of the coastline (Small and Nicholls, 2003) and an estimated 90% of the population live within 10km of a freshwater body (Kummu et al., 2011).

As the human population continues to grow and increase in density in urban areas (Seto et al., 2012), so wildlife communities reliant on both freshwater and coastal habitats are experiencing greater anthropogenic pressures. The threats to freshwater systems are well documented (Dudgeon et al., 2006), and include abstraction, pollution, flow modification, habitat degradation and invasion by exotic species (Dudgeon et al., 2006; Ormerod et al., 2010). Central to these threats are increasing demands on the finite supply of fresh water with the result that two-thirds of the world's rivers are expected to be regulated by the end of the 21st century (Vitousek et al., 1997).

The open and linear nature of oceanic and freshwater aquatic ecosystems respectively limits the use of boundaries for the protection of endangered species and/or ecosystems, as is possible in terrestrial systems (Dudgeon et al., 2006). Conservation strategies in freshwater ecosystems thus require the management of upstream drainage networks, the surrounding land, the riparian zone (Pusey and Arthington, 2003), as well as downstream reaches including floodplains, estuaries and inshore coastal zones (Dudgeon et al., 2006). Management of the confluence of freshwater and marine systems therefore requires a holistic approach, considering the system from source to sea, and the development of partnerships at drainage-basin scales (Dudgeon et al., 2006).

Impacts of urbanisation on freshwater ecosystems

Urbanisation has led to radical changes in freshwater systems and coastal wetlands throughout the globe (Alberti et al., 2007; Lee et al., 2006). The damming and canalising of waterbodies has led to habitat fragmentation and degradation with the loss of numerous aquatic species (Kozlowski and Bondallaz, 2013). The clearing of riparian vegetation and an increase in impervious surfaces such as roads and roofs, has led to enhanced runoff, erosion, and reduced water quality due to the input of metals, oils, and organic chemicals (Brown et al., 2005). Globally, studies have shown that progressively more species are being negatively impacted by water pollution in agricultural and urbanised areas (Bornman et al., 2010). Pollution has been identified as the major cause of the decline in fish diversity in West Africa (Kouamelan et al., 2003), the loss of nesting sites for turtles in the Mediterranean (Kasparek et al., 2001), mortality and malformation of fish embryos off the USA's Atlantic coast (Longwell et al., 1992) and the poisonous bioaccumulation of butyltins in fish around the world (Kannan et al., 1995).

Of greatest concern in urban areas is sewage, and the dumping or run off or waste into waterways. The greatest volume of waste discharged to the aquatic environment is through sewage (Islam and Tanaka, 2004). Sewage effluent contains industrial waste, municipal waste, domestic waste, animal remains and faecal matter, all containing a variety of harmful substances including viral and bacterial pathogens, toxic chemicals such as organochlorines, polychlorinated biphenyls (PCBs) and heavy metals (Islam and Tanaka, 2004). Sewage can therefore have long-term impacts on most aquatic species through the transfer of disease and the accumulation of toxic heavy metals and organochlorines in the food chain.

Otter ecology

Having evolved in habitats that are heavily used and adversely impacted by humans, the Mustelid sub-family of otters, Lutrinae, are endangered or threatened through much of their global distribution. Otters are carnivorous mammals adapted to a semi-aquatic, aquatic and/or marine lifestyle. Each of the thirteen species of otter has adapted to its specific habitat and dietary requirements, but share striking similarities in morphology and life history. Their fur, designed for thermoregulation in the absence of subcutaneous fat, is considered the most dense of all mammals (Liwanag et al., 2012), making them a valuable target for the fur trade. Their reliance on aquatic prey exposes them to competition, and therefore conflict, over both freshwater and fish resources with multiple users and stakeholders. As wetlands are natural 'receivers' of land-use effluents (Dudgeon et al., 2006), they harbour a variety of pollutants – many of which bioaccumulate in aquatic food chains. Therefore in addition to terrestrial habitat loss otters face a multitude of additional pressures and it is thus not surprising that of the thirteen species worldwide, only one remains listed by the IUCN Red List as Least Concern (North American River otter, *Lontra* *canadensis*, Serfass et al. 2015). The other twelve species are listed as either Near Threatened, Threatened, Vulnerable, or Endangered (Table 1.1).

Sea otters, *Enhydra lutris*, are currently listed as Endangered with disease, oil spills and human disturbance impeding their recovery from past extirpation events (Doroff and Burdin, 2015). European otters, *Lutra lutra*, are currently Near Threatened having suffered large declines and local extinctions in the 1900's; due largely to environmental contamination (Roos et al., 2015). Certain toxic compounds (e.g. DDT, dieldrin and PCBs) thought to be responsible for adversely affecting the health of humans and animals were subsequently banned, and otter populations in particular have shown signs of recovery in parts of their distribution. However, road traffic accidents have emerged as the major cause of otter mortality in Europe, potentially threatening the recovery of the species in certain regions (Philcox et al., 1999). In Asia, all three species are either Vulnerable or Endangered due to a combination of habitat destruction and overfishing of their main prey species (Aadrean et al., 2015; De Silva et al., 2015; Wright et al., 2015). In South America, three out of the four species of otters are classified as Endangered; all of them threatened by habitat destruction, gold mining, the development of hydroelectric dams and conflict with local fisheries (Groenendijk et al. 2015; Rheingantz & Trinca 2015).

All three African otter species were listed as Least Concern until 2015, when their status was changed to Near Threatened. The authors cite 'perceived and assumed population decline' due to the 'alteration or degradation of freshwater habitat and riparian vegetation' as the main reasons for the change in status (Jacques et al., 2015). Although otters are being negatively impacted by these factors, the lack of evidence to support these claims points to the paucity of research on the pressures that African otters are facing.

Table 1.1. A summary of the IUCN status, CITES listing and major threats and conservation concerns for the thirteen species of otter found worldwide (IUCN Red List Assessment). IUCN Status abbreviations: LC = Least Concern, NT = Near Threatened, VU = Vulnerable, EN = Endangered. Fisheries*: C = Conflict with fishermen; B = Bycatch in fisheries; O = Impacted by overfishing of prey base.

				Threats and conservation concerns						
Species	**Distribution**	**IUCN Status**	**CITES**	**Vehicle accidents**	**Habitat destruction**	**Pollution**	**Urban development**	**Dogs**	**Disease**	**Fisheries***
Congo clawless otter, *Aonyx congicus*	Africa	NT	II		X	X	X			C,O
Spotted-necked otter, *Hydrictis maculicollis*	Africa	NT	II		X	X	X			C,B,O
Cape clawless otter, *Aonyx capensis*	Africa	NT	II	X	X	X	X	X		
Hairy-nosed otter, *Lutra sumatrana*	Asia	EN	II		X		X			O
Asian small-clawed otter, *Aonyx cinereus*	Asia	VU	II		X	X	X			O
Smooth-coated otter, *Lutrogale perspicillata*	Asia	VU	II		X	X				C,O
Eurasian otter, *Lutra lutra*	Europe	NT	I	X	X	X	X			C,B
North American river otter, *Lontra canadensis*	North America	LC	II			X			X	
Sea otter, *Enhydra lutris*	North America	EN	I			X			X	C,B

				Threats and conservation concerns						
Species	**Distribution**	**IUCN Status**	**CITES**	**Vehicle accidents**	**Habitat destruction**	**Pollution**	**Urban development**	**Dogs**	**Disease**	**Fisheries***
Neotropical otter, *Lontra longicaudis*	South America	NT	I	X	X	X				C
Marine otter, *Lontra felina*	South America	EN	I		X	X	X	X		C,B
Southern River otter, *Lontra provocax*	South America	EN	I		X		X	X	X	C
Giant otter, *Pteronura brasiliensis*	South America	EN	I		X	X	X		X	C

Cape clawless otter ecology

Cape clawless otters, *Aonyx capensis*, are endemic to the African continent and are the most widespread of the four otter species found in Africa. They occur over a broad geographical range; inhabiting landscapes of widely varying altitudes, rainfall and temperature (Nel and Somers, 2007). Their range extends from South Africa to Ethiopia in the Northeast and Senegal in the Northwest (Hoffmann, 2008). They are, however, mostly absent from the arid south-western areas of South Africa and Namibia (Smithers, 1983, Lariviere, 2001). They share their range with the Spotted Necked Otter, *Lutra maculicollis*, in the northeast and central parts of the continent, and with the Congo clawless otter, *Aonyx congicus*, in the central rainforest regions of the Democratic Republic of Congo (Lariviere, 2001), although the extent of the overlap between these two species is currently unresolved (Nel and Somers, 2007).

Figure 1.1. Extant distribution of the Cape clawless otter (*Aonyx capensis*). Data sourced from the IUCN Red List.

Much of our current knowledge on Cape clawless otters originates from Southern African research, where otters were well studied from the 1970's to 2000's. Preliminary research focussed on otter diet, due to the need to understand whether otters were feeding on prized sports fish and game birds. In the latter years, it became apparent that an understanding of their ecology and habitat requirements was required in order to ensure that otter populations could be managed and conserved appropriately in light of rapid rural and urban development of riparian and coastal habitat.

The Cape clawless otter occupies both marine and freshwater habitats, and is adapted physically and behaviourally to forage in both environments. Their unusually large, modified kidneys have a discrete, multirenculate structure adapted to radical changes in salt concentrations of the blood (Beuchat, 1999). *Aonyx* species and sister genus *Amblonyx* (small clawed otter, *Amblonyx cinerus*) both show a unique enlargement of the forelimb sensory projection area of the cerebral cortex, which is associated with the greater tactile sensitivity and dexterity of the forepaws. In addition, and as their name implies, Cape clawless otters have no claws on their forefeet which together with heightened sensitivity are thought to be important adaptations for foraging on crustaceans that seek refuge in cracks and holes of rocky substrates. Despite these adaptations Cape clawless otters are highly opportunistic feeders with records of them attacking diverse prey including sheep, domestic water and terrestrial foul, rats and a broad diversity of indigenous and exotic fish species (Jordaan et al., 2015; Parker and Burchell, 2005; Perrin and Carugati, 2000; Somers and Nel, 2003). The combination of a generalist, opportunistic diet and the use of a broad range of habitat types may explain the wide distribution and prevalence of this otter species throughout central and southern Africa (Nel and Somers, 2007). Despite their ability to adapt and their tolerance of moderate levels of pollution (Somers, 2001), they are constrained by two variables viz., fresh water and dense riparian vegetation. Water is essential for drinking and maintaining the insulation properties of their fur, while riparian vegetation is needed to provide cover and protection for holts (breeding sites).

Currently, little is known of the social structure or reproductive biology of Cape clawless otters. What has been observed suggests that otters occupy separate, occasionally overlapping, single-sex group territories (Arden-Clarke, 1986; Kruuk, 2006). It is generally believed that females will give birth to 2-3 pups once a year, and that males are not involved in caring for offspring. Otter pups are born blind and are dependent on their mothers for up to a year, after which they are thought to disperse into neighbouring habitat. It is at these times when otters are at their most vulnerable in an urban environment as they typically have to traverse human-modified land exposing them to vehicles, dogs and a multitude of pollutants associated with urban waterways.

Cape clawless otter conservation status and threats

Cape clawless otters occur in a number of protected areas across their range, e.g. Tsitsikamma National Park, and are included in CITES Appendix II. Although there is a lack of research on the population status of the Cape clawless otter, populations are thought to be decreasing throughout most of their range based on perceived and assumed threats (Jacques et al., 2015). These threats include the declining state of freshwater systems and the loss of vital freshwater habitat across Africa (Jacques et al., 2015). In agricultural areas, otters come into conflict with fishing communities and poultry farmers (Rowe-Rowe, 1995), either as bycatch in fishing nets or as retributive killing for stock losses. In parts of their range, they may be killed for skins and other body parts (De Luca and Mpunga, 2005), including as traditional medicine (Cunningham and Zondi, 1991). In the Lesotho Highlands, for example, inhabitants report that Cape clawless otters are commonly used for traditional medicine, clothes, hats, and as food (Avenant, 2004).

In South Africa, the major threat facing Cape clawless otters is thought to be habitat loss associated with bush clearing, deforestation, overgrazing, siltation, expansion of human settlements, draining of wetlands, water extraction and denudation of riparian vegetation (CSIR, 2010; Nel et al., 2007; Rowe-Rowe, 1995).

Thesis outline

The overall objective of my thesis is to improve the baseline understanding of otter ecology in an urban environment, and to identify the threats they face due to exposure to a human influenced landscape.

In **Chapter 2**, I provide a brief introduction to the study area, the Cape Peninsula.

In **Chapter 3** I used sign based occupancy surveys to map the distribution of the Peninsula's otter population, and the likely drivers of their distribution within aquatic systems.

In **Chapter 4** I used faecal analysis to quantify the diet of otters across the urban gradient. I also conducted the first isotope analyses on this species to complement the findings of the spraints analysis and explore individual dietary variation in otters.

In **Chapter 5** I involved the local community in collecting data on otter sightings, interactions and vehicle accidents to develop a hotspot map of otter conflict across the Peninsula. I dissected road-killed otters to compare the body condition of the Peninsula otters to previous studies in relatively natural areas, and provide the first study on levels of PCB contamination in Cape clawless otter tissue.

In **Chapter 6** I determined whether citizen science reporting of otter sightings can complement standardized river surveys to monitor the urban otter population in the future.

Finally, in **Chapter 7** I summarise my key findings in the broader context of global otter conservation; and consider the specific management options for the Peninsula's urban otter population.

CHAPTER 2: DESCRIPTION OF STUDY AREA

Study Area

My study area, the Cape Peninsula, is located in the southwestern-most tip of the Western Cape of South Africa (33°56’ - 34°19’S, 18°25’ - 18°26’E). The Western Cape falls within a Mediterranean climate zone, with an annual average rainfall of 595 – 1 015mm, which is above the national average of 450mm per year. It is home to the unique Cape Floristic Region (CFR) - a globally important hotspot of biodiversity for plants and invertebrates, and one of the six floral kingdoms of the world (Cowling et al., 1996). The Cape Peninsula lies in the far south of the Western Cape, forming a narrow, geographically isolated strip of land that extends over 470km^2 and is characterised by summer drought, infertile soils, strong winds and periodic fire (Cowling et al., 1996). As the Peninsula forms part of the Cape Folded Belt, it is characterised by high topographical diversity. In the north, the topography is dominated by a sandstone plateau and ridges that reach a maximum altitude of 1 113m on Table Mountain (Cowling et al., 1996). In the south, the topography is dominated by a low sandstone plateau with few coastal dunes of quaternary sand (Taylor, 1969).

The freshwater environment

The soil on the Cape Peninsula is typical of soils in the Cape Floristic Region in that they are fairly poor and infertile, which has unique consequences for the aquatic systems that drain this region. This soil supports a diverse array of fynbos species, which produce phenol-rich tannins, flavonoids and humic acids in their leaves to deter herbivores (Griffiths et al., 2015). When the fynbos decomposes, these phenols leech into the rivers, leading to relatively acidic freshwater in the Peninsula. Despite these unusual conditions the freshwater rivers and wetlands of the Peninsula support a number of indigenous invertebrate and vertebrate species that together form part of the prey base for otters (Griffiths et al., 2015).

The main freshwater crab species found in the Cape Peninsula, is the Cape river crab, *Potamanutes perlatus*. Frog species include the endangered Table Mountain Ghost frog *Heleophyrne rose*, the endangered Western Leopard Toad *Bufo pantherinus*, the Cape river frog, *Amietia fuscigula*, and both the Cape and Common platanas*, Xenopus gilli* and *Xenopus laevis*. The rivers of the Cape Florisitc Region have 19 indigenous fish species, 16 of which are endemic. However, only three of these species have been recorded in the rivers of the greater City of Cape Town and Cape Peninsula.

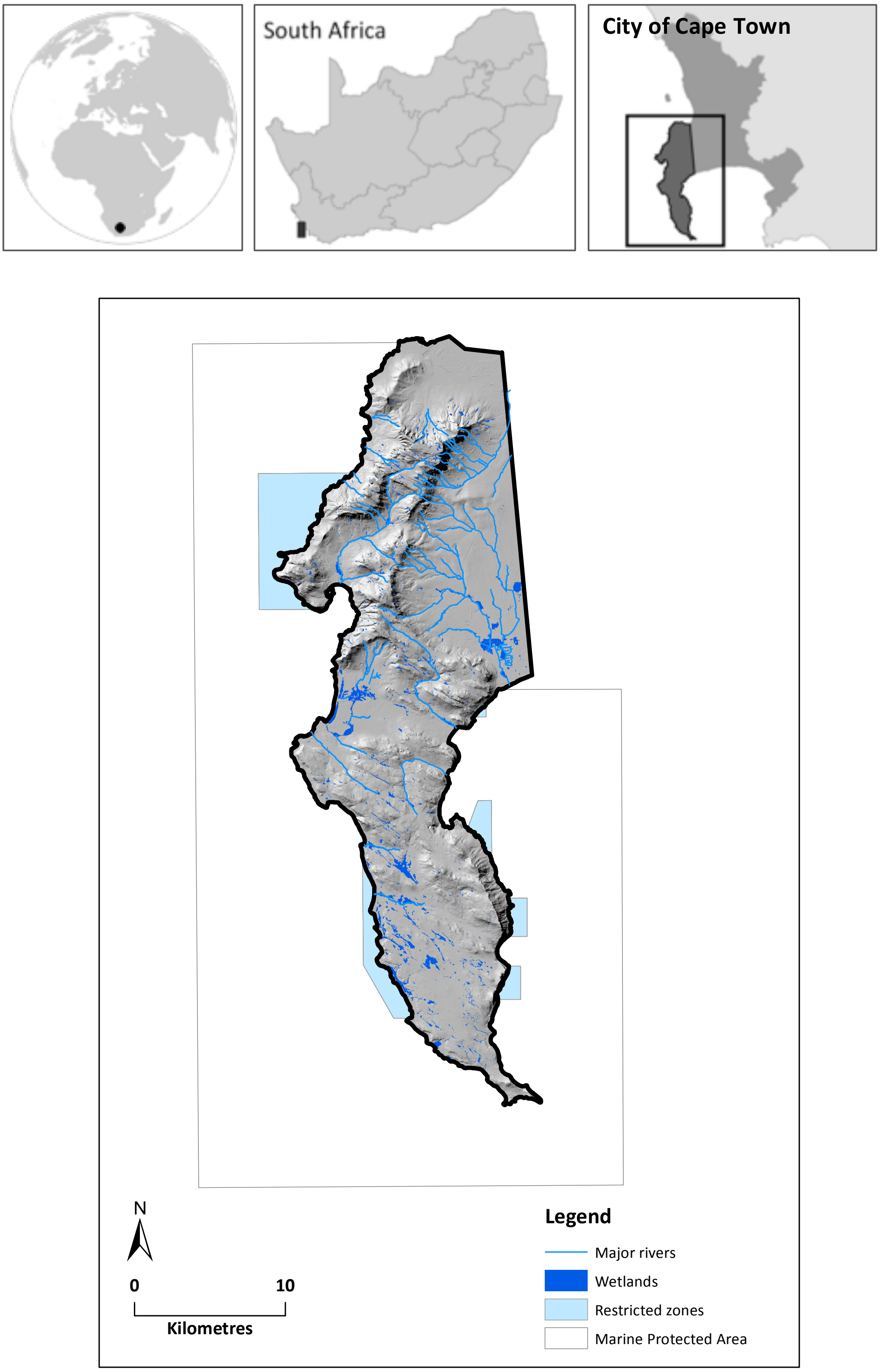


Figure 2.1. The study area, the Cape Peninsula, extending from the City of Cape Town in the North to Cape Point in the South. The Peninsula is the southwestern most tip of the Western Cape, South Africa.

These are the Cape kurper *Sandelia capensis*, Berg River Redfin *Pseudobarbus burgi* and Cape galaxias, *Galaxias zebratus*. Numerous exotic fish species have been introduced from Europe and North America into the CFR rivers in the last 100 years for angling purposes and include Brown trout *Salmo trutta*, Carp *Cyprinus carpio*, Largemouth bass *Micropterus salmoides* and rainbow trout *Oncorhynchus mykiss*. In the last 50 years, fish species from other parts of Southern Africa have also been introduced including, banded tilapia *Tilapia sparmanni*, Mozambique tilapia *Oreochromis mossambicus* and African sharptooth catfish *Clarias gariepinus* – all of which can be found in the lower reaches of most Peninsula rivers (River Health Programme, 2005).

The freshwater systems across Cape Peninsula also support a variety of wetland birds including: gallinules, ducks and herons including Cape teal *Anas capensis*, Cape shoveller *Anas smithii*, Egyptian geese *Alopochen aegyptiaca*, the exotic European Mallard duck *Anus platyrhynchos* and the Yellow billed duck *Anas undulate*. Small mammals include a variety of wetland rodents such as the Vlei rat *Otomys irroratus*, Water mongoose *Atilax paludinosus*, Cape genet *Genetta tigrina* and Cape grey mongoose *Galerella pulverulenta*.

The marine environment

The Cape Peninsula broadly divides the cold Benguela current of the Atlantic Ocean in the west from the warmer waters of the Agulhas current (Indian Ocean) in the east. The eastern coastline abuts False Bay, a relatively shallow (maximum depth of 100m) but large bay, which includes waters derived from both the cold and warm currents. False Bay is home to a diverse range of marine life, including intertidal, benthic and pelagic crustaceans, teleosts, birds and mammals – many of which form the marine prey base for otters. These include West Coast Rock Lobster *Jasus llandii*, Cape rock crab *Plagusia chabrus*; the intertidal Rockfish *Clinus* spp.; numerous pelagic and benthic fish species including Elf *Pomatomus saltatrix* and Rocksuckers *Chorisochismus dentex*; and coastal birds such as Cape cormorants *Phalacrocorax capensis*. Marine apex predators include the Great white shark *Carcharodon carcharias*, and the Broadnosed sevengill cowshark *Notorynchus cepedianus*, which are both resident in False Bay and assumed to predate on otters opportunistically.

Human influences and environmental transformation

The Cape Peninsula falls within the boundaries of the City of Cape Town's Southern District and his home to an estimated 300 000 people and serviced by an extensive road network (City of Cape Town, 2012a). The Peninsula consists of the densely urbanised southern suburbs in the east; winelands and agricultural land in the west, and the bulk of Table Mountain National Park in the far south (City of Cape Town, 2012). Approximately 87% of Table Mountain National Park (TMNP) falls within the Peninsula, and the geology and distinct features of the Table Mountain range have historically shaped the river systems in the area (Brown and Magoba, 2009; City of Cape Town, 2012a).

Peninsula rivers have their source in the Table Mountain Range, and are thus narrow, steep and relatively short, flattening out rapidly into an estuary or floodplain before reaching the sea (Brown and Magoba, 2009). The upper reaches of the rivers mostly lie within the protected borders of Table Mountain National Park, while the low lying areas are dominated by urban development including mixed industrial and residential land use (River Health Programme, 2005).

Polluted storm water, solid waste and sewage overflows are common sources of pollution in Cape Town's urban rivers and are assumed to pose a health risk to the fauna that are dependent on these systems (Davison and Marshak, 2012). Domestic wastewater, for example, carries phosphate and nitrates which lead to eutrophication and sometimes toxic algal blooms, including cyano-bacteria such a *Microcystis*. Although not all algal blooms are toxic, they tend to bloom and die off creating oxygen deficits which in turn have adverse impacts on the fauna in the system.

Figure 2.2. An aerial view of the Cape Peninsula, with the study area to the south and west of the red dashed line. The Cape Peninsula is accurately summarised by Cowling et al. (1996): “The Peninsula represents a microcosm of the forces threatening biodiveristy in the developed (formal urbanisation, pollution, industry, exotic flora and fauna), and developing (informal housing, domestic pollution, plant harvesting, snaring) worlds”.

CHAPTER 3:

OTTER OCCUPANCY IN THE CAPE PENINSULA: ESTIMATING THE PROBABILITY OF RIVER HABITAT USE BY CAPE CLAWLESS OTTERS, *AONYX CAPENSIS*, ACROSS A GRADIENT OF ANTHROPOGENIC INFLUENCE.

Abstract

The distribution of Cape clawless otters, *Aonyx capensis*, in South Africa and their habitat requirements in freshwater and marine systems has been well established. There is, however, a lack of information on how otters are adapting to urbanisation and the transformation of critical freshwater habitat. Within the Western Cape, the Cape Peninsula exhibits substantial variation in levels of human impact over a small geographic range, offering an excellent opportunity to explore the hypothesis that otters are adversely impacted by habitat transformation. I used a single season occupancy model based on otter sign to determine the probability of otter occupancy across a gradient of habitat transformation at both landscape and local scales. The probability of otters occupying river habitat in the Cape Peninsula was low ($p = 0.29$) but increased with proximity to Marine Protected Areas (MPAs) that included estuaries and wetland habitat. Despite being heavily transformed, lowland aquatic ecosystems may still provide critical resources in the form of fresh water and breeding sites, and together with food within the marine habitat may be sustaining the Peninsula's otter population. Otter presence was not influenced by proximity to urbanised areas at the landscape scale, but declined in canalised sections of river that were heavily impacted by human activity. Annual single season occupancy surveys provide a rapid, cost-effective method for monitoring changes in otter occupancy which should be incorporated into current monitoring efforts to provide much needed long-term monitoring of a top predator in freshwater ecosystems.

Introduction

An understanding of a species' distribution and their specific habitat requirements at both landscape and local scales is vital for their effective conservation and management (Barbosa et al., 2003; Jeffress et al., 2011). Such data is particularly important in human-modified ecosystems where the effective conservation of fragmented habitat or restoration of degraded areas may greatly improve a species' ability to persist (Brancalion et al., 2013; Marzluff and Ewing, 2008). Often, however, reliable estimates of a species' key habitat requirements can be difficult to obtain due to the challenges of detecting individuals and inferring habitat choice from presence data (Gese, 2001; Yoccoz et al., 2001).

Due to their elusive nature and aquatic lifestyle, otter species pose unique challenges in obtaining estimates of population parameters and habitat requirements (Gallant, 2007). Thus, globally, otter research has relied upon the standardized otter-specific survey methods that were designed and developed in the United Kingdom in the 1970's in response to the need to monitor the now Near Threatened European otter (*Lutra lutra*) (Lenton et al., 1980; Ruiz-Olmo et al., 2001). The method has since become well established and standardised sign surveys have been used extensively to estimate key population parameters such as relative abundance, density, distribution and habitat use of otter species around the world (Chehebar, 1985; Macdonald and Mason, 1985; Mason and Macdonald, 1987; Parry et al., 2013; Prakash et al., 2012).

Although it is widely accepted that sign surveys provide a reliable method of determining otter presence, the accuracy and validity of this method for inferring these key population parameters has been subject to much debate (Jefferies, 1977; Kruuk and Conroy, 1987; Mason and Macdonald, 1987; Ruiz-Olmo et al., 2001). The benefits of the sampling technique must be weighed against the potential errors caused by variation in individual behaviour (Crowley et al., 2012), the detectability of sign (Reid et al., 2013; Ruiz-Olmo et al., 2001) and the inherent vulnerability of presence/absence surveys to Type II errors (false negatives) (Mackenzie et al., 2005; Reid et al., 2013).

Occupancy models address these concerns by incorporating detection probabilities to account for false negatives and provide a framework which allows for the analysis of environmental variation in the form of model covariates (Mackenzie et al., 2005). Recently, they have been used to aid the understanding of the distribution, habitat and monitoring of otters around the world (Aing et al., 2011; Jeffress et al., 2011; Prakash et al., 2012) and have the potential to be used in long-term monitoring plans for other elusive, riparian mammals (Lesmeister and Nielsen, 2011).

An occupancy approach has not yet been attempted for the Cape clawless otters, *Aonyx capensis* (Near Threatened, Jacques et al., 2015), and this study is the first to investigate the distribution and habitat use of Cape clawless otters in an urban environment using an occupancy framework. Previous research on habitat preferences of otters in South Africa has highlighted the key habitat requirements associated with otter presence, namely freshwater and dense riparian vegetation (Nel and Somers, 2007; Perrin and Carugati, 2000; Van Niekerk et al., 1998). Yet we lack an understanding of how otters are adapting to the transformation of rivers for human use through increased canalisation, changes in riparian vegetation, increased pollution, altered flow regimes and the introduction of exotic prey species. An urban environment provides barriers that may limit dispersal, including weirs, extensive road networks and fences. Within the Western Cape, the Cape Peninsula exhibits substantial variation in levels of human impact over a small geographic range, offering an excellent opportunity to examine otter presence along a gradient of habitat transformation. The northern part of the Peninsula includes a mix of heavy and light industry, dense residential suburbs, and an extensive road network. As one moves south there is a reduction in the levels of urbanisation with the far south comprised of a protected area, the Cape of Good Hope section of Table Mountain National Park.

This chapter aims to use occupancy modelling to firstly, provide a baseline of otter occupancy in river habitat across the Peninsula at the landscape scale, and secondly, to determine the drivers of distribution at a local scale within urban, freshwater rivers. I test the hypothesis that transformation of aquatic ecosystems will have an adverse impact on the presence of otters, and predict that transformation in the form of canalisation, reduced water quality, extensive road networks and a lack of suitable riparian vegetation will have an adverse impact on otter presence and persistence. I propose to use the findings of the occupancy surveys to derive a long-term monitoring for the future conservation of the Peninsula otter population.

Methods

Study area

The study area is described in detail in Chapter 2. I selected ten out of a possible seventeen rivers on the Peninsula (Figure 3.1) for inclusion in the occupancy surveys. Rivers were chosen to provide variation in key variables associated with urbanization including levels of pollution and habitat transformation. The 10 rivers were roughly divided into five heavily transformed and/or polluted rivers in the northern section of the Peninsula and five relatively pristine rivers in the south.

Field data collection

I assumed that otters will frequent rivers, wetlands and other aquatic systems due to their dependence on fresh water (Nel and Somers, 2007; van Niekerk et al., 1998). Surveys entailed searching for otter sign (spraints and/or footprints) along 600m transects. A key assumption of the MacKenzie et al. (2002) occupancy model is that detection of the species at each site is independent of all other sites. To ensure spatial independence transects were spaced at least 2km apart, based on previous estimates of otter home range and density in coastal and river ecosystems (Somers and Nel, 2004; Verwoerd, 1987). I included 'River' and 'Location' as observation-level detection covariates in the occupancy model to account for potential non-independence of sites due to the linear nature of rivers. Variation in total river length resulted in a minimum of two and a maximum of four transects per river. Each 600m transect was divided into six, 100m spatial replicates (segments) and was surveyed on three separate occasions (temporal replicates) over the three month study period. Both banks were thoroughly searched by the same two observers for all surveys. The presence of otter sign (spraint and/or footprints) in each 100m replicate was recorded as 1 and absence as 0.

Surveys were restricted to the austral summer season (January – March, 2014), the driest time of year in the Peninsula. This minimized the chance of heavy rains impacting on the detectability of sign (Fusillo et al., 2007; Parry et al., 2013; Prakash et al., 2012) and increased access to sites along the river edge. Another key assumption of the occupancy model used is that sites are closed to changes in occupancy during the survey period (Mackenzie et al., 2002), meaning that if otters were present in at least one of the three temporally replicated surveys, the model then assumes they were present for all surveys but not detected and therefore recorded as 'false negatives' (Rota et al., 2009). The short duration of my study period (3 months) represents a compromise between obtaining temporal replicates while not violating the assumption of a closed population.

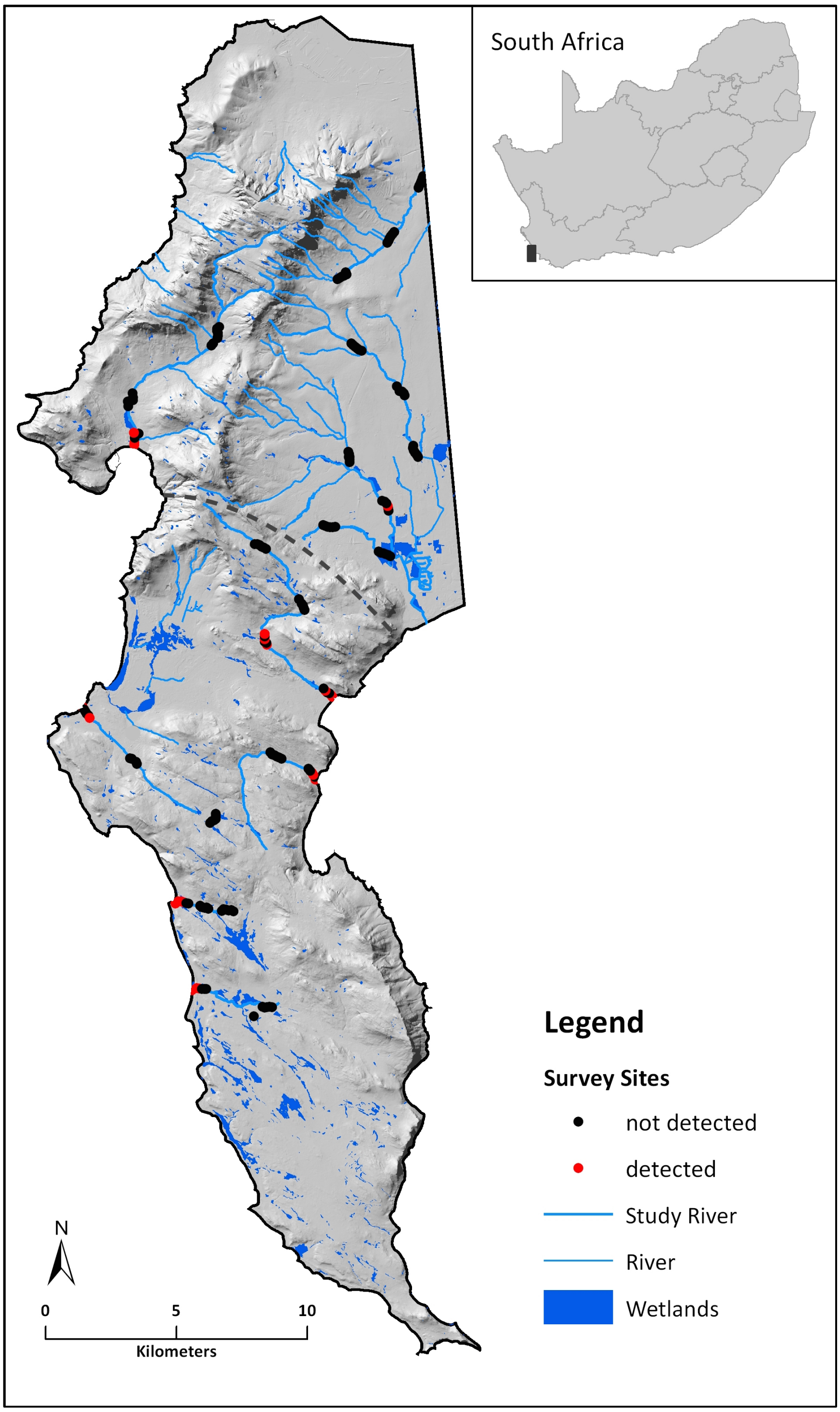


Figure 3.1. Map of the study area indicating all rivers and wetlands on the Cape Peninsula and those that were sampled in this study. The dashed line signifies the divide between the five northern and five southern rivers that together comprise the ten rivers included in the occupancy survey. Black dots indicate sample sites where no otters were detected while red dots denote areas sampled where otters were detected.

Covariate data collection

Covariates describing site-specific habitat, topography, human population density, and conservation status of terrestrial and marine habitat were extracted from GIS layers of the area using ArcGIS v 10.1 Software (Table 3.1). Habitat variables recorded on site were: shore substrate (grass, stone, sand/soil, dense vegetation), canalisation (0/1), bank vegetation (dense, overhanging, emergent, open (sparse, little vegetation), or grass), the presence of reeds on the river bank specifically as a measure of habitat available for holts or resting sites (0/1) and the presence of visible pollution (e.g. solid waste, 0/1) (Table 3.1b). Where more than one classification per covariate was present in a transect, the classification that represented 60% or more of the transect was selected. In addition, observers recorded the level of disturbance at each site as an observation level covariate. Disturbance included recreational use and management interventions and ranged from zero to three according to these criteria: 0 - no disturbance; 1 - limited evidence of recreational use; 2 - moderate evidence of recreational use, including dog activity; and 3 - frequent recreational use and/or vegetation clearing.

Water chemistry data for the past ten years was provided on request by the City of Cape Town. I followed the City of Cape Town in using orthophosphates as a measure of eutrophication, and *E. coli* counts as a measure of bacterial contamination (City of Cape Town, 2012b). For each site I calculated the number of years in the last decade in which orthophosphate levels fell within the eutrophic range (25 – 250 μg/ml) and *E.coli* counts were above the acceptable level for contact (>1000 counts/100ml).

Statistical analyses

Data were analysed using a single species, single season occupancy model (Mackenzie et al., 2006, 2002) using the package 'unmarked' (Fiske and Chandler, 2011) within R 3.2.0 (The R Foundation, 2014). Detection histories were constructed for either sign, and occupancy was analysed at both landscape and local scales. To determine the probability of otter occupancy at the landscape scale I used the 600m transects as the independent variable and to determine local scale predictors of habitat use, I used the 100m spatial replicates within each 600m transect as the independent variable. Initially, a naïve estimate of occupancy was calculated, not accounting for false absences (number of sites where presence was detected/number of sites surveyed). A null model was then developed at the landscape scale, holding both the probability of detection (p) and the probability of occupancy (Ψ)

constant. To build a set of candidate models, I first considered observation-level detection covariates. Holding detection probability constant, univariate analysis of each factor was conducted. Covariates having a significant impact on occupancy estimates were carried forward for inclusion in the univariate analyses of site-specific covariates. Site-specific covariates were chosen for inclusion in the analysis based on my *a priori* hypothesis and predictions. Covariates were analysed in a correlation matrix (Spearmans Correlation, Table 3.2) in R to eliminate redundancy in the data set. For each pair that was strongly correlated ($r_s > 0.7$), I eliminated the covariate with the higher AIC value from subsequent analyses as well as those that had a non-significant effect in univariate form (Midlane et al., 2014). I built a final set of 10 candidate models based on our key hypothesis and organized them using the fitList function and the AIC-based model selection (modSel) process to determine the best model (Fiske and Chandler, 2011). Goodness-of-fit tests were conducted on the top four ranking models using parametric bootstrapping techniques (n = 200) which fits the statistic Pearsons χ^2 as per MacKenzie and Bailey (2004). I plotted the probability of occupancy against the best fitting explanatory covariates, and used the predict function to map the expected distribution of otters across the City of Cape Town based on the best model.

Results from the landscape scale occupancy model were used to inform the local scale analysis of drivers of habitat use within rivers. Only sites that were predicted to have a relatively high occupancy probability at the landscape scale were included in the local scale occupancy model. A total of 77, 100m segments were therefore sub-sampled from the full dataset of 168, 100m segments and analysed together with local habitat covariates (Table 3.1b). Models were built, analysed and selected following the same process described above. Probability estimates from the local scale analysis were interpreted as the probability of habitat use and not probability of occupancy, due to non-independence of sites.

Table 3.1. A description of the covariates used in the occupancy model including their source and how they were measured. Proximity covariates were calculated with the use of the NEAR Tool in ArcGIS® (v 10.2) software by Esri unless otherwise stated. All proximity and area calculations were measured in meters, and standardised using the scale function in R. All GIS layers used in these analyses were sourced from the City of Cape Town (CMA, CityMaps, City of Cape Town 2014), unless otherwise stated.

Covariate	Data source	Analysis
a) Site – specific covariates used to estimate the probability of river habitat occupied at the landscape scale scale (n = 28):		
Location (LOC)	Google Earth	Location of the site North of South of the Noordhoek Valley as a proxy for more and less urban development.
River (RIV)	Rivers GIS Layer, 2014.	Name of river for each site.
Proximity to urban edge (PUE)	Urban Edge GIS Layer, 2014.	The distance from the centre of each transect to the nearest urban edge.
Proximity to streets (PST)	Property GIS Layer, 2007.	The distance from the centre of each transect to the nearest street.
Human population density (POP)	Census GIS Layer, 2007.	The number of people per km^2 residing in the suburb within 2km of the study area.
Household density (HD)	Census GIS Layer, 2007.	The number of households per km^2 for the suburb within 2km of the study area.
Proximity to Urban Conservation Areas (PUCA)	Urban Conservation Areas GIS Layer, 2014.	The distance from the centre of each transect to the nearest urban conservation area - areas within the city proclaimed as natural heritage and/or conservation sites, protected from development. They include green belts, some beaches, few harbours and monuments.
Proximity to Restricted Fishing Zones (PRFZ)	Marine Protected Area GIS Layer, 2014.	The distance from the centre of each transect to the nearest restricted fishing zone. Five of the six restricted fishing zones are no-take zones where no fishing can take place and one is restricted zone where only one species can be caught under certain

Covariate	Data source	Analysis
		conditions.
Proximity to Marine Protected Areas (PMPA)	Marine Protected Area GIS Layer, 2014.	The distance from the centre of each transect to the nearest Marine Protected Area. The MPA controls both recreational and fishing activities to ensure the sustainability of marine resources.
Proximity to Public Open Spaces (POS)	Open Spaces GIS Layer, 2014.	The distance from the centre of each transect to the nearest open spaces - areas of municipal land in the City not necessarily protected, including detention ponds, city parks, non-developed areas and corridors.
Proximity to Natural Estuaries (PNE)	Natural Estuaries GIS Layer, 2009. CSIR, SANBI.	The distance from the centre of each transect to the nearest natural estuary, defined as the floodplain between a river and the sea into which it flows. The estuary may be permanently or periodically open to the sea.
Proximity to the coast (PC)	City of Cape Town GIS Layer, 2014.	The distance from the centre of each transect to the nearest coastline.
Proximity to Wetlands (PW)	Wetland Vegetation GIS Layer, 2014.	The distance from the centre of each transect to the nearest wetland.
Wetland Area available (WA)	Wetland Vegetation GIS Layer, 2014.	The total area (m^2) of the wetland within 200m of each transect.
Elevation (ELEV)	City of Cape Town GIS Layer, 2014.	The elevation (m) of each transect.
Aspect (ASP)	City of Cape Town GIS Layer, 2014.	The aspect of each transect (degrees).
Slope (SLOPE)	City of Cape Town GIS Layer,	The slope of each transect (degrees).

Covariate	Data source	Analysis
	2014.	
Shore substrate (SUB)	Recorded on site by researcher.	Shore substrate was classified as grass, stone, sand/soil, or dense vegetation.
b) Site – specific covariates used to estimate the probability of river habitat use at the local scale (n = 77):		
Frequency of eutrophic conditions as indicated by Summer Ortho-Phoshate levels (PHO)	City of Cape Town Water Chemistry data.	The number of years in the last decade in which summer orthophosphate levels were recorded as eutrophic (25 – 250 μg/ml) as a measure of the frequency of eutrophication at each site.
The human impact on the system as indicated by the frequency of unacceptably high *E. coli* counts (ECOLI)	City of Cape Town Water Chemistry data.	The number of years in the last decade in which *E.coli* counts were recorded above the acceptable level (1000 counts/100ml) as a measure of the risk of exposure at each site.
Canalisation (CAN)	Recorded on site by researcher.	Recorded as 1 if 80% of the 100m segment was canalised and 0 if 0-20% of the 100m segment was canalised.
Bank Vegetation (VEG)	Recorded on site by researcher.	Classified as dense, overhanging, emergent, open (sparse, little vegetation), or grass.
Presence of reeds (REED)	Recorded on site by researcher.	Recorded as 1 if reeds were present (regardless of species) in more than 20% of the 100m segment, and 0 if no reeds were present to provide a measure of whether there was any (even if minimal) reeds for holts and/or resting sites.
Visible pollution (POLL)	Recorded on site by researcher.	Recorded as 1 if visible pollution (e.g. solid waste) was present and 0 if none was visible.

Table 3.2. Spearman's correlation matrix of site-specific covariates used in the landscape scale occupancy model (r_s values). RIV: River; LOC: Location; PUE: Proximity to urban edge; PST: Proximity to nearest street; POP: Population density of residential area within 2km of site; HD: House density of the residential area within 2km of site; PUCA: Proximity to nearest Urban Conservation Area; PMPA: Proximity to nearest Marine Protected Area; PRFZ: Proximity to nearest Restricted Fishing Zone POS: Proximity to nearest Public Open Space; PNE: Proximity to nearest natural estuary; PC: Proximity to nearest coast; PW: Proximity to nearest wetland; WA: Area (m^2) of wetland within 200m of the site; ELEV: Elevation; ASP: Aspect; SLOPE: Slope of the transect. Negative values for the proximity covariates indicate a negative relationship between two covariates.

	RIV	**LOC**	**PUE**	**PST**	**POP**	**HD**	**PUCA**	**PMPA**	**PRFZ**	**POS**	**PNE**	**PC**	**PW**	**WA**	**ELEV**	**ASP**	**SLOPE**
RIV	1.00																
LOC	0.44	1.00															
PUE	0.44	0.24	1.00														
PST	-0.21	-0.36	0.16	1.00													
POP	0.49	0.65	0.14	-0.65	1.00												
HD	0.40	0.69	0.14	-0.63	**0.97**	1.00											
PUCA	0.16	-0.54	0.01	0.22	-0.16	-0.18	1.00										
PMPA	0.43	0.66	0.45	-0.20	0.43	0.51	-0.27	1.00									
PRFZ	0.33	0.53	0.24	-0.34	0.60	0.67	-0.14	**0.80**	1.00								
POS	-0.24	-0.55	0.27	0.53	-0.63	-0.65	0.27	-0.19	-0.43	1.00							
PNE	-0.14	0.13	0.28	0.19	-0.17	-0.04	-0.03	0.54	0.32	0.28	1.00						
PC	0.36	0.40	0.49	-0.01	0.10	0.17	-0.11	**0.83**	0.57	0.15	**0.74**	1.00					
PW	0.20	0.28	0.24	-0.36	0.18	0.20	-0.23	0.51	0.39	0.07	0.41	0.54	1.00				
WA	0.05	-0.04	-0.07	0.27	-0.01	-0.09	0.07	-0.41	-0.45	0.03	-0.37	-0.41	-0.57	1.00			
ELEV	-0.34	-0.21	0.08	0.34	-0.38	-0.30	0.06	0.35	0.19	0.48	**0.81**	0.52	0.39	-0.37	1.00		
ASP	-0.09	-0.43	0.36	0.38	-0.18	-0.25	0.26	-0.18	-0.21	0.38	0.12	-0.05	-0.14	0.03	0.25	1.00	
SLOPE	-0.60	-0.27	-0.09	0.22	-0.45	-0.36	-0.16	-0.03	-0.13	0.31	0.46	0.05	0.14	-0.31	0.64	0.23	1.00

Results

I surveyed 28 transects on three occasions for a total of 84 individual surveys and 168 100m segments, covering a total of 16,8km of river habitat in the Cape Peninsula each month. I detected otter presence in 8 of the 28 transects, producing a naïve estimate of occupancy of 0.29 at the landscape scale with a detection probability of 0.8 during the survey.

a) Probability of occupancy at the landscape scale.

The model was initially run using the covariates 'River' and 'Location' as survey-specific covariates to test whether spatial non-independence along rivers or between northern and southern sites would have an impact on the probability of detection. The null model (Ψ *(.),* ρ *(.)*) resulted in the lowest AIC value, followed by 'Location' and 'River' (Table 3.3). Neither 'Location' nor 'River' had a significant impact ($p > 0.05$) on the detection estimate and were therefore excluded from subsequent analyses.

Table 3.3. Results from the analyses of detection-level covariates analysed at the landscape scale (n = 28). RIV: River; LOC: Location.

Model	**AIC**	**Δ AIC**	***w***	***k***	**(- 2 LL)**
Ψ (.), ρ (.)*	59.05	0	0.29	2	55.05
Ψ (.), ρ (LOC)	59.13	0.08	0.28	3	53.13
Ψ (.), ρ (RIV)	60.46	1.40	0.15	3	54.46
Ψ (.), ρ (LOC+RIV)	60.92	1.86	0.12	4	52.92

*Null model

Univariate analysis of the site-specific covariates revealed that four covariates had a significant impact on the probability of occupancy at the landscape scale, namely proximity to Marine Protected Areas (PMPA, positive); proximity to natural estuaries (PNE, positive); proximity to the coast (PC, positive) and proximity to restricted fishing zones (PRFZ, positive). As all four were significantly correlated with one another (Table 3.2; $p < 0.05$), the models with the lowest AIC values were carried through. Univariate analyses (Table 3.3) ranked proximity to Marine Protected Area (Ψ (PMPA), ρ (.)) as the top model, followed closely by proximity to natural estuary (Ψ (PNE), ρ (.); Δ AIC = 2.26) and proximity to coast (Ψ (PC), ρ (.); Δ AIC = 2.81). The low Δ AIC values indicate that these top three models had substantial support (Burnham and Anderson, 2002; Burnham et al., 2011; Mackenzie et al., 2006), while proximity to restricted fishing zone (Ψ (PRFZ), ρ (.); Δ AIC = 7.06) had little support. However, since restricted fishing zones lay within the Marine Protected Area, the difference in impact on occupancy was of ecological interest, and was therefore carried through into the final multivariate analysis. The covariates of house density (HD) and wetland area (WA) were retained for use in the multivariate analysis to test the key hypothesis. The final set of candidate models therefore included the null model, four univariate and 14 multivariate models.

Table 3.4. Results from the univariate analyses of site-level covariates, analysed at the Peninsula scale (n = 28). PMPA: Proximity to nearest Marine Protected Area; PNE: Proximity to nearest natural estuary; PC: Proximity to nearest coast; PRFZ: Proximity to nearest Restricted Fishing Zone.

Model	**AIC**	**Δ AIC**	***w***	***k***	**(- 2 LL)**	**Est. $\hat{c}$**
Ψ (PMPA), ρ (.)	49.18	0	0.62	3	43.18	1.68
Ψ (PNE), ρ (.)	51.45	2.26	0.20	3	45.45	1.43
Ψ (PC), ρ (.)	51.99	2.81	0.15	3	45.99	1.5
Ψ (PRFZ), ρ (.)	56.25	7.06	0.018	3	50.25	1.46
Ψ (.), ρ (.)*	59.05	9.87	0.004	2	55.05	1.52

* Null model

Multivariate analysis revealed the importance of the proximity to Marine Protected Area (PMPA), the amount of wetland area available (WA) and proximity to natural estuaries (PNE). When competing with multivariate models in the final set of candidate models (Table 3.5), proximity to Marine Protected Area alone (Ψ (PMPA), ρ (.)) was still the top ranked model. The model including proximity to Marine Protected Area and household density ranked second (Ψ (PMPA + HD), ρ (.)) and showed substantial support relative to the top ranked model (Δ AIC = 1.79). However, despite falling below my correlation threshold (r_s = 0.7), household density was significantly and negatively correlated with proximity to Marine Protected Area ($p < 0.05$) and was therefore not considered for final model selection. The model ranked 3rd (Ψ (WA + PMPA), ρ (.)) included proximity to Marine Protected Area and the area of wetland available (WA). PMPA and WA were not correlated, and the small difference in AIC (Δ AIC = 2) suggests it competes with the top ranked model. The first top-ranking models that did not include proximity to Marine Protected Area both included proximity to natural estuaries, ($p < 0.05$). The relationship between probability of occupancy and proximity to Marine Protected Area is plotted in Figure 3.2, and the predicted distribution based on the best model is mapped in Figure 3.3.

Table 3.5. The top ten candidate models of occupancy analysed at the landscape scale (n = 28). PMPA: Proximity to nearest Marine Protected Area; PNE: Proximity to nearest natural estuary; PC: Proximity to nearest coast; HD: House Density; WA: Wetland Area.

Model	**AIC**	**Δ AIC**	***w***	***k***	**(- 2 LL)**	**Est. $\hat{c}$**
Ψ (PMPA), ρ (.)	49.18	0.00	0.29	3	43.18	1.63
Ψ (HD + PMPA), ρ (.)	50.97	1.79	0.12	4	42.97	1.37
Ψ (WA + PMPA), ρ (.)	51.18	2.00	0.11	4	43.18	1.53
Ψ (HD + PNE), ρ (.)	51.21	2.03	0.10	4	43.21	1.55
Ψ (PNE), ρ (.)	51.45	2.27	0.09	3	45.45	1.55
Ψ (PC), ρ (.)	51.99	2.81	0.07	3	45.99	1.58
Ψ (WA + HD), ρ (.)	52.97	3.79	0.04	4	42.97	1.56
Ψ (WA + HD + PNE), ρ (.)	53.18	4.00	0.04	5	43.18	1.51
Ψ (HD + PC), ρ (.)	53.19	4.01	0.04	4	45.19	1.42
Ψ (WA + PNE), ρ (.)	53.42	4.24	0.03	4	45.42	1.62

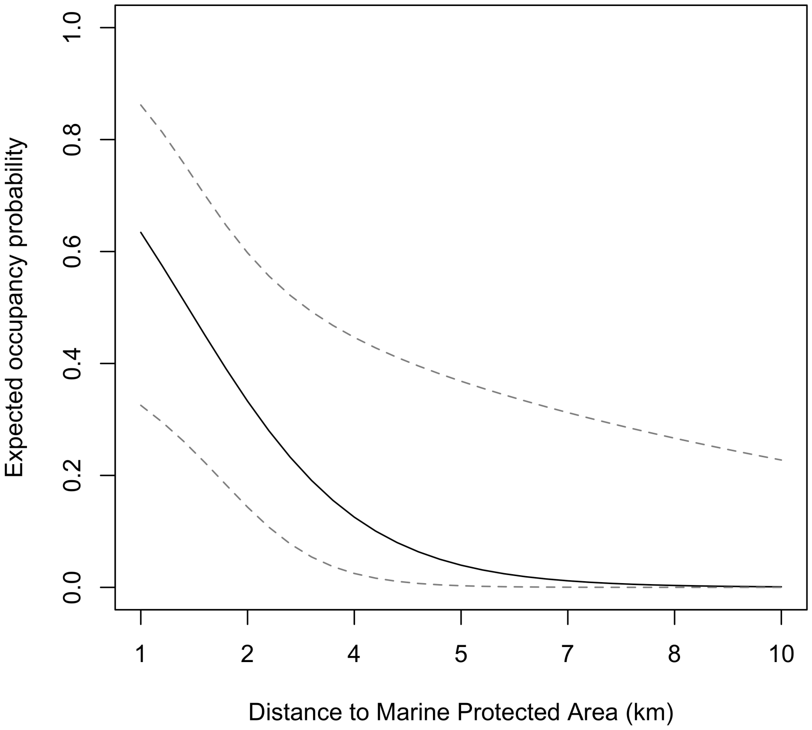


Figure 3.2. The relationship between expected probability of occupancy and proximity to the nearest Marine Protected Area. The broken lines represent 96% confidence intervals.

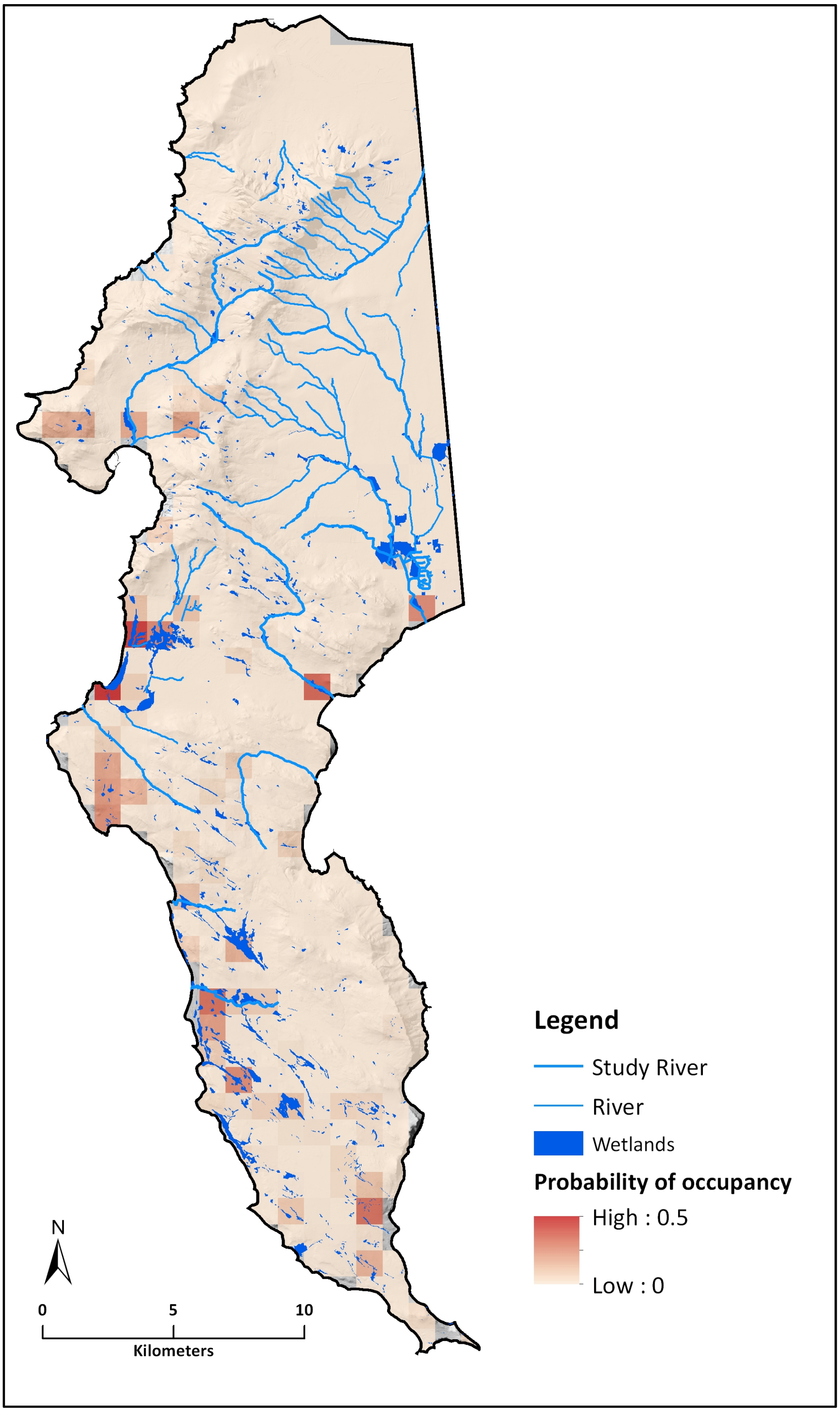


Figure 3.3. Map of the predicted distribution of otters across the Cape Peninsula at a scale of 1 x 1km. Probabilities are based on the best predictor variables as determined by landscape level occupancy modelling.

b) Habitat use at the local scale.

We detected otter presence in 19 of the 77 segments, producing a naïve estimate of habitat use of 0.25 at the local scale. The null model (Ψ (.), ρ (.)) slightly improved this estimate to 0.28, with a detection probability of 0.56 during the survey.

Table 3.6. Results from the analyses of detection-level covariates, analysed at the local scale (n = 77). RIV: River; LOC: Location; SUB: Shore Substrate.

Model	**AIC**	**Δ AIC**	***w***	***k***	**(- 2 LL)**
Ψ (.), ρ (LOC + SUB)	159.35	0.00	0.31	7	145.35
Ψ (.), ρ (LOC + RIV + SUB)	159.76	0.42	0.25	8	143.76
Ψ (.), ρ (RIV+ SUB)	160.44	1.09	0.18	7	146.44
Ψ (.), ρ (RIV)	162.01	2.67	0.08	3	156.01
Ψ (.), ρ (.)*	162.22	2.87	0.07	2	158.22
Ψ (.), ρ (SUB)	162.95	3.61	0.05	8	146.95
Ψ (.), ρ (LOC + RIV)	163.59	4.25	0.04	4	155.59
Ψ (.), ρ (LOC)	164.01	4.67	0.03	3	158.01

*Null model

The detection-level covariate Shore Substrate (SUB) did not have a significant impact on detection probability or probability of occupancy in any model. River (RIV) and Location (LOC) both had a significant impact on the probability of detection ($p< 0.05$). Location was significantly correlated with River ($r_s = 0.8$; $p < 0.05$). Since the univariate model of River (Ψ (.), ρ (RV)) had a lower AIC value than the univariate model of Location (Table 3.6), Location was excluded from subsequent analyses. River was carried through as the main detection-level covariate for all subsequent analyses.

Univariate analysis of the site-specific covariates (Table 3.7) revealed that only three covariates had a significant impact on the probability of habitat use at the local scale: namely whether the site was canalised or not (CAN, negative); the frequency of high *E. coli* counts (ECOLI, negative); and the frequency of eutrophic conditions at the site, as indicated by summer orthophosphate levels (PHO, negative). These three site-specific covariates, together with River as the only detection-level covariate, were therefore carried through for inclusion in the final set of five candidate models for habitat use at the river scale (Table 3.8).

Table 3.7. Results from the univariate analyses of site-level covariates, analysed at the local scale (n = 77). RIV: River; CAN: Canalised; POLL: Visible pollution; ECOLI: *E.coli* counts; PHO: Index of eutrophication; REED: presence of reeds; VEG: Bank vegetation.

Model	**AIC**	**Δ AIC**	***w***	***K***	**(- 2 LL)**
Ψ (CAN), ρ (RIV)*	155.74	0.00	0.57	4	147.74
Ψ (POLL), ρ (RIV)	157.63	1.88	0.22	5	147.63
Ψ (ECOLI), ρ (RIV)*	159.37	3.62	0.09	4	151.37
Ψ (PHO), ρ (RIV)*	159.75	4.01	0.08	4	151.75
Ψ (.), ρ (RIV)	162.01	6.27	0.02	3	156.01
Ψ (REED), ρ (RIV)	163.99	8.25	0.01	4	155.99
Ψ (VEG), ρ (RIV)	165.59	9.85	0.00	7	151.59

*Significant ($p< 0.05$)

Multivariate analysis emphasised the importance of canalisation (CAN), the frequency of high ecoli counts (ECOLI), and the frequency of eutrophic conditions at the site (PHO). The top three models all included canalisation, and produced similar AIC values (ΔAIC < 2) suggesting substantial support for all three models. The frequency of high *E. coli* counts and levels of orthophosphates were significantly correlated (r_s = 0.88, $p< 0.05$). Since the univariate model of ECOLI had a lower AIC score than orthophosphate (PHO), the latter was excluded. The top ranked model (Ψ (ECOLI + CAN), ρ (RIV)) therefore best explained the probability of habitat use by otters at the local scale, revealing the negative impact of canalisation and *E. coli* pollution in driving otter habitat use within rivers (Figures 3.3 and 3.4).

Table 3.8. Final set of candidate models of habitat use analysed at the local scale (n = 75). RIV: River; CAN: Canalisation; ECOLI: *E.coli* counts; PHO: Index of eutrophication.

Model	**AIC**	**Δ AIC**	***w***	***k***	**(- 2 LL)**
Ψ (ECOLI + CAN), ρ (RIV)	153.93	0.00	0.50	5	143.93
Ψ (PHO + CAN), ρ (RIV)	155.46	1.53	0.23	5	145.46
Ψ (CAN), ρ (RIV)	155.74	1.82	0.20	4	147.74
Ψ (ECOLI), ρ (RIV)	159.37	5.44	0.03	4	151.37
Ψ (PHO), ρ (RIV)	159.75	5.82	0.03	4	151.75

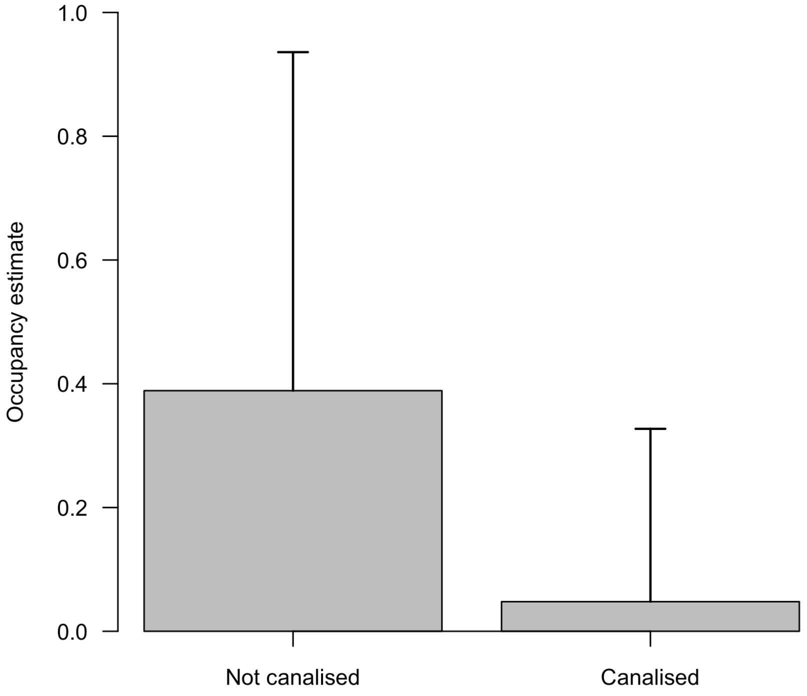


Figure 3.4. The expected probability of occupancy between not canalised and canalised sections of river.

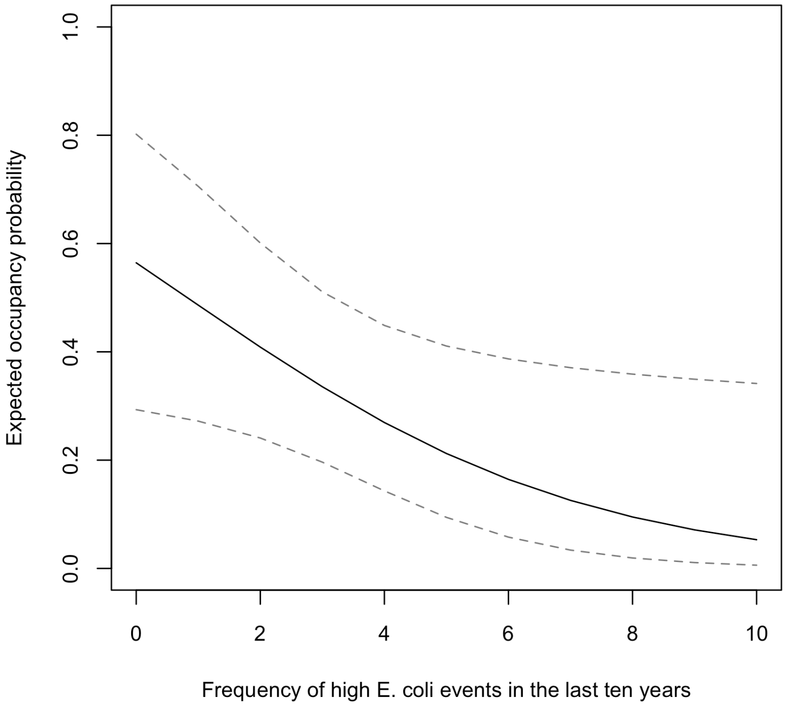


Figure 3.5. The expected probability of occupancy at different frequencies of high *E. coli* counts at sections of river segments surveyed.

Discussion

Occupancy modelling suggests that the probability of otters occupying river habitat in the Cape Peninsula is relatively low (p = 0.29) but increases with proximity to Marine Protected Areas (MPAs) that include estuaries and large areas of wetland habitat. The probability of occupancy was not significantly affected by human population density, proximity to roads and/or the urban edge. Thus there is no support for the null hypothesis that otter presence would be low close to urbanised areas. Analysis of habitat use within rivers suggests a higher probability that otters prefer non-canalised sections of river that are not heavily impacted by human activity. The presence of dense bank vegetation, reeds and visible pollution in the form of solid waste did not have a significant impact on habitat use within rivers.

The Table Mountain National Park MPA, covering approximately 300km of the coastline, surrounds much of the southern Cape Peninsula and includes one restricted fishing zone and five 'no-take' zones. Models assessing otter occupancy in relation to proximity to these restricted zones received little to no support. Instead, proximity to the overall MPA proved to be the most important predictor of presence. Models of wetland area and proximity to natural estuaries also received substantial support with occupancy estimates declining sharply $\geq$1 kilometre from an estuary. Together these findings suggest that otters occupy the interface between coastal and lowland wetland and river ecosystems close to MPAs.

As a result of urbanization, many of the lowland sections of rivers and wetlands in the Cape Peninsula are considered to be in a poor ecological state (Brown and Magoba, 2009; Purves and Holmes, 2013; Rebelo et al., 2011; River Health Programme, 2005) relative to the upper reaches which lie within the Table Mountain National Park. In the last few decades, almost 50% of the historical lowland wetland habitat in the City of Cape Town has been lost to development (Brown and Magoba, 2009; Purves and Holmes, 2013). In addition significant stretches of rivers have been canalised; riparian vegetation has been removed and flows have been modified, radically transforming the habitat structure and ecological function in these systems (Purves and Holmes, 2013; River Health Programme, 2005). Many of these systems receive urban storm water, and are directly impacted by the run off and drainage of sewage from nearby formal and informal settlements. Despite high levels of transformation, pollution and habitat degradation otters are still more likely to be present in the lower reaches of most the Peninsula's rivers.

Many otter species are tolerant of some degree of human disturbance, and a few species have adapted to human modified systems (Kruuk, 2006). For example, the Neotropical otter, *Lontra longicaudis*, occurs throughout Central America, and is known to prefer river habitat that provides deep pools, rock cover and densely vegetated riverbanks (Carillo-Rubio and Lafon, 2004). However, they have been found to preferentially occupy human altered habitat in the form of polders in parts of their range (Sepúlveda et al., 2007). Similarly, European otters inhabit coastal urban centres including Cork in Ireland (White et al., 2013) and make use of artificial water bodies such as reservoirs in Portugal (Pedroso et al., 2007). Small-clawed otters, *Aonyx cinereus* are just as likely to inhabit coffee and tea plantations as they are to inhabit protected areas in the Western Ghats, India (Prakash et al., 2012); and North American river otters, *Lontra canadensis* have recently returned to the now highly urbanized San Francisco Bay in California, U.S.A. (Bouley et al., 2015). Such studies suggest that structurally, modified environments may still provide the necessary habitat for otters to persist within transformed environments. Whether these habitats are sustainable is not known. They may potentially offer ‘substitution habitat’ and increase species resilience in the face of global change as has been suggested for European otters using dams (Martinez-Abrain and Jimenez, 2016; Ruiz-Olmo et al., 2007). Alternatively, transformed habitats may act as ‘ecological trap’ or ‘attractive sink’, whereby an animal makes an error in its assessment of a habitat as a result of a mismatch between environmental cues they use to select habitats and the actual habitat quality (Battin, 2004; Delibes et al., 2009). Ecological traps often exist in rapidly changing landscapes as well as those modified by human activities, for example artificial wetlands, urban areas and habitat edges (Battin, 2004). Threats in the form of contaminants, for example, are impossible for an animal to detect, so polluted aquatic systems may still be used despite potentially dangerous effects (Delibes et al., 2009).

In South Africa, otters are known to prefer habitat characterized by dense vegetation and high food availability (Nel and Somers, 2007; Perrin and Carugati, 2000; Rowe Rowe, 1992). Modified lowland systems are often prone to exotic plant species invasions (Cooper et al., 2013) that form dense stands and offer suitable refugia to otters resting and denning on land. In addition, low flow and increased nutrient supply encourages the growth of both *Typhus capensis* and *Phragmites australis,* which provide dense cover for otters in lieu of large stands of indigenous riparian vegetation. Lowland estuaries and wetlands are also a rich source of prey in the form of exotic freshwater fish species that contribute significantly to otter's diet in rivers and wetlands throughout South Africa (Parker et al., 2005; M.J. Somers and Nel, 2003; Watson and Lang, 2003).

The benefits of human modified habitats for otters may however, be short-lived (Sepúlveda et al., 2007). Exposure to pollutants, traffic and dogs put urban otter populations at risk, and as apex predators, they are directly affected by any impacts along the food chain. Eutrophication may benefit otters in the short term by providing suitable conditions for crab and exotic fish populations to thrive, yet the impacts of potentially harmful cyanobacteria associated with these conditions (e.g. *Microcystis*, Miller et al., 2010) is unknown for cape clawless otters. Similarly, close proximity to urban and residential areas can promote the transfer of disease between domestic and wild animals (e.g. *Toxoplasma gondii*, Shapiro et al., 2010).

Benefits of modified habitats may also be more pronounced at a local scale rather than at the landscape level, as illustrated by research on the marine otter *Lontra feline*. Marine otters occur in marine environments on the coast of Chile, and require safe shelter in sufficiently long stretches of rocky coast close to food resources (Medina-Vogel et al., 2006). At a local scale, marine otters were found in higher concentrations nearest to human activity, and were observed using wharfs, cracks and shipwrecks for resting sites, and feeding off fishery waste products from the local fishing community (Medina-Vogel et al., 2007). At a broader, landscape level, however, Medina-Vogel et al. (2008) found that marine otters were more likely to occupy areas that were not disturbed by humans – a trend that was more pronounced along shorter, more fragmented rocky zones – and that human influence on the seashore was associated with increased isolation of marine otter populations. It is therefore important to understand both local and landscape scale factors driving otter distribution in order to fully recognise the threats faced by otters in an urban environment.

During the course of our research, cape clawless otters regularly inhabited fishing harbours and densely populated beaches, using drains and sewers to navigate between waterbodies, creating holts under the decks of houses and in cracks in the dolosse (anti-erosion structures) adjacent to the coast. Many of these sites were in close proximity to MPAs, natural estuaries or urban wetlands, suggesting that where the landscape level habitat requirements have been met, otters may be able to adapt to transformed environments on a local scale provided that these environments still provide access to critical resources in the form of freshwater, resting and breeding sites. Storm water and flood risk management in the City of Cape Town has ensured that many wetlands and estuaries on the Peninsula are still intact despite being degraded. Currently these freshwater habitats may still provide otters with access to critical resources, which together with the food within the marine habitat may be sustaining the Peninsula's otter population.

The findings presented here suggest that for otters to persist on the Peninsula, conservation authorities must maintain wetland, estuarine and river habitat in close proximity to Marine Protected Areas. In addition, at the local scale, levels of pollution to rivers and wetlands must be curbed and further canalisation of rivers avoided. Research on the impacts of exposure to pollutants, disease risk and genetic isolation in urban otter populations is needed to understand further threats to the species. A long-term monitoring program using the occupancy framework detailed in this study is highly recommended to ensure that any decline in the population is detected immediately. Ideally, annual single season occupancy surveys should be incorporated into current monitoring efforts and coordinated through collaboration between all relevant authorities. To provide information on potential drivers of any changes in occupancy, data on key covariates such as water quality, habitat and potential threats should be collected during the surveys.

This study provides a rapid, cost-effective method for monitoring changes in otter occupancy that could be implemented by the relevant management authorities. Yearly comparisons will provide critical insight into trends in occupancy across the Cape Peninsula, and provide much needed long-term monitoring of a 'Near Threatened' top predator in freshwater ecosystems.

CHAPTER 4:

THE DIET OF CAPE CLAWLESS OTTERS, *AONYX CAPENSIS*, ACROSS AN URBAN LANDSCAPE.

Abstract

Knowledge of a species' dietary needs is important to understanding one of the factors known to limit local populations. Specifically, in areas impacted by rapid urbanisation and industrial pollution, dietary studies can highlight possible routes of contamination of top predators in an aquatic ecosystem. Like many other otter species, the Cape clawless otter is a top predator in freshwater ecosystems, and is thus particularly at risk to bioaccumulation of pollutants in the food chain. In this chapter I use both spraints (frequency of occurrence of dietary items) and vibrissae (stable isotope analysis) to explore the diet of Cape Peninsula otters. I collected a total of 406 spraints and surveyed for prey availability in six freshwater systems over 2.5 years. Vibrissae were sampled opportunistically from 10 road-killed otters collected both within the Cape Peninsula and broader surrounds. Both methods revealed that similar to previous studies Peninsula otters are adaptable generalists occupying a wide trophic niche and feeding largely on a combination of marine and freshwater fish and crustaceans. Their trophic flexibility is likely to be an advantage in an urban transformed landscape but prolonged feeding in polluted systems may expose otters to bioaccumulation of toxins in the food chain in the long term. It is likely that Marine Protected Areas have provided otters with a valuable, stable foraging environment during the history of urban development and the impacts this would have brought to freshwater systems.

Introduction

Knowledge of a species' diet and specific foraging requirements is key to understanding the factors that limit populations (Almeida et al., 2012; Kruuk, 2006). Dietary studies provide valuable insight into a species' role in the ecosystem, their impact on prey populations, and potential competition for resources – thereby contributing to conservation and management decisions (Klare et al., 2011; Mills, 1992; Steenweg et al., 2015). In areas impacted by rapid urbanisation and industrial pollution, wildlife populations are regularly exposed to numerous toxic compounds that enter the food chain and which, through bioaccumulation, can have a chronic negative impact on their health and reproductive success (Vos et al., 2008). Dietary studies can therefore also highlight possible routes of contamination of top predators in an ecosystem.

Globally, otters often occupy the position of top predator in aquatic ecosystems and are thus particularly at risk to bioaccumulation of pollutants in the food chain (Ben-David et al., 2001; Larsson et al., 1990; Nakata et al., 1998). For this reason, both European otters (*Lutra lutra*) and North America river otters (*Lontra canadensis*) are considered sentinel or bio-monitor species in their respective regions (Lemarchand et al., 2010; Carpenter et al., 2014; Jessup et al., 2004; Mayack, 2012). In the Western Cape of South Africa, the Cape Clawless Otter *Aonyx capensis* occupies the role of top predator in freshwater systems, and mesopredator in near-shore marine habitats. The diet of otters in South Africa has been well documented in both environments, yet it is not clear if and how otters have modified their diet in an urban or polluted environment.

An initial detailed assessment of otter diet was conducted in the 1970's, where Rowe-Rowe (1977) determined that otters are physically well adapted to feeding primarily on crustaceans. Their large robust molars are well suited for crushing hard-shelled prey, and they use their highly dextrous forefeet and sensitive vibrissae to feel under rocks and in dense vegetation for crabs and slow moving fish (Rowe-Rowe, 1977). Subsequent research confirmed that in general, otters do preferentially exploit crustacean prey, with the choice of secondary and/or tertiary prey being affected by the environment (freshwater/marine), season and prey availability. In most freshwater systems studied to date the Cape River crab, *Potomanuates perlatus* comprises the bulk of their diet (Parker et al., 2005; Perrin and Carugati, 2000; Somers and Nel, 2003). Watson and Lang (2003) found that in the absence of freshwater crabs, exotic fish formed the bulk of the otter's diet. In marine environments, fish, rock lobster and crabs were the dominant prey in most previous studies, with a variety of cephalopods and molluscs as secondary or tertiary prey (van der Zee 1981; Verwoerd 1987; Somers 2000; Jordaan et al. 2015; Emmerson & Philip 2004).

The most common method of studying otter diet in South Africa follows the international standard of spraint (faecal) analysis as described by Webb (1980), whereby otter faeces (spraints) are collected, dried and separated into major prey categories. The relative frequency of occurrence (presence of each prey species in each spraint) per species can then be calculated to provide an index of prey proportions. Although this is currently the most common method of expressing the content of otter spraints, there are a number of inaccuracies (Carss, 1995; Conroy and French, 1987; Klare et al., 2011). Firstly, soft-bodied or very large animals (where flesh is predominantly eaten), leave little or no undigested remains, and are consequently under-represented in dietary estimates (Conroy et al., 2005). Secondly while frequency of occurrence accurately determines the rank importance of prey species in otter diet the actual proportions of prey in the diet are often misrepresented. Numerous studies have used a combination of statistical techniques to overcome these challenges (Emmerson and Philip, 2004; Somers and Nel, 2003; van der Zee, 1981), but even so, spraint analysis is limited in that it can only provide a 'snapshot' of what the otters have been eating.

Stable isotope analysis is a useful tool used for understanding longer term feeding behaviour, and shifts in diet in response to environmental heterogeneity across space and time (Codron et al., 2009). This technique is based on the fact that ^{13}C:^{12}C ratios in consumer tissues reflect the isotope signature of the sources from which they are derived, and can be used to determine the nutritional status of animals (Petzke et al., 2010), the importance of marine versus terrestrial prey (Hobson and Sealy, 1991), interspecies competition (Codron et al., 2009) and trophic magnification (Borgå et al., 2012). Recently, isotope analysis has been used to understand individual diet specialisation in Californian sea otters, *Enhydra lutris* (Newsome et al., 2010, 2009; Tyrrell et al., 2013). The authors sampled otter vibrissae to analyse stable isotopes ($\delta^{13}C$ and $\delta^{15}N$) to detect and quantify patterns of individual dietary specialisation in a population of wild sea otters exposed to a wide variety of prey. They concluded that although isotopes do not typically reveal detailed information on dietary composition, they can offer a useful proxy for measuring individual and population-level components of dietary variation in sea otters (Newsome et al., 2009).

Thus far, isotopes analyses have not been used to investigate the diet, or variation in diet, of Cape clawless otters, but the method has the potential to complement spraint analyses in providing an understanding of both short and long-term variation in diet in different habitats. In this chapter I aim to use both spraint analysis and stable isotope analysis to determine a) overall otter diet, and b) the spatial and temporal variation in otter diet across the Cape Peninsula's urban gradient. In accordance with previous studies, I would expect otter diet to vary between seasons and according to prey availability. As Cape clawless otters are known to inhabit transformed lowland wetlands in the Cape Peninsula, as well as the coastal estuaries and Marine Protected Area, I would expect that in highly degraded freshwater systems, otters will feed primarily on prey from the less polluted marine environment.

Methods

Study Area

The study area is described in detail in Chapter 2. The following map highlights the specific aquatic systems that were routinely sampled for otter spraint and for prey availability (Figure 4.1).

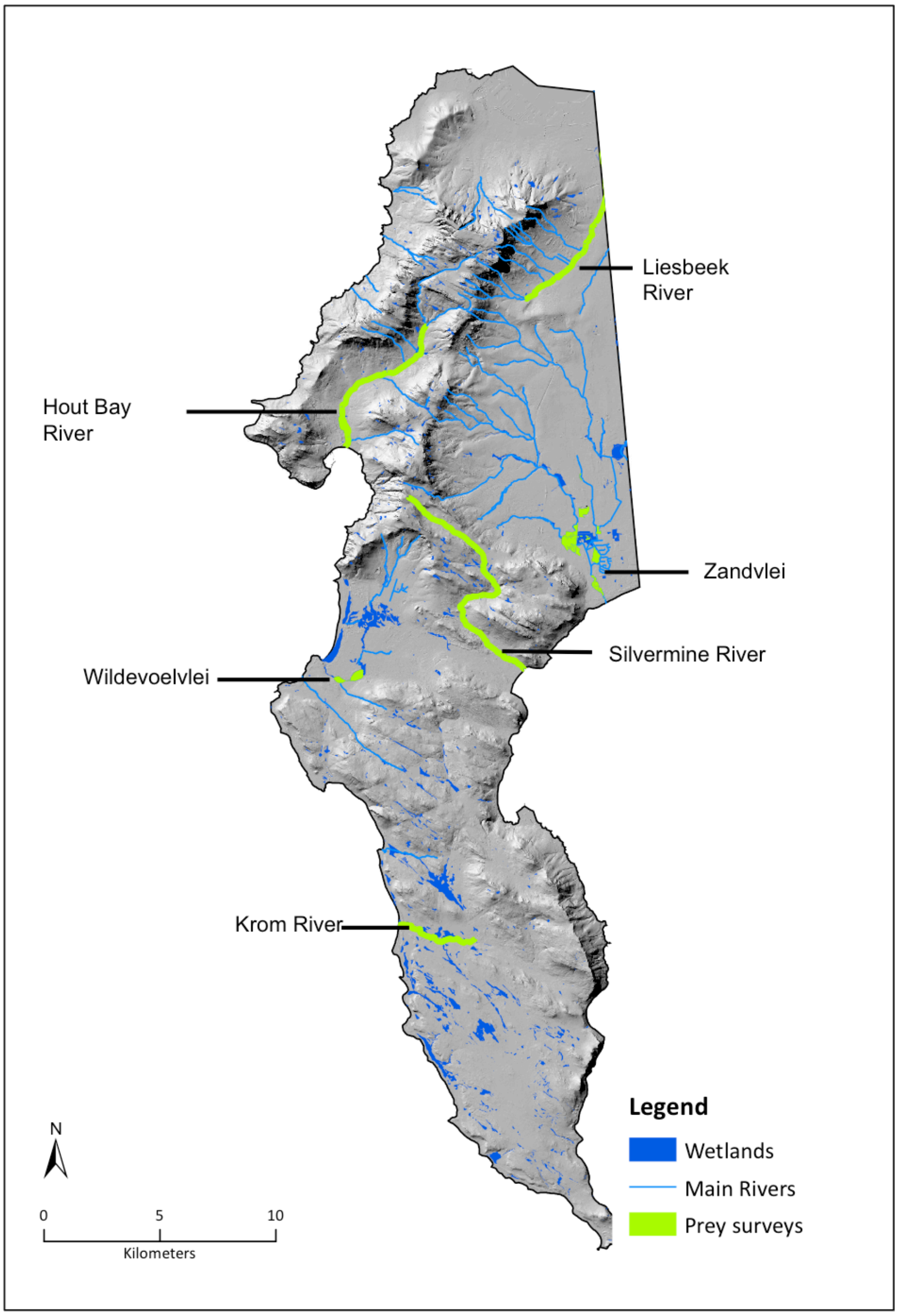


Figure 4.1. The study area highlighting the six main aquatic systems that were routinely surveyed for otter spraint and prey availability.

Prey availability

In order to understand the availability of the otter's main freshwater prey in the rivers and wetlands of the Cape Peninsula, I surveyed each of the six aquatic systems in both summer and in winter for freshwater and estuarine fish and crustaceans. It was logistically not feasible to survey the marine environment for prey availability and I therefore relied on the literature for information on distribution and seasonal variation in marine fish and crustaceans. Each of the six aquatic systems was divided into 2-5 equidistant sites (depending on the total length of the river, Figure 4.1). A total of 21 individual sites were surveyed, across the 6 sites: Hout Bay river (4), Krom estuary in Cape Point (2), Liesbeek river (4), Silvermine river (5), Wildevoelvlei estuary (2), and Zandvlei estuary (4). A combination of survey methods was used. Freshwater crabs were captured with baited conical crab traps. Three traps were placed at each site for an hour. Once collected, crabs were identified, counted and released. Fish and frogs were captured using electro-fishing, fyke nets and seine nets, depending on the section of river and depth of the water. In narrow, shallow sections of rivers or ponds, electro-fishing was used. I placed a low voltage current in the water to temporarily stun fish and frogs. Nets were placed downstream to catch any fish that drifted away. In the dams and at the mouths of rivers, fyke nets (bag-shaped nets held open by 'wings' which help direct the fish into the net) were set overnight with the throat of the net facing upstream and the wings spanning the width of the stream. A seine (purse) net was used in one estuarine system (Krom, Cape Point) where a net wider than a fyke net was needed to sample adequately. In all cases, all fauna captured were released immediately after counting and measuring.

Spraint collection and analysis

From July 2012 to June 2013, spraints were collected twice a month at each river and coastal latrine site along the six aquatic systems (Figure 4.1). I refer to these data as the fixed dataset. Thereafter, from July 2013 to November 2014, spraints were collected opportunistically on an *ad hoc* basis from these same systems. I combined these data with the fixed dataset and refer to these as the overall dataset. The locations of all spraint were recorded with a handheld GPS (Garmin Etrex H). Spraints were collected in in small, plastic (Ziploc) bags and stored frozen (at -20°C) until processed. They were later defrosted, washed with water through a 0.5 mm sieve to remove mucus and sand, and left to air-dry overnight. Each dry spraint was weighed and then teased apart to identify the major prey items. Due to highly fragmented remains and a lack of key identifying features in the spraints, hard prey remains were separated into broad prey groupings as per Somers (2000).

All fish bones and scales were grouped together as fish as it was difficult to determine species without otoliths, which were rare. Rock lobster and marine crab were identified by their carapace; squid by the presence of eye lenses; octopus by the hard beaks; isopods by the presence of whole individuals; freshwater crab by their carapace; frogs by the presence of characteristic urostyles; birds by feathers, and mammals by the presence of fur. Each grouping was noted as present or absent in each spraint and weighed.

Isotope sample collection and preparation

I collected muscle samples of the major prey items (based on the spraint analysis results) opportunistically throughout 2015. Freshwater prey samples included water birds (Mallard duck *Anas platyrhyncos*, Yellow-billed duck *Anas undulata*, Cape teal *Anas capensis*, and Egyptian goose *Alopochen aegyptiaca*), the freshwater crab *Potomanautes perlatus*, the Cape clawed frog *Xenopus laevis* and a variety of freshwater and estuarine fish (Tilapia *Tilapia sparmanii*, Southern mullet *Liza richardsonii* and Flathead mullet, *Mugil cephalus*). Marine prey samples included crustaceans (West coast rock lobster *Jasus lalandii*, the exotic European shore crab *Carcinus maenas* and the Three-spot swimming crab *Ovalipes trimaculatus*), and teleost fish (Panga *Pterogymnus laniarius*, Hottentot *Pachymetopon blochii*, Roman *Chrysoblephus laticeps*, and Fransmadam *Boopsoidea inornata*, and the intertidal Super klipfish *Clinus superficiolis*).

Samples from dead intertidal fish and water birds were sourced from researchers currently working on these species within the Western Cape (University of Cape Town and University of Stellenbosch). Rock lobster, marine rock crabs and frogs were sourced from the remains of student practical teaching laboratory in the Biological Sciences Department at the University of Cape Town. Freshwater crabs were collected from rivers in the Cape Peninsula. All marine line fish species were purchased opportunistically from commercial fishermen fishing in False Bay. Estuarine and freshwater fish were caught from Zandvlei with the assistance of reserve managers and the Department of Environmental Affairs during their quarterly fish surveys. Otter vibrissae (including the root) were collected from road-killed carcasses collected throughout the Western Cape between April 2011 and February 2014 (as described in Chapter 5). Eight of the 10 otter carcasses analysed were collected within the Cape Peninsula; one in Bettys Bay (approx. 100km’s east of the Peninsula), and one in Plettenberg Bay, Western Cape (approx. 500km’s east of the Peninsula). Ethics clearance and the necessary permits were obtained for all collections of live material.

All prey muscle samples were freeze-dried for 24 hours in a Scanvac Coolsafe 55-4 cooling trap (Labogene, Lynge, Denmark). Samples were then homogenised using a Retsch MM 400 mixer mill (VERDER Group, Netherlands). Approximately 0.5mg of the powdered muscle tissue samples were weighed out on a Sartorius M2P microbalance and sealed into tin boats for isotopic analysis. Otter vibrissae were washed in a 2:1 chloroform:methanol solution to remove surface contaminants, and cut into between 6 and 12 0.64cm segments, depending on the length of the vibrissae. The chosen lengths of segments were based on the estimate of vibrissae growth rates in sea otters (approximatley 7.7cm per year, Tyrrell et al., 2013). Each 0.64cm segment was assumed to therefore be representative of approximately one month and was subsampled into approximately 0.5mg segments sealed into tin boats for isotopic analysis. Each segment was assigned a month based on the time of death of the otter.

As lipids are known to introduce bias in stable isotope analysis (Gannes et al., 1997), lipid extraction methods are used to minimise sources of variability related to differing lipid content (Logan et al., 2008; Pinnegar and Polunin, 1999; Skinner et al., 2016). I followed the lipid extraction methods for a subset of muscle and vibrissae samples as outlined in Newsome et al. (2009) for comparison with my non lipid-extracted samples. The subset of samples were soaked in 2:1 chloroform:methanol for 24 hours, then rinsed with de-ionised water and again soaked in 2:1 chloroform:methanol for a further 24 hours. Samples were rinsed again with de-ionised water, freeze-dried and ground into a fine powder. Approximately 0.5 mg of the lipid-extracted powdered muscle tissue and vibrissae samples were weighed out on a Sartorius M2P microbalance and sealed into tin boats for isotopic analysis.

For all samples, in-house standards used during analysis of muscle samples were: a commercial chocolate/egg mixture from the USA (choc), valine (DL valine purchased from Sigma- Aldrich, South Africa) and seal (crushed, demineralized seal bone). All the in-house standards were available from the Stable Isotope Laboratory in the Archaeology Department at the University of Cape Town, South Africa, and had been calibrated against the International Atomic Energy Agency (IAEA) standards. Carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope values of all samples were determined using a Flash 2000 organic elemental analyser and a Delta V Plus isotope ratio mass spectrometer (IRMS) via a Conflo IV gas control unit (Thermo Scientific, Bremen, Germany). The units are expressed as parts per thousand, or per mil (‰). The samples were run by the Archaeology Department, University of Cape Town. Isotopic results are expressed as δ values: $\delta^{13}C$ or $\delta^{15}N = 1000\ [(R_{sam}/R_{std}) - 1]$, where R_{sam} and R_{std} are the ^{13}C:^{12}C or ^{15}N:^{14}N ratios of the sample and standard, respectively.

Statistical analyses

a) Prey availability

I tabled the freshwater prey species present in each system, and plotted the total counts of each species across seasons. I described the availability of marine prey species based on information collected from the literature.

b) Spraint analysis

All statistical analyses were performed in the R programming environment® (R 3.2.0, R Core Team 2014). The reliability of the sample size was determined by plotting prey species accumulation curves per study site to ensure adequate sample sizes for comparison. The full dataset across all years (n=406) was compared to the subset of routinely collected data from July 2012 to June 2013 (n=249), using Fishers test of independence to determine whether the subsample was representative of the full dataset. The composition of overall otter diet across the Peninsula was determined by calculating the frequency of occurrence of each prey item, with the following equations:

$$\text{FO (\%)} = \frac{\text{No. of spraints containing a specific prey type}}{\text{No. of spraints}} \times 100 \qquad (1)$$

$$\text{RFO (\%)} = \frac{\text{No. of occurrences of a specific prey type in all spraints}}{\text{No. of occurrences of all prey types in all spraints}} \times 100 \qquad (2)$$

To investigate the temporal and spatial variation in diet composition, the 2012–2013 dataset was used. The mean relative frequency of occurrence (MRFO) of each prey type per spraint was calculated using equation 2, and calculating the mean per month (Klare et al., 2011; Parker and Burchell, 2005). Normality of each variable (i.e. the MRFO of each prey type) was assessed using the Shapiro Wilks test. Homogeneity of variances was assessed using both Bartletts and Levenes test. Where the assumptions for an ANOVA were violated, the non-parametric Kruskal Wallis test was performed to test for differences between seasons and sites. Polluted and unpolluted sites were grouped separately according to water quality data provided by the City of Cape Town to test whether the diet composition of spraints collected in polluted sites differed from those collected in unpolluted sites. As water quality data was only available for certain systems, I used a subset of the fixed dataset and excluded sites where no water quality data existed resulting in a spatial dataset of n = 150. Polluted sites included Wildevoelvlei, the lower reaches of Hout Bay, Zandvlei and Liesbeek while unpolluted sites consisted of Silvermine and the upper reaches of Hout Bay River.

c) Isotopes analysis

I compared the lipid-extracted values for the subset of muscle and vibrissae samples to non-lipid extracted samples and found no significant difference ($p>0.05$, *t*-test). I therefore used non lipid-extracted values for both prey groups and otter samples for all subsequent analyses.

In order to determine whether $\delta^{13}C$ or $\delta^{15}N$ values of each prey group were significantly different from one another, I used a K nearest-neighbour randomisation test (Rosing et al., 1998). To correct the otter isotope data for trophic discrimination and plot consumers in dietary space, I used trophic discrimination factors as described by Newsome et al. (2010) for a wild population of sea otters. I therefore subtracted 2.5‰ and 3.5‰ from the mean individual $\delta^{13}C$ and $\delta^{15}N$ values, respectively. I plotted the mean $\delta^{13}C$ or $\delta^{15}N$ values of both otters and prey groups in a dual plot (Figure 4.10) for an understanding of otter diet across the Peninsula.

Lastly, to investigate whether the Peninsula otters show specialist or generalist dietary patterns (sensu Newsome et al. 2009), I conducted a two way ANOVA to test whether variation between otter vibrissae was greater than variation between vibrissa segments of the same individual. I therefore compared the variation in $\delta^{13}C$ or $\delta^{15}N$ values firstly, between otter individuals (n = 10), and secondly, variation in $\delta^{13}C$ or $\delta^{15}N$ values between segments within each vibrissa (approximately 9 segments per otter).

Results

Prey availability

Across all sites surveyed for prey, a total of 1 estuarine crab species, 1 freshwater crab species, 10 freshwater fish species, 2 frog species and 1 reptile were found (Table 4.1). The total number of each prey group captured across all sites was highest in the summer compared to winter sampling months (Figures 4.2 – 4.4), indicating a strong seasonal trend in freshwater prey availability.

Table 4.1. The estuarine and freshwater species collected at all aquatic systems surveyed, in both summer and winter. *Indicates that this species was found only in summer surveys.

Prey group	Common name	Scientific name
Estuarine crab	Pea crab*	*Pinnotheres dofleini*
Freshwater crab	Cape river crab	*Potamanautes perlatus*
Estuarine fish	Cape silverside	*Atherina breviceps*
Estuarine fish	Estuarine roundherring	*Gilchristella aestuaria*
Freshwater fish	African Shaptooth Catfish	*Clarius gariepnus*
Freshwater fish	Banded tilapia	*Tilapia sparmanii*
Freshwater fish	Blue gill	*Lepomis macrochirus*
Freshwater fish	Cape galaxias	*Galaxias zebratus*
Freshwater fish	Cape kurper	*Sandelia capensis*
Freshwater fish	Carp	*Cyprinus carpio*
Freshwater fish	Largemouth Bass	*Micropterus salmoides*
Freshwater fish	Mosquito fish	*Gambusia affinis*
Freshwater fish	Mozambique tilapia	*Oreochromis mosambicus*
Freshwater fish	Mullet	*Liza richardsonii*
Frog	African clawed frog	*Xenopus laevis*
Frog	Cape river frog*	*Amietia fuscigula*
Reptile	Cape terrapin*	*Pelomedusa subrufa*

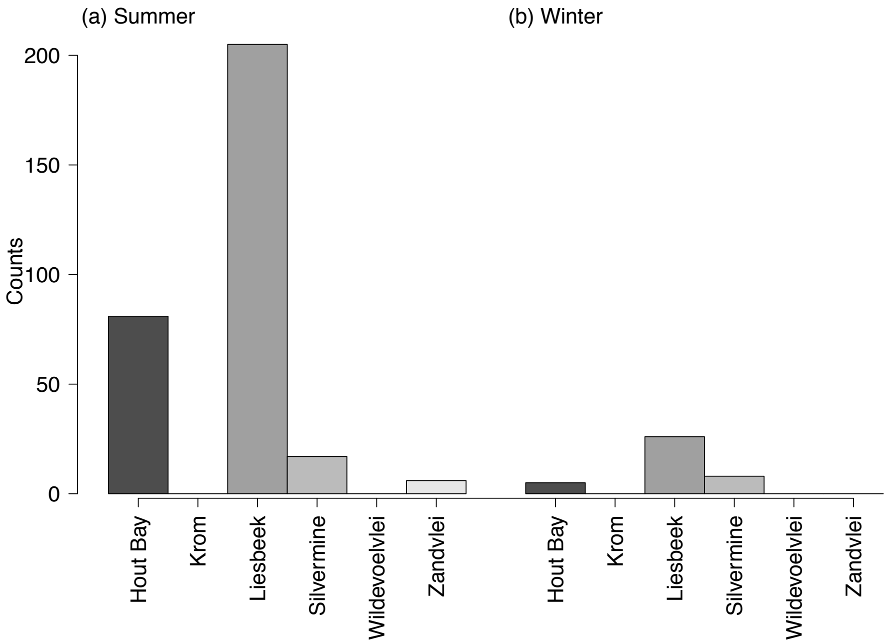


Figure 4.2. The total number of all freshwater crabs collected within each aquatic system, in a) summer and b) winter.

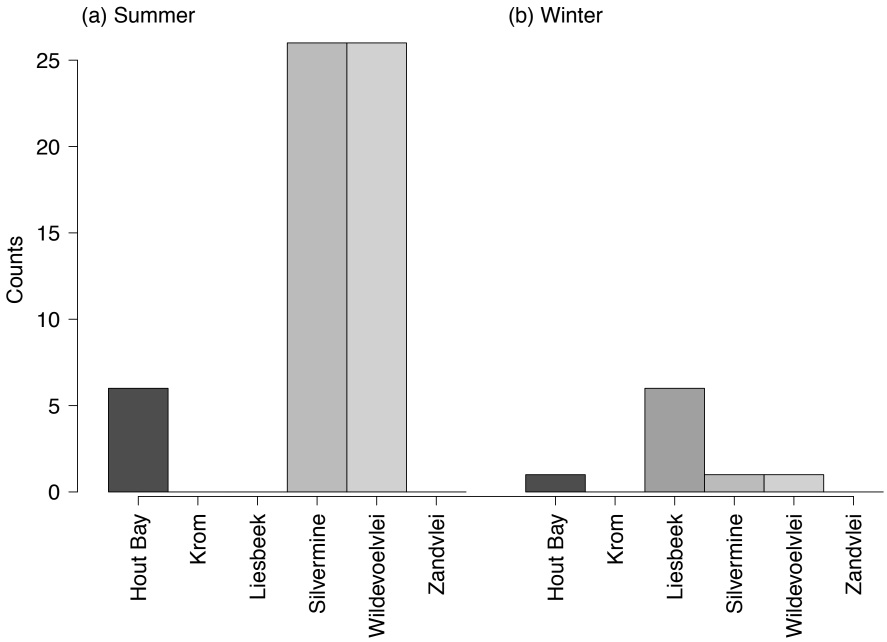


Figure 4.3. The total number of all frogs collected within each aquatic system, in a) summer and b) winter.

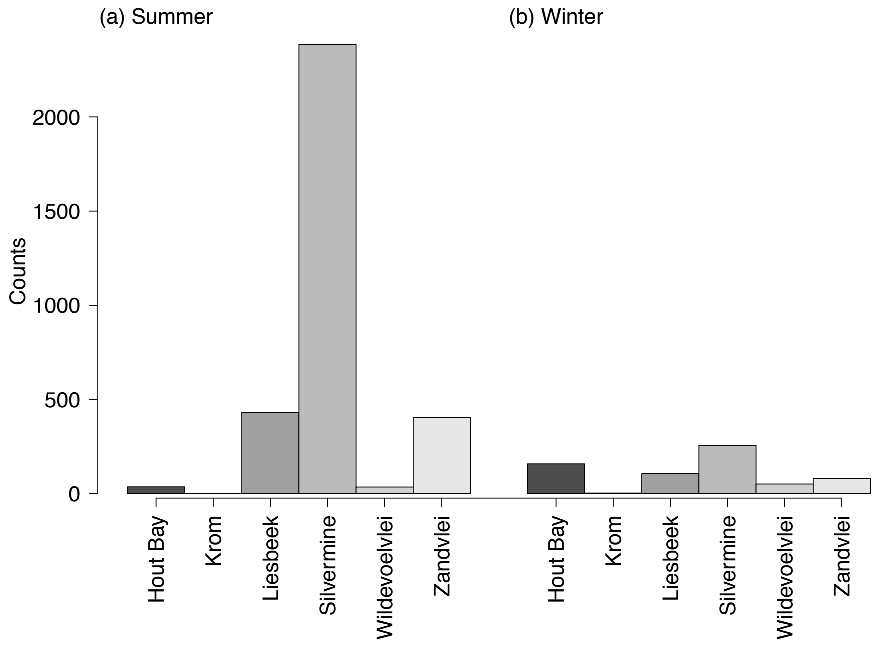


Figure 4.4. The total number of all freshwater and estuarine fish collected within each aquatic system, in a) summer and b) winter.

A literature review of the fauna inhabiting the inshore marine ecosystem surrounding the Cape Peninsula reveals that these systems support approximately 200 species of migratory, nomadic or resident cold and warm water species (Clark et al., 1996a, 1996b; Day, 1970). While many pelagic fish species such as Red roman *Chrysoblephus laticeps*, Hottentot *Pachymetopon blochii* and Strepie *Sarpa salpa*, are migratory and more abundant in summer, reef fish species such as Black tail *Diplodus capensis*, Steentjie *Spondyliosoma emarginatum* and Galjoen *Dichistius capensis* are resident species and hence present year round (Day, 1970). As otters feed on both reef and pelagic fish species (Somers, 2000), they are exposed to a relatively consistent source of marine fish, with no evidence of seasonal variation in overall abundance or availability (Clark et al., 1996a; Somers, 2000). Rock lobster, however, do experience both seasonal inshore to offshore migration (Pollock, 1986) and are thought to be more abundant in False Bay in winter than in summer (Carr, 2014, unpubl thesis). Spatial variation in rock lobster has also been found, with lobster fecundity being noticeably lower at Olifantsbos, Cape Point than other sites off the coast of the Western Cape (Pollock, 1986).

Spraint analysis

A total of 12 prey categories were identified from 406 otter spraints collected from the six main study sites over the course of 27 months, covering all seasons. The majority of spraints collected over the study period were found at latrine sites within Cape Point and Wildevoelvlei, even when standardizing for effort across all sites in one calendar year (July 2012 – June 2013, n = 249) (Figure 4.5). There was no difference between the relative frequencies of occurrence of prey items between the overall dataset and the fixed dataset (p = 0.98, Fishers exact test of independence). Prey species accumulation curves indicated that for all sites except Cape Point, sampling per study site was sufficient to represent the major prey categories (Figure 4.6).

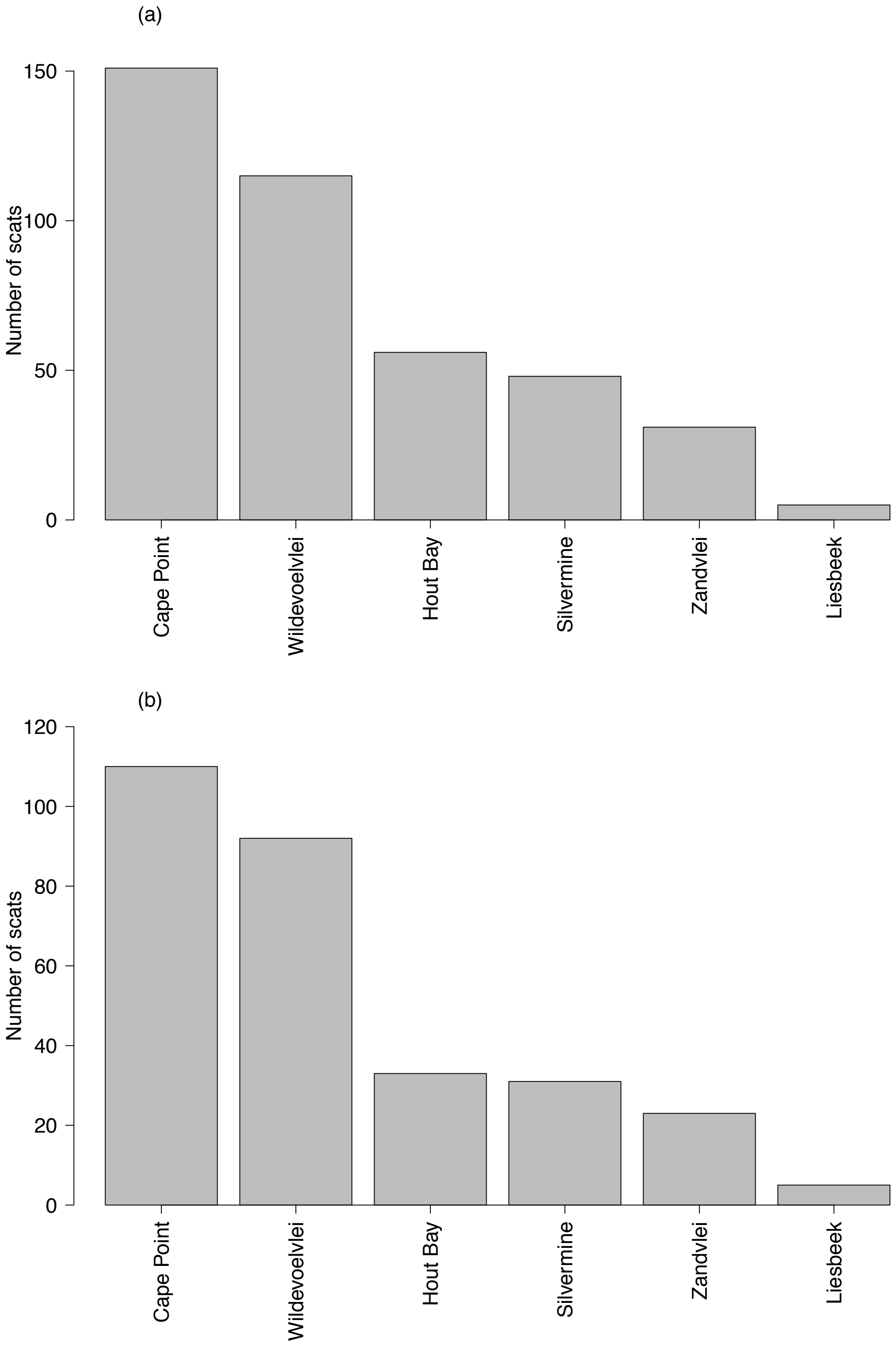


Figure 4.5. The total number of spraints collected per study site in a) the overall dataset from July 2012 – November 2014, n = 406, and b) the fixed dataset from July 2012 – June 2013, n = 249, where equal effort was allocated to each study site.

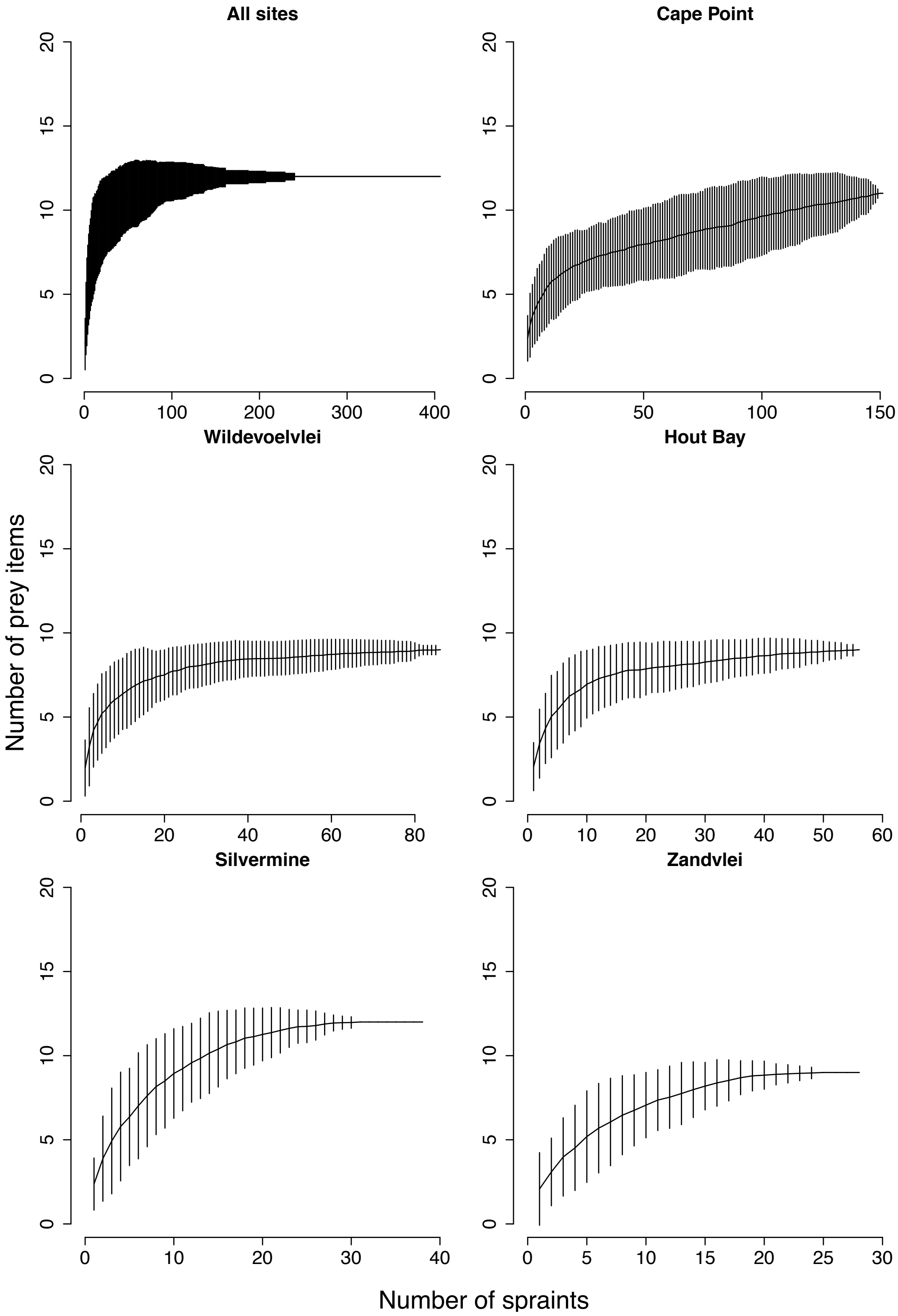


Figure 4.6. Species accumulation curves (method = random, 100 permutations) from spraints collected as part of the overall dataset (n = 406) from five study sites for which I obtained sufficient samples. One study area (Liesbeek, n = 10) was excluded due to low sample size.

a) The overall diet of Cape clawless otters across the Cape Peninsula

During the entire study period, fish were the most common prey of Cape clawless otters across all study sites (41.98% relative frequency of occurrence, Table 4.2). Rock lobster was the second most common prey (23.2%), followed by squid (9.94%). Together fish (marine and freshwater), rock lobster and squid accounted for 75% of the diet of otters across the Peninsula. The remaining 25% was made up of isopods (6.41%), freshwater crab (6.08%), frog (4.42%), marine crab (3.54%), insects (1.66), octopus (0.99%), birds (0.99%) and mammals (0.77%).

Table 4.2. The frequency of occurrence of prey categories recorded in Cape clawless otter spraints (n = 406) collected from six main study areas across the Peninsula for the duration of the study, July 2012 – November 2014. FO – Frequency of occurrence; RFP – Relative frequency of occurrence.

Prey category	**Observed**	**FO (%)**	**RFO (%)**
Fish	380	93.59	41.98
Rock lobster *Jasus lalandii*	210	51.72	23.20
Squid	90	22.17	9.94
Isopods *Tylos capensis*	58	14.29	6.41
Freshwater crab *Potamonautes perlatus*	55	13.55	6.08
Frog	40	9.85	4.42
Marine crab *Plagusia chabrus*	32	7.88	3.54
Insect	15	3.69	1.66
Octopus	9	2.22	0.99
Bird	9	2.22	0.99
Mammal	7	1.72	0.77

b) Spatial and temporal variation in the diet of Cape clawless otters across the Cape Peninsula

The frequency of occurrence and the relative frequency of occurrence of main prey categories as analysed from the fixed dataset are presented in Table 4.3. During this year, fish was still the most common prey category in all study sites combined (42.9% relative frequency of occurrence, Table 4.3). Rock lobster was the second most common prey (18.4%), followed by fish with scales (13.9%), squid (9.7%) and freshwater crab (8%). Together fish, rock lobster, squid and freshwater crab accounted for almost 80% of the diet of otters across the Peninsula. The remaining 20% was made up of frog (6.2%), isopods (5.7%), marine crab (3.4%), insects (2.8%), birds (1.8%), mammals (1.2%) and octopus (0.8%). Monthly variation in each of these prey items is plotted in Figure 4.7.

Table 4.3. The frequency of occurrence of prey categories recorded in Cape clawless otter spraints collected routinely from six main study areas across the Peninsula, July 2012 – June 2013 (total n = 249 for seasonal variation, total n = 150 for spatial variation). FO = frequency of occurrence; RFO = relative frequency of occurrence. Seasonal variation (n) and spatial variation (n) = number of samples containing that prey category. Asterisk (*) indicates significance of variation (Kruskal – Wallis, $p < 0.05$). The numbers [1-3] indicate grouping by prey source: [1]Freshwater, [2]Marine and [3]both.

Prey category	FO (%)	RFO (%)	Seasonal variation (n)	Spatial variation (n)
[3]Fish	57.9	42.9	235*	139*
[2]Rock lobster *Jasus lalandii*	24.9	18.4	101*	28*
[2]Squid	13.1	9.7	53	35
[1]Freshwater crab *P. perlatus*	10.8	8.0	44*	43*
[1]Frog	8.8	6.2	34*	33
[2]Isopods *Tylos capensis*	7.6	5.7	31*	9
[2]Marine crab *Plagusia chabrus*	7.6	3.4	17*	5*
[1]Insect	6.2	2.8	14*	14
[1]Bird	4.0	1.8	9	8
[1]Mammal	2.7	1.2	6	5
[2]Octopus	1.8	0.8	4	1

All prey categories except for bird, mammal, squid and octopus showed significant seasonal variation in relative frequency of occurrence (Kruskal-Wallis, $p < 0.05$, Table 4.3, Figure 4.7). Variation for only the top five prey categories constituting 80% of otter diet is described. Fish were found in otter spraints across all months, with a slightly higher contribution in winter. Rock lobster contributed significantly less to otter diet in spring and summer. Squid did not vary significantly across seasons. Freshwater crabs were found in otter spraints more frequently in summer than in other seasons and were never found in winter.

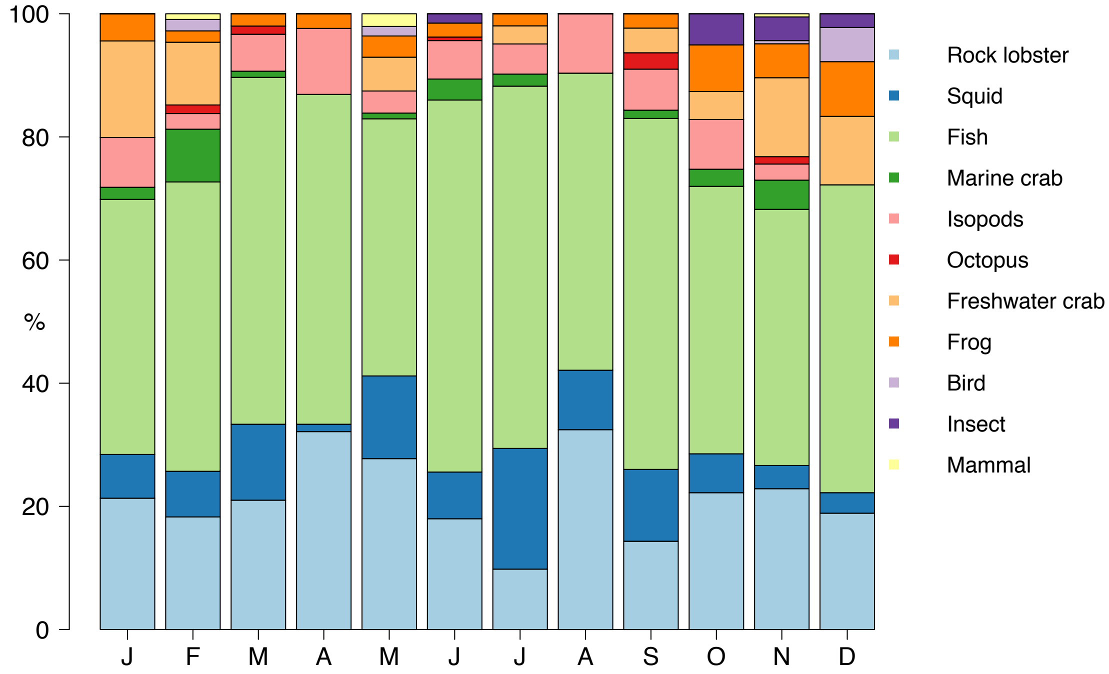


Figure 4.7. The relative frequency of occurrence (RFO) of the major prey categories found in otter spraints across the Cape Peninsula per month, June 2012 – July 2013 (n = 249).

When prey items were grouped into categories based on their source (freshwater prey, marine prey and fish; see designations in Table 4.3), each group showed significant seasonal variation (Figure 4.8). Freshwater prey items contributed to otter diet more frequently in spring and summer months, while marine prey items contributed more frequently in autumn and winter months. Fish remained consistent across all seasons but did show a significant increase in frequency of occurrence in winter. These results reflect similar variation in prey availability as described earlier (see Prey Availability and Figures 4.2-4.4).

The MRFO of some prey items also varied across sites (Kruskal-Wallis, $p < 0.05$, Table 4.3). There was no difference between the relative frequencies of occurrence of prey items between the spatial dataset and the fixed dataset ($p = 0.98$, Fishers exact test of independence). In general, fish was consumed significantly more frequently at polluted sites, while freshwater crabs were consumed significantly more at unpolluted sites. Rock lobster contributed significantly less to otter diet at polluted sites than at unpolluted sites, and there was no significant difference in the frequency of occurrence of squid and frog between sites. When grouped by prey source, freshwater prey was consumed more frequently at unpolluted sites than at polluted sites; marine prey did not differ between sites, and fish prey was found significantly more frequently in otter spraints collected at polluted sites (Figure 4.9).

Isotopes analysis

Otter prey items showed large variation in isotope values, with mean $\delta^{13}C$ values ranging from -21 ‰ to -9‰ and mean $\delta^{15}N$ values ranging from 12‰ to 17‰. Prey types vary along a $\delta^{13}C$ continuum from freshwater to estuarine and marine prey (lowest to highest) with individual otters grouped into clear groups along these lines. Prey groups did not separate significantly along $\delta^{15}N$ values, and with the exception of two otter outliers, neither did the otters. The variation in $\delta^{13}C$ and $\delta^{15}N$ values of potential prey groups suggests that otters on the Cape Peninsula can potentially occupy a relatively large isotopic prey space (Figure 4.10). There was a significant difference in the mean $\delta^{13}C$ and $\delta^{15}N$ values between individual otters (vibrissae), as well as a significant difference between segments of each vibrissa of the same individual (two way ANOVA, $p < 0.05$). These results suggest that otter diet consists of a combination of freshwater and marine prey items, and is significantly variable both within and between individuals (Figure 4.11).

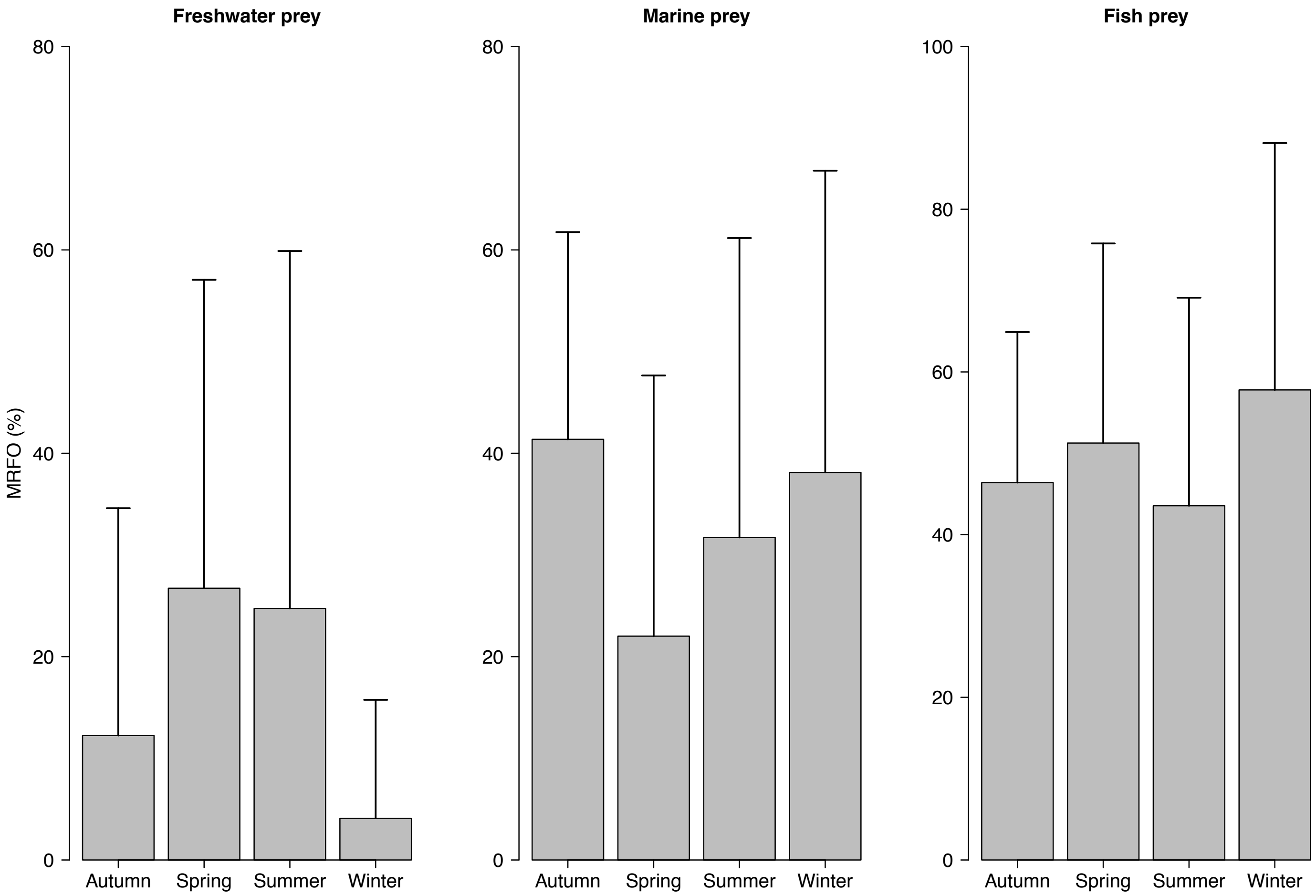


Figure 4.8. Seasonal variation in the mean relative frequency of occurrence (MRFO) of the major prey items groupings found in otter spraints across the Cape Peninsula, June 2012 – July 2013 (n = 249).

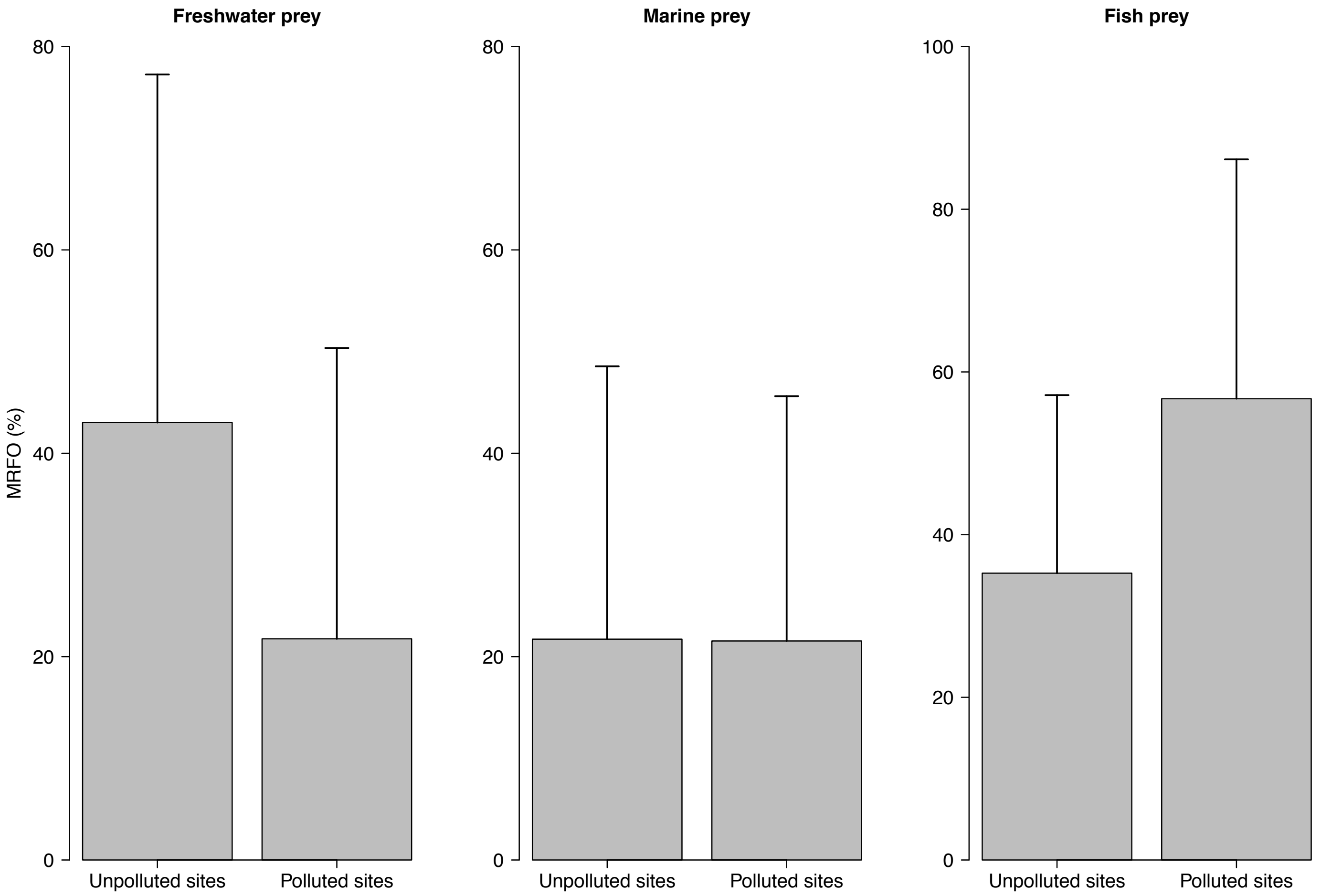


Figure 4.9. The mean relative frequency of occurrence (MRFO) of the major groupings of prey items found in otter spraints across the Cape Peninsula at unpolluted and polluted sites, June 2012 – July 2013 (n = 150).

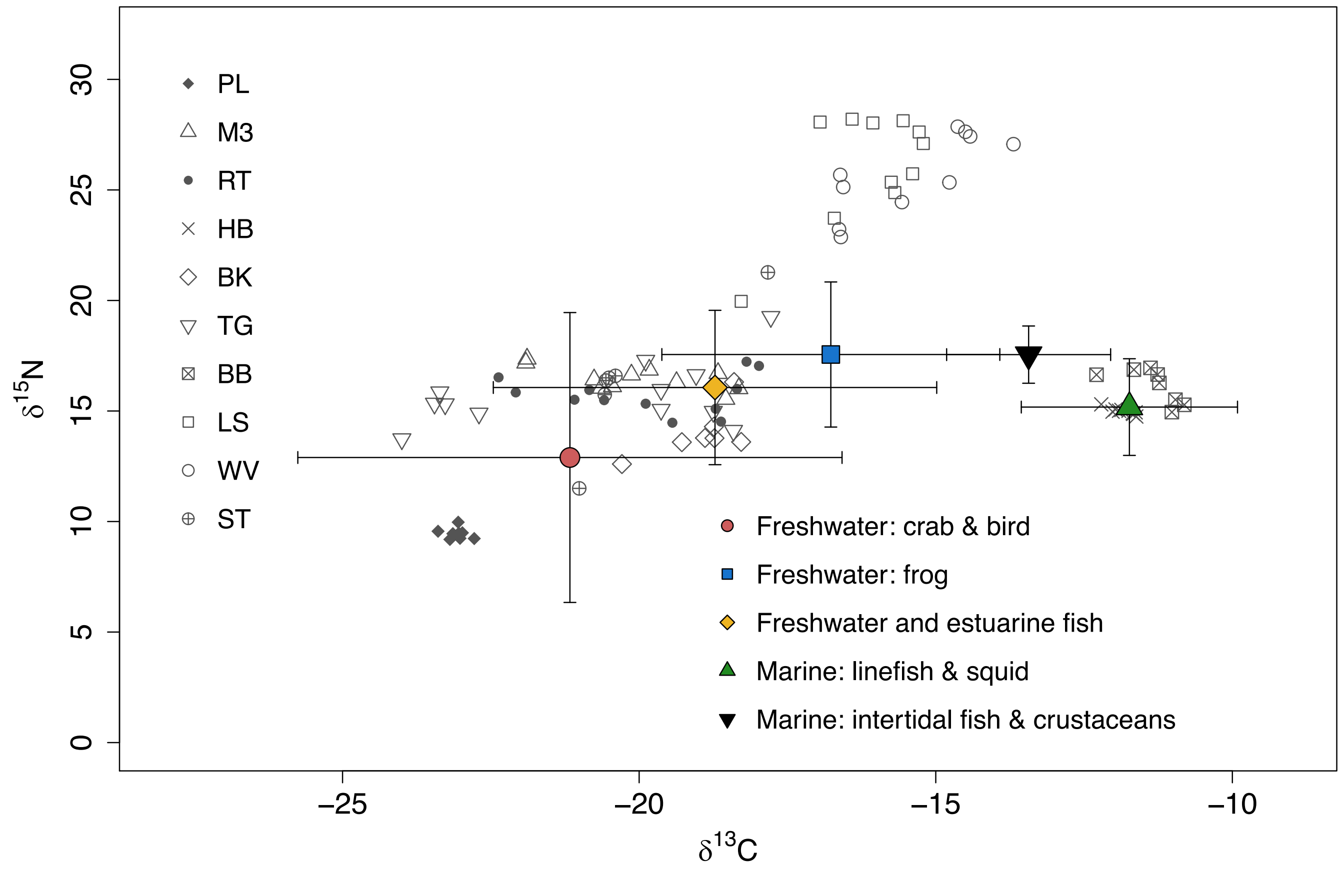


Figure 4.10. Dual isotope plot showing $\delta^{13}C$ and $\delta^{15}N$ of individual otter vibrissa segments (n = 95 segments, n = 10 otters) and mean ±SD $\delta^{13}C$ and ±SD $\delta^{15}N$ of potential prey groups.

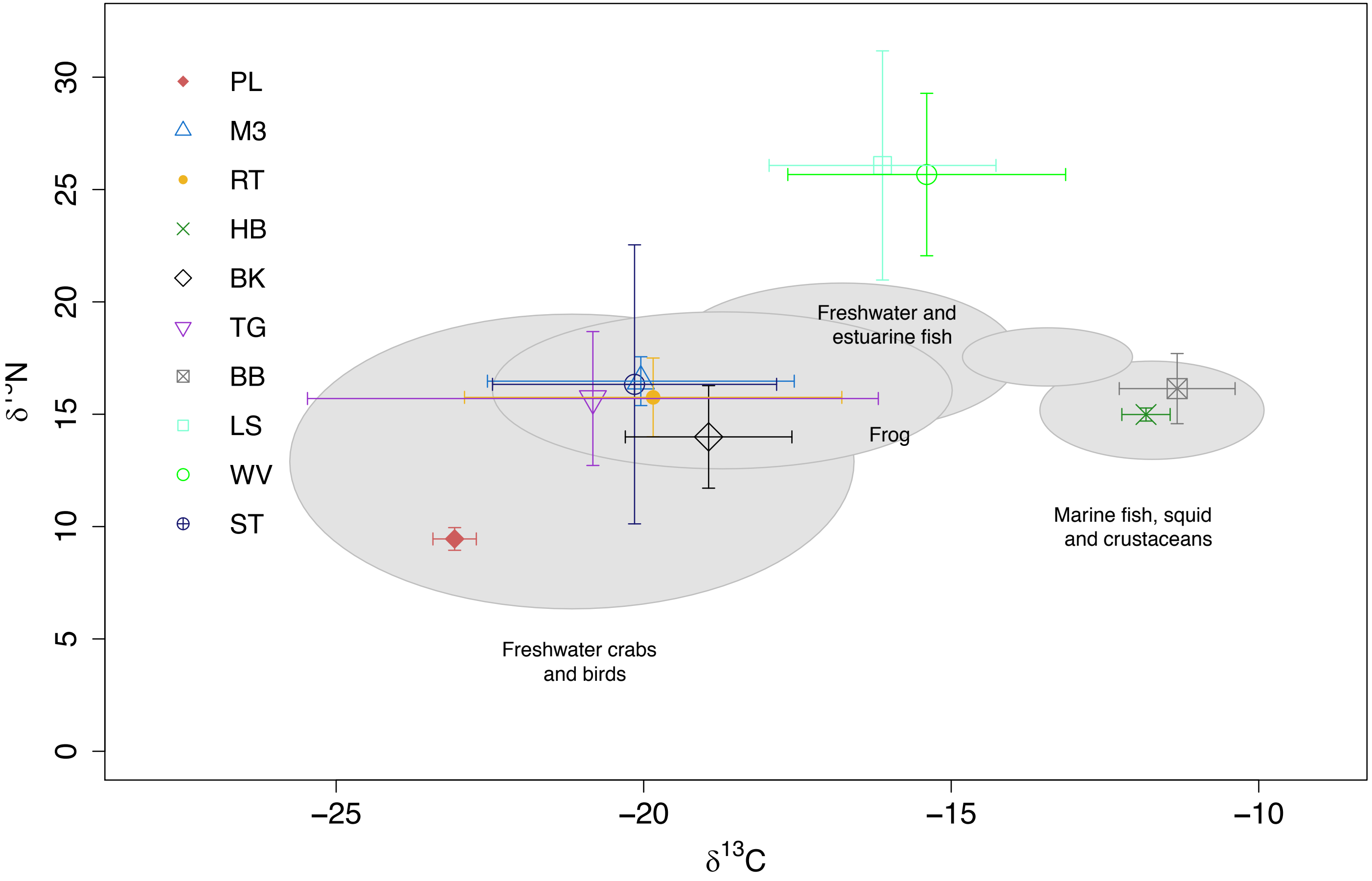


Figure 4.11. Dual isotope plot of the mean and standard error $\delta^{13}C$ and $\delta^{15}N$ of individual otters, illustrating the variation within and between individual otter vibrissa segments (n = 95 segments, n = 10 otters). Prey groups are superimposed on the plot and represented by the grey ellipses.

Discussion

Previous studies on the diet of Cape clawless otter also show marked variation across both sites (Parker et al., 2005; van der Zee, 1981; Verwoerd, 1987; Watson and Lang, 2003) and seasons (Jordaan et al., 2015; Rowe-Rowe, 1977; Somers, 2000). This is, however, the first study on this species to use stable isotopes analysis to a) provide support for their generalist diet, and b) explore individual variation. Newsome et al. (2009) explored individual dietary specialisation in Southern sea otters *Enhydra lutris*, within the framework of intra-population niche variation developed by Roughgarden (1972, 1974) and expanded on in Bolnick et al. (2003). Using stable isotope data from vibrissae as the continuous variables to describe prey consumed, Newsome et al. (2009) predicted that if otters were dietary generalists, they would occupy a large isotopic space, and that most of the variation observed would reflect differences between segments within individual vibrissae (Bolnick et al., 2003; Newsome et al., 2009). Conversely, in the case of dietary specialisation, most of the variation observed would reflect differences between individual vibrissae (Bolnick et al., 2003; Newsome et al., 2009). Newsome et al. (2009) concluded that due to high inter-individual variation and low intra-individual variation, Southern sea otters showed highly individualised diets that were maintained through time.

In my study however, Cape clawless otters occupied a large isotopic space, and showed a high degree of intra-individual isotopic variation, suggesting that the relative proportion of prey items in their diet does vary significantly over time. Only two individuals in this study show little variation in intra-vibrissae variation, both of which were found outside of the Peninsula, in areas with larger protected marine and freshwater habitats that perhaps offer a more stable food source and allow a greater degree of specialisation. Our isotope results therefore complement the spraint analyses in suggesting that the Peninsula otter population would more accurately fit the model of generalist foraging with some individuals showing a degree of specialisation on either freshwater and marine prey (Bolnick et al., 2003)(Bolnick et al., 2003)(Bolnick et al., 2003)(Bolnick et al., 2003)(Bolnick et al., 2003)(Bolnick et al., 2003)(Bolnick et al., 2003)(Bolnick et al., 2003)(Bolnick et al., 2003)(Bolnick et al., 2003).

Trophic niche flexibility is known to contribute to a species' ability to persist and adapt to anthropogenically-altered ecosystems (Crooks, 2002; Manfredi et al., 2004). While some otter species, such as the European otter, exhibit considerable trophic flexibility (Remonti et al., 2008), others, such as the Southern river otter in Chile, and the Neotropical otter in

Brazil, have a particularly narrow trophic niche (Franco et al., 2013; Sousa et al., 2013). Ruiz-Olmo and Jiménez (2009) suggest that the European otter's diet is less diverse in more stable habitats, where otters would feed mostly on their preferred prey, and that lower habitat stability forces them to forage more frequently on the edges of aquatic ecosystems. For example, in Poland, European otter diet consisted of mostly amphibians and water birds in canal-river systems, which are poor in fish resources (Kloskowski et al., 2013). By contrast, Smiroldo et al. (2009) found that European otter diet consisted mainly of fish within the main river of a catchment in Italy, but was dominated by amphibians, roaches and eels in the tributaries, where habitat features or human interference reduced fish abundance. In this study, the exclusively marine foraging individuals did not stray from their food source over time. However, the urban Cape clawless otters were able to access additional prey in polluted systems that provide a favourable environment for crabs and exotic freshwater fish, due to the increase in nitrates and phosphates in transformed lowland rivers and wetlands.

Feeding opportunistically between marine, freshwater, polluted or unpolluted systems may facilitate Cape clawless otter's ability to inhabit transformed systems and disperse through an urban environment. However, prolonged feeding in polluted systems may be detrimental in the long term due to the insidious threat of bioaccumulation of toxins in urban aquatic food chains. Similarly to in Chapter 3, where I found that otters are capable of inhabiting suboptimal urban habitat, the availability of suboptimal prey in these environments may reinforce these altered systems as 'ecological traps' (Battin, 2004) with numerous long-term costs for urban wildlife. The importance of the Marine Protected Areas for sustaining otter populations with a diet that is not too heavily impacted by pollution relative to freshwater systems is therefore reinforced in this chapter.

CHAPTER 5:

INVESTIGATING THREATS TO CAPE CLAWLESS OTTERS, *AONYX CAPENSIS*, IN AN URBAN ENVIRONMENT, THE CAPE PENINSULA.

Abstract

Across trophic levels, urban-adapted wildlife are exposed to numerous threats in the form of increased risk of persecution, disease, pollution, poisons and disturbance. Otters are particularly vulnerable to these threats due to their reliance on freshwater ecosystems and their ecological role as top predators. However, despite the potential risks, otters in the Cape Peninsula occupy and forage in areas that are heavily impacted by urban development. In this chapter, I involved the local community in collecting data on otter sightings, interactions and vehicle accidents to develop a hotspot map of otter conflict across the Peninsula. In addition, I collected and dissected road-killed otters to compare the body condition of the Peninsula otters to previous studies in comparatively more natural areas, and provide the first study on levels of PCB contamination in Cape clawless otter tissue. I found that the Peninsula otter population experiences low to moderate levels of conflict throughout most of their distribution on the Peninsula. High conflict areas are associated with optimal habitat that has been fragmented by canalisation and urban development. Peninsula road-killed otters were significantly smaller than otters surveyed in Tsitsikamma National Park, yet showed no evidence of poorer body condition. There was evidence of the accumulation of PCBs in the liver tissue of a third of the otters examined, suggesting that despite otters being adaptable generalists, their dependence on polluted freshwater systems may have long-term health impacts. I propose that educating communities that live in conflict hotspots may improve otter welfare and conservation. As a charismatic mammal, the Cape clawless otter has an important role to play in encouraging both public and policy engagement over wastewater management in the City of Cape Town.

Introduction

Globally, across trophic levels, wildlife species have adapted to human-modified landscapes (Bateman and Fleming, 2012) and some have even flourished in urban landscapes (e.g. Hoffman & O'Riain 2012; Gloor et al. 2001). However living in close proximity to people exposes wildlife to increased risk of persecution (Beamish and O'Riain, 2014; Mukherjee et al., 2015), disease (Bradley and Altizer 2007; Ahlers et al. 2015), pollution (Cannicci et al., 2009; Skei et al., 2000), poisons (Stone et al., 1999) and disturbance. Roads, dams and urban settlements also fragment the natural habitat and form barriers to dispersal, placing populations at risk of genetic isolation (Major et al., 2014) and individuals at risk of collisions with vehicles (Roe et al., 2006; Collins and Kays 2011). Together these threats are adversely impacting on the survival of amphibians, reptiles and wetland mammals across the globe (Crooks, 2002; Hamer and Mcdonnell, 2010; Hamer and McDonnell, 2008).

Of the thirteen species of otters worldwide, twelve are regarded as Near Threatened or worse. Sea otters, *Enhydra lutris*, are currently listed as Endangered with disease, oil spills and disturbance impeding their recovery (Doroff and Burdin, 2015). European otters, *Lutra lutra*, are currently Near Threatened having suffered large declines and local extinctions in the 1900's; due to environmental contamination (Roos et al., 2015). Certain toxic compounds (DDT, dieldrin and polychlorinated biphenyls – PCBs) thought to be responsible were subsequently banned, and the population has shown signs of recovery in parts of their range. However, road traffic accidents are now considered the major cause of otter mortality in Europe, potentially threatening the recovery of the species in certain regions (Philcox et al., 1999). In Asia, all three species are either Vulnerable or Endangered due to a combination of habitat destruction and overfishing of their main prey species (Aadrean et al., 2015; De Silva et al., 2015; Wright et al., 2015). In South America, three out of the four species of otters are classified as Endangered; all of them threatened by habitat destruction, gold mining, the development of hydroelectric dams and conflict with local fisheries (Groenendijk et al. 2015; Rheingantz & Trinca 2015).

In contrast to otters in other regions, the threats to otters in Africa are poorly understood. All three African otter species were listed as Least Concern until 2015, when their status was changed to Near Threatened. The authors cite 'perceived and assumed population decline' due to the 'alteration or degradation of freshwater habitat and riparian vegetation' as the main reasoning for the change (Jacques et al., 2015). Although otters are being negatively impacted by these factors, the lack of evidence to support these claims points to the paucity of research on the pressures African otters are facing. For Cape clawless otters in particular, Jacques et al. (2015) list urbanisation, vehicle accidents and interactions with dogs as the most likely threats to the species across their range.

In South Africa, much of the baseline data on otter ecology originates from relatively pristine environments (Perrin and Carugati, 2006; Somers and Nel, 2004; van der Zee, 1982; Verwoerd, 1987). In particular, research conducted by Arden-Clarke (1986) and van der Zee (1981) in Tsitsikamma National Park include morphometric measurements which can be used to derive baseline data on the body condition of otters in protected areas. However, few studies have monitored otter populations in disturbed environments. Kubheka et al. (2013) presents some evidence that Cape clawless otters may have retreated upstream throughout much of their range as the lower reaches are transformed by agriculture, while Mason & Rowe-Rowe (1992) found that contaminants including PCBs were present in low concentrations in the spraints of otters in the same area. There is however, no baseline data on the pollution loads, body condition and/or causes of injury and death for Cape clawless otters in urban areas of their current distribution.

Throughout the Western Cape, and particularly in the Cape Peninsula, urbanisation has radically altered aquatic ecosystems and led to increased pollution loads (Brown and Magoba, 2009) and extensive road networks and housing developments in close proximity to otter's natural habitat. The Peninsula therefore provides an appropriate study site to investigate the threats to otters in an urban space including: a) known causes of disturbance, injury and mortality; b) body condition of otters in comparison to previous studies in relatively natural areas, and c) levels of contamination of PCBs found in otter carcasses. I use these data to derive a hotspot map highlighting areas of greatest threat to otters within the Peninsula. These data are to be used by the City of Cape Town municipality and the national authority responsible for managing protected areas (South African National Parks, SANParks) to improve the health and welfare of the Peninsula otter population with important lessons for other otter populations impacted by urbanization in southern Africa.

Methods

Known causes of disturbance, injury and mortality.

The low occupancy (Chapter 3) and cryptic nature of otters in addition to the large size of the study area precluded a systematic research design for assessing physical threats to otters within the study period. Consequently I was largely reliant on citizen sightings and the assistance of NPO's such as the SPCA Wildlife Unit to obtain data on disturbance, injury and mortality of otters in the greater Cape Town region. To facilitate citizen reporting on otters I designed a Google form (see Appendix A) that once completed could be submitted online. The form was hosted on a designated website, allowing information to be uploaded online, and included my cell phone number and email address to allow people to report sightings, interactions and events directly to me. Direct sightings of otters reported between 2011 and 2015 were used for this chapter. Each sighting was scored as either neutral (0: an otter in its natural habitat with no injuries or negative interactions with dogs, cars or people) or negative (1: an otter being harassed by dogs, people, hit by a car, dead or otherwise injured). No indirect signs in the form of spraint or spoor were used in this chapter.

For each sighting, covariate data on proximity to important habitat types (e.g. MPA, wetlands and estuaries as outlined in Chapter 3) and suspected causes of disturbance, injury and mortality were collected (e.g. roads, canalised sections of river, household density; see Table 5.1). Using the scored sightings and the covariate data, I built a generalised linear model (GLM) to predict and map the probability of otter conflict across the Cape Peninsula. The top model was selected using Akaike Information Criterion (AICc) for small sample sizes and used to produce a hotspot map representing the predicted probability of conflict across both the study area landscape and the greater City of Cape Town following methods described by Miller et al. (2015). Both internal and external model validation was carried out. I conducted internal model validation by calculating the area under the receiver operating characteristic (ROC) curve in R, using the package 'ROCR' in R. ROC curves are obtained by plotting all sensitivity values on the y-axis against the false positive proportion values on the x-axis (Fielding and Bell, 1997; Pearce and Ferrier, 2000). The area under this curve (AUC) indicates the overall ability of the model to accurately predict the data used to create it (Fielding and Bell 1997; Pearce and Ferrier 2000). AUC values range from 0.5 (not better than a null model) to 1.0 (100% accurate) (Long et al., 2011; Pearce and Ferrier, 2000).

I followed standard external model validation methods for hotspot analyses as described and reviewed by Miller (2015). In order to maximize the data that could be used for external model validation, I a) used the best conflict risk model to create a prediction of conflict risk across the greater City of Cape Town (i.e. not just the Cape Peninsula), and b) used independent data on otter conflicts occurring outside the study period and from across the greater City of Cape Town region to validate the model ($n = 14$). Data was provided by the Iziko Museum in Cape Town.

Body condition calculations.

The carcasses of 12 otters were collected opportunistically between 2012 and 2014. The suspected cause of death (from beaching or road traffic accidents) and GPS location was recorded for each carcass. Carcasses were then stored at -20°C until a necropsy could be performed. In an initial external examination I recorded the sex, reproductive status (lactating or not), and measured the total length (nose to anus, anus to tail-tip) and weight to calculate a body condition index (*K*), following Kruuk (2006):

K = Weight/5.02*(Total Length)$^{2.33}$ for female otters, and
K = Weight/5.87*(Total Length)$^{2.39}$ for male otters

Body condition was compared between sexes, and between the Peninsula's urban otters and non-urban otter datasets derived from Arden-Clarke (1986) and van der Zee (1981).

Levels of contamination

I followed the Cardiff University Otter Project protocol for performing necropsies (Chadwick, 2007; see datasheet in Appendix B). I examined, weighed and retained all internal organs for future research. For the purposes of this study, I removed approximately 3 x 5g samples of liver for analysis of polychlorinated biphenyls (PCBs). In addition, I plucked approximately 5-10 vibrissae (including the root) for isotope analyses (Chapter 4).

Three 5g samples of liver from each of the 12 carcasses were sent to the Food and Drug Assurances Laboratory (Pty–Ltd, Brooklyn, Pretoria, South Africa) to be tested for 12 PCB congeners (PCB 28, 52, 118, 128, 101, 105, 138, 153, 156, 170, 180, 187). These congeners were chosen based on research around the world that suggests they are impacting adversely on otter species (Carpenter et al., 2014; Chadwick, 2007; Gutleb and Kranz, 1998; Lemarchand et al., 2010; Nakata et al., 1998). The results received from the laboratory are the concentrations of the various PCB congeners found in each sample, expressed in ug/kg (parts per billion). A value of <10 ug.kg^{-1} (the detection limit) means that the PCB congener was not detected in the sample. Total PCB was calculated as the sum of all 12 PCB congeners. Both geometric and arithmetic means were calculated. Samples with values of <10ug.kg^{-1} (i.e. where PCBs were not detected) were counted as part of the dataset at half the detection limit and included in the mean (as per Ritter et al., 1995).

The concentrations of PCBs determined in the livers of Peninsula otters are presented here as wet weight for ease of comparison with other otter species. These values can also be compared to the thresholds of no observed adverse effect level (NOAEL: 170 ug.kg^{-1} wet weight) and lowest observed adverse effect level (LOAEL: 460 ug.kg^{-1} wet weight) determined for European otters (Smit et al., 1996; Murk et al., 1998, reviewed in Kannan et al., 2000).

PCB concentrations can be converted to lipid weight if the lipid content of the tissue is known. Previous studies report lipid content values for liver fat in the range of 1.9 – 8.1% for European otters (Leonards et al. 1997) and 2.4 – 8.2% for sea otters (Kannan et al. 2004). Kannan et al. (2000) suggest an average of 5% liver lipid content for marine mammals. Based on this range of estimates, I converted the Peninsula otter PCB concentrations wet weight to lipid weight using OrgMassSpecR (function Convert.Concentration) so that I could compare the concentrations to previous research that did not provide wet weights.

Results

Known causes of disturbance, injury and mortality.

Between 2011 and 2015, a total of 152 sightings of otter were recorded in the Cape Peninsula. Photographic evidence was provided for only 69 (45%) of these sightings, but all sightings were included in the analyses given the high confidence in the sighting reports. Of the 152 sightings, 26 (17%) involved negative interactions with dogs (9), people (4) or vehicles (13). All otter sightings as well as important covariates including key habitat types (rivers, wetlands, estuaries and water bodies) and suspected causes of disturbance, injury and mortality (road density, urban land use, household density and canalisation) are plotted in Figure 5.1.

The top conflict risk models arising from a step-wise Generalised Linear Model were compared using AICc model selection. All models presenting AICc values within ΔAIC <2 were considered (n = 13, Table 5.3). The most important covariates explaining negative interactions (i.e. that were present in the majority of the top 13 models) were: proximity to canalised sections of river (CAN), proximity to nearest estuary (PNE) and proximity to nearest water body (PWATER). Thus the top conflict risk model selected was: $\text{Probability}_{(of\ conflict)}$ = CAN + PNE + PWATER. Each of the predictor variables and their relationship with the probability of conflict are plotted in Figure 5.2.

Internal model validation results are plotted in Figure 5.3. The area under the receiver operating characteristic (AUC) value was 0.76, showing that the model performs better than the null model (Long et al., 2011; Pearce and Ferrier, 2000). For the external model validation, I created a 1km x 1km grid over the entire City of Cape Town and assigned each cell a probability of conflict based on the results from the top conflict risk model, thereby creating a predicted conflict landscape. A threshold value for what constituted a conflict was determined by comparing model sensitivity and selectivity based on the ROC plot (Figure 5.3, threshold value = 0.2). I then selected a random subset of points from the predicted conflict risk landscape (n = 14, iterations = 1000), and plotted the distribution of the number of predicted conflicts with 95% confidence intervals out of this random subset (Figure 5.4). I then plotted the number of conflicts predicted by the model for the validation dataset (the black dot, Figure 4). Predictions for the validation data sites exceeded the 95% limits of the random data sites, meaning that the conflict risk model performed differently from random (Figure 4). Using this threshold value calculated from the ROC plot (Figure 5.4, threshold = 0.2) to classify predicted risk, I mapped the predicted spatial distribution of conflict risk across the Cape Peninsula in Figure 5.5.

Body condition calculations.

Of the 12 otter carcasses collected, eight were killed in road traffic accidents, two were euthanized by the SPCA after being found injured through unknown causes, and one was found washed up on a beach with no obvious cause of death. Six of the otters were male and six were female. Sightings were more common in autumn and winter with the months of April, May and July all having more than one conflict incident.

The mean body condition (*K*) of adult male otters across all study sites was significantly lower than that of females (Welch two sample t-test, t = 3.22, df = 21.58, p-value < 0.05, Table 5.1). There was no difference in the average body condition of both male and female adult otters in the Cape Peninsula compared to the Tsitsikamma National Park (Welch two sample t-test, t = 1, df = 5.8, p > 0.05). However, adult Peninsula otters that were killed by motor vehicles were significantly shorter in total length (t = -2.37, df = 27, p-value < 0.05) and had a lower body weight than otters captured in Tsitsikamma (t = -2.29, df = 27, p-value < 0.05).

Levels of contamination

PCBs were present in four of the 12 otters tested. Of the 12 PCB congeners tested, only four were found to be present (viz., 153, 180, 118 and 138). Concentrations ranged from not detected (<10ug.kg^{-1}) to a maximum of 242.5 ug.kg^{-1} (Table 5.2). The geometric mean of the total PCB concentrations of all samples was 84.4 ug.kg^{-1} wet weight (1 039 – 4 431 ug.kg^{-1} lipid weight based on sea otter and European otter liver lipid weights).

Table 5.1. A description of the covariates used in the Generalised Linear Model, including their source and how they were measured. Proximity covariates were calculated with the use of the NEAR Tool in ArcGIS® (v 10.2) software by Esri. All proximity and area calculations were measured in meters, and standardised using the scale function in R. All GIS layers used in these analyses were sourced from the City of Cape Town (CMA, CityMaps, City of Cape Town 2014).

Covariate	**Data Source**	**Analysis**
Proximity to the coast (PC)	City of Cape Town GIS Layer, 2014.	The distance from each sighting to the nearest coastline.
Proximity to City Park (PCP)	City of Cape Town GIS Layer, 2014.	The distance from each sighting to the nearest city park.
Proximity to urban edge (PUE)	Urban Edge GIS Layer, 2014.	The distance from the location of each sighting to the nearest urban edge.
Proximity to Natural Estuaries (PNE)	Natural Estuaries GIS Layer, 2009. CSIR, SANBI.	The distance from each sighting to the nearest natural estuary, defined as the floodplain between a river and the sea into which it flows. The estuary may be permanently or periodically open to the sea.
Household density (HD)	Census GIS Layer, 2007.	The number of households per km^2 for the suburb within 2km of each sighting.
Household (HH)	Census GIS Layer, 2007.	Number of household in the suburb within 2km of each sighting.
Proximity to Marine Protected Areas (PMPA)	Marine Protected Areas GIS Layer, 2014.	The distance from each sighting to the nearest marine protected area. The MPA controls both recreational and fishing activities to ensure the sustainability of marine resources.
Proximity to Canalisation (CAN)	City of Cape Town GIS Layer, 2014.	The distance from each sighting to the nearest canalised (concrete) sections of stream or river.
Human population density (PD)	Census GIS Layer, 2007.	The number of people per km^2 residing in the suburb within 2km of each sighting.
Population (POP)	Census GIS Layer, 2007.	Population of the suburb within 2km of each sighting.
Proximity to roads (PST)	Property GIS Layer, 2007.	The distance from the location of each sighting to the nearest road.
Proximity to Urban Conservation Areas (PUCA)	Urban Conservation Areas GIS Layer, 2014.	The distance from each sighting to the nearest urban conservation area - areas within the city proclaimed as natural heritage and/or conservation sites, protected from development. They include green belts, some beaches, few harbours and monuments.

Covariate	Data Source	Analysis
Proximity to Water body (PWATER)	City of Cape Town GIS Layer, 2014.	The distance from each sighting to the nearest water body.
Proximity to Wetlands (PWET)	Wetland Vegetation GIS Layer, 2014.	The distance from each sighting to the nearest wetland.
Otter occupancy (OCC)	Occupancy model, Chapter 3	The probability of an otter occupying the 1km x 1km grid cell in which the sighting occurred, extracted from the shape layer of otter occupancy across the Cape Peninsula created in Chapter 3.

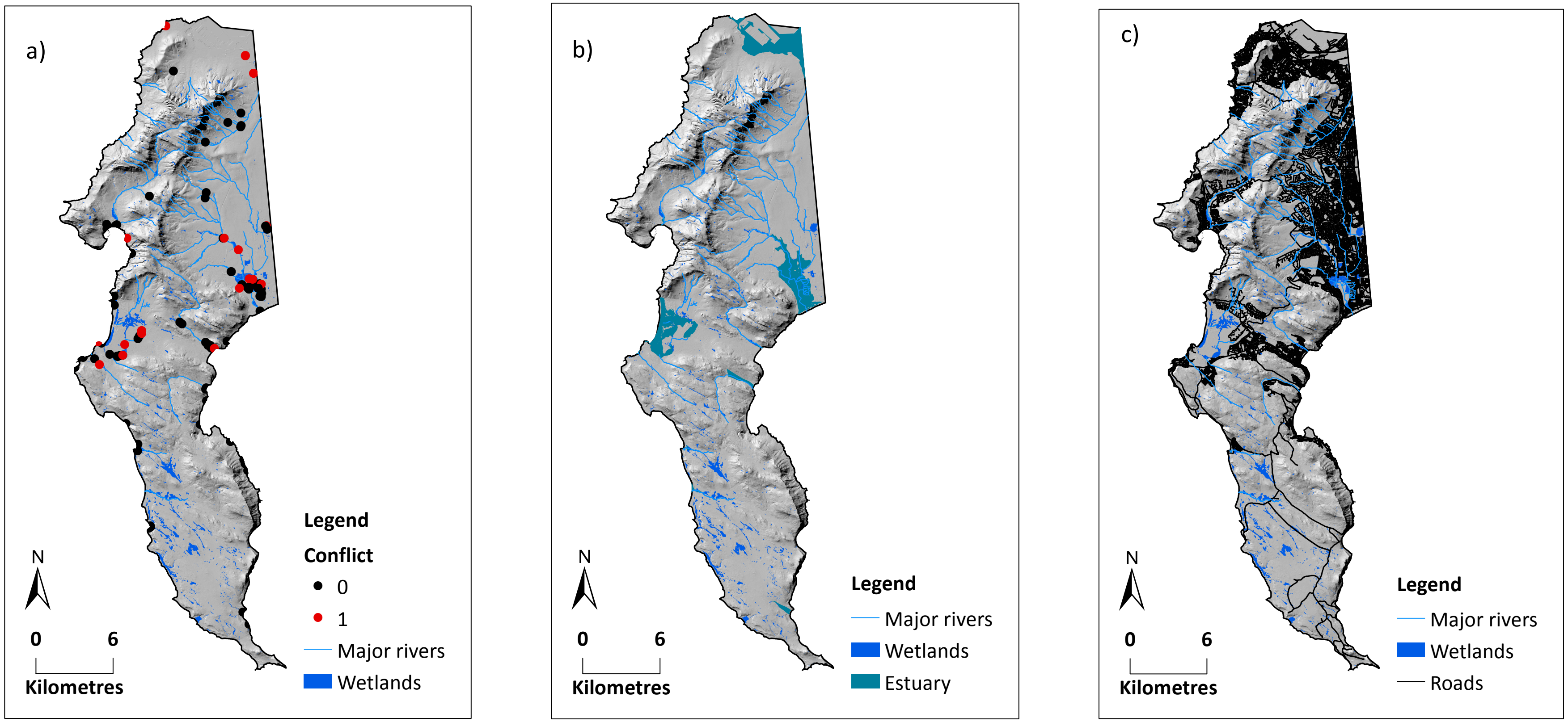


Figure 5.1. Maps of a) the otter sightings reported by citizen scientists and modeled in a GLM to explain the probability of conflict across the Peninsula; and (b-e) the important factors used as covariates in the model, namely; b) distance to estuaries, c) road density, d) household density (per km^2), and e) distance to canalised section of river.

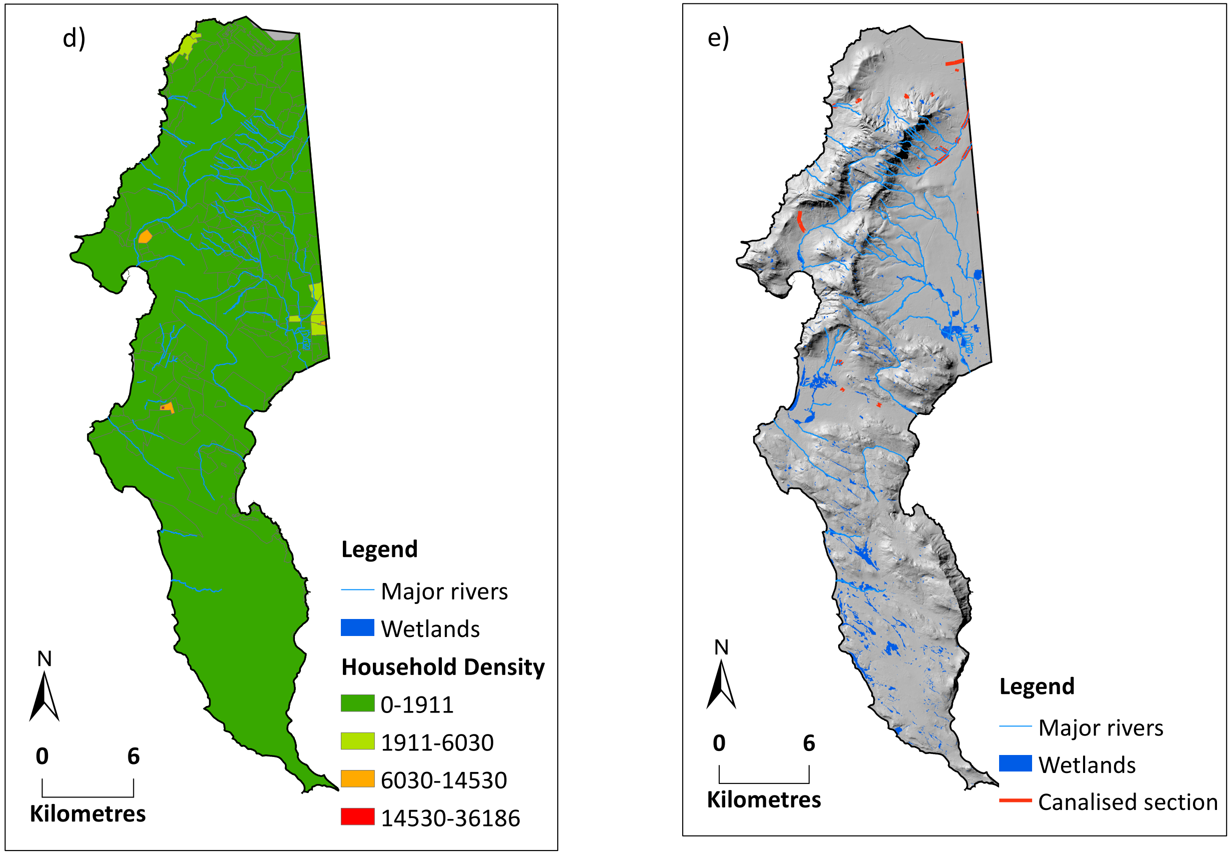


Figure 5.1 continued. Maps of a) the otter sightings reported by citizen scientists and modeled in a GLM to explain the probability of conflict across the Peninsula; and (b-e) the important factors used as covariates in the model, namely; b) distance to estuaries, c) road density, d) household density (per km^2), and e) distance to canalised section of river.

Table 5.2. Spearman's correlation (Spearman's rho, r_s, values) matrix of the covariates used in the Generalised Linear Model. PC: Proximity to the coast; PCP: Proximity to City Park; PUE: Proximity to urban edge; PNE: Proximity to Natural Estuaries; HD: Household density; HH: Households; PMPA: Proximity to Marine Protected Areas; CAN: Proximity to canalised sections of river; PD: Human population density; POPN: Population; PST: Proximity to streets; PUCA: Proximity to Urban Conservation Areas; PWATER: Proximity to Water body; PWET: Proximity to Wetlands; OCC: predicted probability of occupancy. Values in bold indicate correlations above the $r_s > 0.7$ threshold chosen for this study. Negative values for the proximity covariates indicate a negative relationship between two covariates.

	PC	**PCP**	**PUE**	**PNE**	**HD**	**HH**	**PMPA**	**PCAN**	**PD**	**POPN**	**PST**	**PUCA**	**PWATER**	**PWET**	**OCC**
PC	1.00	0.25	0.39	0.32	-0.26	-0.28	0.44	0.01	-0.22	-0.21	0.39	0.38	0.32	0.15	-0.10
PCP	0.25	1.00	0.18	0.42	**-0.73**	-0.62	-0.38	0.36	**-0.70**	-0.60	0.54	0.27	0.42	0.33	-0.16
PUE	0.39	0.18	1.00	0.25	-0.09	-0.11	0.32	0.18	-0.06	-0.07	0.32	0.30	0.32	0.31	-0.37
PNE	0.32	0.42	0.25	1.00	-0.37	-0.43	-0.30	0.50	-0.38	-0.44	0.38	0.35	0.60	0.64	-0.49
HD	-0.26	**-0.73**	-0.09	-0.37	1.00	**0.80**	0.43	-0.49	**0.98**	**0.78**	-0.51	-0.43	-0.29	-0.18	0.15
HH	-0.28	-0.62	-0.11	-0.43	**0.80**	1.00	0.35	-0.56	**0.81**	**0.98**	-0.46	-0.52	-0.40	-0.35	0.16
PMPA	0.44	-0.38	0.32	-0.30	0.43	0.35	1.00	-0.47	0.47	0.39	-0.15	-0.01	-0.18	-0.19	0.13
PCAN	0.01	0.36	0.18	0.50	-0.49	-0.56	-0.47	1.00	-0.50	-0.56	0.31	0.56	0.42	0.36	-0.29
PD	-0.22	**-0.70**	-0.06	-0.38	**0.98**	**0.81**	0.47	-0.50	1.00	**0.81**	-0.49	-0.44	-0.29	-0.17	0.13
POPN	-0.21	-0.60	-0.07	-0.44	**0.78**	**0.98**	0.39	-0.56	**0.81**	1.00	-0.44	-0.48	-0.36	-0.35	0.16
PST	0.39	0.54	0.32	0.38	-0.51	-0.46	-0.15	0.31	-0.49	-0.44	1.00	0.33	0.33	0.20	-0.14
PUCA	0.38	0.27	0.30	0.35	-0.43	-0.52	-0.01	0.56	-0.44	-0.48	0.33	1.00	0.45	0.14	-0.05
PWATER	0.32	0.42	0.32	0.60	-0.29	-0.40	-0.18	0.42	-0.29	-0.36	0.33	0.45	1.00	0.60	-0.44
PWET	0.15	0.33	0.31	0.64	-0.18	-0.35	-0.19	0.36	-0.17	-0.35	0.20	0.14	0.60	1.00	-0.62
OCC	-0.10	-0.16	-0.37	-0.49	0.15	0.16	0.13	-0.29	0.13	0.16	-0.14	-0.05	-0.44	-0.62	1.00

Table 5.3. Model selection based on AIC of the five best conflict risk models in the Cape Peninsula (n = 152). CAN: Proximity to canalised sections of river; PNE: Proximity to natural estuaries; PWATER: Proximity to water body; PUE: Proximity to urban edge; PMPA: Proximity to Marine Protected Area; PCP: Proximity to city park; PUCA: Proximity to urban conservation areas; PC: Proximity to the coast; PST: Proximity to streets; PWET: Proximity to wetlands. df = degrees of freedom, logLik = Log Likelihood, AICc = Akaike's Information Criterion, ΔAIC = Akaike's Information Criterion.

Model	**df**	**logLik**	**AICc**	**ΔAICc**
CAN + PNE + PWATER	5	-60.27	130.95	0.00
CAN + PWATER	4	-61.64	131.54	0.59
CAN + PUE	4	-61.83	131.94	0.99
CAN + PNE + PMPA + PWATER	6	-59.81	132.21	1.25
CAN + PCP	4	-62.09	132.45	1.50
CAN + PNE + PST + PWATER	6	-59.96	132.50	1.55
CAN + PNE + PUCA + PWATER	6	-60.01	132.59	1.64
CAN + PC + PNE + PWATER	6	-60.01	132.61	1.65
PNE + PMPA	4	-62.19	132.66	1.71
CAN + PST + PWATER	5	-61.16	132.73	1.78
CAN + PUCA + PWATER	5	-61.17	132.75	1.80
CAN + PUCA	4	-62.33	132.92	1.97
CAN + PWATER + PWET	5	-61.27	132.95	2.00

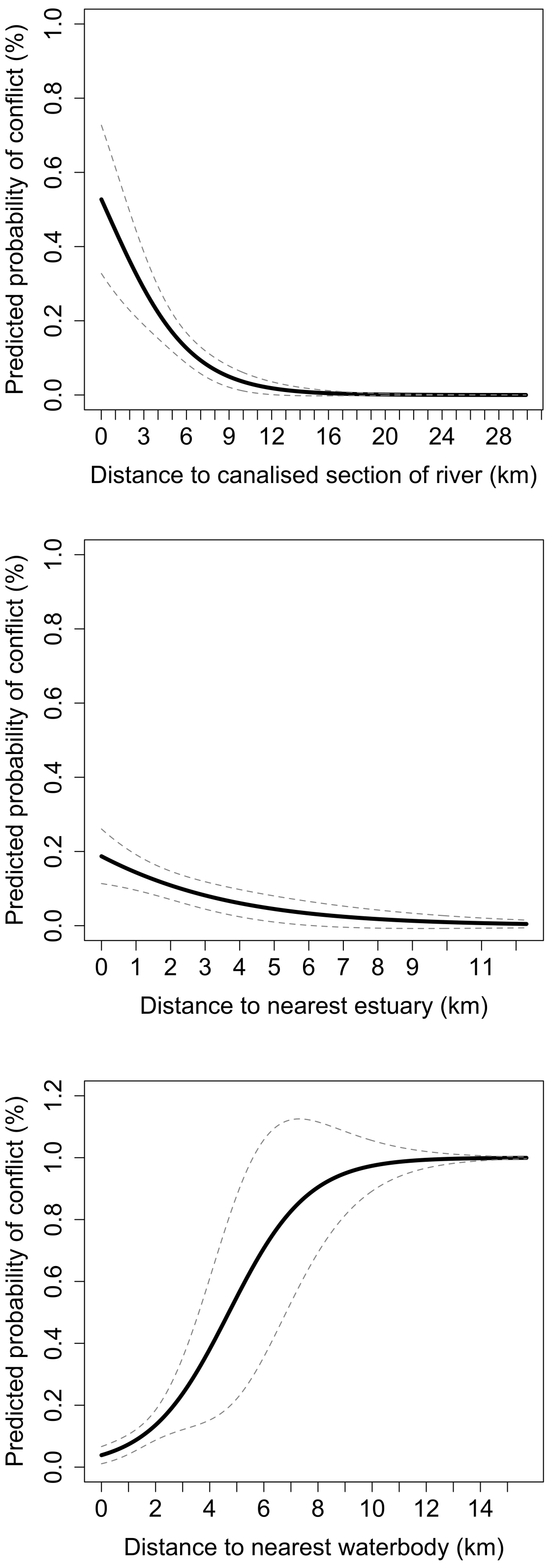


Figure 5.2. The relationship between the probability of otter conflict and a) distance to canalised section of river, b) distance to the nearest estuary and c) distance to nearest water body as determined by the best model. The 95% confidence intervals are represented by the dotted lines.

Table 5.4. The average weight, total length and body condition of Cape clawless otters recorded in this and previous studies from the Western and Eastern Cape Provinces.

Data source	**Year/s**	**Location**	**Sample size (n)**	**Average weight (kg)**		**Average total length (m)**		**Average body condition (K)**	
				Female	*Male*	*Female*	*Male*	*Female*	*Male*
[1]Van der Zee	1977	Tsitsikamma National Park, Eastern Cape, South Africa	9	12.35	13.10	1.21	1.22	1.58	1.39
[2]Arden-Clarke	1981	Tsitsikamma National Park, Eastern Cape, South Africa	12	11.77	14.62	1.18	1.32	1.62	1.28
[3]Iziko Museum	2000 – 2002	Stellenbosch, Western Cape, South Africa	2	11.63	-	1.20	-	1.57	-
[4]This study captures	2013 – 2014	Cape Town, Western Cape, South Africa	3	15.70	13.15	1.27	1.24	1.79	1.34
[5]This study vehicle accidents	2011 – 2014	Western Cape, South Africa	12	9.50	10.92	1.07	1.12	1.58	1.31

[1] Van der Zee, D. 1979. Food and status of the Cape clawless otter, *Aonyx capensis Schinz*, in the Tsitsikamma Coastal National Park, South Africa. (Unpublished M.Sc. thesis). Pretoria, South Africa: University of Pretoria.

[2] Arden-Clarke, C.H.G. 1983. Population density and social organization of the Cape clawless otter, *Aonyx capensis Schinz*, in the Tsitsikamma Coastal National Park. (Unpublished M.Sc. thesis). Pretoria, South Africa: University of Pretoria.

[3] Iziko Museums: South African Museum, Terrestrial Collections

[4] Otters captured and fitted with VHF transmitters in this study (see Appendix C).

[5] Road-killed adult otters collected for necropsies and pollutant analyses in this study (see Methods), excluding pups.

Table 5.5. The weight, length, body condition (K) and polychlorinated biphenyls (PCB) concentrations in the liver (ug/kg wet weight) of 12 dead Cape clawless otters opportunistically collected in the Western Cape between 2011 and 2014.

ID	Date	Location	$^{\delta}$Primary foraging environment	Sex	Age class	Weight (kg)	Total length (m)	K	PCB153	PCB180	PCB118	PCB138
PL	17-Oct-13	Plettenberg Bay	Freshwater	F	Adult	11	1.09	1.81	<10.0	<10.0	<10.0	<10.0
BB	26-Feb-14	Bettys Bay	Coastal	F	Pup	5	0.91	1.24	<10.0	<10.0	<10.0	<10.0
HB	21-Apr-11	Hout Bay	Coastal	M	Adult	13	1.19	1.46	**28.90**	<10.0	<10.0	<10.0
BK	21-Dec-11	Kommetjie	Freshwater	M	Adult	15	1.24	1.53	<10.0	<10.0	<10.0	<10.0
ST	23-Feb-12	Strand	Freshwater	M	Pup	6	0.73	2.19	***	***	***	***
LS	13-Apr-12	Lakeside	Both	F	Sub-adult	6	1.06	1.04	<10.0	<10.0	<10.0	<10.0
RT	08-Jan-13	Retreat	Freshwater	F	Adult*	14	1.14	2.06	<10.0	<10.0	<10.0	<10.0
M3	17-Jul-13	Retreat	Freshwater	F	Adult	11	1.06	1.91	**18.80**	<10.0	<10.0	<10.0
LP	27-Sep-11	Observatory	Both	M	Adult	11	1.10	1.42	<10.0	<10.0	<10.0	<10.0
TG	05-Aug-13	Tygervalley	Freshwater	M	Adult	6	1.16	0.72	**78.70**	**31.20**	<10.0	<10.0
WV	10-Oct-13	Wildevoelvlei	Both	F	Adult	10	1.17	1.40	<10.0	<10.0	<10.0	<10.0
BP	12-Nov-13	Muizenberg	Freshwater	M	Adult	15	1.32	1.33	**242.5****	**110.90**	**49.90**	**116.80**

$^{\delta}$ As determined by the isotope analyses in Chapter 4

*Lactating

**Above the upper limit of quantification.

***Extraction could not be proven, sample in a state of advanced deterioration.

Table 5.6. A summary of liver PCB concentrations (ug.kg^{-1}) obtained for otters in this study and in other otter species around the world. Concentrations of PCBs were converted from the original measurements in each study to ug.kg^{-1} for ease of comparison with my results.

Species	Locality	Sample size	Time frame	Range of ∑PCBs (ug/kg)	Source
Aonyx capensis	**Cape Town, South Africa**	**12**	**2011 – 2014**	^{ww}**84.4 ± 2**	**This study**
Lutra lutra	France	20	2004 - 2008	^{lw}11 930 ± 6900	Lemarchand et al. (2010)
Lutra lutra	Netherlands	5	1982 - 1988	^{lw}4 441 – 222 300	Leonards et al. (1997)
Lutra lutra	South West England	22	1989 - 1991	^{lw}10 – 109 000	Mason and Macdonald (1994)
Lutra lutra	Czech Republic	9	1990 - 1994	^{lw}4 200 – 130 000	Gutleb and Kranz (1998)
Lutra lutra	United Kingdom	350	1992 - 2003	^{ww}19.3 - 247.3	Chadwick (2007)
Lutra lutra	Scotland	116	1987 - 1992	Not detected - ^{ww}14 404	Kruuk and Conroy (1996)
Lontra canadensis	Illinois, U.S.A.	23	2009 - 2011	Males ^{ww}851 ± 924; Females ^{ww}282 ± 344	Carpenter et al. (2014)
Lontra canadensis	British Columbia, Canada	32	1994 - 1996	Not detected - ^{ww}610	Harding et al. (1999)
Enhydra lutris	California, U.S.A.	80	1992 - 2002	^{ww} 81 – 210 000	Kannan et al. (2007)
Enhydra lutris	California, U.S.A.	20	1992 - 1996	^{ww} 120 - 8700	Nakata et al. (1998)
Enhydra lutris	Aleutian Islands, Alaska	7	1988 - 1992	^{ww}310	Bacon et al. (1999)
Enhydra lutris	California, U.S.A.	9	1988 - 1992	^{ww}190	Bacon et al. (1999)
Enhydra lutris	South East Alaska	7	1988 - 1992	^{ww}8	Bacon et al. (1999)
Enhydra lutris	California, U.S.A.	6	1995 - 1998	^{ww}1100 ± 2000	Kannan et al. (2008)
Enhydra lutris	Washington, U.S.A.	6	1995 - 1998	^{ww}210 ± 180	Kannan et al. (2008)
Enhydra lutris	Alaska	3	1995 - 1998	^{ww}420 ± 230	Kannan et al. (2008)
Enhydra lutris	Adak Island	2	1995 - 1998	^{ww}390 ± 380	Kannan et al. (2008)
Enhydra lutris	Kamchatka, Russia	5	1995 - 1998	^{ww}28 ± 9	Kannan et al. (2008)

^{lw} Lipid weight ^{ww} Wet weight

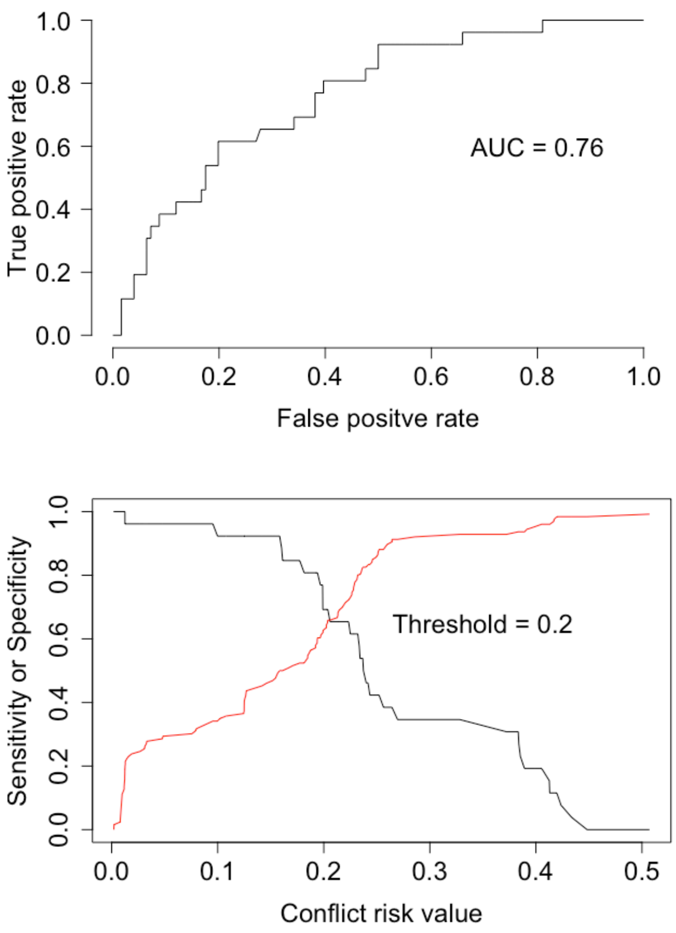


Figure 5.3. Internal model validation results: a) receiver operating curve (ROC) plot showing an AUC value of 0.76, and b) the calculated threshold where the model maximizes sensitivity and selectivity based on the ROC curve (threshold value = 0.2).

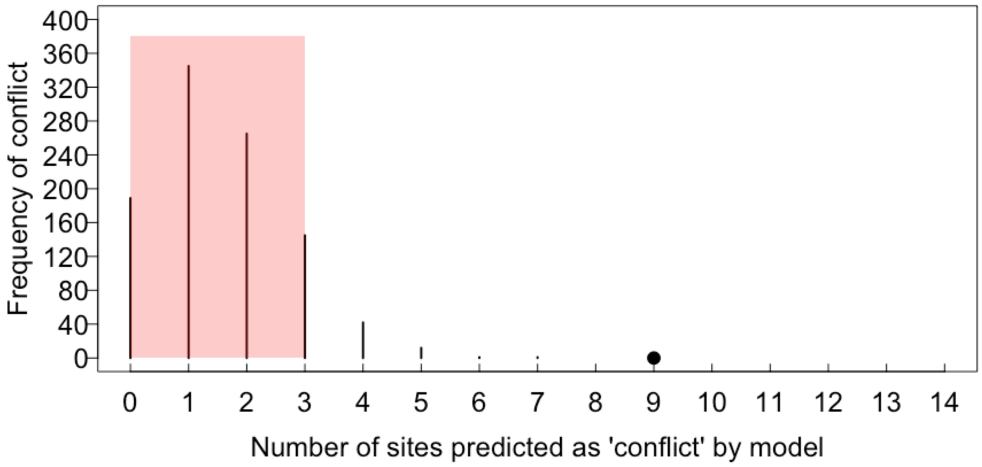


Figure 5.4. The predicted relationship between the frequency of conflict and the number of sites derived from the external model cross validation for randomised sample tests using an independent dataset of known otter conflicts (n = 14).

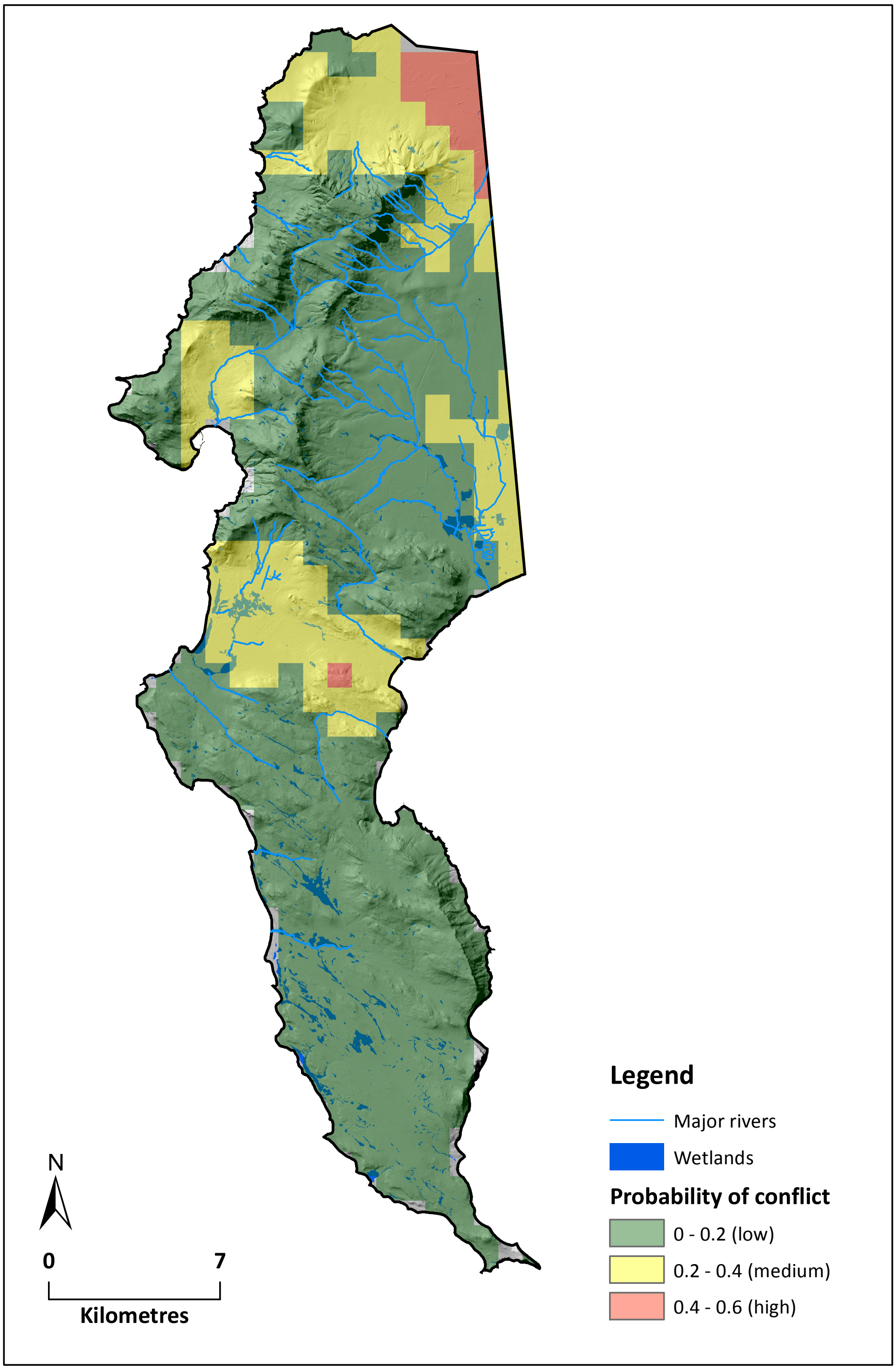


Figure 5.5. Hotspot map (1km x 1km) of the predicted probability of otter conflict for the Cape Peninsula. Probabilities are based on the best predictor variables as determined by generalised linear modelling of citizen sightings.

Discussion

Humans and their dogs were the major cause of non-lethal conflict for otters on the Cape Peninsula during my study period, while vehicles are the most common cause of confirmed mortality. The overall conflict risk (lethal and non-lethal) to otters across the entire Cape Peninsula was low (see Figure 5.5) and concentrated in two broad bands. The smaller band is in the middle of Peninsula where two wetland areas (Noordhoek and Clovelly) are separated by an extensive belt of residential and light industrial land use. The second (larger) band is in the north at the confluence of the Black and Liesbeek rivers before they pass through a heavy industrial and canalised area. Both of these areas are characterized by the three variables that the GLM identified as the best predictors of conflict on the Peninsula viz., proximity to estuaries, canalisation of the river, and far from freshwater bodies such as wetlands or lakes. It is my suggestion that when otters encounter these areas they are more likely to attempt to move overland in search of other suitable habitat (i.e. wetlands and estuaries in proximity to MPAs, Chapter 3) and this exposes them to people, dogs and vehicular accidents.

This suggestion is supported by data from three otters that were radio-tracked (see Appendix C) during the course of my research in the Noordhoek/Clovelly area (i.e. in the lower band of high risk, Figure 5.5). All three otters used at least two wetland or estuarine systems separated either by a major road and/or residential suburb within their home range. This necessitated daily crossing of roads, residential areas and public open spaces frequented by people and their dogs and consequently a high risk of conflict. Habitat fragmentation thus appears to be the overarching driver of current conflict with otters having to commute through and even sleep within transformed areas in their search for food, mates and suitable sleeping sites.

Globally, at present, the main cause of conflict with otters stem from human-wildlife interactions over prey resources (i.e. drowning in fishing nets or persecuted by fishermen over perceived competition, Václavíková 2011), the transfer of disease from domestic animals to wild populations (Gerber et al., 2005), and road mortality (Philcox et al., 1999). Road mortality is not considered a major conservation concern for otter species in general (see Table 1.1, Chapter 1), but it has been well studied in urban-dwelling European otter populations where roads pose a serious threat (Roos et al., 2015). The majority of otters killed in road accidents in UK and Germany were killed close to lakes or within 100m of freshwater and coastal habitats (Jancke and Giere, 2011; Philcox et al., 1999). Males and females of all ages were impacted equally (Hauer et al., 2002), and were more vulnerable during autumn and winter months with high rainfall (Haigh, 2012). These findings are similar to those presented here with equal number of male and female otters being collected from road accidents, and most sightings and more conflicts occurring in autumn and winter. The generality of these findings is however limited by the low sample size.

Mitigation measures for road related wildlife fatalities tend to fall within either of two categories: those with a focus on traffic control, including signage and driver awareness; and those that focus on creating structures to assist animals crossing roads, e.g. wildlife passages (Glista et al., 2009). Currently there is insufficient evidence to show that road signage, reduced speeds in hotspot areas or driver awareness can help reduce road related mortality (Rytwinski et al., 2016). This is mostly due to a lack of before and after studies, as well as insufficient monitoring and evaluation to determine whether these measures are having a significant impact on reducing vehicle related mortality (van der Grift et al., 2013). Crossing structures or underpasses have been found to be successful when designed for specific taxa (Fahrig & Lesbarre 2012). For example, the combination of both fences and crossing structures or culverts proved to be successful for large mammals (Rytwinski et al., 2016), but not very effective for turtles (Baxter-Gilbert et al., 2015). The appropriate and effective implementation of wildlife passages is complex as different species avoid different structures and mitigation measures may have unintended impacts (e.g. further fragmenting habitats) on other important species in the area (Mata et al. 2008). Therefore, going forward, road mitigation measures in the Peninsula need to be designed not only for the target species but also while considering other vulnerable species inhabiting the larger ecosystem.

Otters are considered to be sentinel species in Northern Europe, providing information on the overall health of the aquatic systems they live in (Chadwick, 2007). The carcasses collected from road traffic accidents are analysed for overall indicators of health including size, body condition and levels of contaminants. Recent studies in the UK indicate that otter body size (both weight and length) has declined steadily from the 1960's and through the 1990's and early 2000's. While no consistent link between pollutant load and body condition or other health indicators has yet been established, these otters are still showing signs of bioaccumulation of pollutants such as DDT and PCBs despite these chemicals being banned for use in manufacturing in 1970 and 1984 respectively (Chadwick, 2007). Chadwick (2007) notes however, that although negative impacts on health may be expected to result in a loss of body condition, lipophilic pollutants tend to be associated with high fat prey and therefore otters with high quality diet may still be exposed to high levels of pollutants.

While the Cape Peninsula otters were smaller than conspecifics living in a protected area (i.e., Tstsikamma National Park) there was no evidence to suggest that their body condition was any worse. Peninsula otters have access to diverse food resources in the form of naturally occurring marine and freshwater crustaceans and fish in addition to introduced exotic fish and birds (see Chapter 4). Together with their good body condition this suggests that food is not a limiting factor for Peninsula otters in general. However consuming prey in polluted and eutrophic aquatic systems may exact a cumulative cost in the form of toxins that bioaccumulate. One third of the Peninsula otters tested positive for PCBs with one individual having concentrations that exceed the lowest level beyond which adverse effects are typically observed. This individual was found in the vicinity of a large landfill site that adjoins a wastewater treatment plant – both of which are known sources of PCB contamination (Jepson et al., 2016; Kampire et al., 2016; Samara et al., 2006).

Although PCBs were never manufactured in South Africa (or anywhere in Africa), products containing high levels of PCBs are imported for use in the energy sector (NIP Stockholm Convention, 2011) and have been found to be present in both human (Röllin et al., 2009) and wildlife tissues across the country including seabirds (Bouwman et al., 2015), water birds (Bouwman et al., 2008) and crocodiles (Bouwman et al., 2014). Potential sources of PCBs in South Africa include waste incineration, leaching of oils from electrical power transformers into the soil, leakage from landfills containing illegally recycled electrical equipment (Gioia et al. 2014), micro-plastics (Ryan et al., 2012) and the continued generation and import of e-waste (Robinson, 2009). South Africa is party to the Stockholm Convention on Persistent Organic Pollutants, which aims to phase out the use of PCBs and PCB contaminated materials by 2028. South Africa has therefore committed to phasing PCB use out by the year 2023, with an extra few years provided for industries to appropriately dispose of any stockpiled materials or waste contaminated with PCBs by 2026 (South Africa, 2014).

Together these findings suggest that the Peninsula otter population experiences low to moderate levels of conflict throughout most of their range on the Peninsula. High conflict areas are associated with optimal habitat that has been fragmented by canalisation and urban development. Commuting through transformed landscapes exposes otters to people, dogs and vehicles, the latter of which accounts for most confirmed causes of mortality. Maintaining existing corridors between patches of optimal habitat in addition to designing mitigation strategies for road mortality are thus important priorities for the City of Cape Town and South African National Parks (SANParks) to consider in their efforts to ensure a sustainable otter population with improved welfare. In addition the finding that PCBs are present in one third of the otters sampled suggests that water quality and the biota that they sustain are being adversely impacted and that otters may serve as both sentinel and flagship species for improved water quality. Educating communities that live in conflict hotspots may further improve otter welfare and conservation. As a charismatic mammal, the Cape clawless otter has the potential to encourage public engagement over water, and in particular, wastewater management in the City. Improved solid waste disposal and wastewater management is not only vital for the provision of suitable habitat for otters, but will vastly improve the hygiene and sanitation of surrounding communities.

CHAPTER 6:

CAN OPPORTUNISTIC CITIZEN SIGHTINGS ASSIST IN THE MONITORING OF AN ELUSIVE, CREPUSCULAR MAMMAL IN AN URBAN ENVIRONMENT?

Abstract

Central to appropriate wildlife management is an effective monitoring program. Monitoring wildlife in urban environments offers unique challenges in the form of barriers, prohibited access and risk of crime. However, it also provides a unique opportunity to leverage the eyes and ears of local communities to collect data on the presence and distribution of a number of species. Opportunistic sightings data has its flaws, including the lack of data on species absences, and unequal sampling effort. Yet these data may complement localized, hypothesis driven research and provide reliable data on the distribution of species and should be validated where possible. In this chapter, I used Maxent to model citizen-reported otter sightings to determine whether citizen science reporting of otter sightings can complement standardized river surveys to continue monitoring of an elusive, widely distributed species living within a fragmented urban/natural matrix. The predicted distribution of otters modelled from citizen sightings mirrored that provided by occupancy models, and highlighted further areas of suitable otter habitat and routes for dispersal. In addition to alleviating the pressure on local authorities to allocate resources to routine monitoring, citizen involvement can promote awareness and encourage coexistence with otters and other urban adapted wildlife.

Introduction

Scientifically sound data is needed to accurately depict spatial and temporal trends in population distribution and abundance (Yoccoz et al., 2001), evaluate management decisions and adapt conservation strategies (Gibbs et al., 2016). Research programs to monitor trends in wildlife populations are typically designed to be hypothesis-driven (Lindenmayer and Likens, 2010), long-term and geographically broad (Lesmeister and Nielsen, 2011). Yet this can often be difficult to implement due to the cost, effort and challenges in collecting sufficient data at the appropriate scale and hence meeting the assumptions of various survey techniques.

In Chapter 3 I suggest that annual single season occupancy surveys provide a rapid, cost-effective method for monitoring changes in the presence of Cape clawless otter, *Aonyx capensis* within the Cape Peninsula. While this approach would allow for a question-driven monitoring program which is fine scale and process-based, the limited spatial extent of the survey and the assumption that otter habitat is restricted to freshwater limits spatial extrapolations to larger scales (Lindenmayer and Likens, 2010). In addition, occupancy surveys fail to detect threats to the population and how these vary spatially and temporally.

In the Cape Peninsula, surveying potential otter habitat outside of their assumed core aquatic habitat, in addition to the likely threats, would require considerably more effort and cost than I was capable of delivering. Monitoring wildlife in urban areas poses unique challenges, including multiple barriers around private property risk of theft of equipment and personal risk from robbery and assault. In these situations, the involvement of the citizens that live within this matrix has proven to be a useful method for collecting data on a range of variables including the presence of species for mapping species distribution. Involving the public in the collection, entry or analysis of scientific data is referred to as citizen science (Bonney et al., 2014, 2009; Dickinson et al., 2010) and is seen as a cost effective method of collecting data over a wide spatial or temporal scale (Higby et al., 2012).

Over the years, citizen science has been successful in advancing scientific knowledge (Jaine et al., 2012) primarily in the discipline of biology and the fields of diversity and distribution of species (Follett and Strezov, 2015). The contribution from citizen scientists has proven to be particularly useful in distribution studies involving species that are invasive (Bonter et al., 2009), cryptic (Pearson et al., 2007), rare and elusive (Palma et al., 1999) or that exist at low densities (Broman et al., 2014). In addition to occurrence data, citizen science can provide further information on demographics (Black, 2009), behaviour (Higby et al., 2012), novel prey use (Broman et al., 2014) and disease (Bouley et al., 2015) in areas where such data may normally be difficult to obtain. These data are valuable and can provide insight into habitats that are either limiting the distribution of the species (Brambilla and Saporetti 2014), or aiding the recovery (Bouley et al., 2015), re-introduction (Savage and Klingel, 2015) or invasion of a population (Gormley et al., 2011). Many citizen science programs include the benefit of simultaneously educating the public on wildlife and actively contributing to conservation (Jackson et al., 2015).

Despite these advantages, opportunistic sightings data provided by citizen science to model species distribution has its flaws, including the lack of data on species absences, and unequal sampling effort. It is usually not possible to determine whether areas where sightings are not reported represent a true absence (Elith et al., 2011). Low sampling effort in areas not easily accessible can lead to omission errors, resulting in an underestimation of a species occurrence while high sampling effort in easily accessible areas could lead to commission errors, and an overestimate of species occurrence (Rondinini et al., 2006). Misidentification and/or inaccurate records can also lead to either an under- or overestimation of the species distribution, sometimes having serious consequences for the conservation of the species (McKelvey et al., 2008).

For long-term, intensive studies it may be possible to deduce absence data and analyse these in an occupancy framework should the dataset meet the required assumptions (Van Strien et al., 2013). Alternatively, validation of data collected through citizen science programs could be achieved by comparing them against more scientifically robust methods that include appropriate sampling design and address assumptions of detectability (Jones, 2011). Few studies have done this, but those that have suggest that despite the disadvantages, citizen science collected data can complement localized, hypothesis driven research and provide reliable data on the distribution of species, sometimes with additional, often unintended benefits (Broman et al., 2014; Danielsen et al., 2005; Dickinson et al., 2012).

In this chapter, I aim to determine whether citizen science reporting of otter sightings can complement standardized occupancy surveys (Chapter 3) to monitor an elusive, widely distributed species living within a fragmented urban/natural matrix. Due to otter's cryptic nature, I expected citizen contributions to predict a smaller distribution and to be concentrated in areas of high overlap between people and otters. Differences in predicted distributions and the value of citizen involvement are discussed in context of on-going and future monitoring requirements of the Peninsula otter population.

Methods

Study area

The study area is described in detail in Chapter 2.

Occurrence data

A citizen science initiative, the Peninsula Otter Watch, was introduced in 2011 and residents across the Cape Peninsula were asked to record direct sightings of live otters and indirect signs of otter spoor and spraint. To facilitate citizen reporting on otters I conducted a number of community talks, displayed posters at libraries and community centres, and designed a Google form (see Appendix A) that once completed could be submitted online. The form was hosted on a designated website, allowing information to be uploaded online, and included my cell phone number and email address to allow people to report sightings, interactions and events directly to the project. For the purposes of this study, I used data that was collected from residents between 2011 and 2015. Where no GPS coordinates were provided, I assigned coordinates from Google Earth based on a detailed description of the location provided by the observer. Spatial error was limited due to individual sightings being subsumed by the scale of the analyses into 1km x 1km grids. In addition to citizen contributions, I received information from the Cape of Good Hope SPCA Wildlife Unit when they were called out to assist with otters living in or around human structures or being found injured or dead on roads, in residential areas and in natural areas.

Covariate data collection

For each sighting, covariate data (covariates were identified in Chapter 3) including site-specific habitat, topography, human population density, and conservation status of terrestrial and marine habitat were extracted from GIS layers of the area using ArcGIS v 10.1 Software (Table 6.1). Proximity to each covariate (with the exception of population and household density) was calculated using the Euclidean distance function in ArcGIS 10.1. All the data layers used for the modelling were converted to raster files of the same projection and extent, at 1km x 1km resolution to match the output of the occupancy model produced in Chapter 3. Collinearity of the covariates was analysed in a correlation matrix (Pearsons Correlation, Table 6.2) using LayerStats (for Raster layers) in R.

Model building

All sightings were analysed using the software Maxent (Version 3.3.3.k), a program that allows the use of presence-only data to model species distributions (Merow et al., 2013). Maxent estimates a species distribution across a geographic space by finding the probability distribution of maximum entropy, subject to a set of constraints that represent incomplete information about the target distribution (Phillips et al., 2006). When Maxent is applied to presence-only species distribution modelling, the grid cells of the study area make up the space on which the Maxent probability distribution is defined (Phillips et al., 2006). Grid cells with known species occurrence records constitute the sample points, and the features are the environmental variables of interest (Phillips et al., 2006).

I built one model that included all important habitat types and covariates that were not collinear. I used default values for convergence threshold, maximum iterations (500) and a regularization multiplier of 1 because these settings have been found to achieve the best output distribution to prevent over-fitting (Phillips and Dudík, 2008). I initially ran the model using Maxent's logistic output. The logistic output is a post-transformation of the Maxent raw output that assumes unbiased sample selection to give an estimate of probability of presence, given the distribution of covariates across the landscape (Phillips and Dudík, 2008). In order to account for biased sampling inherent in opportunistic citizen sighting records, I created a bias layer that contained the areas more likely to be sampled, i.e. coastline accessible to people, and roads. I merged the two spatial layers of coastline and roads into one layer called 'sampling effort', and created a raster layer of proximity to sampling effort (Euclidean distance), which was used as the bias layer in Maxent.

Model outcomes

The logistic output of the model was analysed in Maxent. I extracted the data to recreate graphs in R and to map the predicted probabilities of otter presence in ArcGIS 10.2. I used Maxent's jackknife test to evaluate the importance of each predictor in the model. The per cent contribution of each variable was calculated as the proportional contribution by each variable to the model training gain (Phillips et al., 2006). These results are presented in relation to the regularized training gain of the model (Figure 6.1). A high loss of training gain when one variable is omitted compared with the complete model would suggest that this variable contains information that is already provided by other variables, whereas a low training gain on individual variables suggest that no variable on its own was useful for estimating presence (e.g. Swanepoel et al., 2013).

The relationships between individual variables and otter presence were plotted, holding all other variables constant at their average (Figure 6.2). To classify the model predictions into areas where otters were predicted to be present and not present, I applied three different logistic threshold values to account for three different estimates of omission errors. First, I assumed that the minimum number of presence points suffered from spatial error (minimum training presence), and used the logistic score of the presence points after the minimum number of presence points had been omitted as a threshold for defining otter presence. This corresponded to a logistic score of 0.178. I classified grid cells with logistic scores below 0.178 as unoccupied, and above this value as occupied. I followed the same procedure using thresholds defined by equal test sensitivity and specificity (logistic threshold of 0.385) and the maximum test sensitivity plus specificity (logistic threshold of 0.456). The predicted distribution of otters across the Peninsula using each of these thresholds is presented in Figure 6.3.

Results

Occurrence data

Between 2011 and 2015, a total of 210 sightings of otter were recorded, 180 of which were sightings of the animal itself while the remaining 30 were of otter signs (i.e., spoor or spraint). Photographic evidence was provided for 88 (49%) of these sightings. From the total dataset, I took a random subsample of 93 live otter sighting records that fell within the boundary of the study area to create a species distribution model using Maxent.

Model outcomes

As the Maxent model was analysed at a scale of 1km x 1 km, sightings falling within the same grid cell were ignored, resulting in a training dataset of 59 sightings. A random sample of 50 known presence locations of otter spraints used in Chapter 4 was used as the test dataset. The model included on all non-colinear environmental variables, i.e. proximity to estuary, the population density of the suburbs closest to the sightings, elevation, proximity to the MPA and proximity to natural wetland. Otter presence was influenced by all of these variables in varying importance: proximity to estuary accounted for the greatest contribution of relative gain (31.7%), followed by the population density of the suburb within 2km of the sighting (22.4%), proximity to the MPA (21.5%), elevation (12.2), and proximity to natural wetlands (12.1%). The environmental variable with highest gain when used in isolation is proximity to estuary, which therefore appears to have the most useful information by itself (Figure 6.1). The environmental variable that decreases the gain the most when it is omitted is proximity to MPA, which therefore appears to have the most information that isn't present in the other variables (Figure 6.1).

Otter presence responded similarly to each predictor variable, with the exception of population density (Figure 6.2). Otter presence declined with distance from each variable and was highest (predicted probability of 0.6 – 0.8) within a km of an estuary, MPA, or natural wetland. However, otter presence increased with surrounding population density and peaked at a density of 2.5 people per square kilometre before declining.

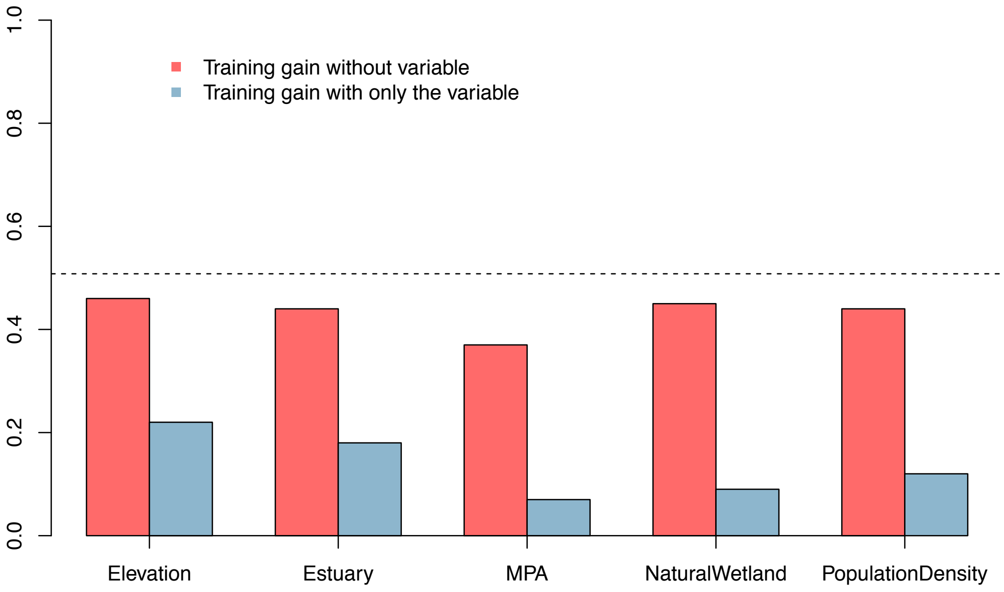


Figure 6.1. Results from the Maxent model, showing the importance of each environmental variable to the regularized training gain (dashed line). The high loss of training gain when one variable is omitted compared with the complete model suggests that this variable contains information that is already provided by other variables.

Table 6.1. A description of the covariate raster layers created for inclusion in the Maxent model including their source and how they were measured. All distances are euclidean, and all GIS layers used in these analyses were sourced from the City of Cape Town (CMA, CityMaps, City of Cape Town 2014), unless otherwise stated.

Covariate	**Data source**	**Analysis**
Proximity to urban edge (PUE)	Urban Edge GIS Layer, 2014.	Distance from centre of each 1km x 1km grid cell to nearest urban edge.
Human population density (POP)	Census GIS Layer, 2007.	Number of people per km^2 in suburbs within 2km of the sighting.
Proximity to Urban Conservation Areas (PUCA)	Urban Conservation Areas GIS Layer, 2014.	Distance from centre of each 1km x 1km grid cell to nearest urban conservation area - areas within the city proclaimed as natural heritage and/or conservation sites, protected from development. They include green belts, some beaches, few harbours and monuments.
Proximity to Restricted Fishing Zones (PRFZ)	Marine Protected Areas GIS Layer, 2014.	Distance from the centre of each 1km x 1km grid cell to the nearest restricted fishing zone. Five of the six restricted fishing zones are no-take zones where no fishing can take place and one is restricted zone where only one species can be caught under certain conditions.
Proximity to Marine Protected Areas (PMPA)	Marine Protected Areas GIS Layer, 2014.	Distance from the centre of each 1km x 1km grid cell to the Marine Protected Area. The MPA controls both recreational and fishing activities to ensure the sustainability of marine resources.
Proximity to Natural Estuaries (PNE)	Natural Estuaries GIS Layer, 2009. CSIR, SANBI.	Distance from the centre of each 1km x 1km grid cell to the nearest natural estuary, defined as the floodplain between a river and the sea into which it flows. The estuary may be permanently or periodically open to the sea.
Proximity to the coast (PC)	City of Cape Town GIS Layer, 2014.	Distance from the centre of each 1km x 1km grid cell to the nearest coastline.
Proximity to Wetlands (PW)	Wetland Vegetation GIS Layer, 2014.	Distance from the centre of each 1km x 1km grid cell to the nearest natural wetland.
Elevation (EL)	City of Cape Town GIS Layer, 2014.	Elevation (in meters) of the exact area of the sighting.
Proximity to open water bodies (POW)	City of Cape Town GIS Layer, 2014.	Distance from the centre of each 1km x 1km grid cell to the nearest open fresh water body.

Table 6.2. Pearson's correlation matrix of the covariate raster layers used in the Maxent models. Proximity to urban edge (PUE); Human population density (POP); Proximity to Urban Conservation Areas (PUCA); Proximity to Restricted Fishing Zones (PRFZ); Proximity to Marine Protected Areas (PMPA); Proximity to Natural Estuaries (PNE); Proximity to the coast (PC); Proximity to Wetlands (PW); Elevation (ELEV); Proximity to open freshwater bodies (POW). Negative values for the proximity covariates indicate a negative relationship between two covariates.

	PUE	**POP**	**PUCA**	**PRFZ**	**PMPA**	**PNE**	**PC**	**PW**	**ELEV**	**POW**
PUE	1.00	-0.31	**0.84**	-0.14	-0.29	**0.85**	0.60	0.44	-0.29	**0.80**
POP	-0.31	1.00	-0.45	0.59	**0.73**	-0.46	0.01	-0.39	0.00	-0.48
PUCA	**0.84**	-0.45	1.00	-0.19	-0.52	**0.72**	0.39	0.36	-0.27	**0.76**
PRFZ	-0.14	0.59	-0.19	1.00	**0.72**	-0.54	0.20	-0.16	-0.09	-0.23
PMPA	-0.29	**0.73**	-0.52	**0.72**	1.00	-0.48	0.23	-0.46	0.13	-0.51
PNE	**0.85**	-0.46	**0.72**	-0.54	-0.48	1.00	0.43	0.45	-0.13	**0.76**
PC	0.60	0.01	0.39	0.20	0.23	0.43	1.00	0.30	-0.15	0.54
PW	0.44	-0.39	0.36	-0.16	-0.46	0.45	0.30	1.00	-0.16	0.69
ELEV	-0.29	0.00	-0.27	-0.09	0.13	-0.13	-0.15	-0.16	1.00	-0.32
POW	**0.80**	-0.48	**0.76**	-0.23	-0.51	**0.76**	0.54	0.69	-0.32	1.00

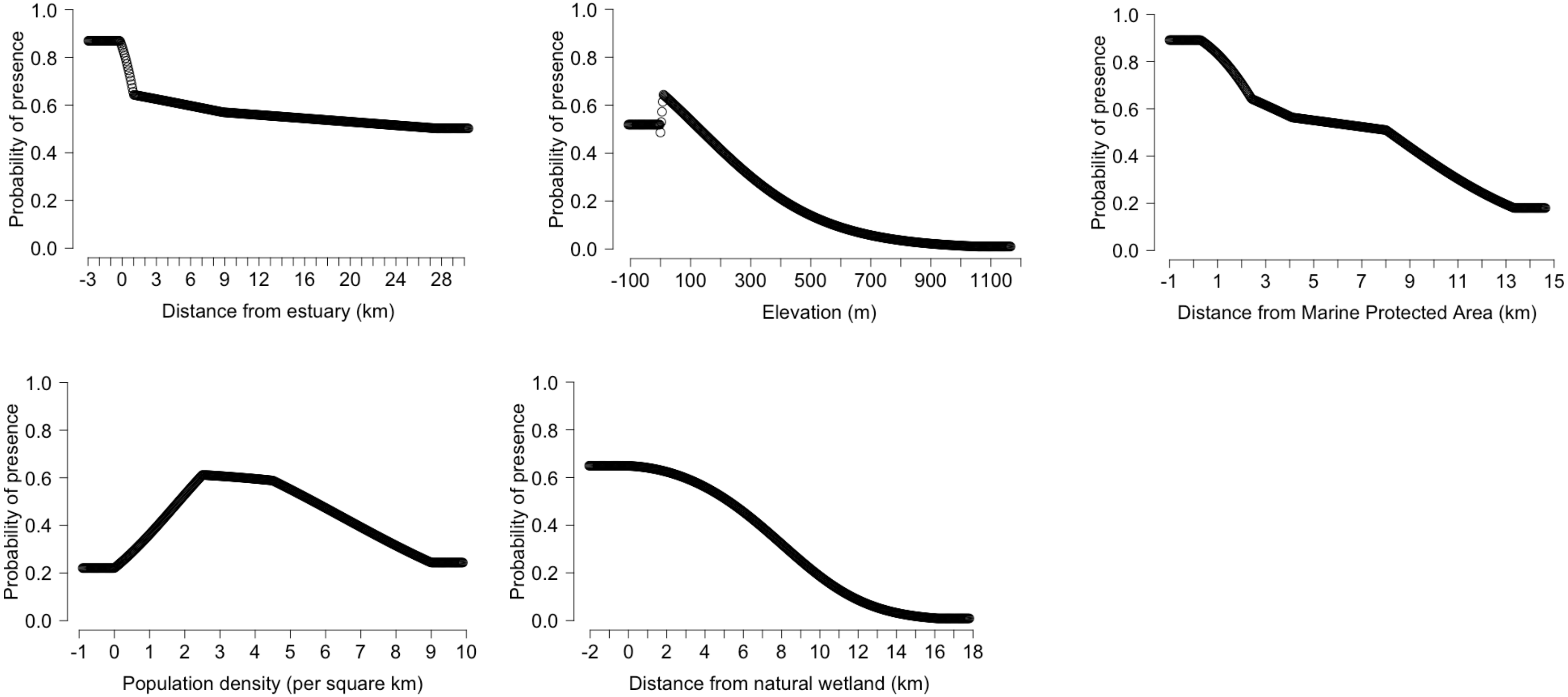


Figure 6.2. The relationships between each environmental variable and the predicted probability of otter presence (Maxent logistic output). The curves show how the logistic prediction changes as each environmental variable is varied, keeping all other environmental variables at their average sample value.

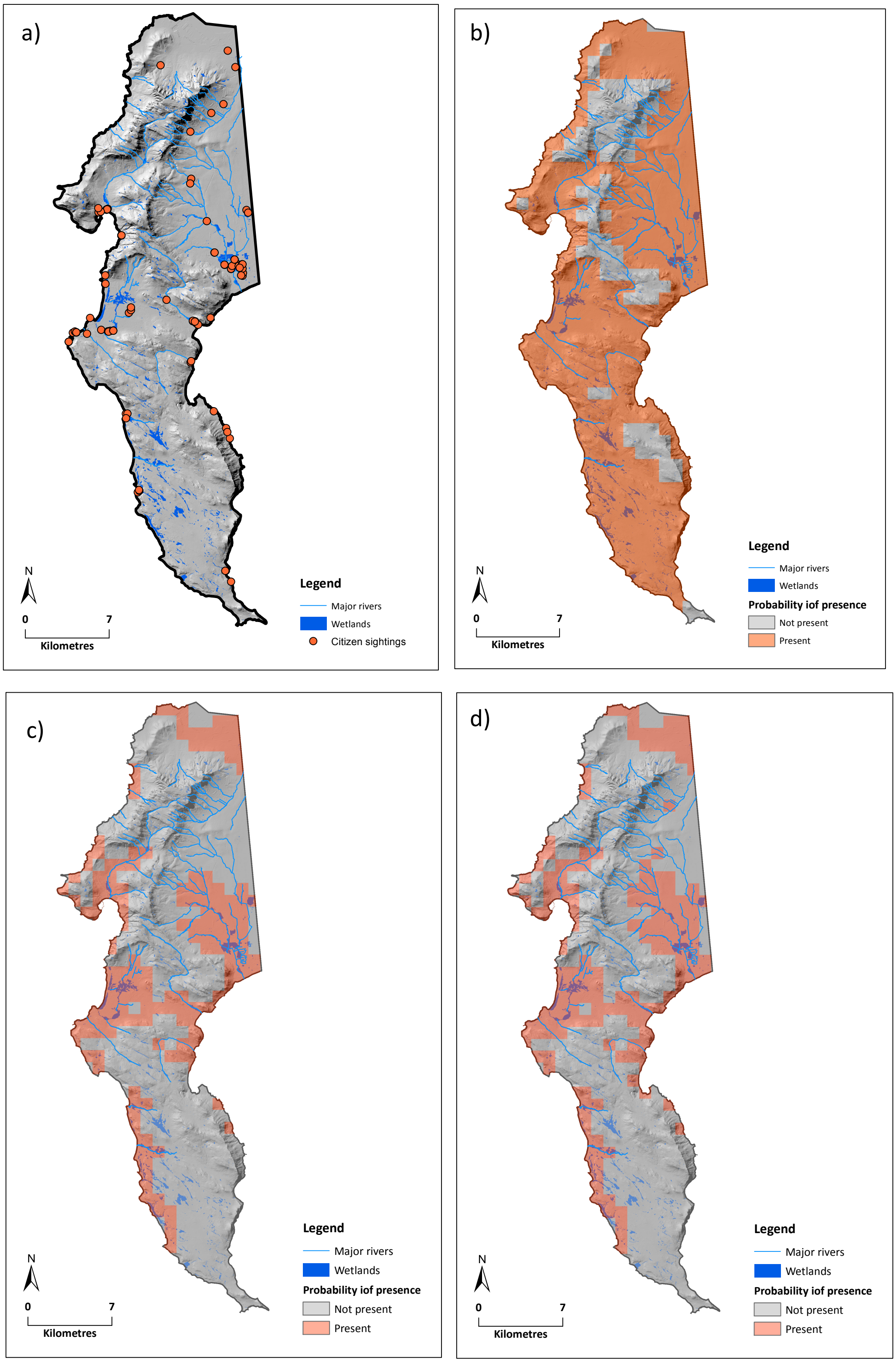


Figure 6.3. Maps showing a) all citizen sightings of otters recorded between 2011 and 2015 on the Cape Peninsula, b) the predicted distribution of otters as modelled by Maxent using the minimum training threshold; c) the predicted distribution using equal sensitivity and specificity threshold, and d) the predicted distribution using the maximum training threshold.

Discussion

The Maxent model derived from citizen sightings of otters reveals that proximity to estuaries, the MPA and natural wetlands are the most important variables determining otter presence on the Peninsula. Encouragingly, these habitat variables mirror those produced by the occupancy model predictions in Chapter 3, providing further evidence that Peninsula otters preferentially inhabit the interface between the coast and freshwater aquatic systems.

A limitation of the occupancy surveys was that they were restricted to sampling along perennial rivers; linear systems that can be sampled with limited effort and resources. Citizen sightings are not similarly constrained and numerous sightings of otters were made by different observers along sections of the coastline without any perennial river. This suggests that otters are capable of feeding almost exclusively on marine food using small freshwater springs and pools for grooming and drinking purposes only. Consequently the Maxent models using citizen sightings greatly expands the total available habitat to otters and highlights areas of the far south (e.g. Cape of Good Hope Nature Reserve) that despite being devoid of perennial rivers may serve as important refugia for otters should the quality of freshwater in rivers and wetland outside of protected areas continue to decline in quality. Clearly the otter's dietary flexibility (Chapter 4) has served as an advantage to Peninsula otters whose freshwater habitat has been progressively eroded by development, canalisation and pollution. It is possible that most urban rivers are more important as dispersal corridors and breeding sites than they are for sustaining the food requirements of otters, which can be entirely supported with marine food resources.

Citizen sightings are therefore more than just complementary to the standardised occupancy surveys, providing an increase in both the sampling effort and area surveyed, and allowing greater insights into habitat use of otters in an urban space. Similar findings were obtained in other urban species studies, corroborating previous suggestions that the benefits of citizen science may outweigh the shortcomings in some instances (e.g. Danielsen et al., 2005). For example, Broman et al. (2014) compared citizen science observations with more standardized monitoring (i.e. telemetry) approaches in an effort to identify habitat features that may be important to expanding populations of bobcats in New Hampshire, U.S.A. They found that although the two approaches identified similar productive habitat features, models based on observations failed to identify unfavourable habitat features. However, observation models did provide information on a recent range extension within the state, and identified certain behaviour as a possible explanation for how bobcats are coping with increased human populations (Broman et al. 2014).

Likewise, White et al. (2013) increased their search effort and sample detection rate by incorporating citizens in their non-invasive survey of Eurasian otters, *Lutra lutra*, in an urban environment (Cork, Ireland). By training members of the public in spraint collection, the authors could also obtain genetic samples for quantifying otter numbers in the city (White et al., 2013). Bouley et al. (2015) combined sightings from an otter spotter network with field investigations to document the return of the North American river otter, *Lontra canadensis*, to coastal habitats of San Francisco Bay, California – an area where otters had not been detected for decades. By involving citizens they were able to successfully document the first otter sightings in decades and use this to motivate for formal population assessment. In addition, the collection of road-killed otters reported by citizens allowed for a health check and revealed pathogens and diseases that pose a threat to the continued recovery of the population. Similarly, in our study, citizens reported useful information on conflict, novel interactions and dead otters which together enabled an analysis of potential threats to the population including the largely hidden long-term costs of bioaccumulation of pollutants (Chapter 5).

The United Kingdom has a well-established citizen science program whereby citizens are asked to report road-killed European otters through England and Wales (Chadwick, 2007). Through collaboration with the Environmental Protection Agency and the Royal Society for the Protection of Birds, road-killed otters are collected, stored and dissected by the Cardiff University Otter Project. Morphometric data, tissue weights and body condition indices are measured and samples of key tissues are sent for analyses of potential pollutants. As top predators, otters can serve as an important sentinel species and provide information on the level of contamination integrated into aquatic ecosystems. Thus, the Cardiff University Otter Project provides long-term monitoring that greatly benefits the conservation and management of not only otters, but also the urban aquatic systems and the wildlife they support. A similar approach would greatly benefit the understanding, conservation and management of otters in South Africa. However, due to the otter's large range, the lack of infrastructure to ensure timely collection of carcasses and a shortage of laboratories available to test for specific chemicals, such an approach may be difficult to implement. I propose a smaller, pilot project be initially tested in the Cape Peninsula of the Western Cape, to specifically develop relationships with the city's conservation and management authorities and roll out a carcass collection, examination, and contaminant testing program in collaboration with local universities. Such a program would not be species specific, but rather focus on the threats that all urban wildlife face in the Peninsula. Involving conservation authorities and research institutions will ensure both rigorous scientific design and direct implementation of findings by management. It will help to alleviate pressure on already under resourced management authorities, provide much needed contaminant monitoring as well as opportunities to train conservation students and raise public awareness on the threats that face urban adapted species.

Typically, citizen involvement in specific research projects includes an opportunity to educate and create awareness around specific human-wildlife interactions and the conservation and management challenges that a particular species or community may face. Education has been shown to be vital in increasing public awareness and changing attitudes around wildlife, particularly in conflict situations (Espinosa and Jacobson, 2012; Okes et al., 2012). In sub-Saharan Africa, where local awareness of the three otter species inhabiting the continent is very poor (Akpona et al., 2015b), otter-specific citizen science programs could be key to educating communities about the role of otters in aquatic systems and concurrently collecting much needed data on otter presence and conflict in these areas (Akpona et al., 2015a).

Citizen science has a valuable role to play in the continued monitoring, conservation and management of otters and other wildlife in an urban environment. Maxent models of presence-only citizen sightings complement the more standardized river occupancy surveys, reinforcing the fact that, in order to conserve otters in an urban environment, management needs to actively restore, rehabilitate and conserve estuaries and wetlands – especially those in close proximity to the MPA. Citizen sightings provide an opportunity to collect data on the threats otters face (Chapter 5) and shed light on the potential routes otters can use to disperse through the Peninsula. Involving the local communities in reporting otter sightings provides an opportunity to educate local communities not only on species-specific issues, but also on the conservation of top predators and the habitats they need in order to persist in the matrix of urban and natural land that typifies much of the modern worlds landscapes.

CHAPTER 7: SYNTHESIS

Freshwater ecosystems are heavily impacted by rapid urban development, and face disproportionate extinction risks relative to other environments (Collen et al., 2014). Their linear, highly connected nature exposes them to multiples stressors in the form of overexploitation, altered flow regimes, canalisation and pollution (Vörösmarty et al., 2010). Top predators reliant on aquatic habitats are therefore among the most threatened species worldwide (He et al., 2017; Veron et al., 2008) with local otter extinctions in Europe being attributed largely to habitat loss and the accumulation of contaminants in the aquatic food chain (Jefferies, 1989; Macdonald and Mason, 1992; Prigioni et al., 2007).

Freshwater systems within the City of Cape Town are no exception to the global trend and the middle and lower reaches of most rivers have been heavily impacted by urban development with reduced flow, canalisation, pollution and loss of natural habitat all combining to threaten indigenous fauna (Brown and Magoba, 2009). Despite this, distribution models revealed that otters were more likely to be present in the lower reaches, at the narrow interface between marine and freshwater ecosystems and seldom detected in the relatively pristine upper reaches. Rather than suggesting a preference for degraded habitat I interpret this pattern as a function of the greater prey availability in both the lower reaches of rivers, particularly within large estuaries and wetlands, and the adjacent MPAs (see Chapter 4). The otter's ability to persist in these degraded habitats does, however, come at a cost. In addition to the moderate levels of conflict and vehicle related mortality, the Peninsula's urban otters are exposed to the more subliminal threat of bioaccumulation of contaminants in the food chain.

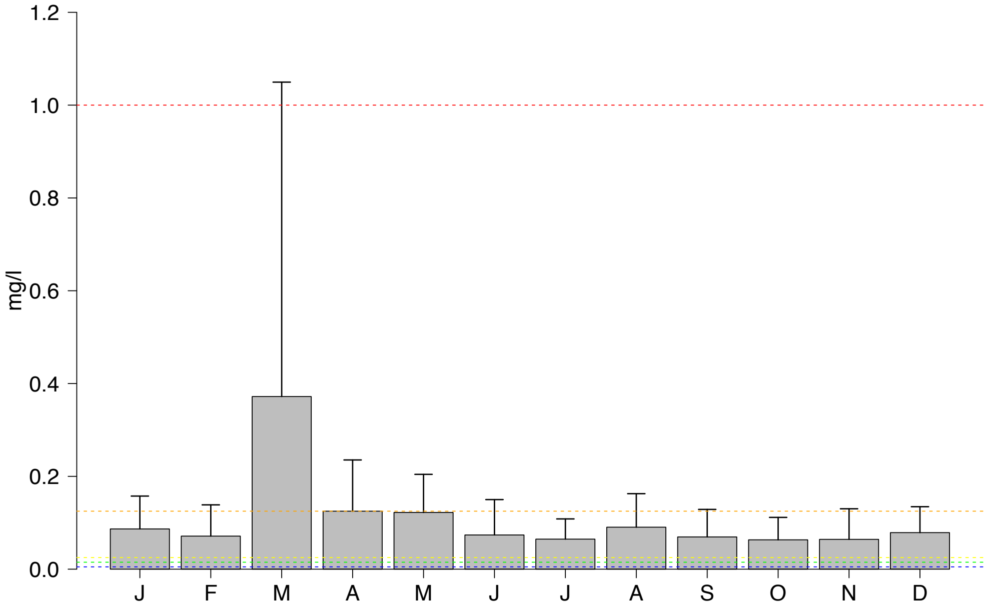
Although the contaminants relevant in this study – PCBs – have been banned for decades, their ubiquitous use in the past and persistent nature means they remain an insidious threat to otters globally (Foster-Turley et al., 1990). Although it may be impossible to eradicate PCBs from aquatic ecosystems in the Cape Peninsula in the short term, it is possible to limit their availability in the environment by restricting the burning of e-waste, locating future landfill sites far from aquatic systems, conducting regular river clean ups and improving storm and waste water management to reduce the amount of toxin-harbouring plastics and other harmful substances entering the freshwater environment.

Transformed wetlands and estuaries: ecological traps or substitution habitats?

Urbanisation transforms aquatic ecosystems (Faulkner, 2004; Mackintosh and Davis, 2013), reducing the availability and quality of habitat for the species reliant on them (Hamer and McDonnell, 2008; Kozlowski and Bondallaz, 2013). Most managed wetlands, whether they are maintained as part of a flood or storm water management system for example, may still retain or mimic many features of natural wetlands, creating a mismatch between habitat quality and functionality, resulting in an ‘ecological trap’ (Battin, 2004; Delibes et al., 2009; Hale et al., 2015). These traps often exist in rapidly changing landscapes as well as those modified by human activities, for example artificial wetlands, urban areas and habitat edges (Battin, 2004), and an animal’s presence in these systems must be interpreted with caution. The return of the otter to numerous freshwater systems in Europe, for example, is often hailed as a conservation success. However, Delibes et al. (2009) found that in Spain, otters that recolonized a heavily impacted river within a year of a toxic spill carried a significantly higher heavy metal burden than otters inhabiting a clean river system. As contaminants are unlikely to be detectable to animals, functional yet polluted aquatic systems may still be used despite potentially dangerous impacts (Delibes et al., 2009).

In some cases, it may be possible for seemingly sub-optimal habitats to confer an advantage to the animal inhabiting them. For example, excess nutrients and the introduction of exotic fish species may transform urban wetlands and provide an abundant prey base for otters. Martinez-Abrain and Jimenez (2016) recently introduced the concept of ‘substitution habitats’, where, similar to ecological traps, human modified systems functionally resemble the essential features of the original habitat. Unlike traps, however, substitution habitats may not have a negative impact on the health or reproductive success of affected wildlife and may actually result in increased resilience against global change (Martinez-Abrain and Jimenez, 2016). The authors also cite European otters as an example of a species capable of making use of dams as substitution habitats. However, again, caution must be applied to the generality of such findings, as otters elsewhere have failed to reap the benefits of additional habitat creation in the form of hydroelectric dams (Palmeirim et al., 2014).

In my study area both wetlands (e.g., Wildevoelvlei) and estuaries (e.g., Zandvlei) have been artificially extended to provide large open bodies of water and canals suitable for housing developments and water sports. While I do not have estimates of how otter abundance or reproductive success have been affected by these new aquatic habitats, residents in both developments regularly report otter sightings.



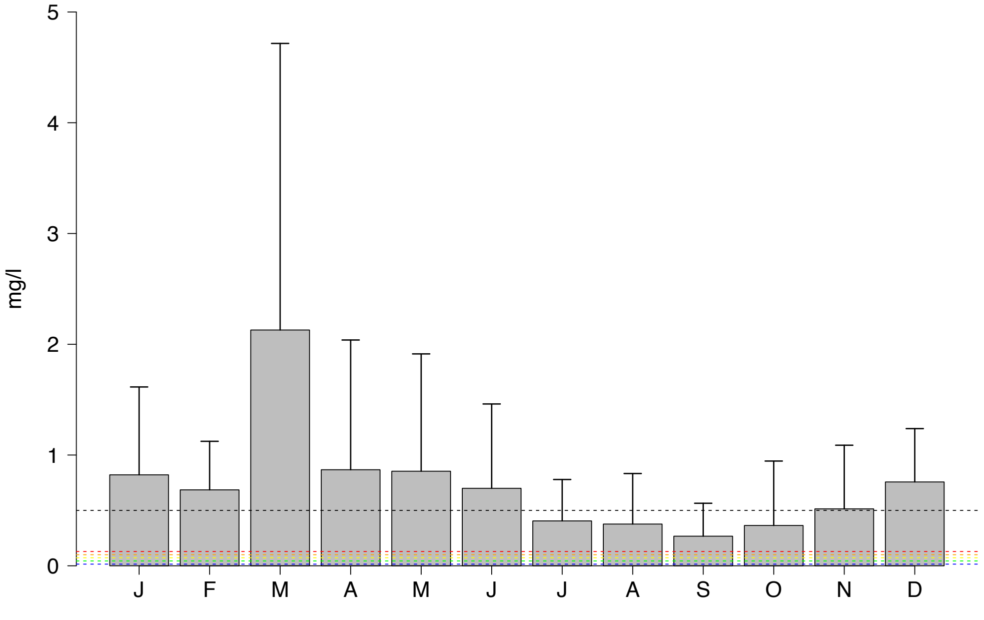


Figure 7.1. Average trends in monthly orthophosphate (top) and nitrate (bottom) levels in the lower reaches of the Hout Bay River, 2009 – 2013. The horizontal lines indicate thresholds of acceptable levels according to the City of Cape Town's river monitoring program, from blue, green and yellow being within acceptable levels, and red and black being unacceptably high.

Both sites are also prone to regular eutrophication events that promote the growth of various cyanobacteria including *Microcystis spp.*, a bacteria that targets the mammalian liver, and therefore poses a threat to otters (e.g. Miller et al., 2010). Despite this I have camera trap evidence to show that otters are breeding at both sites (Figure 7.2) in addition to the Hout Bay river site which with seven of the 12 months in a calendar year having unacceptably high levels of Nitrates, is classified as eutrophic (Figure 7.1). In addition, three of the four individual otters that I found to carry a PCB burden were found near polluted freshwater systems, and isotope analyses revealed them to have been feeding predominantly on a freshwater diet in the last year. Together these findings suggest that the Peninsula otters are experiencing both ecological traps in persisting in polluted, eutrophic systems in addition to benefitting from substitution habitats through the establishment of artificial aquatic habitats within existing freshwater and estuarine habitats.

Prey as a limiting factor

Otters in general are considered to be a food-limited species (Kruuk, 2006). Sea otters, *Enhydra lutris*, exhibit significant dietary specialization thought to be in response to low resource availability (Johnson et al., 2009; Tinker et al., 2008), and European otters manage to persist in human modified habitats due to their adaptability to a shifting prey base (Kloskowski et al. 2013). Similarly, otters in the Peninsula are currently opportunistically taking advantage of the abundant crab and exotic fish populations in the transformed, nutrient rich lowland systems. The long-term costs of feeding on prey in these polluted systems may however result in contaminant burdens which make them vulnerable to infertility, poor health and disease in the long term (Kruuk, 2006).

My findings also suggest that the availability of freshwater prey is not guaranteed year round, with seasonal low flows, drought and water abstraction reducing the habitat for both crabs and large exotic fish. The otter's need for fresh water (grooming and drinking) and reed beds for breeding sites tie them to the freshwater environments, but the large, consistent marine component of their diet suggests that otters might not have survived historically or currently on the Cape Peninsula in the absence of the more stable and less impacted marine environment. Reliance on the marine environment has its own limitations, however; namely high energetic costs due to the thermoregulatory demands of foraging in cold water (mean Sea Surface Temperature on west coast in summer is 9^{o}C) and exposure to predators such as great white sharks and seven-gills (both of which frequent the same inshore coastal zones as otters). High levels of poaching and an ongoing decline in their main prey, rock lobster, will also place otters at risk of food shortages in the future.

Figure 7.2. Images from camera traps placed within Zandvlei wetlands, an impacted urban wetland, showing otter pups present in the area for two consecutive years despite the system being eutrophic.

Figure 7.2 contd. Images from camera traps placed within (Obree, 2004)Noordhoek wetlands, an impacted wetland adjacent to a wastewater treatment plant showing otter pups present in the area for two consecutive years despite the system being heavily transformed and eutrophic.

Current challenges of urban storm water management

The greater City of Cape Town is one of the fastest growing cities in South Africa, with the current census results showing the population increasing at an average rate of 2.6% per year (Western Cape Government, 2012). As the city expands, the growing demand for resources places additional pressure on already stressed infrastructure, and most importantly for otters, the quality of the run-off from urban areas via the storm water system. Continuous urban development throughout the City over the last 40 years has resulted in the loss of floodplains due to infilling, an increase in peak flow due to the increase in impervious surfaces, reduced ecological reserve in summer, and a decrease in water quality due to the continuous discharge of treated sewage effluent into urban rivers (Obree, 2004).

Due to the steep slopes of Table Mountain, the Peninsula's rivers are relatively short and narrow and therefore not very productive along the upper reaches of their length (Brown and Magoba, 2009). Where they flatten out and form more productive floodplains the rivers are surrounded by urban development and heavily impacted by industrial and domestic waste. A number of the City's informal settlements are located on or close to aquatic systems which are used extensively for informal dumping of solid waste, waste water from washing and human waste disposal. In addition, the City's official storm water management strategy involves collecting and channelling runoff from both informal and formal settlements into the nearest watercourse, designed to address flooding and public safety risks by removing runoff as quickly and efficiently as possible (Armitage et al., 2013).

Cape Town is currently challenged by the housing and sanitation needs associated with high population growth resulting in inadequate levels of refuse and sewer services (Obree, 2004). Current estimates suggest that a minimum of 500 000 people living in informal settlements across Cape Town do not have access to basic sanitation (Overy, 2013). Not only is this unsustainable and socially unacceptable (Pan et al. 2015) but it has enormous impacts on urban aquatic systems. Until city storm water management and sanitation services in informal settlements is improved, pollution events (as shown above in Figure 7.1) will be the norm and urban aquatic systems will continue to harbour contaminants, cyanobacteria and high levels of *E.coli*.

There are numerous challenges associated with improving sanitation, storm and waste water management systems, not least the current socio-political landscape in the Western

Cape (Pan et al., 2015). The current short term strategy to address the demand for sanitation in the form of temporary chemical toilets is unsustainable as they eventually become 'temporary permanent' due to lack of progress on the more permanent solutions (Pan et al., 2015). Permanent solutions demand progress in upgrading of informal settlements and addressing the chronic underfunding, lack of accountability, lack of infrastructure (for example, only one waste water treatment plant deals with non-sewered sanitation systems), and the tension between the mandate for local government to provide basic services and the sentiment that informal settlements should not exist (Pan et al., 2015).

Looking beyond a top-down approach to restrict the damage to urban waterways through storm water management, Fisher-Jeffes and Armitage (2013) propose that residents pay an additional fee for the provision and management of storm water infrastructure (Campbell, 2011). They suggest that the money should go towards improved management of storm water in line with international best practice to prevent further degradation to the environment and avoid public health problems related to poor water quality. Residents could be incentivized to implement their own on-site storm water management, and thus reduce the burden on municipal infrastructure. A difficulty could be in guaranteeing residents willingness to participate particularly in low-income areas. Ward and Winter (2016) found that local residents in Cape Town, from low to upper income, have a poor understanding of their impacts on the quality of a local urban river. Technological solutions, flood prevention and drainage infrastructure fails to connect citizens with their downstream impacts on environmental systems and services (Ward and Winter, 2016). The authors concluded that most residents 'miss the link' – between their actions on land, their impacts on runoff and river water quality, and, in turn, their ability to influence societal patterns and processes (Ward and Winter, 2016).

Otters as flagships for improving waste water management in the City of Cape Town

In these circumstances, a flagship wildlife species such as the Cape clawless otter may be useful in communicating the connection between human actions and the downstream impacts on the environment. Flagship species are most appropriately defined as 'popular, charismatic species that serve as symbols and rallying points to stimulate conservation awareness and action' (Watson et al., 1995), and can be used to successfully communicate the challenges of urban conservation to the public (Weckel and Wincorn, 2016). Flagship species are generally easy to observe, have some anthropogenic features, are taxonomically relatively close to humans and are perceived by the public to be under threat (Kalinkat et al., 2016). Freshwater species are not frequently used as flagship or umbrella species (He et al., 2017), likely due to their cryptic nature, smaller body size than their marine or terrestrial counterparts, and the lack of public awareness over the threats to freshwater systems (Kalinkat et al., 2016). Traditionally otters have been considered indicator, sentinel and flagship species for freshwater ecosystems globally (Chadwick, 2007; Foster-Turley et al., 1990; Mayack, 2012). Although numerous studies show that otters are not necessarily good indicator species, they have been effective umbrella species for environmental stewardship in many parts of their range (Barua et al., 2011; Krauss, 2005; White et al., 1997).

In the Cape Peninsula, otters have the potential to act as an ambassador for improving waste and storm water management across the city and specifically in informal settlements. As a charismatic species reliant on urban rivers, improved otter management may spur policy makers to improve waste disposal mechanisms for informal settlements, and at the same time educate and raise awareness around water conservation in these communities. Educating a highly urbanised population has been shown to greatly improve species conservation, (McKinney, 2002) which in turn has potential to assist in the conservation of the broader ecosystem. I believe that the charismatic Cape clawless otter is capable of capturing the imagination of the public and will play an important role in the future management of urban waterways in the City of Cape Town.

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LIST OF ACRONYMS

AIC	Akaike's Information Criterion
AICc	Akaike's Information Criterion for small sample sizes
AUC	Area under the curve
MPA	Marine Protected Area
PCB	Polychlorinated biphenyls
ROC	Receiver Operating Curve
TMNP	Table Mountain National Park

APPENDIX A:

PENINSULA OTTER WATCH SIGHTING RECORDS GOOGLE FORM

Otter Spotter Google Form

Name
Email address

Did you see an otter?

What was the otter doing?

Please describe what the otter looked like (size, shape, coloring, markings).

Any other information (injuries, unusual behaviour, number of dogs in the area).

When did you see an otter?

Where did you see an otter

Longitude
Latitude

Please describe the location of the sighting.

Do you have a photo of the otter online? You can post the url here:

Thank you!

APPENDIX B:

DISSECTIONS DATASHEET

UCT Cape Clawless Otter Project

Nicola Okes (Biological Sciences Lab 3.20) Cell 082 961 9082

DISSSECTIONS DATA SHEET					
Examined by	-	State of Decomposition		-	-
Volunteers	-		-	-	
Details of carcass					
Date collected:					
Cause of death:					
Location:					
Sex:	Age class*:		Total weight (kg):		
Length (anus to tail):		Length (nose to tail):		Legs (RH, RF):	
Length (nose to anus):		Axillary girth:		Girth:	
*Retain a tooth: lower right canine					
Samples	Retained	Weight		Notes	
		Left	Right		
Lungs					
Adrenal					
Kidney					
Kidney stones					
Thymus gland					
Thyroid glands					
Heart					
Spleen					
Gall bladder					
Baculum (length, weight, injuries):					
Testes					
Liver				**DNA study: sliver in ethanol**	
Retain 5g Sample for pollutant testing					
Retain 5g Sample for PCB testing					
Retain 5g Sample for backup sample					
Muscle					
Retain thumbnail sized sample for shark research					
Retain thumbnail sized sample for DNA analysis					

Markings (take a photo of throat, chin and moustache; note any markings):					
Teeth (check for wear, breakages, missing teeth or infections):					
Injuries:					
Fighting injuries (bite marks, cuts, particularly in the anogenital, head an feet areas):					
Ectoparasites (remove and identify; check ears for ticks):					
Vibrissae (including root, for isotope analysis) and hair samples:					
Reproductive condition (check females nipples for no. of pairs, protruding nipples indicate she has recently fed pups, lactation indicates she has recently had pups or is at a late of stage pregnancy):					
Fat layer (categorise as poor, moderate, good/excellent, judging by the extent to which fat covers the abdomen/thorax. In animals with good fat levels there are often also intramuscular fat deposits - note these): FAT SAMPLE (5g) FOR PCB TESTING (3 x 5g samples required; note if peritoneal or subcutaneous):					
Muscle layer (categorise as poor/moderate/good/excellent, judging by the thickness of the sheets of muscle covering the thorax and abdomen):					
Thoracic cavity (the thoracic cavity is opened by cutting along the central line of cartilage)					
Presence of free blood and/or blood clotting:					
Two samples of blood taken for disease testing:					
Reproductive organs:					

<table>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="6">Uterus (check for thickening or any convolutions, which can indicate a recent or current pregnancy; note foetal development, placental scarring; weighed (left and right horn weighed and measured):</td></tr>
<tr><td colspan="6">Testes (weigh and check for an abnormalities (e.g. have they descended through the abdominal wall), check vas deferens for cysts which could be indicative of exposire to EDCs):</td></tr>
<tr><td colspan="6"><u>Gastro-intestinal tract and stomach, with contents: retained for research on endoparasites</u></td></tr>
<tr><td colspan="6"></td></tr>
<tr><td colspan="6">NOTES:
- endoparasites in liver (fluke worm)
- check gall bladder for gall stones and flukes
- note size of adrenal glands (enlarged?)
- kidney stones, if found weigh and retain
- any abnormalities and/or infections</td></tr>
</table>

APPENDIX C:

PRELIMINARY RESULTS FROM THE VHF TRACKING OF THREE INDIVIDUAL OTTERS IN THE CAPE PENINSULA, JULY 2013 – SEPTEMBER 2014.

Introduction.

The spatial organisation of otters in South Africa has previously been studied using radio telemetry in a marine environment (7 radio-tagged individuals - Arden-Clarke, 1983), and in a freshwater environment (7 individuals - Perrin and Carugati, 2000; Somers and Nel, 2004). Otters were tracked continuously at times of usual otter activity, and periodically (or monthly) for 24 hours. Home range, core range, and time spent (active/inactive) in each habitat types was analysed. Somers and Nel (2004) found that otters had a linear home range that varied from 4.9 to 54.1 km with the core range being 0.2 - 9.8 km. Somers and Nel (2004) found that total home-range length was correlated with high food density patches (mean reed bed neighbour distance) in accordance with the resource dispersion hypothesis. The pattern of home-range use by females was suggestive of territoriality, yet male Cape clawless otters had overlapping home ranges, both with other males and with females (Somers and Nel, 2004). Arden-Clarke (1986) also found extensive overlap in male and female home ranges, and that males tended to have larger home ranges than females. All studies found that otters spent the majority of their time in reed beds, possibly due to the abundance of their preferred prey – freshwater crab, *Potamanautes perlatus*.

It has been suggested that human disturbance and pollution may also influence holt utilisation (Verwoerd, 1987) and home range size (Somers and Nel, 2004). However, currently, little is known about the habitat use of otters in an urban environment close to human disturbance and pollution. If otters were negatively influenced by human disturbance and/or pollution, I would expect that otters would spend less time in urbanised, polluted areas than in more natural systems. In polluted freshwater systems, I would expect that otters would spend more time in the marine environment than in the freshwater. In unpolluted freshwater systems, I would expect that otters would spend more time in the freshwater environment than in the sea.

Methods

The transmitters used were Sirtack VHF Model ZV21 161A, with dimensions 75mm long, 17mm wide and a weight of 28g, with a 0.5AA battery. At a pulse rate of 40ppm, the lifetime of the battery was expected to be 420 days. This approach ensured I could collect long-term (1 year) broad scale movement patterns (weekly fixes). I planned to use these data to determine home range size and ranging patterns of both males and females in addition to habitat preference in different aquatic systems. Trapping sites were identified in the camera trap survey. Animals were trapped using walk-in cage traps monitored by an MMS-enabled camera trap to alert me to the presence of an animal in a cage. Traps were set in the early mornings (3am) or early evenings (6pm) to match the crepuscular peak in otter activity (Kruuk 2006).

Captured otters were transported to the veterinarian in a wooden holding box to ensure the otter could not damage itself. The veterinarian anaesthetised the otter, and I took morphometric measurements including weight and length. The veterinarian performed the procedure to insert the VHF tracking device into the abdominal cavity of the otter following standard procedures of (McKenzie et al., 1990; Ó Néill et al., 2008; Somers and Nel, 2004). The otters were released at the capture site following full recovery from the anaesthetic procedure. Each otter was followed for the first 24 hours, and then tracked 3-5 times per week to collect a location fix in the morning and evening. For the purposes of this report, I plotted the individual locations of each tracked otter in ArcGIS 10.1 (Figure AC.1).

Results

A total of 3 otters (two males and one female) were trapped and fitted with an internal VHF transmitters. Otter 150.581 was tracked over a year, with 106 individual, independent fixes collected over the 12-month period (July 2013 – July 2014). Otter 150.520 was tracked over the course of a year, with 120 individual, independent fixes recorded over the 12-month period (September 2013 – September 2014). Otter 150.481 was tracked over the period of 6 months, with 49 individual, independent fixes collected over the 6-month period (April 2014 – September 2014).

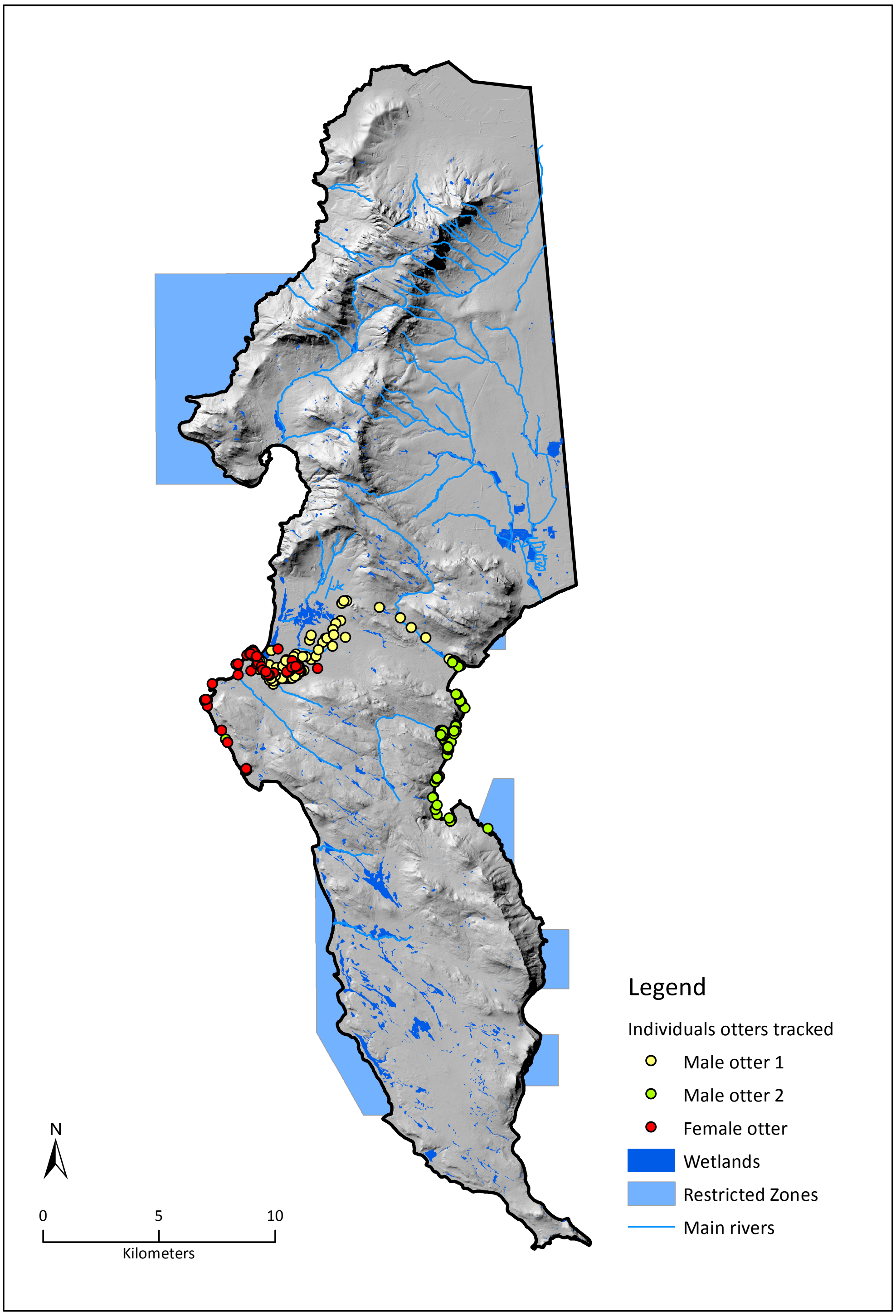

Figure AC.1. The location fixes as obtained from VHF tracking of three otters radio tracked across the Cape Peninsula.