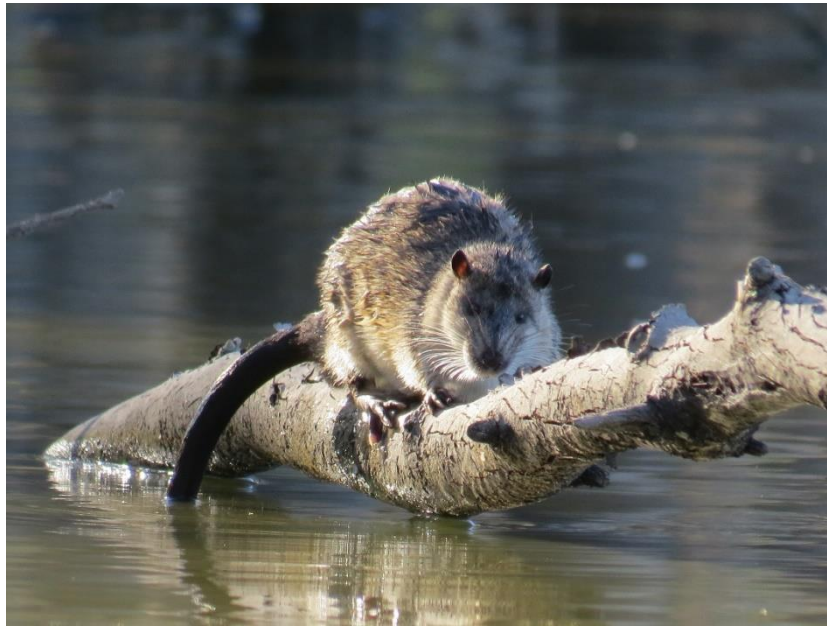


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# Investigating the presence and distribution of Rakali across an urban gradient.



Hannah Mckennall

*Thesis*

*Submitted to Flinders University for the degree of  
Bachelor of Science (Animal Behaviour) (Honours)*

*College of Science and Engineering*

*13<sup>th</sup> November 2025*

**Supervised by:**

Dr Ryan Baring

Dr Gilad Bino

Dr Tahneal Hawke

# DECLARATION

I certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Hannah Mckennall

Signed: 13<sup>th</sup> November 2025

I acknowledge the use of ChatGPT in the early stages to brainstorm the structuring and to assist in my understanding for this project (OpenAI, 2025). Links to relevant prompts and outputs from ChatGPT are included in Appendix 5.

# PREFACE

## STATEMENT OF PROJECT INTELLECTUAL PROPERTY

This thesis represents a novel body of scientific work that has been prepared by the candidate under direction of their supervisors. The final dissertation presented herein is work of intellectual merit that has been produced by various inputs as follows:

**Funding acquired by:** Ryan Baring

**Funding provided by:** Government of Australia: Department of Climate Change, Energy, Environment and Water, (via Goyder Institute for Water Research and CLLMM Research Centre), Nature Foundation.

**Project Concept by:** Ryan Baring, Hannah Mckennall

**Project Design by:** Ryan Baring, Hannah Mckennall, Gilad Bino, Tahneal Hawke

**Field work done by:** Hannah Mckennall, Ryan Baring, Gilad Bino, Tahneal Hawke, Bethany Treglown

**Data processed by:** Gilad Bino, Hannah Mckennall

**Thesis written by:** Hannah Mckennall

**Illustrations, photography by:** Hannah Mckennall, Bethany Treglown

**Input to shaping thesis drafts by:** Ryan Baring, Gilad Bino, Tahneal Hawke, Bethany Treglown

**Inputs to methodology:** Ryan Baring, Gilad Bino, Tahneal Hawke, Emmalie Sanders, Bethany Treglown

**Intellectual discussions into results:** Hannah Mckennall, Ryan Baring, Gilad Bino

The candidate acknowledges that authorship of any resulting publication from this work will be guided by advice from the supervisors and may include other authors who contributed intellectual merit in the project.

**SIGNED:** Hannah Mckennall

**DATE:** 13<sup>th</sup> November 2025

# FORMAT OF THESIS

This thesis has been written as a journal article and is therefore adhering to a short format following Australian Mammalogy instructions to authors. The referencing list has been aligned with the formatting as detailed in the ‘CSIRO journals Harvard reference style’ pdf (accessible by: <https://connectsci.au/DocumentLibrary/Harvard-refs.pdf>). For readability the tables and figures are inserted within the text. The following appendices have been included to show additional work that was not presented in the journal article.

**Appendix 1:** Live Trapping Methodology and Outcomes

**Appendix 2:** Additional Illustrations for Methodology

**Appendix 3:** Study Design and Flow Charts

**Appendix 4:** Additional Figures and Tables

**Appendix 5:** Author Guidelines for Australian Mammalogy

**Appendix 6:** STEM 7001 Literature Review: Behavioural responses of freshwater semi-aquatic mammals to anthropogenic pressures: a review.

In addition, the literature review for STEM7001 has been included as a non-assessable Appendix.

**Note to assessors:** In the original research proposal, two methods; camera and live trapping were planned to be conducted for this project. While we began surveying for live trapping, due to an Unexpected Adverse Event, methodology for live trapping needed to be refined, which caused increased time constraints for this study. The number of Rakali surveyed, and the survey effort for live trapping will need to be continued before we can confidently analyse data and report on results. Therefore, this thesis will focus on the camera trapping portion of my study, using data gained from camera surveys to address and interpret results. Methodology, preliminary data, and a small report on results from live trapping is included in Appendix 1. This small sample size provides a novel dataset, constituting the first time Rakali have been put under anaesthesia in the field and biologically sampled from.

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First, I want to thank my primary supervisor, Dr Ryan Baring for all his hard work and support this year. Not only to take time out of his extremely busy workload to coach myself and my honours peers through this year, but for being so dedicated and passionate about his work. Thank you for taking extra time to be in the field with me and the team until late, even after a full day of university teaching. I really appreciate all the work you've put in to help my honours experience be as rewarding as it has been. Thank you to my co-supervisors Dr Gilad Bino and Dr Tahneal Hawke, for the many teams meetings answering all of my questions, and for taking the time to travel interstate to teach me directly in the field, you have both been invaluable to getting this project off the ground. Thank you to Emmalie Sanders, for providing me with insights and experience from working with this special species. Thank you to Lewis Vaughan, not only for your expertise and assistance in the field, but your wisdom about professional development, careers, and life. I appreciate your ongoing support, even until my final honours seminar, your encouragement means a lot to me. And thank you to Helen Conguista, for jumping in the deep end right with me, being open to teach me, and learn new things alongside all of us. I appreciate the extra work that you undertook to help my project be as successful as it could be. Thank you to the people in NERF at Flinders, particularly Sarah Young. You've been wonderfully supportive through this whole experience and extremely patient (I'm sorry for the equipment, I'll move it soon). Thank you to Bethany Treglown, who has been a warm and welcoming presence in the ERRG lab since the beginning of the year. From moving around personal commitments to assist me in the field, to introducing me to the food at the Finnis Supply Store Café, you have been a fundamental part of my honours experience. I really appreciate your dedication, patience, and commitment to mentoring me, and giving me important tips and tricks to get through this year.

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Thank you to everyone who encouraged me through my undergraduate years as well. From 1<sup>st</sup> year demonstrators to academics who continue to encourage me, thank you for helping me to become the student and person that I am today. And lastly, happy 22<sup>nd</sup> birthday to me. I hope next year is as exciting and rewarding as this year has been.

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1

## 2 **Investigating the presence and distribution of** 3 **Rakali across an urban gradient**

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12

13 **Abstract.** Freshwater ecosystems are becoming increasingly damaged and overconsumed in  
14 the Anthropocene era, due to the effects of anthropogenic activities involved in urbanisation  
15 and human consumption of resources. Freshwater species, including semi-aquatic taxa, are  
16 disproportionately threatened due to these disturbances across terrestrial and aquatic habitats,  
17 yet population assessments for many semi-aquatic species are significantly lacking. The order  
18 Rodentia has among highest proportion of data deficient semi-aquatic species, and these  
19 species are often highly unique and culturally important. This research aimed to investigate the  
20 presence of an under researched semi-aquatic freshwater mammal; the Rakali (*Hydromys*  
21 *chrysogaster*) across an urban to reserve gradient, to ascertain potential species response to  
22 increased urbanisation across diverse freshwater habitats. Through baited camera trap surveys  
23 conducted in 2025, results found that Rakali presence was not significantly impacted by  
24 location, site, or weather conditions, with the exception of a positive correlation between Rakali  
25 detection rate and decreasing minimum daily temperatures. Rakali detection rates also differed  
26 between baiting periods, with indications of differing responses to bait across urban locations.  
27 This study provides the first population assessment of Rakali in Goolwa, South Australia, and  
28 findings will assist in understanding the dynamics of Rakali response to increasing urbanisation  
29 and human disturbance in freshwater habitats.

30 **Keywords:** Rakali, urbanisation, habitat, behaviour, scavenging, distribution, human  
31 disturbance, freshwater, rodent.

## 32 **Introduction**

### 33 *Global decline of freshwater ecosystems*

34 Severity and frequency of adverse climatic events are increasing globally (Dudgeon *et al.*  
35 2019). Coupled with increasing demands of freshwater resources and urban development to  
36 support an escalating human population (Dudgeon 2019; Reid *et al.* 2019; Torres-Romero *et*  
37 *al.* 2024), freshwater systems are becoming damaged and overconsumed (Dudgeon *et al.* 2006;  
38 Reid *et al.* 2019; Woodward *et al.* 2010). Freshwater ecosystems are particularly sensitive to  
39 environmental changes and anthropogenic disturbance due to limited connectivity of habitats  
40 (Sanders *et al.* 2024) and complex above- and below-ground hydrological cycles (Dudgeon *et*  
41 *al.* 2006; van Rees *et al.* 2023), causing them to be among the most threatened ecosystems in  
42 the Anthropocene era (Reid *et al.* 2019).

43 Freshwater environments are among the most biodiverse ecosystems (Strayer & Dudgeon  
44 2010), supporting 9.5% of the world's described animal species (Reid *et al.* 2019). Since the  
45 1980's there has been an 83% decrease of freshwater vertebrates worldwide (Dudgeon *et al.*  
46 2006). Underrepresented taxa within freshwater vertebrates include semi-aquatic mammals  
47 (Sanders *et al.* 2024). Semi aquatic mammals have been described as disproportionately  
48 threatened compared to marine and terrestrial taxa (Sanders *et al.* 2024). Due to their  
49 dependency on both terrestrial and aquatic environments, anthropogenic pressures across both  
50 ecosystems place these animals in a position of extreme vulnerability (Torres-Romero *et al.*  
51 2024). Many semi-aquatic mammals are also important for supporting ecosystem functioning  
52 (Wilson *et al.* 2020), acting as ecosystem indicators (Schneider 2010) and can be top predators  
53 that assist in the regulation of complex trophic systems and pathways (He *et al.* 2024; Lacher  
54 *et al.* 2019; Manenti *et al.* 2017). They are also highly unique and adapted, and are often  
55 socially and culturally significant (Dudgeon *et al.* 2006; Griffith *et al.* 2025). Habitat  
56 degradation and modification of waterflow are among the leading threats to freshwater systems  
57 (Dudgeon *et al.* 2006; Reid *et al.* 2019). Landscape modification of natural landscapes into  
58 agricultural, industrial, or urban zones leads to displacement of species from their preferred or  
59 optimal habitats, impacting their capacity to meet numerous functional aspects of their biology  
60 and ecology, and can ultimately increase extinction vulnerabilities (Torres-Romero *et al.* 2024).  
61 Compared to terrestrial mammals, semi-aquatic mammals in freshwater habitats lack sufficient  
62 research (Hawke *et al.* 2020; Reid *et al.* 2019, Sanders *et al.* 2024). Recent scientific literature  
63 reviews have documented that of all threatened freshwater taxa, the order Rodentia has one of

64 the largest proportions of ‘not evaluated’ or ‘data deficient’ species, despite many being  
65 regarded as ‘least concern’ on the International Union for Conservation of Nature (IUCN)  
66 RedList (Sanders *et al.* 2024; Torres-Romero *et al.* 2024). The lack of information about  
67 freshwater Rodentia species and their international conservation classification based on  
68 insufficient data (Sanders *et al.* 2024), can result in reduced conservation initiative, support,  
69 and funding, ultimately drive potential species’ extinction (Bland *et al.* 2016).

### 70 *Responses of species to urbanisation*

71 Some species have displayed a degree of behavioural flexibility to ecosystem modification,  
72 allowing them to adapt and even benefit from urbanisation (Bateman and Flemming 2012;  
73 Dammhahn *et al.* 2020; Etherington *et al.* 2023; Lowry *et al.* 2013). The benefits from  
74 urbanisation include increased food resources, provision of artificial shelters and habitats, and  
75 reduced predation risk due to human presence (Bateman and Flemming 2012; Lowry *et al.*  
76 2013). Such adaptation also means that in an increasingly urban environment, some animals  
77 are less subject to declines if their habitat options are supplemented by appropriate refuges in  
78 which they can persist (Boakes *et al.* 2024; Gentili *et al.* 2024; Reside *et al.* 2019). Rivers and  
79 streams in parks and urban reserves for example, have been shown to provide additional habitat  
80 for the European Water Vole (*Arvicola amphibius*), a freshwater species experiencing rapid  
81 declines due to habitat degradation (endangered on the UK red list) (Boakes *et al.* 2024).

82 However, multiple risks have been identified in urban dwelling species too, including  
83 increased human-animal conflict during foraging, consumption of non-food materials,  
84 nutritional deficiencies, and facilitation of adverse behaviour modifications (Bateman and  
85 Flemming *et al.* 2012; Birnie-Gauvin *et al.* 2016; Lowry *et al.* 2013). Literature remains  
86 inconsistent regarding how animals living in urban environments may experience stress  
87 (Lowry *et al.* 2013). Researchers have raised concerns that increased behavioural modifications  
88 induced by urban environments may negatively impact species fitness, such as increasing  
89 alertness/vigilance behaviours, adjusting reproduction or foraging timings, and ultimately  
90 increase stress levels due to anthropogenic disturbance exposure (Ditchkoff *et al.* 2006; Lowry  
91 *et al.* 2013). Other studies however find no correlation to stress increases in urban individuals  
92 at all (Birnie-Gauvin *et al.* 2016), suggesting potential decreases in resource-related stress  
93 (food) in urban areas (Schoech *et al.* 2004). Scavenging, opportunistic, and generalist species  
94 may be more vulnerable to risks associated with foraging behaviour change in urbanised  
95 habitats, as they more flexibly supplement their diet with anthropogenic food resources  
96 (Bateman and Flemming 2012; Murray *et al.* 2015; Streicher *et al.* 2022), which often contain

97 high densities of non-food materials when present in urban areas (Bateman and Fleming 2012;  
98 Jankowiak 2016; Murray *et al.* 2015). Even for primarily generalist species, scavenging  
99 behaviour increases when in urban environments compared to rural areas (Crandall *et al.* 2024),  
100 and is more commonly observed in meso-carnivores such as the Water Mongoose (*Atilax*  
101 *paludinosus*) which have been reported to supplement their diet using anthropogenic food  
102 resources in areas closer to urban environments (Streicher *et al.* 2022). An overall deficiency  
103 in understanding of how species are responding to urbanisation, alongside the rapid increase in  
104 the quantity and spread of urban areas (Dammhahn *et al.* 2020) may pose greater risks to  
105 understudied species than anticipated.

### 106 *Focal species: Rakali*

107 Ancestors of *Hydromys chrysogaster*, or Rakali radiated from New Guinea between 3.0-3.7  
108 million years ago (MYA), with the first lineages diverging in Tasmania 1.9 MYA (Bettink  
109 2016). The species was hunted extensively for its fur until the mid-1900s (Bettink 2016; Watts  
110 and Aslin 1989), but Rakali can now be found across all Australian states (Williams 2019).  
111 Various phenotypes of Rakali are evident, which present morphological differences such as  
112 colour and size morphs that may be dependent on their distribution (Bettink 2016; Serena and  
113 Williams 2018). Rakali primarily inhabit a wide variety of freshwater ecosystems including  
114 urban or man-made waterways, and sheltered coastal marine regions in some cases (Watts and  
115 Aslin 1981; Williams 2019). Rakali construct burrows in riverbanks, which are used for resting  
116 and rearing young (Atkinson *et al.* 2008; Watts and Aslin 1989). One or two litters of young  
117 are produced in a year, depending on environmental conditions (Atkinson *et al.* 2008) and  
118 young Rakali will stay with their mother for a total of eight weeks until they individually  
119 disperse into the population (Atkinson *et al.* 2008). Although it is assumed that Rakali can  
120 breed year-round, the spring and early summer months (from November to January) is  
121 estimated to be their peak breeding season (Atkinson *et al.* 2008; Leigh and Breed 2020).  
122 Individuals have overlapping home-ranges, with male dispersal distance being more extensive  
123 than females (average of 253m and 74m respectively) (Leigh and Breed 2020). Some studies  
124 have identified that male Rakali are territorial and intrasexually aggressive, exhibiting fighting  
125 behaviours with other males that results in bodily injury (Atkinson *et al.* 2008). Rakali are  
126 opportunistic carnivores, primarily feeding on freshwater fish, crustaceans, aquatic  
127 invertebrates, and plant matter depending on prey availability (Atkinson *et al.* 2008; Sanders  
128 *et al.* 2024; Watts and Aslin 1989). In urban environments, sightings have indicated Rakali may

129 scavenge on alternate food resources, such as leftover fishing bait, pet food or in rubbish bins  
130 (Gardner and Serena 1995; Atkinson *et al.* 2008).

131 Rakali has long-standing significance for Australian Aboriginal people in south-eastern  
132 Australia and have recently been identified as an ‘Iconic Species’ in a South Australian based  
133 research workshop in collaboration with indigenous peoples, identifying Rakali’s importance  
134 to humans through cultural histories (Hatswell *et al.* 2025 (in-press)). However, the species  
135 remains significantly understudied throughout its entire distribution in Australia and New  
136 Guinea (Williams 2019). Management efforts have attempted to ‘redefine’ Rakali in the  
137 broader public community, primarily to reflect indigenous cultural significance (Williams  
138 2019), but also to gain increased conservation attention (Rääbus 2018). Citizen science  
139 initiatives including a compilation of public sightings of Rakali by the Australian Platypus  
140 Conservancy have also been created (Williams and Serena 2018). Although such initiatives can  
141 provide benefits to scientific research including their low-cost, widespread reach, and  
142 community-minded method of data collection, they also have limitations (Williams 2019). For  
143 example, incorrect species identification and observer bias are among the most prevalent issues  
144 with citizen science initiatives, which has been identified in the public assessments of Rakali  
145 populations (Williams and Serena 2018).

146 Updating information on Rakali’s ecology, particularly in urban areas or where there is  
147 increased possibility of human interaction with the species, will have significant implications  
148 for their conservation classification. Rakali is currently listed as ‘Least Concern’ on the IUCN  
149 Red list (Sanders *et al.* 2024), however literature has indicated that the degradation of habitats,  
150 pollution, and changes in waterways and urbanisation may be causing a significant decline in  
151 Rakali populations across Australia (Atkinson *et al.* 2008; Speldewinde *et al.* 2011). In  
152 conjunction with a significant lack of formal literature, this may contribute to a severe  
153 underestimation of threats to Rakali and their population stability, particularly in urban  
154 environments.

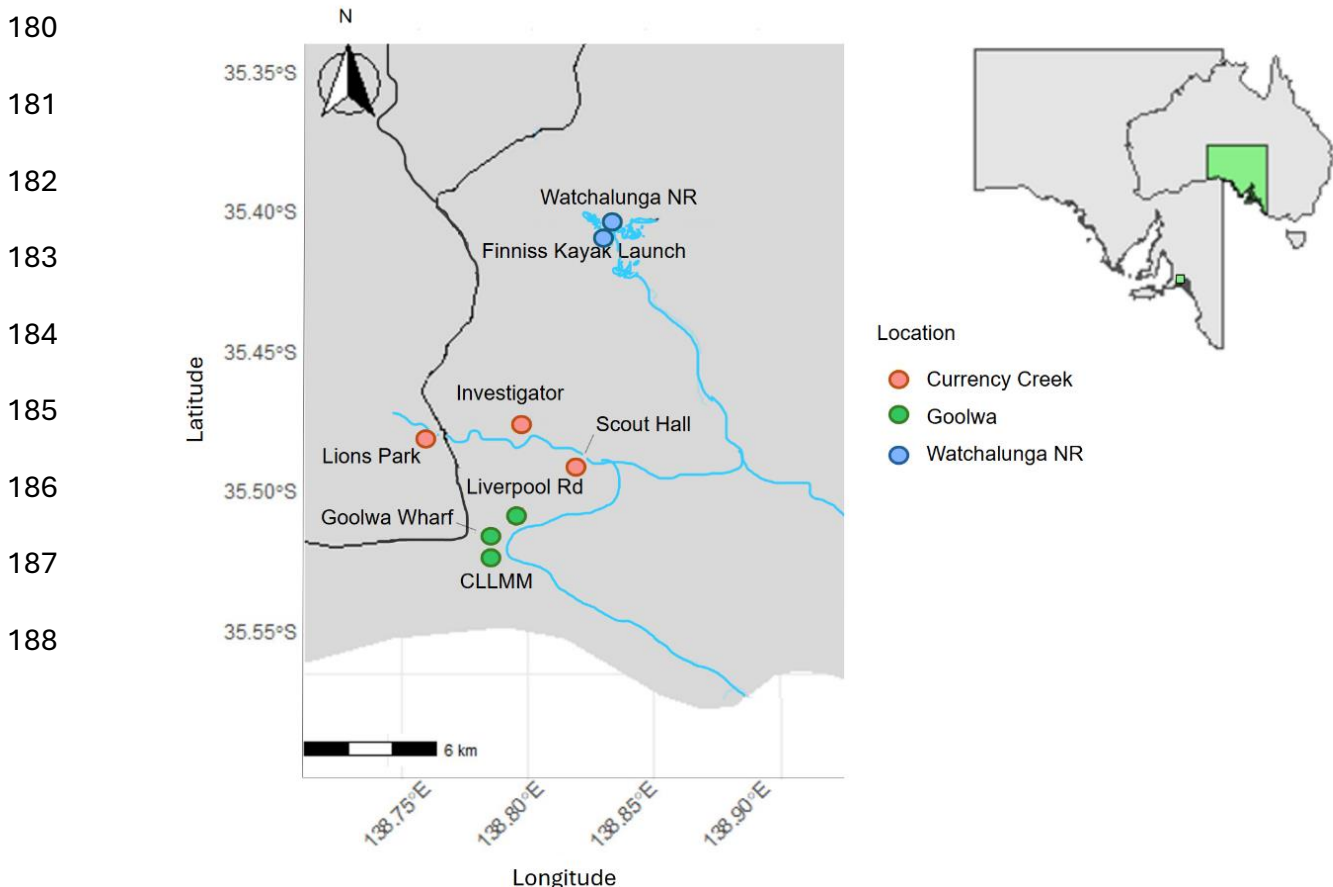
155 This study aimed to evaluate the distribution of Rakali across a gradient from a semi-urban  
156 township through to a nearby reserve. The study objectives were to: (1) investigate how Rakali  
157 presence varies along an urban to protected reserve gradient; (2) investigate whether  
158 environmental variables were associated with Rakali detections across the semi-urban to  
159 natural reserve gradient; and (3) investigate whether Rakali detections differ in relation to  
160 baiting lures across an urban to protected reserve gradient. It was hypothesised that: (1)

161 significant differences would occur in Rakali presence between urban and reserve locations;  
162 (2) Rakali detections would be influenced by environmental conditions across semi-urban and  
163 reserve locations; and (3) Rakali detections under baiting conditions would significantly differ  
164 between urban and reserve locations. The findings from this study will provide the first formal  
165 identification and population assessment for Rakali in the semi-urban township of Goolwa  
166 (South Australia) and nearby reserves. This research will contribute to understanding the  
167 dynamics of Rakali's response to increasing urbanisation pressure and human disturbance, and  
168 considering their role as key predators and potential indicator species, will further improve  
169 South Australian freshwater ecosystem management by identifying their presence across  
170 freshwater habitats on the Fleurieu peninsula.

## 171 **Methods**

### 172 *Study region*

173 The study was conducted in South Australia across the Goolwa Channel, Currency Creek and  
174 Finniss River catchments within the Alexandrina Council region (Figure 1), located  
175 approximately 85km south-east of the city of Adelaide. Located on the Fleurieu peninsula, this  
176 region primarily consists of agricultural land use and residential areas, with an environmentally  
177 diverse set of aquatic habitats (including wetlands, lagoons and creek systems). The Goolwa  
178 township is a historic river port where the Murray River mouth meets the Southern Ocean  
179 (South Australian Tourism Commission 2025).



189 **Figure 1:** Selected study region with the three study locations (Goolwa = green, Currency  
190 Creek = pink, Watchalunga Nature Reserve (NR)/Finniss = blue). Coloured dots refer to study  
191 sites within each location. Blue lines indicate key waterways, and black lines indicate major  
192 roads/highways in the region.

193 The surveys for this study extended over three key locations that vary in their environmental  
194 composition, including habitat type and degree of human disturbance: Goolwa, which features  
195 a comparatively high density of urban settlement compared to other sites (n=2,558 human  
196 population), and contains a large stretch of the Murray River with sparse and disturbed riparian  
197 vegetation; Currency Creek, which is a small locality (n= 443 human population), with a  
198 seasonal waterway that discharges into the lower Murray and; Watchalunga Nature Reserve  
199 (WNR), which is privately owned by Nature Foundation and consists of restored agricultural  
200 land near Finniss (n = 293 human population) that supports a diverse range of native species in  
201 an extensive network of swamp and lagoon habitat (Australian Bureau of Statistics 2021).  
202 Three sites were surveyed in each of Goolwa and Currency Creek, and two sites within the  
203 Watchalunga NR (WATCH/FIN) location: one site surveyed inside the WNR boundaries, and  
204 one site within a connected channel at a public access launch site Finniss Kayak Launch Site  
205 (KLS), approximately 2km outside of the reserve. Public sightings and anecdotal data have  
206 identified Rakali to be present in all of these locations and sites within the last five years (B.  
207 Treglown, personal communication, 2025). The survey period for all fieldwork was from 19<sup>th</sup>  
208 of June to the 9<sup>th</sup> of September 2025. Annual air temperatures in the Goolwa region across  
209 survey months fluctuated between 8°C to 18.7°C (Australian Bureau of Meteorology 2025).  
210 The mean rainfall in the region ranged from 39.5mm to 56.6mm, with the highest mean rainfall  
211 occurring during July (Australian Bureau of Meteorology 2025).

212 This study used camera trapping to survey Rakali presence within the Goolwa, Currency Creek  
213 and Watchalunga Nature Reserve locations. Camera trapping was used for its convenience in  
214 improving capture rates versus resource effort compared to traditional visual or spotlighting  
215 surveys (Sanders *et al.* 2024). Pilot surveys for camera trapping were conducted during April  
216 and May of 2025 to optimise the setup arrangement to maximise the ability for cameras to  
217 detect Rakali presence. The pilot surveys involved cameras being deployed across the Goolwa  
218 study location for two weeks, with modifications being made to site selection and camera  
219 settings throughout. After finalisation of camera settings and station configuration, surveys for  
220 the main study occurred with camera deployments between 19<sup>th</sup> of June to the 9<sup>th</sup> of September  
221 2025 and occurred across 125 whole (24h) sampling days.

## 222 *Camera trapping*

223 For camera trap surveys, trail cameras (Reconyx HF2X Hyperfire 2, Wisconsin, USA) were  
224 mounted on steel star pickets (180cm in length) on an angle between 45° and 80°, facing the  
225 water surface or at the wetland shoreline (Appendix 2). Site selection for cameras was limited  
226 by accessibility, but all were randomly selected along vegetated areas of appropriate potential  
227 Rakali habitat. Cameras were baited with an ~100g tin of sardines or equivalent weight of fresh  
228 pilchards in a tin container with punctured holes as a scent lure, to maximise detection of Rakali  
229 as described in Sanders *et al.* (2025) (Appendix 2). Cameras were rebaited with fresh pilchards  
230 or sardines within a maximum of seven days after initial deployment, and camera settings were  
231 adjusted as necessary. n=9 cameras were deployed across the three Goolwa sites, n=9 cameras  
232 were deployed across the three Currency Creek sites, and n=8 cameras were deployed across  
233 the two Watchalunga NR sites (Appendix 3).

234 The default settings of the cameras, except for minor modifications depending on  
235 environmental trigger factors (e.g. clear frame available or vegetation covering portion of  
236 frame) that were made as necessary, were as follows: (Motion Pictures – ON, Pictures Per  
237 Trigger – 5, Picture Interval – 1sec, Motion Videos – OFF, Quiet Period – 30sec, Sensitivity –  
238 MED/HIGH). Using thermal recognition and motion sensor technology, the cameras took five  
239 images when triggers such as Rakali entered the field of view frame.

240 Upon deployment, redeployment and collection of cameras, environmental variables at the  
241 habitat level for each site were recorded. Water quality variables collected included pH, salinity,  
242 and temperature, and were measured using a Hanna multimeter (Hanna Instruments, parameter  
243 HI98195, Rhode Island, USA). Also, weather metadata for all sampling days (including air  
244 temperature, precipitation, and wind) were sourced using the Australian Bureau of  
245 Meteorology historical dataset from the Hindmarsh Island weather station (Bureau of  
246 Meteorology 2025) (<https://www.bom.gov.au/climate/data/>).

## 247 *Data handling*

248 The number of images produced by cameras across the entire study region and sampling period  
249 totalled to ~60,000. All images were manually screened for animal presence/absence, which  
250 resulted in a dataset of ~3,000 animal images (including *Pelecanus conspicillatus*, *Cygnus*  
251 *atratus*, *Ardea alba*, *Anhinga novaehollandiae* and more). Images with Rakali present were  
252 extracted from the animal dataset, resulting in n=119 Rakali images. Due to the cameras taking  
253 five photographs per trigger event, one photo was selected from each trigger event to represent

254 that specific Rakali detection. Where photos were outside of a particular trigger event (as  
255 indicated to by the camera temporal records), or further apart than a predetermined minimum  
256 5-minute window (whichever was smallest), they were regarded as independent. This resulted  
257 in a final dataset of n=43 ‘Independent Detection Events’, which were used to analyse Rakali  
258 detection rate across locations and sites.

259 Environmental condition data (minimum daily temperature, maximum daily temperature,  
260 precipitation levels and wind speed (max gust)) was extracted from historical datasets  
261 published online by the Australian Bureau of Meteorology  
262 (<https://www.bom.gov.au/climate/data/>) using measurements taken from the Hindmarsh  
263 Weather Station (approximately 4 km away from Goolwa). To investigate diel patterns, dawn  
264 and dusk times were calculated by taking the minimum and maximum recorded sunrise and  
265 sunset times during the sampling period and adding a buffer period of +/- 30 minutes to either  
266 side of each sunrise and sunset time. This created a representative window of the dawn and  
267 dusk durations across the whole sampling period.

### 268 *Analysis and modelling*

269 Rakali count data were analysed using Poisson generalised linear mixed models (GLMMs)  
270 with log- links and log-exposure offsets. For overall activity, total detections were modelled as  
271 a function of location with random intercepts for site and camera\_code and an offset of  
272 log\_days. Estimated marginal means for location were obtained on the response scale, with  
273 unadjusted pairwise contrasts. For baiting, daily detections were modelled as functions of  
274 period and location, again with random intercepts for site and camera\_code and an offset of  
275 log\_exposure; estimated marginal means were computed for period with unadjusted pairwise  
276 contrasts. An interaction specification included period × location, with simple effects estimated  
277 as period contrasts within each location on the response scale. For weather, daily detections  
278 were modelled separately against minimum temperature, maximum temperature, precipitation,  
279 and maximum wind gust, each including location as a covariate, random intercepts for site and  
280 camera\_code, and a log\_exposure offset. Overdispersion was assessed from Pearson residuals  
281 as  $\chi^2/df$ ; values near or below about 1.5 indicated adequate fit, and residual Q–Q plots were  
282 inspected (Appendix 4). Analyses were conducted in R (R Core Team, 2024); mixed models  
283 used the lme4 package (Bates et al., 2015), estimated marginal means and contrasts used  
284 emmeans (Lenth, 2024), and graphics used ggplot2 (Wickham, 2016).

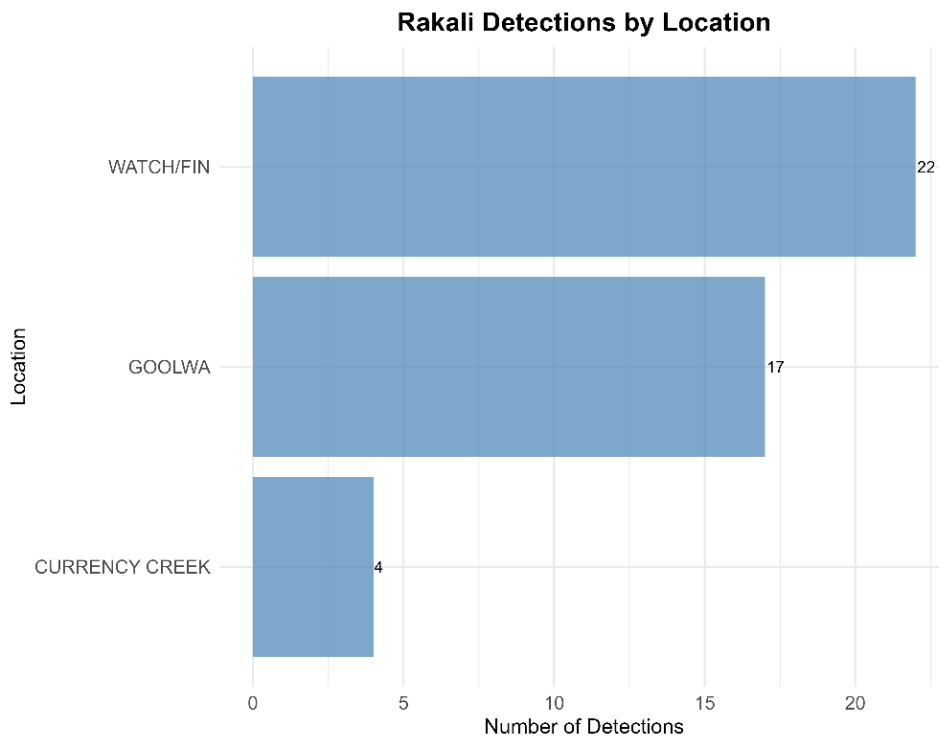
285

286 **Results**

287 Across June to September of 2025 (total of 125 sampling days) cameras recorded Rakali across  
288 all three locations and eight sites surveyed, with at least one Rakali detection event in each site  
289 during the sampling period.

290 *Location, site, and camera-level detection rate*

291 Rakali detections differed across locations throughout the whole survey, with the most  
292 detections at WATCH/FIN (n = 22), followed by Goolwa (n = 17) and Currency Creek (n = 4;  
293 Figure 2). The Poisson GLMM with a log link and an offset for sampling days indicated no  
294 statistically detectable effect of location on Rakali detection rates (locationGOOLWA: z =  
295 0.646, p = 0.518; locationWATCH/FIN: z = 1.544, p = 0.123; Table 1). Estimated marginal  
296 mean rates (per camera-day) were 1.25 (95% CI 0.34–4.65) for Currency Creek, 2.09 (0.86–  
297 5.07) for Goolwa, and 4.32 (1.76–10.59) for Watchalunga/Finniss; all Tukey-adjusted pairwise  
298 comparisons between locations were non-significant (Currency Creek vs Goolwa: ratio = 0.60,  
299 p = 0.795; Currency Creek vs Watchalunga/Finniss: ratio = 0.29, p = 0.270; Goolwa vs  
300 Watchalunga/Finniss: ratio = 0.48, p = 0.475).



301 **Figure 2:** Total number of Rakali (*Hydromys chrysogaster*) detections at the three study  
302 locations across the Goolwa region of South Australia.

303

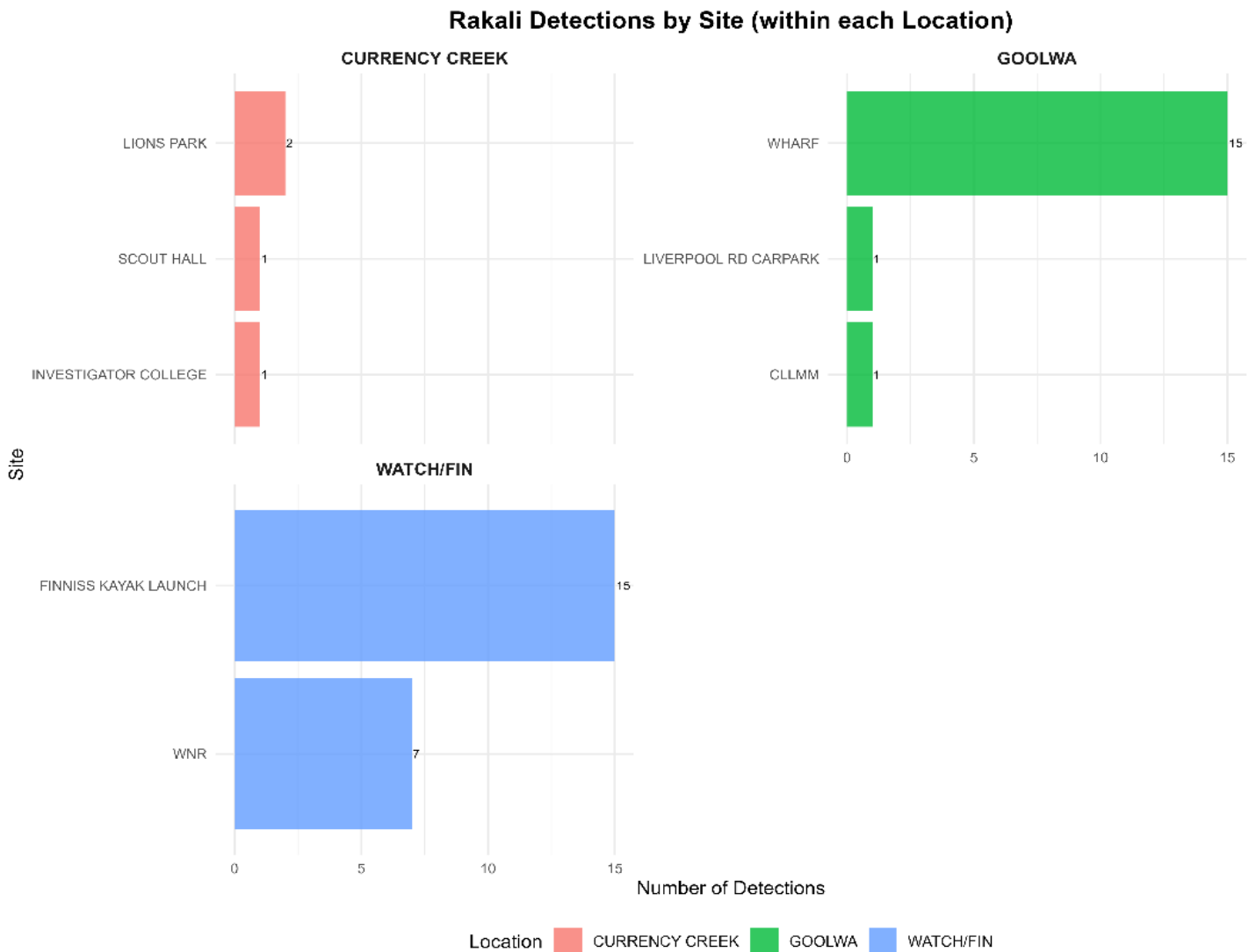
304 **Table 1:** Generalised linear mixed model output based on Poisson distribution, log- links and  
 305 log-exposure offsets were used to model the relationship between location and Rakali detection  
 306 rate with random intercepts for site and camera.

<i>Predictors</i>	<b>total detections</b>		
	<i>Incidence Rate Ratios</i>	<i>CI</i>	<i>p</i>
(Intercept)	0.08	0.02 – 0.30	< <b>0.001</b>
location [GOOLWA]	1.67	0.35 – 7.96	0.518
location [WATCH/FIN]	3.45	0.72 – 16.65	0.123
<b>Random Effects</b>			
$\sigma^2$			
$\tau_{00}$ camera_code	0.53		
$\tau_{00}$ site	0.00		
$N_{\text{site}}$	8		
$N_{\text{camera\_code}}$	12		
Observations	12		

307

308

309



310

311 **Figure 3:** Number of Rakali detections across locations and sites in the Goolwa region of South  
 312 Australia.

313 At the site level, Goolwa Wharf and Finnis KLS had the highest number of Rakali detections  
 314 (n=15). Finnis KLS contributed to 68% of detections within the WATCH/FIN location, and  
 315 Goolwa Wharf contributed 88% of detections within the Goolwa location (Figure 3). All sites  
 316 across Currency Creek had low Rakali detection counts: Lion’s Park (n = 2); Scout Hall and  
 317 Investigator College (n = 1 each) (Figure 3).

318 Random-effect estimates showed near-zero variance in Rakali detections among sites (Var  $\approx$   
 319  $4.2 \times 10^{-10}$ ), yielding a singular fit, whereas camera identity contributed substantial  
 320 heterogeneity (Var = 0.529; SD = 0.727), consistent with camera-level differences in detection  
 321 rates (Table 1).

322 Across deployed cameras, Goolwa had five cameras with Rakali detections (mean 3.4 SD =  
 323 4.34 per camera). In Currency Creek, Rakali detections were captured on three cameras with  
 324 very little variation (mean 1.33 SD = 0.57). Within the WATCH/FIN location, Rakali detections  
 325 that occurred at Finnis KLS were constrained to one camera ('F3', n=15 detections), while  
 326 60% of the cameras (n=3) deployed at WNR obtained Rakali detections.

327 *Environmental conditions*

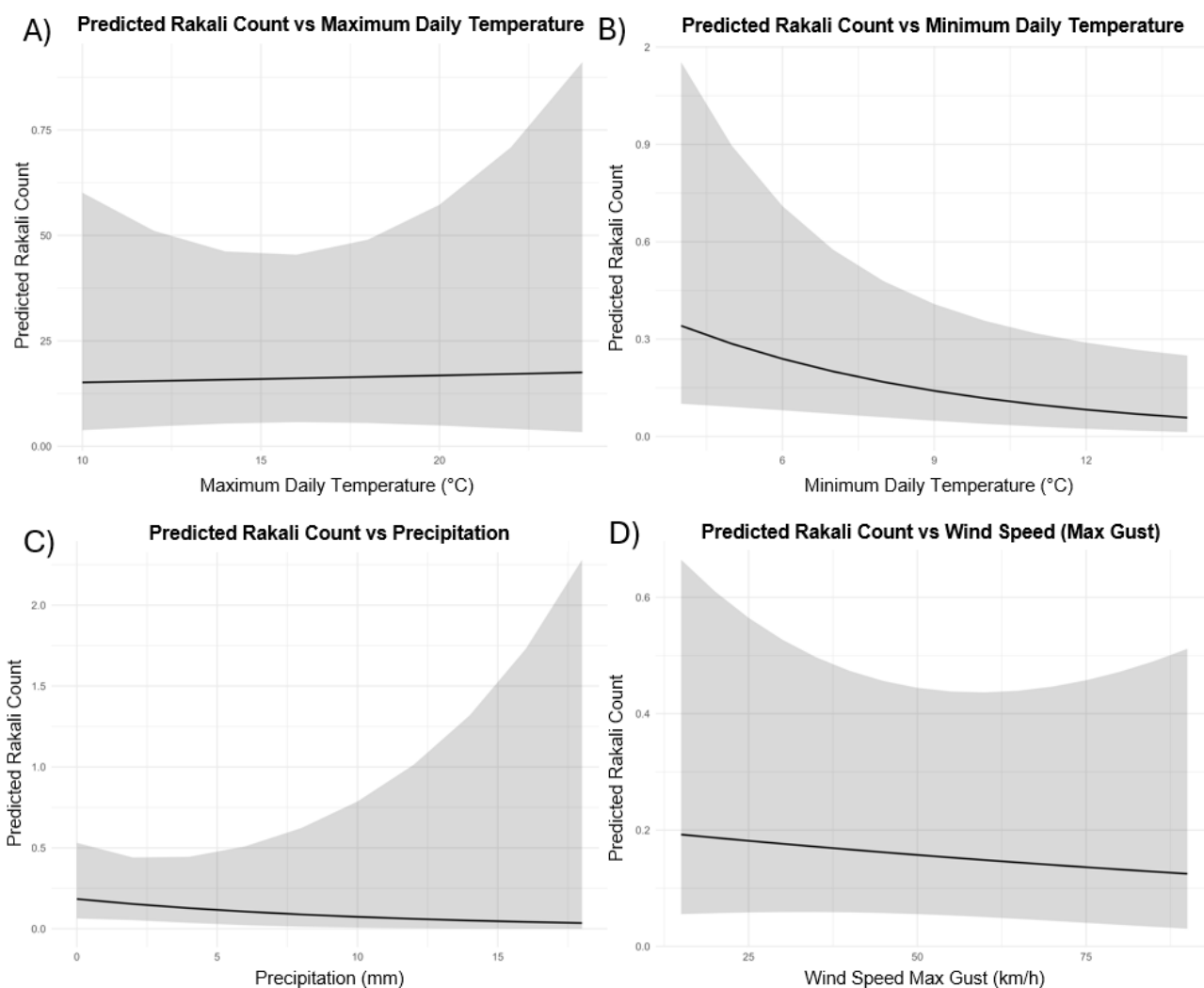
328 A Poisson GLMM with a log link and an offset for exposure modeled Rakali counts as a  
 329 function of minimum daily temperature, maximum daily temperature, precipitation, and wind  
 330 speed (maximum gust), with random intercepts for location and site.

331 **Table 2:** GLMM modelling output for Rakali detections against predictor weather conditions.  
 332 Conditional R<sup>2</sup> of 0.527 indicates moderate fit of the model.

<i>Predictors</i>	<b>rakali count</b>		
	<i>Incidence Rate Ratios</i>	<i>CI</i>	<i>p</i>
(Intercept)	0.85	0.05 – 15.21	0.910
min daily temp	0.84	0.72 – 0.99	<b>0.032</b>
max daily temp	1.01	0.87 – 1.18	0.895
precipitation	0.91	0.73 – 1.15	0.432
wind spd max gust	0.99	0.97 – 1.02	0.592
<b>Random Effects</b>			
$\sigma^2$	1.42		
$\tau_{00}$ site	0.97		
$\tau_{00}$ location	0.32		
ICC	0.48		
$N_{\text{location}}$	3		
$N_{\text{site}}$	8		
Observations	142		
Marginal R <sup>2</sup> / Conditional R <sup>2</sup>	0.098 / 0.527		

333

334



335

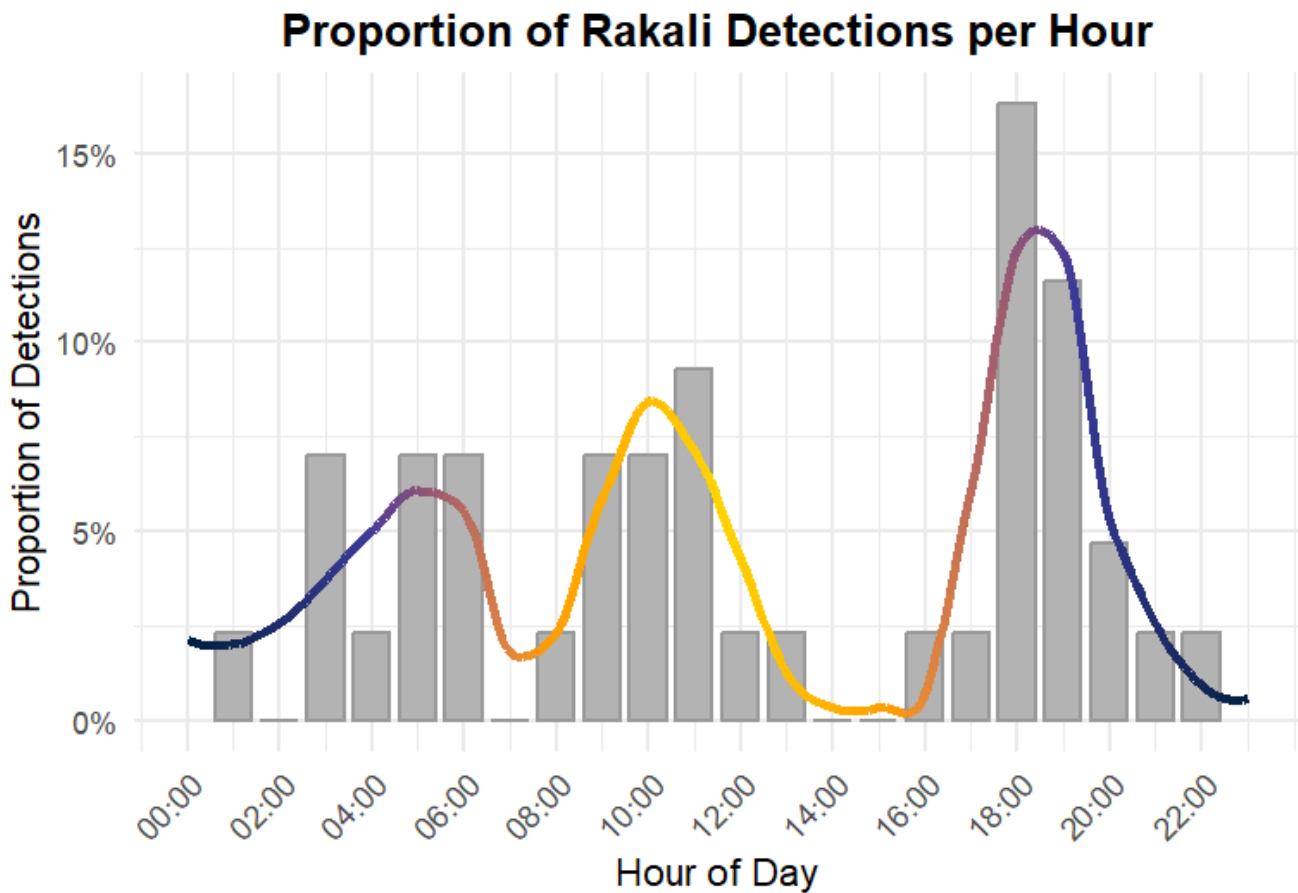
336 **Figure 4:** GLMM modelling figures for Rakali detection rates against investigated  
 337 environmental conditions (A= Maximum Daily Temperature, B= Minimum Daily  
 338 Temperature, C= Precipitation, D= Wind Speed (Maximum Gust)).

339 Maximum daily temperature ( $\beta = 0.010$ ;  $p = 0.895$ ), precipitation ( $\beta = -0.092$ ;  $p = 0.432$ ), and  
 340 wind speed (maximum gust) ( $\beta = -0.006$ ;  $p = 0.592$ ) were not significant (Table 2). Minimum  
 341 daily temperature showed a negative association with detection rate ( $\beta = -0.172$ ; rate ratio =  
 342 0.84; 95% CI 0.72–0.99;  $p = 0.032$ ), indicating fewer detections as minimum temperature  
 343 increased.

344 The conditional  $R^2$  was 0.527, consistent with moderate variance explanation by the full model.  
 345 Random-effect standard deviations were larger for site (SD = 0.987) than for location (SD =  
 346 0.562), indicating greater heterogeneity at the site level.

347 *Diel activity*

348 Graphing demonstrated that Rakali peak activity occurred at the dusk period (between 16:41-  
349 18:32) leading into the night (Figure 5). From the hours of ~5:00-6:00 Rakali activity increased  
350 into the dawn period (5:54-7:53). A third stable peak of activity was evident during mid-  
351 morning (~9:00-11:00) before quickly subsiding into the afternoon. Various spikes of activity  
352 occurred during the night (~1:00 and ~3:00), however these were not as significant as the main  
353 peaks (Figure 5).



354

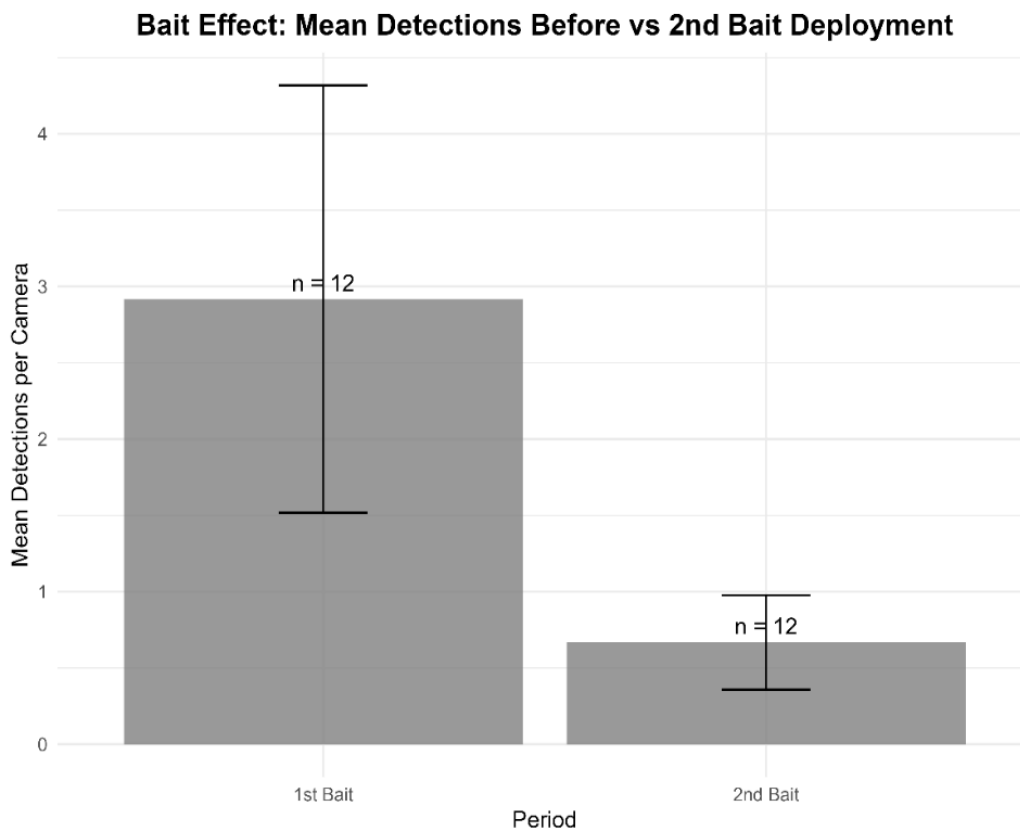
355 **Figure 5:** Proportion of Rakali detections plotted across times of day (on a 24hr timeline).  
356 Trendline indicates the pattern of detections, from dark blue (night), to purple (dawn/dusk),  
357 and yellow (daytime).

358 *Bait attractant patterns*

359 The potential impact of baiting period on Rakali detection was investigated using a Poisson  
360 GLMM with a log link and an offset for exposure modeled detections as a function of baiting  
361 period and location, with random intercepts for camera and site. The second baiting period was

362 associated with a substantially lower detection rate than the first ( $\beta = -1.476$ ; rate ratio = 0.23),  
363 consistent with a large reduction in activity; this contrast was highly significant ( $p = <0.001$ ;  $Z$   
364 = 3.77). Location coefficients were positive relative to Currency Creek (GOOLWA  $\beta = 0.262$ ;  
365 WATCH/FIN  $\beta = 1.135$ ), but inference on location effects is uncertain in this model. Random-  
366 effect standard deviations indicated pronounced heterogeneity among cameras ( $SD = 0.698$ )  
367 and negligible variation among sites ( $SD \approx 4.8 \times 10^{-5}$ ). Model fit statistics were  $AIC = 103.28$   
368 and  $BIC = 110.34$  ( $n = 24$ ; cameras = 12; sites = 8).

369 Observed counts aligned with the model; the first baiting period averaged 1.88 detections per  
370 camera ( $SE = 0.60$ ), whereas the second averaged 0.43 ( $SE = 0.19$ ; Figure 6). Four cameras  
371 increased between periods, eight decreased, and none were unchanged, resulting in a net mean  
372 change of  $-2.25$  detections (Appendix 4).



373

374 **Figure 6:** Mean Rakali detection rates per camera, across the first and second baiting period.  
375 Error bars display standard deviations for both baiting periods.

376 Site-specific patterns were pronounced; all detections at Goolwa Wharf and Finnis KLS  
377 occurred in the first period, with none in the second (Figure 7). Cameras showing increases in

378 the second period had small absolute changes (<3 detections), in contrast to a maximum decline  
 379 of 15 detections on camera F3 at Finnis KLS



380

381 **Figure 7:** Displays the variation in number of Rakali detections across the first and second  
 382 baiting periods for all sites and locations.

383 A Poisson GLMM with period  $\times$  location interaction and an offset for exposure improved fit  
 384 slightly by AIC (102.69 vs 103.28) but not by BIC (112.12 vs 110.34). Relative to Currency  
 385 Creek in the first period, detection rates were higher in the first period at Goolwa (rate ratio =  
 386 2.44) and WATCH/FIN (4.80). Period effects were location-specific: at Currency Creek the  
 387 second period showed no change (rate ratio  $\approx$  1.00), at Goolwa detections fell by  $\approx$ 94% (rate  
 388 ratio = 0.063), and at WATCH/FIN by  $\approx$ 71% (0.294). Back-transformed estimated rates per  
 389 camera-day were: Currency Creek first = 0.079, second = 0.079; Goolwa first = 0.194, second

390 = 0.012; WATCH/FIN first = 0.380, second = 0.112. Random intercept SDs indicated  
391 substantial camera-level heterogeneity (SD = 0.698) and negligible site-level variation (SD  $\approx$   
392 0.0006).

## 393 **Discussion**

394 The potential relationships between Rakali presence and detection rates across an urban to  
395 reserve gradient were investigated. The results found that while location and sites were not  
396 significant factors for Rakali presence, the likelihood of detection differed under environmental  
397 and baiting conditions. The findings suggest a degree of species' resilience to adverse weather  
398 conditions, and potential habituation to bait, particularly in areas of high recreational fishing  
399 activity. These findings are important for understanding how increased urban development and  
400 human disturbance may impact Rakali populations.

### 401 *Detection differences between location and sites*

402 The first objective was to understand how Rakali presence changed across an urban to reserve  
403 gradient. Results showed no significant effect of location or site on Rakali detection rate  
404 (location: location GOOLWA:  $z = 0.646$ ,  $p = 0.518$ ; location WATCH/FIN:  $z = 1.544$ ,  $p =$   
405  $0.123$ , site variance:  $\text{Var} \approx 4.2 \times 10^{-10}$ ). This finding indicates that Rakali are using a diverse  
406 range of freshwater habitats in the Goolwa region, from expansive, exposed river systems to  
407 sheltered creeks. Previous research has suggested potential Rakali habitat preferences (Sanders  
408 *et al.* 2025; Williams 2019), including proportion of ground-cover vegetation and percentage  
409 of canopy, attributing these preferences to the increased cover that vegetation provides from  
410 aerial predators (Sanders *et al.* 2025; Smart *et al.* 2011; Speldewinde *et al.* 2013). This study  
411 found no statistically significant differences in Rakali detection rate between locations, despite  
412 a high variety of different habitat variables presented between all three. Habitat variables were  
413 visually assessed rather than formally quantified in this study. Furthermore, given the small  
414 sample size ( $n=43$  detections), wide confidence intervals of locations (maximum and minimum  
415 CIs ranging between 95% CI 1.76 – 10.59 across locations), and high variance between  
416 cameras ( $SD= 0.73$ ), the non-significance observed may be inconclusiveness rather than no  
417 effect at all. Finer habitat-scale relationships may be present regarding Rakali occupancy across  
418 locations, that were not able to be exploited by the presence/absence data in this study. Future  
419 research should endeavour to use different metrics and models, such as n mixture models and  
420 habitat selection functions, to further understand Rakali presence and occupancy across varying  
421 habitats.

422 The lack of preferences by Rakali for areas that are distanced from anthropogenic disturbance  
423 and urban development is consistent with previous observations across other Australian states,  
424 where Rakali have been reported to exploit urban zones and artificial waterbodies for the  
425 anthropogenic food and shelter resources they provide (Gardner and Serena 1995; Williams  
426 2019). These results suggest that Rakali may be a habitat generalist, only needing basic habitat  
427 requirements to be met to persist in a variety in environments (Gardner and Serena 1995;  
428 Williams and Serena 2018; Williams 2019). Water permanence has been reported to be a major  
429 requirement of Rakali (Sanders *et al.* 2025; Smart *et al.* 2011; Speldewinde *et al.* 2013), which  
430 may be more consistently present in anthropogenic environments (like man-made waterbodies)  
431 than natural, unmanaged habitats subject to climatic impacts (Chester and Robson 2013;  
432 Halliday *et al.* 2015). The importance of urban areas as refuges for animals, including  
433 vulnerable and endangered mammals, has been demonstrated in literature (Bateman and  
434 Flemming 2012; Boakes *et al.* 2024; Gibbons *et al.* 2023). Small bodied animals that are  
435 flexible to anthropogenic disturbances have been able to benefit from the additional resources  
436 urban waterbodies provide (Gibbons *et al.*, 2023), such as increased food availability, increased  
437 connectivity of habitats, and reduced predation pressure and competition, which has been  
438 observed in multiple freshwater turtle species (*Chelodina longicollis*, *Chrysemys picta* and  
439 *Chelydra serpentina*) across Australia and America (Roe *et al.* 2011; Schnetler *et al.* 2020;  
440 Winchell and Gibb 2016). Supplementation of habitats using modified environments or urban  
441 refuges for species that are behaviourally flexible may be important for the assurance of  
442 population's survival (Boakes *et al.* 2024; Møller *et al.* 2012) and community composition  
443 (Chester and Robson 2013). Similar habitat flexibility demonstrated by Rakali may assist the  
444 species to persist even in highly modified and disturbed freshwater systems (Sanders *et al.*  
445 2025; Williams *et al.* 2019). As modification of habitat and human disturbance couldn't be  
446 quantified beyond location level assumptions in this study, future studies should develop  
447 appropriate proxies to further investigate how anthropogenic activity impacts Rakali  
448 distribution.

#### 449 *Diel patterns*

450 Rakali temporal activity was investigated during this study, with results demonstrating that  
451 Rakali detections peaked at dusk within the hours of 16:41-18:32. There was another peak of  
452 detections before dawn (~5:00-6:00), and again during the mid-morning. This pattern of  
453 activity is consistent with what is expected for Rakali, given their crepuscular behaviour  
454 (Gardner and Serena 1995; Watts and Aslin 1981; Williams 2019). Recent research has shown

455 that anthropogenic activity can negatively impact species in urban habitats (including their  
456 foraging patterns) (Etherington *et al.* 2022), due to factors such as light and noise pollution,  
457 and human disturbance emitted from urban zones that impact temporal activity patterns  
458 (Dowding *et al.* 2010; Tigas *et al.* 2002; Willems *et al.* 2022). The adoption of flexible feeding  
459 strategies in regard to temporal activity has been shown to assist scavengers in optimising their  
460 foraging in anthropogenic environments (Etherington *et al.* 2022). Considering the behavioural  
461 plasticity observed in this study, Rakali may be more likely to adjust their diel activity in  
462 relation to anthropogenic disturbance, as has been observed in other nocturnal and crepuscular  
463 species, such as European hedgehogs (*Erinaceus europaeus*) (Dowding *et al.* 2010) and  
464 carnivorous scavengers (*Felis rufus* and *Canis latrans*) (Tigas *et al.* 2002). Future research  
465 should investigate whether Rakali diel activity changes across urban gradients, focussing on  
466 how this may impact foraging success, exposure to predation, and diet composition.

#### 467 *Influence of environmental conditions*

468 The second objective was to investigate how Rakali detection is impacted by environmental  
469 conditions including weather. After investigating maximum daily temperature, minimum daily  
470 temperature, precipitation and wind speed (maximum gust), results demonstrated very little  
471 correlation between weather condition and Rakali detections. The only significant factor was  
472 minimum daily temperature. As minimum daily temperatures got cooler, Rakali detections  
473 increased. Previous research on the foraging strategies of another Australian semi-aquatic  
474 mammal; the Platypus (*Ornithorhynchus anatinu*), shows that during the winter months  
475 Platypus need to spend more time in the colder waters foraging due to a decreased proportion  
476 of prey items in the water (Easton *et al.* 2008; Otley *et al.* 2000). Rakali have demonstrated  
477 dietary flexibility during winter when typical food items are low (Sanders *et al.* 2024), but  
478 while Platypus are highly adapted to withstanding cold water temperatures, Rakali are less-so  
479 adapted due to the lack of a counter current retia vascular system that benefits the Platypus  
480 (Dawson and Fanning 1981). Thermal studies on Rakali have indicated that during the  
481 wintertime when foraging activity might be prolonged in adverse weather, they may use  
482 terrestrial burrows for re-warming between foraging efforts (Dawson and Fanning 1981;  
483 Gardner and Serena 1995). The requirement of Rakali to emerge from and re-enter a waterbody  
484 during extended foraging in winter may have increased the proportion of detections of Rakali  
485 during lower minimum daily temperatures as captured in this study.

486 The wide CIs observed across the modelling for environmental conditions (95% 0.72-1.18),  
487 coupled with a restricted number of cameras deployed per site may have resulted in an

488 insufficiency in results to confidently interpret the effects of other weather variables such as  
489 wind speed and precipitation on Rakali detections. The effects of rain and wind on Rakali  
490 activity is largely understudied, however existing papers report contradicting directions of  
491 effect (Sanders *et al.* 2025), and studies on Platypus report little effect of weather variables on  
492 activity levels (outside of extreme weather events) (Roberts and Serena 2025; Serena *et al.*  
493 2001). It must be acknowledged that these weather conditions may additionally impair the  
494 ability of cameras to detect target species (Sanders *et al.* 2025). This study was also restricted  
495 to sampling during the winter season, which has a limited temperature range from 4°C to  
496 23.7°C during the sampling period. Future research should investigate how Rakali foraging  
497 activity is affected by warmer conditions and greater temperature ranges across contrasting  
498 seasons. Given the increase in temperature fluctuations and intensity of summers in Australia  
499 due to climate change (Coleman *et al.* 2021; Dowdy *et al.* 2019; Klamt *et al.* 2011; Pittock *et*  
500 *al.* 2011), this may provide more understanding of how Rakali activity and distribution may  
501 change during climatic shifts and extreme weather events, as has already been initiated in  
502 Platypus studies (Bino *et al.* 2021; Coleman *et al.* 2021; Hawke *et al.* 2025; Klamt *et al.* 2011).  
503 Due to Rakali's genetic history being adapted to cool and moist environments, it may be that  
504 heat stress and drought is a more significant environmental factor for Rakali activity (Watts  
505 and Aslin 1981) than those of winter conditions. Multi-seasonal studies should be conducted  
506 to eliminate the assumption of anomalies from this limited sampling period, and observe  
507 patterns over a longer temporal scale.

### 508 *Bait efficacy and patterns in detection rate*

509 The third objective of this study sought to investigate how Rakali detections would differ in  
510 regard to the scent lures deployed across the urban gradient. Results demonstrated a high  
511 proportion of detections during the first week that bait was deployed, in comparison to  
512 significantly reduced detections in the second week. While baiting can be a successful strategy  
513 for gaining data on a wide range of animal groups (Hollinda *et al.* 2020; Randler *et al.* 2020),  
514 including elusive species (Mills *et al.* 2019), the success of baiting and scent lures can be  
515 impacted by factors such as the target species, baiting densities, prey availability, and duration  
516 of time that bait is left in the environment for (Balme *et al.* 2014; Fancourt *et al.* 2021; Fidino  
517 *et al.* 2020; Iannarilli *et al.* 2021). Reduced efficacy of baiting can also be due to habituation;  
518 the process of a decreased response over time (Parker *et al.* 2023; Parsons *et al.* 2017). Rodent  
519 species including house mice (*Mus musculus*) have demonstrated high habituation and rapid  
520 learning behaviours in relation to odours in experimental settings (Arbuckle *et al.* 2015;

521 Sundberg *et al.* 1982). The reduced visitations to the cameras due bait repeatedly being  
522 associated with no food-reward, may explain the reduced number of Rakali detections in the  
523 second week of baiting.

524 Results demonstrated that heterogeneity was high at the camera-level ( $SD = 0.698$ ) compared  
525 to the variation among sites ( $SD \approx 4.8 \times 10^{-5}$ ). While the deployment method of the cameras  
526 was recommended by previous research on Rakali (Sanders *et al.* 2024), it is acknowledged  
527 that inconsistencies in camera setups in the form of placement within study sites, and variation  
528 in the olfactory strength of scenting lures may be responsible for high variation at the camera-  
529 level. Formulating a rigid, standardised deployment procedure and site-selection for cameras,  
530 deploying more cameras per site, and across a longer temporal scale to accommodate more  
531 baiting periods ( $n=24$  investigated in this study) may reduce high camera-level variation and  
532 increase the validity of results.

533 Stronger patterns in detection rate per baiting period emerged at Goolwa Wharf and Finniss  
534 KLS. Both sites featured a peak in detections ( $n=15$ ) during the first baiting week, with no  
535 detections occurring during the second baiting week. These two sites are comparable by their  
536 high volume of recreational fishing activity, and subsequent discarded fish and bait that is often  
537 left at nearshore areas (Appendix 4). Discarded carrion such as leftover fishing materials has  
538 been observed to attract scavenging and opportunistic predators such as European Red Foxes  
539 (*Vulpes vulpes*) and the Dingo (*Canis lupus dingo*) (Déaux *et al.* 2016; Rees *et al.* 2014), and  
540 encourage adoption of these locations as key feeding sites (Bateman and Flemming 2012;  
541 Lowry *et al.* 2013). The repeated enticement of animals to sites of abundant alternate food  
542 resources increases habituation and decreases fear response to human disturbance (Bateman  
543 and Fleming 2012), resulting in scavengers to be more efficient and effective at scavenging in  
544 urban areas than rural locations (Patterson *et al.* 2023). Previous studies have also shown how  
545 rodents in urban areas can develop behavioural and personality traits that improve their  
546 capacity to adapt and benefit from urban foraging strategies, such as Urban common voles  
547 (*Microtus arvalis*) and Striped Field Mice (*Apodemus agrarius*). Both studies displayed higher  
548 degrees of boldness and exploration in urban rodents than in rural individuals (Dammhahn *et al.*  
549 *et al.* 2020; Mazza *et al.* 2020), and it was suggested that these behaviours assist in the  
550 exploitation of important resources in highly fragmented habitats (like urban environments)  
551 and increase habituation success (Dammhahn *et al.* 2020). The demonstration of these  
552 scavenging behaviours in anecdotal sightings of Rakali suggests that the species may be

553 flexible to foraging in urban areas, and less impacted by human disturbance than once  
554 anticipated (Atkinson *et al.* 2008; Williams 2019).

555 Adverse effects have also been observed in animals that forage in urban environments  
556 (Bateman and Flemming 2012; Lowry *et al.* 2013). While urban adapted animals are often  
557 highly attracted to forage in human refuse sites (including bins and landfills due to the easily  
558 accessible anthropogenic food sources they provide) (Bateman and Flemming 2012; Lowry *et al.*  
559 *et al.* 2013), foraging at human refuse sites can result in large quantities of non-food items to be  
560 ingested, potentially harming individuals (Bateman and Flemming *et al.* 2012; Jankowiak *et al.*  
561 *et al.* 2006; Murray *et al.* 2015; Streicher *et al.* 2022). For example, rubber, plastic, and food  
562 packaging have been found in the scats of small mammals like stone martens (*Martes foina*) in  
563 urban areas (Eskreys-Wójcik and Wierzbowska 2007). This has also been observed in the semi-  
564 aquatic water mongoose (*Atilax paludinosus*), where scat samples found closer to urban spaces  
565 contained higher proportions of anthropogenic materials than those in protected areas  
566 (Streicher *et al.* 2022). Not only do human supplemented food resources result in physiological  
567 nutritional issues, as has been identified in both carnivores and avian species (Bateman and  
568 Flemming *et al.* 2012; Murray *et al.* 2012; Murray *et al.* 2015; Chamberlain *et al.* 2009), but  
569 anthropogenic food resources can adversely impact behaviour, and have potential population  
570 and ecosystem-wide impacts (Bateman and Flemming 2012; Birnie-Gauvin *et al.* 2016;  
571 Crandall *et al.* 2024). The attraction from human food resources has been shown to constrict  
572 mammals' home ranges and dispersal distances (Crandall *et al.* 2024; Prange *et al.* 2004; Meade  
573 *et al.* 2021). This concentration of more individuals of a species in one location (such as around  
574 a designated key anthropogenic feeding site), increases competition and conflict with  
575 conspecifics, can facilitate the spread of disease, and reduce gene flow (Birnie-Gauvin *et al.*  
576 2016; Crandall *et al.* 2024; Prange *et al.* 2004). Rakali may be subject to similar threats from  
577 increased inhabitation and attraction to urban zones. The consumption of anthropogenic food  
578 resources could impact nutrition and health of Rakali that inhabit or exploit urban habitats.  
579 Furthermore, greater human-animal conflict and mortalities through means like poison control  
580 for pest rodent species, or entanglement/capture in fishing materials, (Williams and Serena  
581 2018; Williams 2019) may increase vulnerabilities of Rakali population in urban areas. Species  
582 conservation has begun targeting these threats, such as the banning of opera house traps in  
583 South Australia in 2023 to reduce native animal mortalities (Green Adelaide 2023), however  
584 literature indicates that the increased presence of animals (like Rakali) around urban areas can  
585 exacerbate existing negative perceptions and subsequent harmful actions of humans toward

586 species without appropriate public education or intervention such as community involvement  
587 (Ditchkoff *et al.* 2006; Moran 2025; Soulsbury and White 2016).

## 588 **Conclusions**

589 This study found that Rakali presence did not significantly differ at the location and site level,  
590 providing support that the species has a generalised set of habitat requirements. Environmental  
591 variables did not significantly impact detections, except for minimum daily temperatures which  
592 may have been influenced by the species' foraging strategy during winter. Rakali presence did  
593 differ between baiting periods, and patterns emerged indicating potential behavioural  
594 differences among locations with concentrated anthropogenic food resources. Findings from  
595 this study provide base-line data for Rakali populations and presence on the Fleurieu peninsula,  
596 however more population assessments across South Australia are necessary, particularly across  
597 urban gradients of varying composition and intensity. Further understanding into potential  
598 complex relationships between urban disturbance and Rakali presence is important for effective  
599 conservation and management. Investigation of Rakali presence and behaviour across varying  
600 habitats will have significant impacts for broader freshwater ecosystem management.

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612 **Author statements**

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639 [edition-3/jul2021-jun2026/significant-urban-areas-urban-centres-and-localities-section-state](https://www.abs.gov.au/statistics/standards/australian-statistical-geography-standard-asgs-edition-3/jul2021-jun2026/significant-urban-areas-urban-centres-and-localities-section-state).

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## 936 **Appendix 1: Live Trapping Methodology and Outcomes**

937 Due to time constraints, I could not complete work on live trapping as originally planned in my  
938 Honours Research Proposal. While we began live trapping work during 2025, the sampling  
939 effort and size did not provide sufficient data for analysis and discussion in this thesis  
940 manuscript. However for clarity, below is the relevant methodology used for live trapping, and  
941 results from the sampling undertaken.

### 942 **Methods**

943 Considering the lack of information on Rakali's general biology, and the difficulty for camera  
944 traps to determine factors including sex and age of individuals, live trapping was conducted to  
945 supplement camera trap data. Live trapping was conducted during August and September of  
946 2025. In August, live trapping involved putting animals under anaesthesia for biological  
947 sampling ('anaesthesia protocols'). However, due to an Unexpected Adverse Event, sampling  
948 for September was restricted to weighing and bodily measurements ('capture and weigh  
949 protocols'). Each study site was sampled twice across two separate surveys in August (4<sup>th</sup> to  
950 the 8<sup>th</sup>) and September (8<sup>th</sup> to the 11<sup>th</sup>) 2025, consisting of 9 trapping nights overall. n=9 traps  
951 were deployed across each location, with two nights of surveying effort per site.

952 While Rakali peak season is estimated to be during the spring and summer months, the species  
953 is still reportedly active in the cooler winter months (Atkinson *et al.* 2008; Leigh and Breed  
954 2020). For live trapping nights, we set constraints for surveying in calm conditions, not  
955 subceeding  $\leq 5^{\circ}\text{C}$  air temperature or exceeding 35 km/h wind speeds to prioritise animal welfare  
956 and minimise the probability that weather conditions would reduce Rakali capture rates. Live  
957 trapping surveys were conducted using 66cm (L) x 23cm (W) x 25cm (H) metal possum traps  
958 (SKU: POM519; NSW, Australia) baited with sardines, that were secured alongside the water's  
959 edge with metal pegs. Site selection was aligned to positions where Rakali had already been  
960 observed via previous camera trap observations. A calico bag as well as vegetation from the  
961 surrounding area were placed over the top of each trap, for camouflage and to reduce exposure  
962 of captured Rakali to the open environment (Figure 1).



963 **Figure 1:** Wire traps deployed in the field. Calico bag is draped over the top, and covered in  
964 surrounding vegetation for camouflage. Traps were pegged into the ground to secure them, and  
965 baited with sardines.

966 Traps were deployed at sites for ~7 hours each night (from approximately 5pm until midnight)  
967 and were checked every 1-2 hours for Rakali captures. This timing was set in place to uphold  
968 ethical considerations for trapped animals, while minimising trap disturbance that may affect  
969 Rakali capture rates. The time period (5pm until midnight) for trapping was selected due to  
970 preliminary findings from camera traps identifying Rakali activity peaking between dusk and  
971 nighttime.

972 For 'anaesthesia protocols', Rakali were transferred from metal cage to a calico bag, and  
973 transported to a set-up processing station (Figure 2), and if healthy, underwent a set of  
974 procedures while anaesthetised. Isoflurane was used to anaesthetise animals at a 3% Isoflurane  
975 concentration and 4L oxygen flow rate (gradually decreasing to a 2% Isoflurane concentration  
976 after a few minutes). These procedures included a body condition assessment (weight, health,  
977 sex, age), blood sampling, cheek pouch and anal swabbing, fur clipping and PIT tag insertion.  
978 Animals recovered before for a minimum of an hour before being released at their point of  
979 capture. Once the first live trapping survey was completed, animals were scanned for their  
980 identification chip prior to anaesthesia and processing to identify recaptures. The sample size  
981 is currently unknown, due to a lack of literature to predict the population numbers in the  
982 Goolwa region.



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984 **Figure 2:** Live trapping setup at Investigator College Currency Creek, featuring Field  
985 Anaesthesia Machine, and relevant equipment for retrieving biological Rakali samples.

986 For ‘capture and weigh protocols’, Rakali were transferred from metal traps into a calico bag  
987 and weighed using an electronic scale to the nearest gram. Rakali were then manoeuvred within  
988 the bag to expose the tail for measurement. The measurement of the full tail and white tipped  
989 posterior end along with the total body measurement (snout to vent) was recorded using a  
990 flexible measuring tape. After Rakali were processed, they were released back to the  
991 environment at their point of capture.

992 For all live trapping, relevant metadata including time of capture and weather metadata were  
993 recorded.

## 994 **Results**

995 Live trapping sampling was conducted twice during 2025, from the 4<sup>th</sup> to the 8<sup>th</sup> of August, and  
996 from the 8<sup>th</sup> to the 11<sup>th</sup> of September 2025, totalling to n=9 trapping nights. Across 9 trapping  
997 nights, a total of n=8 Rakali were captured across 6/8 of the sites sampled (Rakali were caught  
998 at least once across all study locations). Most locations only obtained n=1 Rakali per trapping  
999 night, however Goolwa Wharf obtained n=2 Rakali on the 5/8/25, and on the 10/9/25 n=2  
1000 Rakali were retrieved across the Goolwa locations.

1001 While traps were laid after 17:00 for most sampling nights, Rakali captures did not begin until  
1002 19:00. Most Rakali captures occurred from 22:00-00:00 (n=5 individuals). Four Rakali were  
1003 captured and put under anaesthesia to undergo biological sampling. Rakali ‘G4’ became an  
1004 Unexpected Adverse Event through mortality whilst under anaesthesia, which restricted  
1005 sampling for G5, G6, G7, and G8 to be restricted to capturing, observations/photographs,  
1006 weighing and bodily measurements. Approximate sex and age were ascertained for Rakali G1-  
1007 G4, which constituted of n=3 adults and n=1 juvenile Rakali (denoted in age categories by  
1008 body size and weight), n=3 of which were assumed males (through observable dropped or  
1009 palpable testes), and n=1 female (confirmed during postmortem examination). Weights of  
1010 captured Rakali ranged from 0.45kg to 1kg, with the smallest being an assumed juvenile male  
1011 and largest being an adult male (visible dropped testes) (Figure 3).

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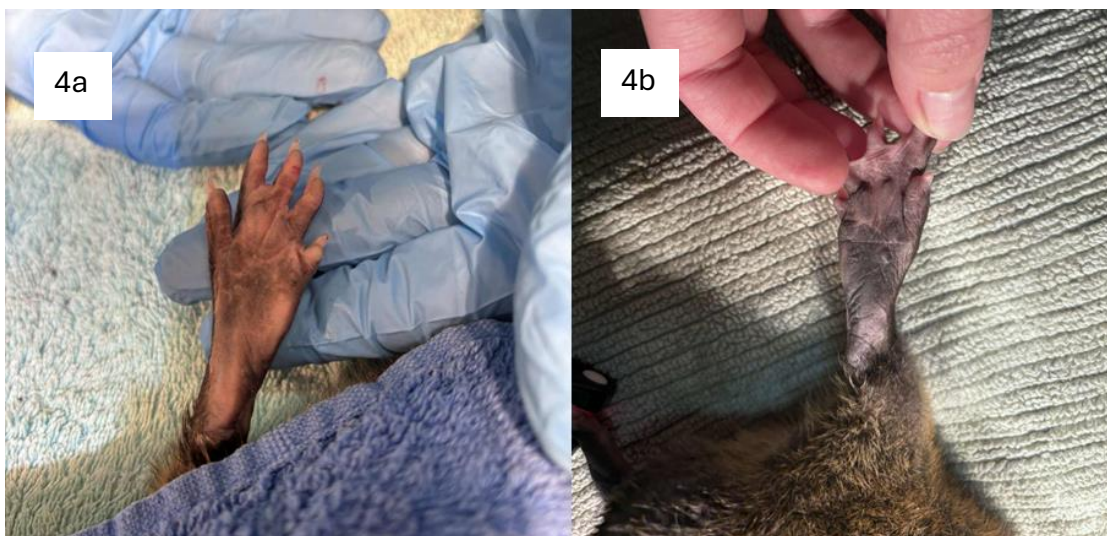
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1015 **Figure 3:** Rakali G1 with observable dropped testes, indicating male sex status. Smaller Rakali  
1016 with no observable testes were palpated to assess sex status.

1017 Toe webbing was expected on animals due to previous findings (Atkinson *et al.*2008; Watts  
1018 and Aslin 1998; Williams 2019), however the first Rakali caught (G1) did not have observable  
1019 toe webbing present on hind feet (Figure 4a). During subsequent sampling efforts, presence of  
1020 toe webbing was recorded to verify or refute previous findings. While this sample size is very  
1021 limited, toe webbing did often appear on the smaller (potentially younger) Rakali (G2 and G4)  
1022 of the sampling group, compared to little-no toe webbing on larger (adult) Rakali (Figure 4b).



1023 **Figure 4:** Shows differences between proportion/presence of toe webbing on hind feet of  
1024 Rakali. Left image (4a) shows hind foot of Rakali G1, with no observable toe webbing. Right  
1025 image (4b) shows hind foot of Rakali G2, with a high proportion of toe webbing present.

1026 Large male Rakali (G1 and G3) had observable minor injuries to their tails, presumed to be a  
1027 result of intrasexual aggression between males as has been described in literature (Watts and  
1028 Aslin 1998; Sanders *et al.* 2024). However, two Rakali (G4 and G7) had major tail injuries,  
1029 dissimilar to the minor injuries on the males. They appeared to be aged, and necropsied tissue  
1030 indicated a form of previous infection. One of these Rakali (G4), died whilst under anaesthesia,  
1031 although postmortem testing did not confirm whether this was associated with the tail injury,  
1032 or instead attributed to other physiological factors.



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044 **Table 1:** Total Rakali captures across location and site during sampling period. Columns also described weather conditions on capture days, including  
 045 Minimum and maximum daily temperature, precipitation levels and wind speed (maximum gust), as derived from Hindmarsh Island Weather Station Records  
 046 from the Bureau of Metereology website (<https://www.bom.gov.au/climate/data/>)

LOCATION	SITE	DATE	RAKALI COUNT	MIN DAILY TEMP	MAX DAILY TEMP	PRECIPITATION	WIND SPD (MAX GUST)
GOOLWA	WHARF	5/08/2025	2	9.8	15.8	0.4	57
CURRENCY CREEK	LIONS PARK	6/08/2025	1	11.3	15.4	0.8	33
FIN/WATCH	FINNISS KAYAK LAUNCH	7/08/2025	1	6.5	14.3	0	31
FIN/WATCH	WNR	7/08/2025	1	6.5	14.3	0	31
GOOLWA	CLLMM	8/08/2025	1	5.1	13.2	0	31
GOOLWA	CLLMM	10/09/2025	1	10.9	15.1	0.6	52
GOOLWA	LIVERPOOL RD	10/09/2025	1	10.9	15.1	0.6	52

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048 **Table 2:** Individual Rakali captures and relevant variables (including location caught, time caught, sex and age estimates, weight and bodily measurements (S=  
 049 snout, V= vent, T= tail), presence of toe webbing, estimated body condition, details for PIT tagging and additional notes).

ID	DATE	LOCATION	TIME	SEX	AGE	WEIGHT	LENGTH (S-V)	LENGTH (S-T)	LENGTH (T)	LENGTH (WT)	TOE WEB	BODY CONDITION	TAG ID	NOTES
G1	5/08/2025	Goolwa Wharf	20:00	M	Adult	1kg	330	655	325	35	N	Skinny	953010100145724	Testes dropped
G2	5/08/2025	Goolwa Wharf	23:00	M	Juvenile	0.45 kg	225	435	210		Y	Skinny	953010100079816	Tag ejected Testes not dropped
G3	6/08/2025	Lion's Park	23:30	M	Adult	0.87 kg	295	540	245	38	N	Good	953010100050430	N/A
G4	7/08/2025	Finniss Kayak Launch site	19:00	F	Adult	0.59 kg	285	535	350	50	Y	Wound on tail, good body condition	Not tagged	Deceased, postmortem necropsy performed
G5	7/08/2025	Watchalunga NR	19:00	N/A	N/A	0.48 kg	N/A	N/A	N/A	N/A	N/A	N/A	Not tagged	Released without processing

G6	8/08/2025	Goolwa CLLMM	22:40	N/A	N/A	0.91kg	N/A	N/A	273	65	N/A	N/A	Not tagged	Weighed, measured, released. No observa testes	1050 1051
G7	10/09/2025	Goolwa CLLMM	23:03	N/A	N/A	0.71 kg	330	620	255	47	Y	Wound on tail, good body condition	Not scanned	Weighed, measured, released	1052
G8	10/09/2025	Goolwa Liverpool Rd	12:45	N/A	N/A	0.84 kg	337	615	278	66	Y	N/A	PIT scan negative	Weighed, measured, released	1053 1054

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1068 **Appendix 2: Additional Illustrations for Methodology**



1069 **Figure 3:** Described camera deployment setup in the field.



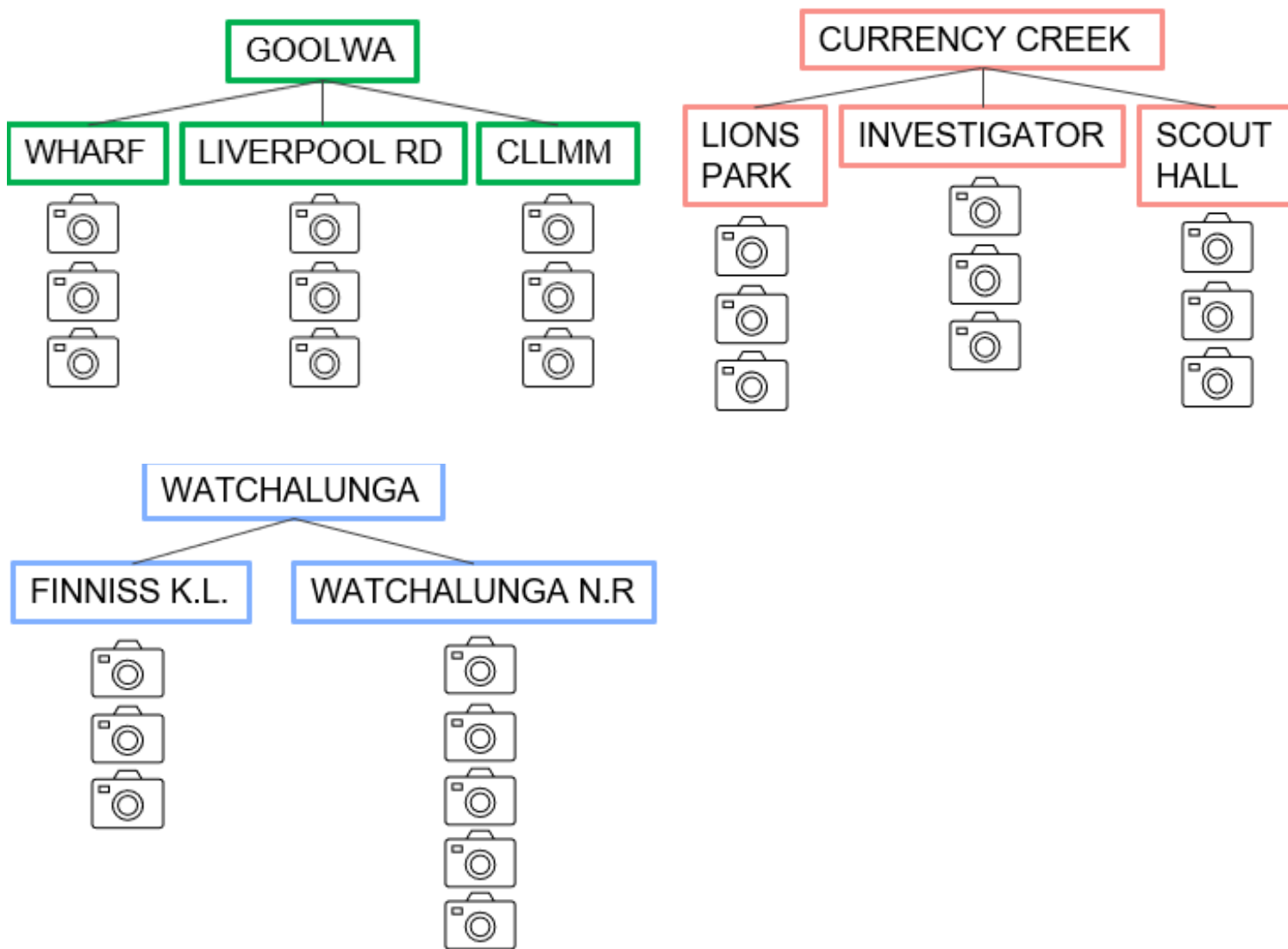
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1071 **Figure 4:** Discarded carrion left by recreational fishermen at Finnis Kayak Launchsite.

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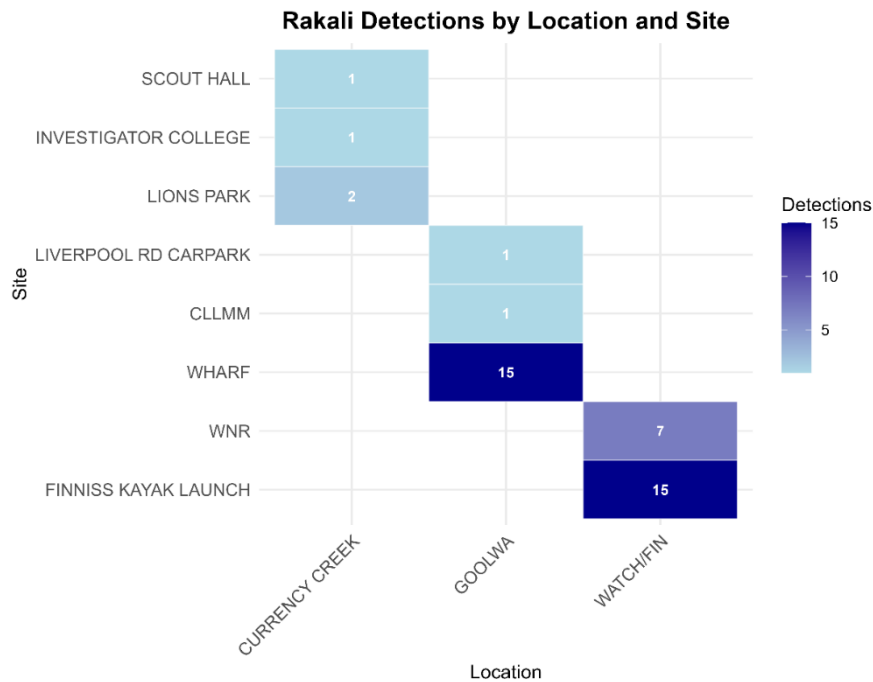
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1086 **Figure 5:** Flow charts for camera deployment across sites within locations.

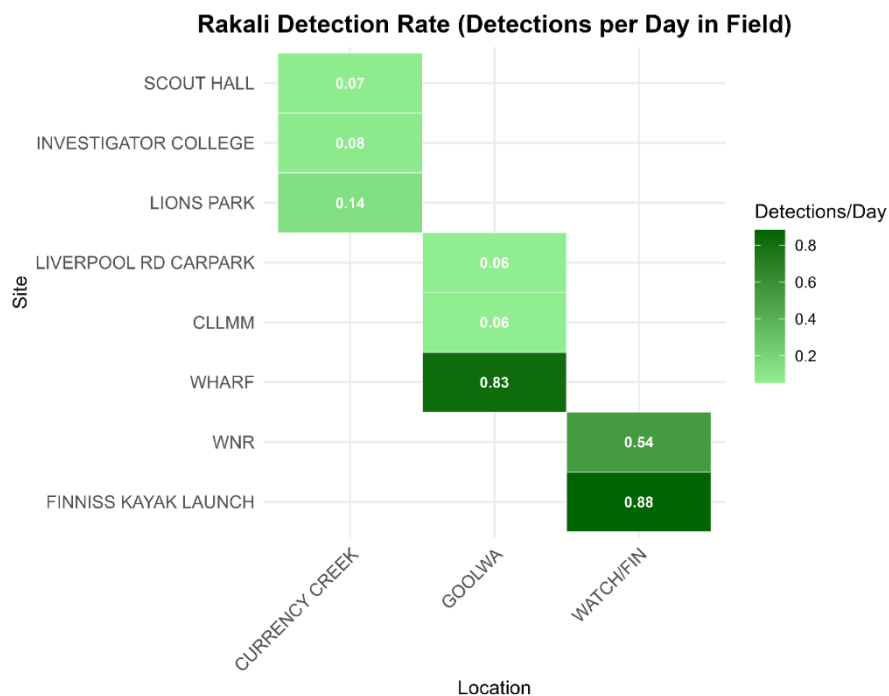
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1089 **Appendix 4: Additional Figures and Tables**

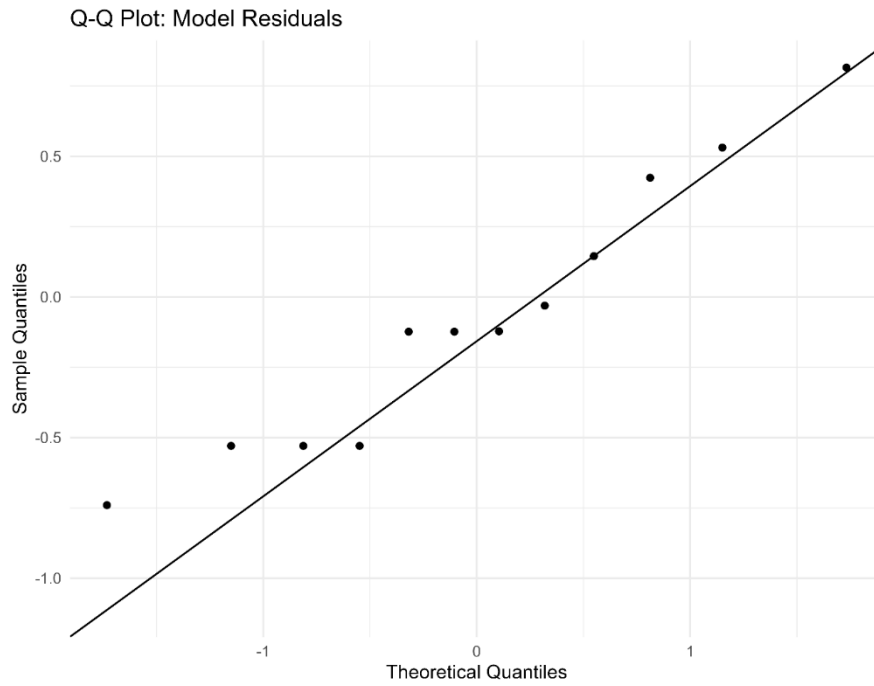


1090 **Figure 6:** Standardised heatmap of Rakali camera detections across location and sites. Darker  
 1091 blue corresponds to a higher number of detections, while lighter blue corresponds to less  
 1092 detections.



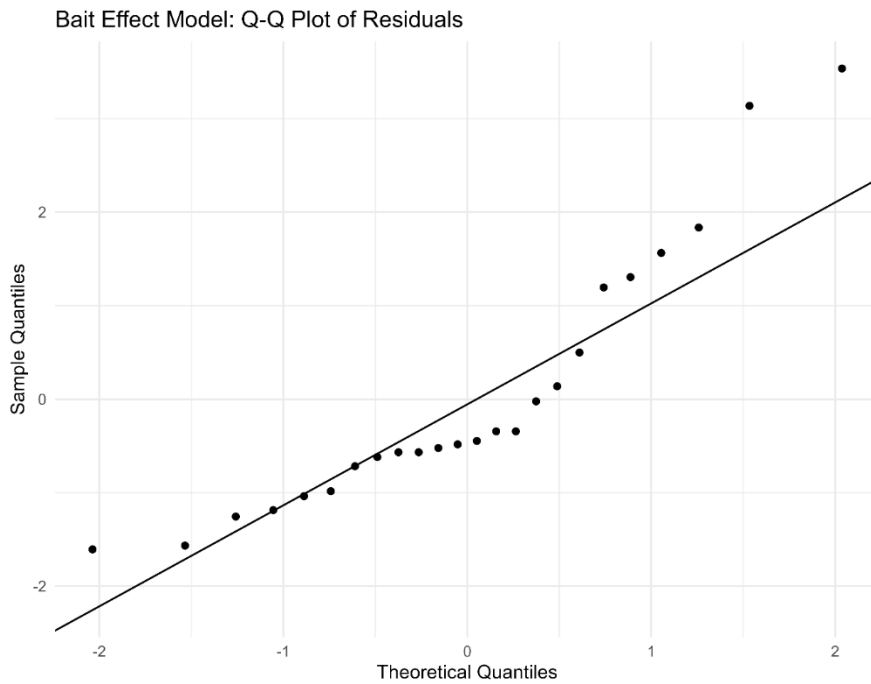
1093 **Figure 7:** Standardised heatmap of Rakali detection rate by sampling effort (days cameras  
 1094 were deployed in the field) across sites and locations. Darker green indicates a high rate of  
 1095 detections per deployment day, while light green indicates a smaller detection rate per  
 1096 deployment day.

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1099 **Figure 8:** Q–Q plot of Rakali detections against theoretical quantities. Data points loosely  
 1100 fall along the linear line indicating a normal distribution.



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1104 **Figure 9:** Q–Q plot for the bait effect model. Data points show a loose inverted-S curve  
 1105 indicating potential leptokurtic distribution.

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1108 **Table 3:** Total Rakali detections across location and sites.

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location	site	camera_code	total_detections	total_days_in_field	log_days
CURRENCY CREEK	INVESTIGATOR COLLEGE	CI1	1	13	2.564949
CURRENCY CREEK	LIONS PARK	CL3	2	14	2.639057
CURRENCY CREEK	SCOUT HALL	GC1	1	15	2.70805
GOOLWA	CLLMM	GC2	1	18	2.890372
GOOLWA	LIVERPOOL RD CARPARK	GL1	1	18	2.890372
GOOLWA	WHARF	GW2	3	18	2.890372
GOOLWA	WHARF	GW3	11	18	2.890372
GOOLWA	WHARF	HYPERFIRE 2 COVERT	1	18	2.890372
WATCH/FIN	FINNISS KAYAK LAUNCH	F3	15	17	2.833213
WATCH/FIN	WNR	W1	3	13	2.564949
WATCH/FIN	WNR	W3	1	13	2.564949
WATCH/FIN	WNR	W5	3	13	2.564949

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**Table 4:** Rakali camera detections in regards to baiting period (1<sup>st</sup> and 2<sup>nd</sup> bait) with offset variables (exposure days and log exposure) as used for modelling.

location	site	camera_code	period	detections	exposure_days	log_exposure
CURRENCY CREEK	INVESTIGATOR COLLEGE	CI1	1st Bait	1	7	1.945910149
CURRENCY CREEK	INVESTIGATOR COLLEGE	CI1	2nd Bait	0	7	1.945910149
CURRENCY CREEK	LIONS PARK	CL3	1st Bait	0	6	1.791759469
CURRENCY CREEK	LIONS PARK	CL3	2nd Bait	2	6	1.791759469
CURRENCY CREEK	SCOUT HALL	GC1	1st Bait	1	9	2.197224577
CURRENCY CREEK	SCOUT HALL	GC1	2nd Bait	0	9	2.197224577
GOOLWA	CLLMM	GC2	1st Bait	1	12	2.48490665
GOOLWA	CLLMM	GC2	2nd Bait	0	12	2.48490665
GOOLWA	LIVERPOOL RD CARPARK	GL1	1st Bait	0	12	2.48490665
GOOLWA	LIVERPOOL RD CARPARK	GL1	2nd Bait	1	12	2.48490665
GOOLWA	WHARF	GW2	1st Bait	3	12	2.48490665
GOOLWA	WHARF	GW2	2nd Bait	0	12	2.48490665
GOOLWA	WHARF	GW3	1st Bait	11	12	2.48490665
GOOLWA	WHARF	GW3	2nd Bait	0	12	2.48490665
GOOLWA	WHARF	HYPERFIRE 2 COVERT	1st Bait	1	12	2.48490665
GOOLWA	WHARF	HYPERFIRE 2 COVERT	2nd Bait	0	12	2.48490665
WATCH/FIN	FINNISS KAYAK LAUNCH	F3	1st Bait	15	11	2.397895273
WATCH/FIN	FINNISS KAYAK LAUNCH	F3	2nd Bait	0	11	2.397895273
WATCH/FIN	WNR	W1	1st Bait	1	7	1.945910149
WATCH/FIN	WNR	W1	2nd Bait	2	7	1.945910149
WATCH/FIN	WNR	W3	1st Bait	1	7	1.945910149
WATCH/FIN	WNR	W3	2nd Bait	0	7	1.945910149

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WATCH/FIN	WNR	W5	1st Bait	0	7	1.945910149
WATCH/FIN	WNR	W5	2nd Bait	3	7	1.945910149

- 1129 **Appendix 5: Relevant ChatGPT (AI) links to outputs**
- 1130
- 1131 Statistical Methods in Research
- 1132 <https://chatgpt.com/share/69156460-3874-800d-98d3-5d568dee8ab7>
- 1133 Thesis Wordcount Breakdown
- 1134 <https://chatgpt.com/share/691564fb-c23c-800d-a242-717fb821d0b4>
- 1135 Code Explanation for Mapping
- 1136 <https://chatgpt.com/share/6915661d-d9f0-800d-a770-aaaac38ad148>
- 1137 Customising Coordinate Labels
- 1138 <https://chatgpt.com/share/69156659-2510-800d-8756-4363652c8c25>
- 1139 Graph Creation Guide
- 1140 <https://chatgpt.com/share/69156696-c884-800d-b3a2-df532d9c66ae>
- 1141 Interpreting Statistical Outputs
- 1142 <https://chatgpt.com/share/691566e0-b360-800d-b6b2-9fea78bf43b2>
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## 1155 **Appendix 6: Author guidelines for Australian Mammalogy**

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### 1157 **Author instructions**

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1202 Example author list

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1204 <sup>A</sup>Department name, University name, City, State, Country.

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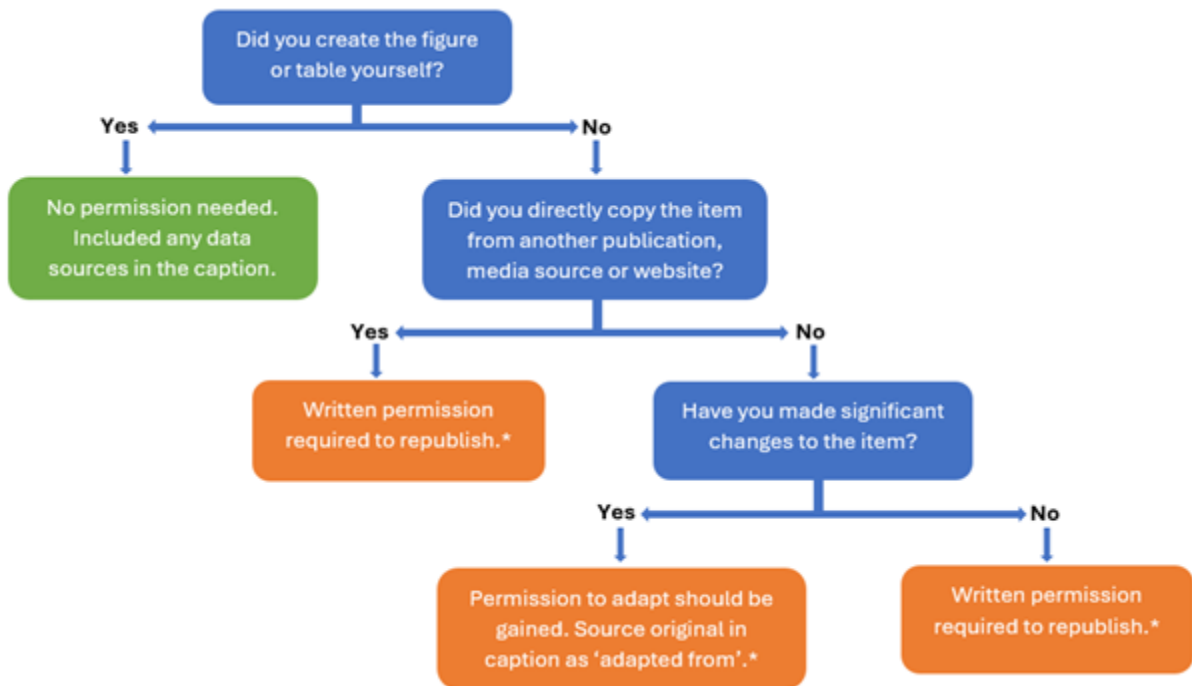
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1285

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## 1323 **Enzymes**

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1329 Nomenclature. Other biologically active compounds (metabolic inhibitors, plant growth  
1330 regulators, buffers, etc.) should be referred to once by their correct chemical name (in  
1331 accordance with IUPAC rules of Chemical Nomenclature) and then by their most widely  
1332 accepted common name.

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1335 in Nomenclature (LPSN) available from DSMZ. Fungal nomenclature should conform to the  
1336 'International Code of Nomenclature for Algae, Fungi, and Plants' (Chapter F of the Shenzhen  
1337 code). The names used for viruses should be those approved by the International Committee  
1338 on Taxonomy of Viruses (ICTV).

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1402 *Information Act 1982* (Cth) (FOI Act)).

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1404 language in square brackets at the end of the reference (e.g. Wang JX, Kong FZ, Chen  
1405 ZF, *et al.* (2019) Characterization of pigment composition of six strains  
1406 of *Phaeocystis globosa*. *Oceanologia et Limnologia Sinica* **3**, 611–620 [In Chinese  
1407 with English title and abstract].)

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1471 **Appendix 7: STEM 7001 Literature Review**

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1473 **Behavioural responses of freshwater semi-**  
1474 **aquatic mammals to anthropogenic pressures:**  
1475 **a review**

1476

1477

1478

1479 Hannah Mckennall | 2276172

1480 Primary supervisor: Dr Ryan Baring

1481 Word count: 3452

1482

1483 I acknowledge the use of ChatGPT in the early stages of understanding how to  
1484 structure/prepare a literature review, including brainstorming my search terms, what  
1485 data to extract, and the steps to take. None of this literature review was written by AI, it  
1486 was solely used during the preparation of my screening sample. The prompts and  
1487 outputs from ChatGPT are included in Appendices F.

1488

1489 **Abstract**

1490 This systematic literature review aims to collate and synthesise the current body of  
1491 literature in the field of freshwater semi-aquatic mammalian behavioural responses to  
1492 anthropogenic pressures. A total of 45 papers, published between 1998 and 2025 were  
1493 thoroughly screened, and relevant data was extracted to analyse patterns of vulnerability  
1494 between biogeographical regions, taxa, and behavioural response (response type and  
1495 nature). The key findings identified that there are significant gaps in freshwater semi-  
1496 aquatic mammal research, alarmingly within regions experiencing disproportionate  
1497 severity of anthropogenic pressures, and for taxa that are understudied and ecologically  
1498 significant. Furthermore, anthropogenic pressures largely elicit avoidant responses from  
1499 wildlife, which may have significant impacts on fitness and survival. Future research is  
1500 recommended to further investigate traits that allow for behavioural plasticity to  
1501 anthropogenic impacts, and what adverse effects semi-aquatic mammal inhabitants of  
1502 urban areas may be experiencing. Practical management should seek to continue and

1503 initiate monitoring programs for vulnerable species, particularly those in high impact  
1504 environments (such as urban landscapes). This study presents the first review in  
1505 literature to investigate the effects of various anthropogenic pressures on behavioural  
1506 responses of freshwater semi-aquatic mammals globally.

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## 1511 Introduction

1512 Freshwater ecosystems are speciose and highly diverse, supporting one third of the  
1513 world's vertebrate species (Strayer & Dudgeon, 2010). However, freshwater habitats and  
1514 their biodiversity are among the most threatened ecosystems in the Anthropocene era  
1515 (Reid et al., 2019). Due to the rapid increase in anthropogenic pressures, such as habitat  
1516 degradation, anthropogenic landscape modification, and increased resource  
1517 consumption to maintain rising population numbers, (Reid et al., 2019; Torres-Romero et  
1518 al., 2024) freshwater ecosystems are becoming unsustainably overconsumed and  
1519 seriously damaged (Reid et al., 2019). Since 1980, there has been an 83% decrease of all  
1520 freshwater vertebrates (Dudgeon et al., 2006). Freshwater taxa, primarily freshwater  
1521 semi-aquatic mammals, have been described as disproportionately threatened  
1522 compared to marine and terrestrial taxa (Reid et al., 2024) as they traverse both terrestrial  
1523 and aquatic environments, where anthropogenic pressures across both ecosystems  
1524 places these animals in a position of extreme vulnerability (Torres-Romero et al., 2024).

### 1525 *Semi-aquatic mammals in anthropic environments*

1526 Semi-aquatic mammals are impacted by direct and indirect anthropogenic stressors,  
1527 which vary in severity (Reid et al., 2019). Direct harassment by humans (e.g. touching or  
1528 feeding of wildlife by the public, or interactions with domestic pets), wildlife-human  
1529 conflict (e.g. human retaliation to animal-caused damage to agricultural crops), and the  
1530 general presence of humans in habitats can elicit unfavourable effects on mammal  
1531 fitness (Wilson et al., 2020). However, the broader, indirect impacts of anthropogenic  
1532 activity can be most severe. For example, landscape modification of natural regions into  
1533 agricultural land, industrial, or urban areas displaces species from their preferred or  
1534 optimal habitats, impacting their capacity to meet numerous functional aspects of their  
1535 biology and ecology, and ultimately drives extinction rates (Torres-Romero et al., 2024).  
1536 Furthermore, the indirect flow on effects of land use change facilitates pollution, runoff  
1537 and discharge to enter ecosystems, increasing the anthropogenic load in existing  
1538 waterways (Reid et al., 2019). A more recent phenomena includes microplastics in  
1539 freshwater and sediments that are being detected in the stomach contents and faeces of

1540 native animals, which increases mortality rates of already threatened species (Ried et al.,  
1541 2019). Studies show how these threats are highly concentrated in urban areas, like cities  
1542 (Johnson & Munshi-South, 2017) and considering the high density of people in urban  
1543 landscapes, anthropogenic pressure via direct interactions with wildlife also increases  
1544 (Abdenurm, Cavia, & Corriale, 2025; Ciach, Wrazidło & Fedyń, 2023). While some mammal  
1545 species display a degree of plasticity to these pressures, this does not always equate to  
1546 increases in their fitness. Often increased inhabitation of urban landscapes reduces  
1547 fitness by constraining gene flow and reducing genetic diversity (Johnson & Munshi-  
1548 South, 2017). The genetic constraints can lead to native mammal populations being more  
1549 vulnerable to other extinction drivers (Johnson & Munshi-South, 2017).

#### 1550 *Current scope of literature*

1551 Currently, there are no literature reviews in the peer-reviewed scientific literature that  
1552 have investigated behavioural responses of freshwater semi-aquatic mammals in  
1553 relation to anthropogenic pressures. While there are scientific journal papers available,  
1554 when searching databases for broad terms including ‘freshwater’, ‘urbanisation’,  
1555 ‘response’, it was apparent that the majority of literature can be classified into one of the  
1556 following two categories. Studies on urbanisation of freshwater ecosystems either  
1557 focussed on (1) the responses of invertebrate or non-mammalian taxa to anthropogenic  
1558 pressures, or (2) research investigated biological or physiological impacts of  
1559 anthropogenic pressures (e.g. epidemiological impacts, mortality rates, or  
1560 bioaccumulation) to animals.

#### 1561 *Importance of behavioural understanding*

1562 While this research is highly beneficial, a gap in the behavioural understanding remains.  
1563 The behavioural ecology of animals is not just limited to the individuals of a particular  
1564 species, but how their role in their environments has broader implications for ecosystem  
1565 functioning and community composition (Wilson et al., 2020). For example, many  
1566 mammals or large vertebrates act as top predators in their food webs (Lacher et al.,  
1567 2019). They are responsible for the balance of complex trophic systems, that support a  
1568 myriad of different species (Lacher et al., 2019). Furthermore, mammals can act as  
1569 ecosystem indicators, particularly if they are highly sensitive anthropogenic stressors  
1570 that could be severely affecting their ecosystem (Schneider, 2010). Therefore,  
1571 understanding semi-aquatic mammalian behaviour in highly threatened ecosystems like  
1572 freshwater habitats is essential for the monitoring, management, and conservation of  
1573 many species.

#### 1574 *Review aims*

1575 This systematic review aims to: 1) understand and collate the current body of evidence  
1576 regarding the relationship of aquatic or semi-aquatic mammals in freshwater habitats; 2)  
1577 identify the taxa and geographical regions that may be most vulnerable to anthropogenic

1578 pressures and; 3) identify the patterns of anthropogenic stressors to aquatic and semi-  
 1579 aquatic freshwater mammals (i.e. severity and frequency of stressors and the nature of  
 1580 elicited response by mammals). Assessing the global literature to identify the most  
 1581 vulnerable semi-aquatic freshwater mammal taxa and the anthropogenic stressor risk to  
 1582 those animals will provide a good basis for identifying future management priorities of  
 1583 freshwater taxa during this Anthropocene era.

1584 **Methods**

1585 A systematic literature review approach was used to establish what research has already  
 1586 been conducted, patterns across the literature, and where knowledge gaps may need  
 1587 further investigation in this field. For this study, a three-step approach was used; 1) Initial  
 1588 preparation for research and database searching; 2) first screening of literature using  
 1589 database searches of key search terms and; 3) secondary screening of abstracts  
 1590 identified as potential literature sources based on key search terms.

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1603 *Categorisation of variables for results*

1604 Behavioural responses of semi-aquatic freshwater mammals varied significantly,  
 1605 resulting in approximately 16 different variables among the literature. To make results  
 1606 more easily comparable, behavioural responses were categorised into groups with  
 1607 similar terms. The four categories created were: ‘Spatial patterns’, ‘Habitat use &  
 1608 preference’, ‘Dietary’, and ‘Activity budget & patterns’. The categories and their  
 1609 descriptions are available in Appendix D.



- Preliminary search across Google Scholar, Scopus & Web of Science.
- Multiple combinations of relevant terms (e.g. freshwater, semi-aquatic, mammal, response, behaviour, anthropogenic, urbanisation).
- RQ: *How are semi-aquatic mammals responding behaviourally to increased anthropogenic pressure?*
- Review scope narrowed to be realistic and relevant
- Boolean search string developed (appendix A)



- Rigid eligibility criteria developed (Appendix B)
- Title and abstract screening (using RQ and eligibility criteria to assess relevance)
- 57 papers remained for secondary screening



- Full text screening of paper
  - Apply same eligibility criteria and extracting relevant data for the review (Appendix B)
  - 45 papers remained for formal review (appendix E).
- \*Categories/terms developed post data extraction to make comparisons among literature more effective (Appendix D)\*

1610 To greater quantify the impact of anthropogenic pressures on semi-aquatic freshwater  
1611 mammals, behavioural responses were classified by the nature of response. The terms  
1612 ‘avoidant’, ‘neutral’, ‘attractive’ and ‘mixed’ were used generated to describe the  
1613 different nature of the behavioural responses. The descriptions of these terms is  
1614 available in appendices D.

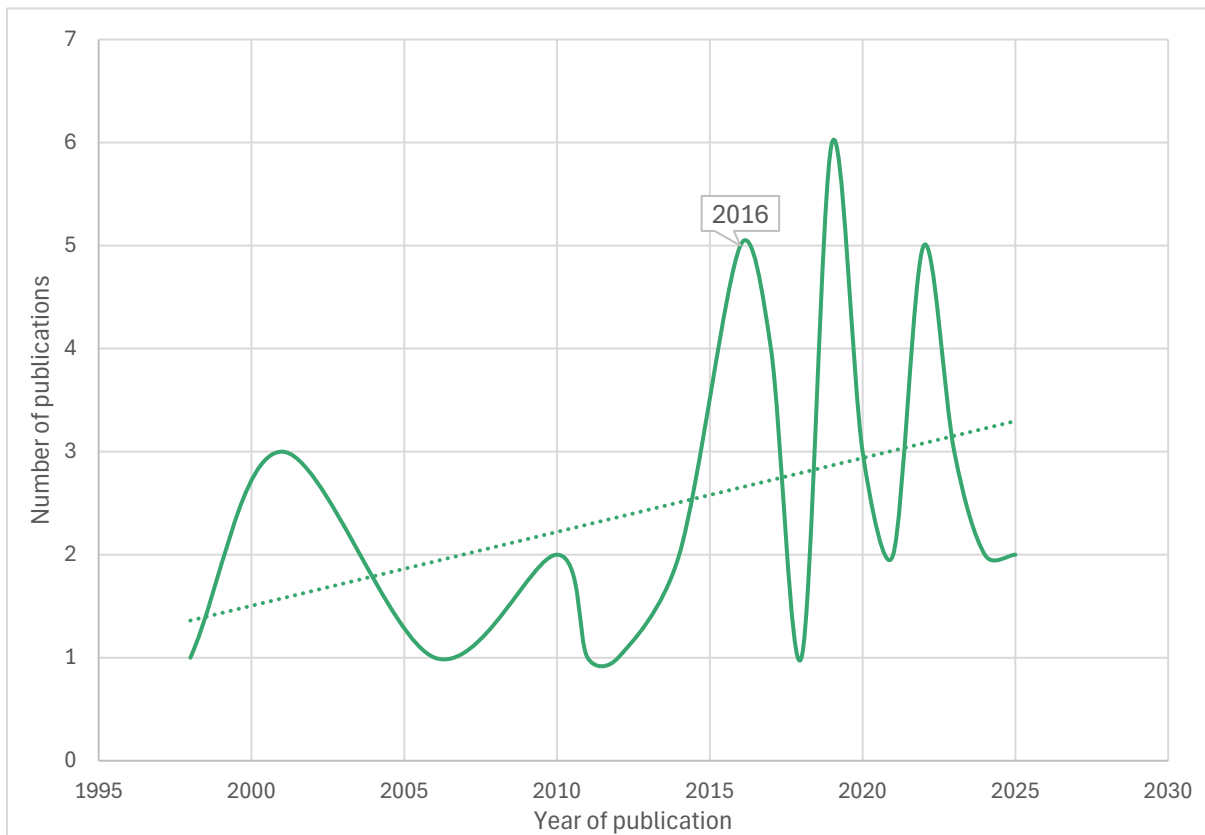
## 1615 Results and Discussion

### 1616 *Publication information*

1617 The date range of the reviewed scientific literature spanned across 27 years, from 1998  
1618 to 2025. Across those studies there was a high concentration (75%) of publications from  
1619 2016 onwards (Figure 1), showing an increased focus on semi-aquatic freshwater  
1620 mammals in recent years. This is most likely attributed to improvement in technology and  
1621 scientific processes, but also may be a reflection of the increased necessity of research  
1622 due to rapid increases in urbanisation and anthropogenic pressures over the last decade.

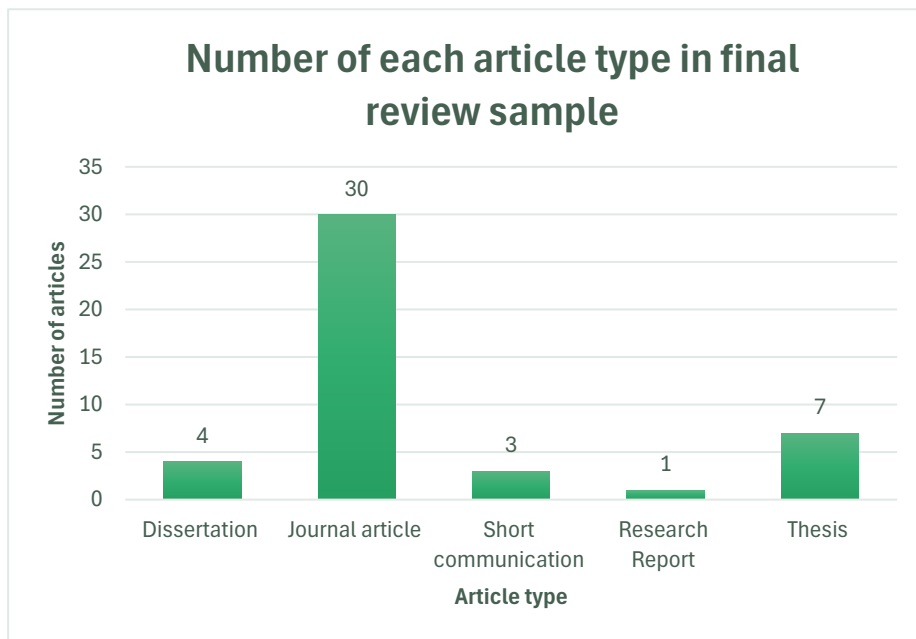
1623

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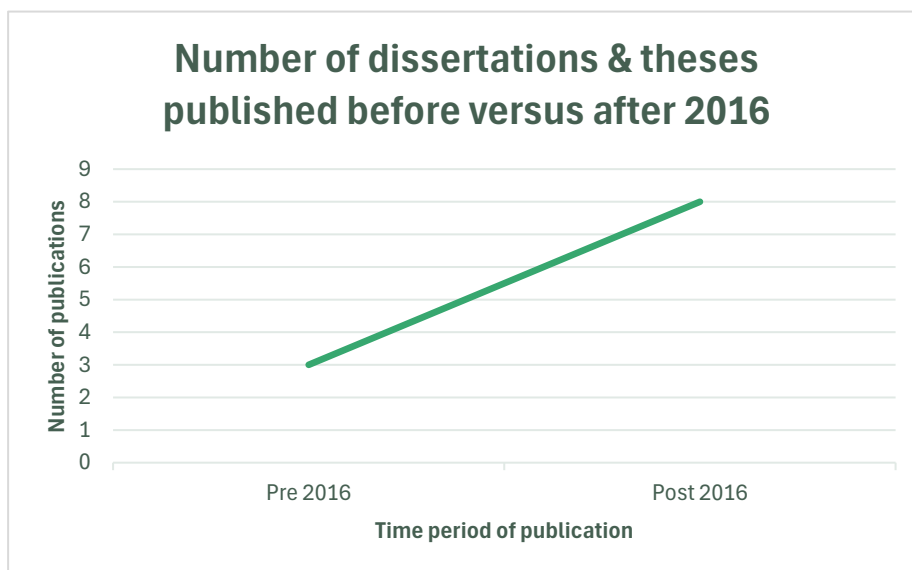


**Figure 1:** Depicts the distribution of publication date of sources in this literature review. Trendline shows the direction of relationship, with a steady increase to the current year (2025). Key data point ‘2016’ is marked, to highlight the significant increase in publication

1625 In total, there were 26 different journals represented across the reviewed literature.  
 1626 Excluding theses & dissertations, the most frequent journal represented in this review  
 1627 was the '*Journal of Mammalogy*', however, only 11% (n = 3) publications came from this  
 1628 journal. The journals, '*Diversity and Distributions*', '*Mammalia*', '*Mammalian Biology*', and  
 1629 '*The Journal of Wildlife Management*', collectively comprised 30% of publications, and 20  
 1630 other journals represented the rest of the literature sources. It is possible that the  
 1631 understudied nature of freshwater mammals in general (Sanders et al., 2024), coupled  
 1632 with the recent realised importance of anthropogenic pressures on these animals,  
 1633 resulted in the wide distribution of journals in this review. As expected, this review  
 1634 contained a high proportion of journal articles (73.3%, including short communication



**Figure 2:** Number of the different types of publications comprising the final review sample.



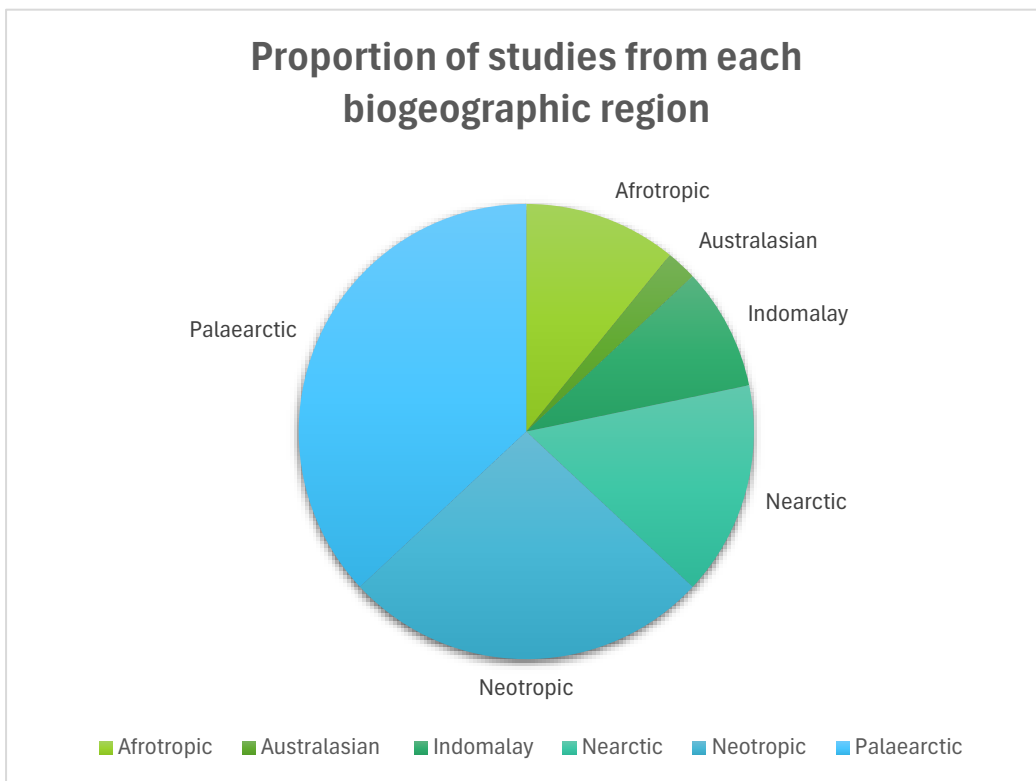
1635 articles). Dissertations and theses comprised 24.4% of publications, with 72% of  
**Figure 3:** Number of dissertations & theses in the review that were published pre- and post- 2016, highlighting the recent escalation of the field.

1636 dissertations and theses produced in the last ten years (figure 3). This is an additional  
1637 indicator of upcoming expansion of this field in the near future.

1638

1639 *Geographical distribution*

1640 In this review, semi-aquatic mammals were studied in 6 of the 8 biogeographic realms  
1641 (Figure 4). The Palearctic realm had the highest proportion of studies, comprising  
1642 36.95%, followed by the Neotropics (26.08%), then the Nearctic with 15.21%, the  
1643 Afrotropics (10.86%), Indomalay with a similar 8.69% and finally Australasia with one  
1644 singular study (Figure 4).

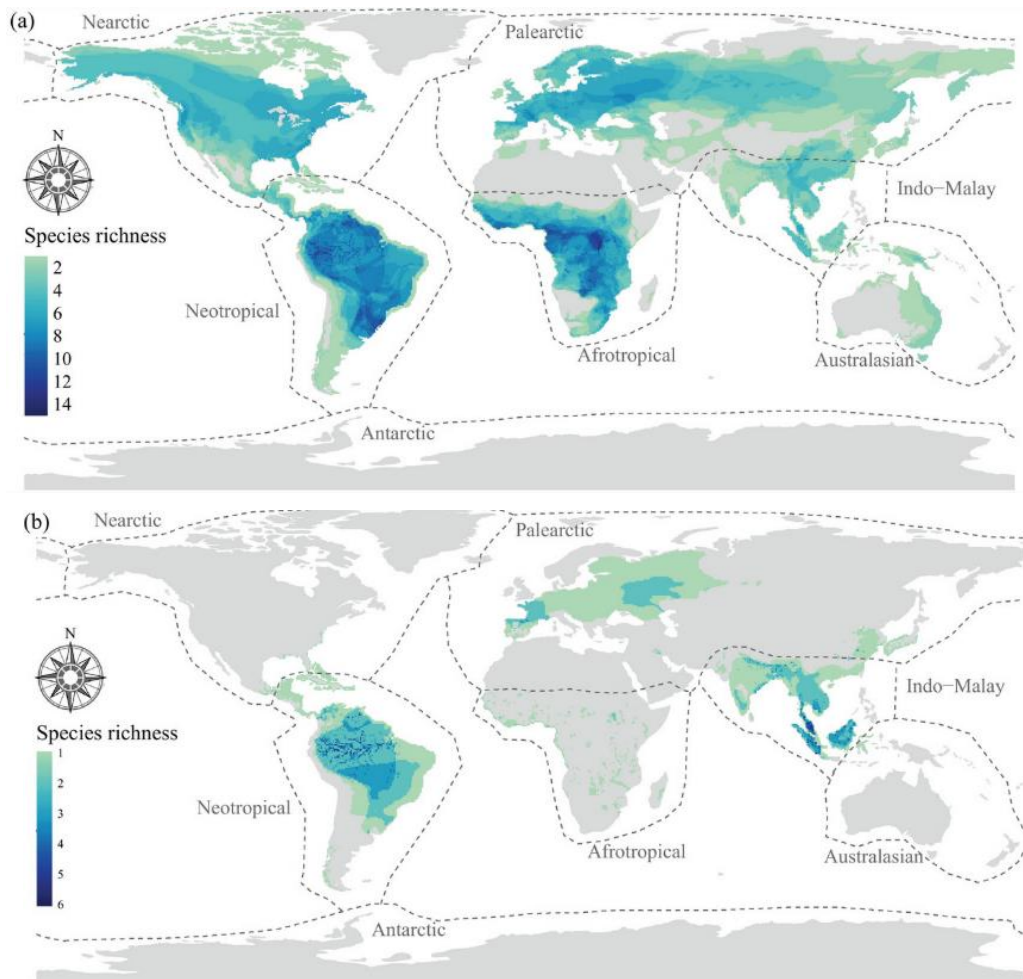


1645

**Figure 4:** Pie chart depicting the proportion of studies sourced from various biogeographic regions included in the review sample.

1646 Increasing anthropogenic pressure is a global issue (Sanders, 2024), however different  
1647 regions and ecosystems experience varying levels of these pressures (Bowler et al.,  
1648 2020), due to a multitude of factors (Geldmann, Joppa & Burgess, 2014). The Palearctic  
1649 region, and Europe in particular, has an extensive history of land-use change, with few  
1650 fragmented areas that remain naturally 'wild' (Antrop, 2004). Sanders et al., (2024)  
1651 identified that of all biogeographic realms, the Palearctic contained the greatest number  
1652 of freshwater mammal species that are impacted by ecosystem modification. In recent  
1653 years however, there has been a growing focus on rewilding and restoration of native

1654 species (Hart, Haigh, & Ciuti, 2023). For example, the Eurasian Beaver (*Castor fiber*), has  
1655 been the centre of significant human-wildlife conflict, but has received a surge of  
1656 attention due to the ecosystem services they provide. Through their damming behaviour,  
1657 beavers’ transformation wetland and riparian ecosystems, increasing habitat complexity,  
1658 and subsequently improving biodiversity in these habitats (Lacher, 2019). It is possible



1659 **Figure 5a, b** : Note: Sourced from “Extinction risk of the world's freshwater mammals” by Sanders  
1 et al, 2024, Conservation Biology, 38, e14168. <https://doi.org/10.1111/cobi.14168>

1 The top figure (a) depicts species richness of freshwater mammals in each biogeographical region.  
1 Bottom figure (b) depicts the richness of threatened freshwater mammal species across

1664 Romero et al., 2024), and supports the highest proportion of threatened species (n=15)  
1665 (Sanders et al., 2024) (Figure 5). Concerningly, the Neotropics also contains the highest  
1666 number of threatening processes that occur in the region (Sanders et al., 2024). Pollution,  
1667 agriculture and aquaculture, and residential development are among the leading causes  
1668 of threat to freshwater mammals in the Neotropics (Sanders et al., 2024). Thus, it is  
1669 promising that the second highest proportion of studies in this review were identified  
1670 from the Neotropical region.

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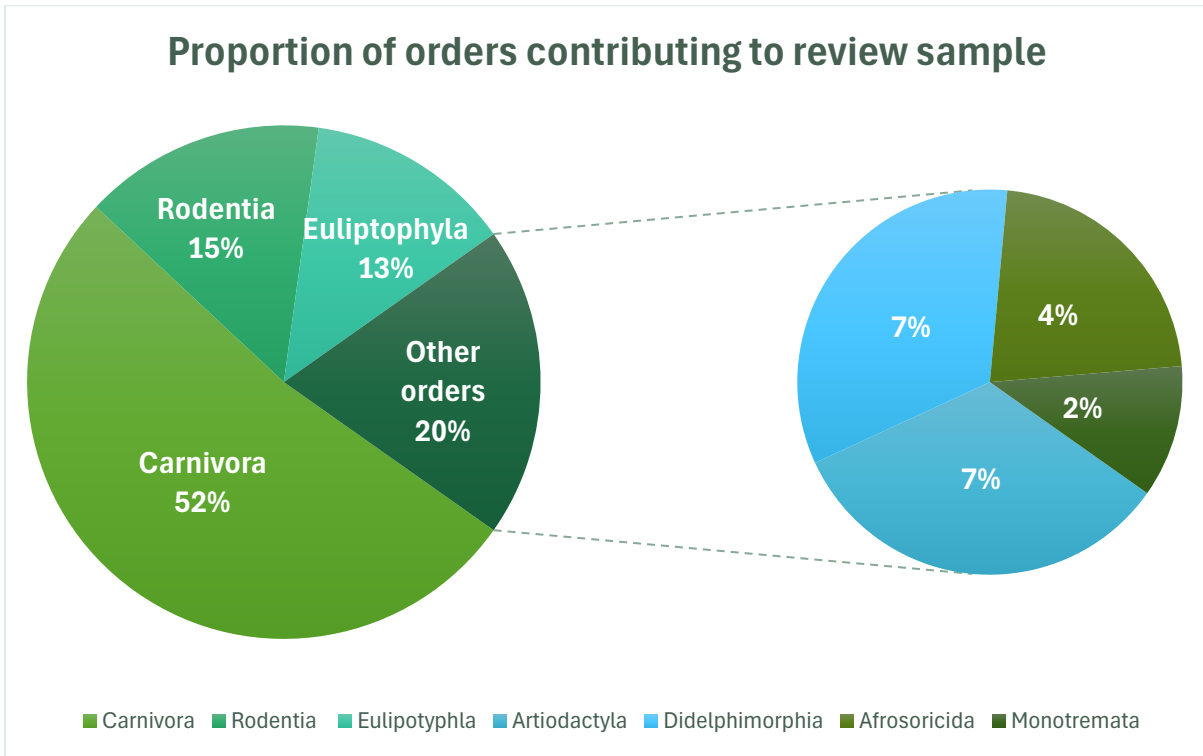
1675 This review revealed that there are geographical areas being significantly impacted by  
1676 anthropogenic pressures, which are not receiving an appropriate amount of attention for  
1677 research. The Afrotropics is the third least represented region in this review, while  
1678 simultaneously being second to the Neotropics in freshwater mammal species richness  
1679 (Torres-Romero et al., 2024), and having the highest number of freshwater mammal  
1680 species impacted by human disturbance (Sanders et al., 2024). Additionally, the  
1681 Indomalay region is the most impacted by urban and residential development, and is  
1682 second in the number of threatened freshwater mammal species that the region  
1683 supports (Sanders et al., 2024). While the five studies from the Afrotropics were  
1684 distributed across five different countries, it is concerning that of the four studies from  
1685 the Indomalay region, three were located in India. The Indomalaya region has been  
1686 documented to experience disproportionate increases in human pressure (64%) across  
1687 the last 15 years (Geldmann, Joppa & Burgess, 2014), which may be attributed to intense  
1688 industrialisation and urban development to support a dense human population (Shi et  
1689 al., 2005). Therefore, research attention should be split across a range of Indomalayan  
1690 countries, to understand how threatened freshwater mammal species are responding to  
1691 anthropogenic stressors across the region.

1692 Another significant gap identified in this review is the singular publication sourced from  
1693 the Australasian region. While this may be attributed to the lack of semi-aquatic mammal  
1694 species in Australasia in general, Australia has been identified to have a high degree of  
1695 freshwater endemism (Collen et al., 2014). For instance, the only Australasian semi-  
1696 aquatic species represented in this study was the Platypus (*Ornithorhynchus anatinus*),  
1697 an iconic monotreme (Bino et al., 2019). Due to the unique and endemic status of  
1698 platypus (Bino et al., 2019), there have been efforts to understand their habitat  
1699 requirements to inform conservation and potential reintroduction of populations to  
1700 urban areas (Zukowski & Whiterod, 2022). Papers have identified that platypuses have a  
1701 high sensitivity and distinct preferences for habitat characteristics, including sensitivity  
1702 to urban factors (Coleman et al., 2021; Danger & Walsh, 2008). This literature review has  
1703 identified a lack of empirical studies quantifying how these stressors may be influencing  
1704 platypus behavioural responses, including spatial distribution in anthropic areas. This  
1705 data is essential for the effectiveness of any future restoration and reintroduction plans  
1706 for the species.

1707 *Taxonomic variation*

1708 The publications analysed in this review represented 7 orders containing semi-aquatic  
1709 mammals including Carnivora, Rodentia, Eulipotyphla, Artiodactyla, Didelphimorphia,

1710 Monotremata, and Afrosoricida. There was a clear difference between the proportion of  
1711 the represented semi-aquatic mammal orders, with species from the order Carnivora  
1712 comprising >50% of the studied species (Figure 6).



1713  
1714 Mustelids made up over 90% of the Carnivores studied, primarily including species of  
1715 Otters (*Lutrinae*) and Minks. Many species in the order Carnivora have been subject to  
1716 historical human pressure in the form of hunting (Wright, Croose, & Macpherson, 2022).  
1717 In recent years, there has been a strong focus on the rehabilitation of these populations,  
1718 both naturally and facilitated by reintroduction and translocation programs (Clavero et  
1719 al., 2010; Marcelli et al., 2012; Stepkovich, Kingsford, & Moseby, 2022), particularly  
1720 throughout Europe and the North Americas (Wright, Croose, & Macpherson, 2022). While  
1721 there has been an extensive effort for human facilitated recovery of Carnivora  
1722 (particularly Mustelid) populations (Stepkovich, Kingsford, & Moseby, 2022), there have  
1723 been mixed results across taxa. This literature identified several papers that indicated  
1724 some species to recover naturally, especially after the reduction of anthropogenic  
1725 pressure in their habitats. For example, improvement of environmental conditions,  
1726 reduction in anthropogenic land-use (particularly agricultural), and improved water  
1727 quality (by reducing pollution) facilitated Eurasian Otter (*Lutra lutra*) re-expansion  
1728 throughout European provinces (Clavero et al., 2020; Marcelli et al., 2012). However, for  
1729 some Mustelid species including the European Mink (*Mustela lutreola*), recovery has not  
1730 been effective (Maran et al., 2017). In a review of captive breeding programs, Maran et  
1731 al., (2017) identified that anthropogenic impacts, in the form of intentional killing and  
1732 habitat fragmentation due to anthropogenic barriers (such as concrete walls, drainage  
1733 pipes and dams), slowed *M. lutreola* colonisation and reduced habitat availability (Maran

**Figure 6:** The left pie chart depicts the proportion of each major order (Carnivora, Rodentia, Euliptophyla) and its contribution to the review sample (including wedge titled 'other orders'). The right pie chart shows the contribution of orders, Artiodactyla, Didelphimorphia, Afrosoricida & Monotremata, to the 'other orders' wedge.

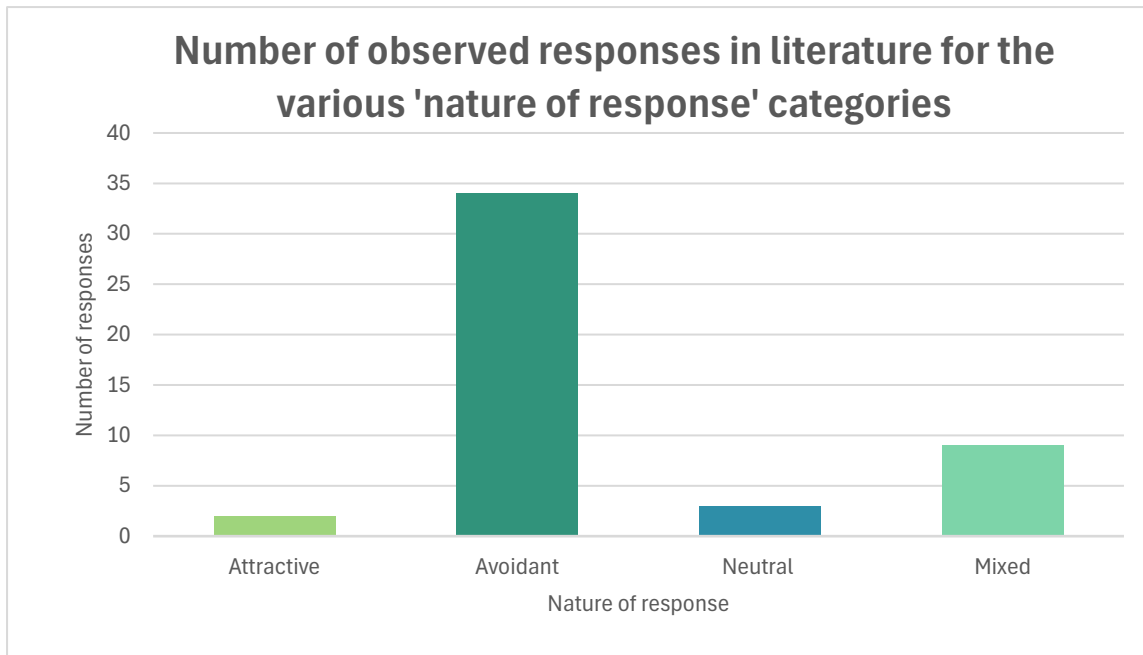
1734 et al., 2017; Zuberogoitia et al., 2013). This indicates that anthropogenic pressure is  
1735 suppressing the success of Mustelid (particularly Mink) recovery, and additionally that  
1736 management and reduction of anthropogenic pressure loads is essential for supporting  
1737 semi-aquatic mustelid populations.

1738 Rodentia was the second largest order in this review, comprising 18.75% of studied taxa.  
1739 Within this order, the proportion of families represented was limited, but more balanced,  
1740 including Cricetidae (n=4), Castoridae (n=3), Echimyidae (n=3), and Muridae (n=1).  
1741 Previous reviews have identified that the order Rodentia globally had the most 'Not  
1742 Evaluated' or 'Data Deficient' species (Sander et al., 2024; (Torres-Romero et al., 2024).  
1743 There is an evident bias of research towards certain orders, which is a major concern  
1744 considering that 'Data Deficient' mammals are more likely to be threatened and are  
1745 experiencing significant declines (Sanders et al., 2024).

1746 Various species of the Desman (family: Talpidae), majorly contributed to the third largest  
1747 order (n=5), Eulipotyphla, while the remaining orders had very small representation,  
1748 together contributing to <20% of the studied taxa in this review. This is partially due to  
1749 some orders only containing a small proportion of (or one (Monotremata &  
1750 Didelphimorphia)) freshwater semi-aquatic mammal species. The research of these  
1751 understudied species, especially those which occupy specific ecological niches and  
1752 roles are important for the broader ecosystem (Lacher et al., 2019).

#### 1753 *Type and nature of behavioural response*

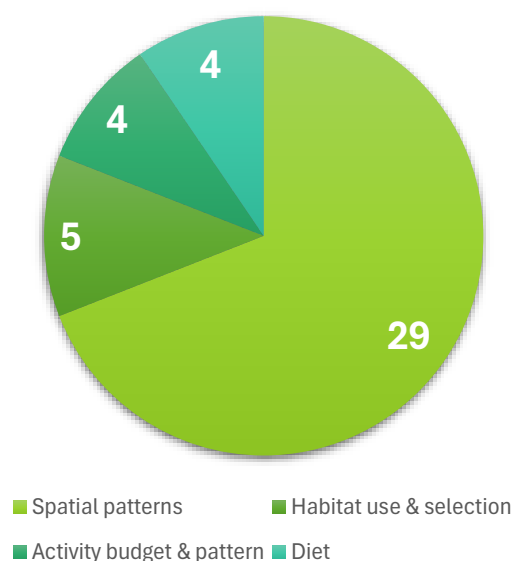
1754 Unsurprisingly, a pattern of avoidant responses by semi-aquatic mammals emerged  
1755 from the literature. This category contributed to >70% of the behavioural responses  
1756 observed across the studies, while only two studies reported attractive responses. While  
1757 the mixed group still involves a variety of avoidant and attractive responses, the  
1758 proportion in figure 7 shows a clear overarching relationship between anthropogenic  
1759 pressures and the avoidant direction of behavioural responses from semi-aquatic  
1760 mammals.



1761 **Figure 7:** Depicts the different amounts of responses (in regards to their  
 1762 nature/direction) as extracted from literature.

1763 The behavioural response categories ‘spatial patterns’ contributed the most to the  
 1764 avoidant responses (69%), and the remaining categories, ‘habitat use and selection’,  
 1765 ‘activity budget’ and ‘dietary’ were represented relatively evenly (n=5, n=4, and n=4  
 1766 respectively). Among the ‘Spatial patterns’ category, ‘Presence’ was the most  
 1767 represented variable, documented 48% of the time. Of the ‘Habitat use & selection’  
 1768 category, ‘Habitat preference’ was affected most, making up >50% of that category, and  
 1769 similarly within the ‘Activity budget’ category, ‘Activity Patterns’ also contributed to 50%

**Number of avoidant responses in each behavioural category**



**Figure 8:** Shows the number of different behavioural categories contributing to the avoidant responses as extracted from literature.

1770 of the avoidant responses. Among all responses, the ‘dietary’ category had the fewest  
1771 variables included (n=2), and was only comprised of changes to regular dietary behaviour  
1772 (n=4) and ingestion of micro/plastics and anthropogenic particles (n=2).

1773 Attractive responses were extremely limited in this review (n=2), and were only reported  
1774 by two species (*Myocaster corpus* and *Ondatra zibethicus*). Mixed responses, which  
1775 include some degree of attractive responses were also limited (n=9). While not all  
1776 attractive & mixed responses were attributed to this, the presence of an invasive species  
1777 (*M. corpus*) in this review contributed to these results. Invasive species are notorious for  
1778 being well-adapted, flexible and plastic to their environments, which are all traits that  
1779 assist in the success of their invasive and establishment in a variety of places (Borden &  
1780 Flory, 2021). Therefore, feral species like the Coypu, (*M. corpus*) can adapt and reap the  
1781 benefits of increased anthropogenic pressure in the form of urbanisation. Coypu  
1782 populations have established in highly urbanised areas throughout South America, due  
1783 to the increased food resources and protection from predators that these habitats  
1784 provide (Abdenurm, Cavia & Corriale, 2025). In this review, one of the ‘attractive response’  
1785 papers involved Coypu abundance correlating positively with human settlement.  
1786 However, it must also be recognised that some native mammals, including species of  
1787 otter (Ramalheira et al., 2021; Rahul, 2023), the American Mink (*Neovision vision*) the  
1788 Muskrat (*O. zibethicus*) may be similarly capable of this plasticity, or at least neutrality.  
1789 For example, in this review multiple studies reported *O. zibethicus* to demonstrate  
1790 increased abundance in areas of higher urbanisation (Cotner & Schooley, 2011; Holland et  
1791 al., 2019; Holland, 2016). However, this often varied between different scales (e.g.  
1792 landscape and local), meaning papers with this finding were often assigned to the  
1793 ‘mixed’ category. The contradiction between the scales used, and the papers findings’  
1794 shows the need for more fine-scale investigation to understand what variables are  
1795 impacting how Muskrats, and other native species, may be responding to anthropogenic  
1796 pressures like urbanisation.

#### 1797 *Strengths, limitations, applications & future directions*

1798 This review was able to identify a significant research gap, that to my knowledge has not  
1799 been explored thus far. While research in the scientific literature has addressed  
1800 physiological responses of mammal taxa, mammalian taxa in general, and other  
1801 freshwater vertebrates, this review is the first to collate multiple behavioural responses  
1802 of semi-aquatic mammals in relation to anthropogenic pressures. Providing behavioural  
1803 data rather than just physiological extends to the understanding and management of  
1804 broader species too. As mentioned, behaviour of mammals can influence significant  
1805 aspects of ecosystem and community functioning (Lacher et al., 2019). Therefore,  
1806 understanding the overall response to anthropogenic disturbances can indicate patterns  
1807 of ecosystem responses as well.

1808 While the 46 papers reviewed here can mainly be attributed to a lack of literature on the  
1809 topic, it is possible that not all available literature was explored (e.g. publications that  
1810 include specific terminology that was not included in the Boolean string, or grey literature  
1811 that was unavailable via databases used for this review). There were a few papers which  
1812 were not available in English and therefore were excluded based on the first screening  
1813 eligibility criteria. Considering the global nature of this topic, this may have reduced the  
1814 representation of the total number of scientific papers reviewed.

1815 In this literature review, publications which included a clear reference point for  
1816 comparison (e.g. historical data, non-urban versus urban areas with little variation) had  
1817 increased clarity and effectiveness in communicating the impacts of anthropogenic  
1818 pressure on freshwater semi-aquatic mammal behaviour. It is therefore important to  
1819 continue (or initiate) regular monitoring programs of freshwater ecosystems, particularly  
1820 where semi-aquatic mammals are known to occur, to facilitate effective long-term  
1821 management of populations. The literature involved in this review had a high degree of  
1822 variability for which proxies were used to measure level of anthropogenic impact, which  
1823 decreases validity of conclusions. It should be considered how developing a framework  
1824 to standardise characteristics and measures of anthropogenic pressure can increase the  
1825 comparability of results from different papers, and across various taxa. As identified in  
1826 previous work, understanding the traits involved in plasticity to and colonisation of urban  
1827 environments (e.g. differences between invasive and native species) may assist in  
1828 management. However, it should not be overlooked that adaptations to anthropic  
1829 habitats may contribute negatively to species and population genetic health, and  
1830 therefore this research should also be further exploited.

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2121 *Appendix A)*

2122 Documented process of sourcing and refining sample for the review.

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## Appendices

SEARCH TERM	GOOGLE SCHOLAR	SCOPUS	WEB OF SCIENCE	NOTES	TOTAL
("freshwater mammal" OR "semi-aquatic mammal") AND (rodentia OR carnivora OR monotreme OR marsupial OR eulipotyphla OR mustelidae OR talpidae) AND (urban OR urbanisation OR urbanization OR "human disturbance" OR "human presence" OR anthropogenic OR "human transformed landscapes") AND ( behaviour OR behavior OR response OR "behavioural response" OR "habitat use" OR movement OR adaptation OR foraging OR distribution OR activity)	381	95	2	(as of 26/5/25)	478
Imported into Mendeley	363	0	0	(less with google scholar due to it's estimation feature for search results)	363
Imported into Rayaan	363	95	2		460
Post de-duplication in Rayaan	330	93	0	(69 duplicates detected)	423
	<b>INCLUDED</b>	<b>EXCLUDED</b>			
Post 1st screening (title & abstract, using inclusion/exclusion criteria)	57	366			57
Post 2nd screening (full text screening)					45

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2126 *Appendix B)*

2127 Inclusion and exclusion criteria developed for the screening processes.

INCLUSION	EXCLUSION
The focal species of the study is a semi-aquatic freshwater mammal	Source is a literature review
The study focused on the impact of anthropogenic pressures (or human pressures, disturbances, or anthropogenically transformed/modified landscapes)	Source is not available in English language
The paper primarily discussed an external behavioural response by semi-aquatic freshwater mammals (e.g. foraging or activity pattern change, or habitat use/distribution/abundance shifts)	Source does not identify or discuss a key behavioural response by semi-aquatic freshwater mammals
	Study focusses on human perspective or response (e.g. surveys to assess what the public think regarding wildlife responses in anthropogenic landscapes, or to investigate human-wildlife conflict in urban areas)
	Study focuses on physiological or biological response (e.g. toxicological, haematological, or ecoimmunology studies).
	Focal species of the study is not a freshwater or semi-aquatic mammal (e.g. fully aquatic, terrestrial, or marine mammals excluded)

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*Appendix C)*

List of questions to guide data extraction during secondary screening (full text screening)

1. When was the study published (year)?
2. Where was the study conducted (geographically)?
3. What were the main habitat variables of the study sites?
4. What species/taxa were studied?
5. What methodology was used (e.g. non-invasive surveys, live trapping, radio tracking)?
6. What anthropogenic pressure/variables were the key contributors?
7. What was the key behavioural response/s?
8. What was the nature of the response/s (avoidance, neutral, attractive, mixed)?

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2181 *Appendix D)*

2182 Categories and respective descriptions developed for more simple classification & comparison of 1) the

2183 type of behavioural response elicited, and 2) the nature of the behavioural response across literature in

2184 the review.

2185 1) Type of behavioural response

Spatial Patterns	Used to group terms describing the spatial distribution, presence, abundance, or occurrence of animals across landscapes.
Habitat Use & Preference	Used to group terms describing the use, preference, or selection of particular habitats within a particular region by animals.
Dietary	Used to group responses relating to diet, ingestion, or consumption of matter by animals.
Activity budgets & Patterns	Used to group responses relating to the selection or distribution of time/energy budgets to activities (e.g. foraging, resting, travelling), or changes in patterns of activity of animals (e.g. nocturnal, diurnal).

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2187 2) Nature of response

<del>2188</del> Avoidant	A response that drives animals away from anthropogenic pressure, subsequently (typically) having negative flow on effects for their survival or fitness (e.g. moving away from preference habitat or niches, altering diet, changing activity patterns etc.).
Attractive	A response where animals are further engaging with anthropogenic pressures, rather than avoidance.
Neutral	A circumstance where the study found no discernible impact of the anthropogenic pressure on a behavioural response. While this does not discount the presence of an impact, it represents studies where a clear nature of response was not observed.
Mixed	When there is a combination of responses, with no clear majority in either of the other categories.

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2190 *Appendix E*

2191 Shows the full text screening and extracted data of the final literature review sample. This is a cleaned and reduced version of the table  
2192 (including only a portion of extracted information for space and clarity purposes)

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In text citation	Title	Journal	Article type	Continent	Habitat (site)	Order	Methods	IV	DV	Nature of response
Dávila Raffo et al., 2022	Anthropogenic influences on the distribution of a threatened apex-predator around sustainable-use reserves following hydropower dam installation	PeerJ	Journal article	South America	Protected reserve	Carnivora	Census	Dam presence Anthropogenic disturbance	Presence Relative abundance	Avoidance
Gallitelli et al., 2022	Anthropogenic particles in coypu ( <i>Myocastor coypus</i> ; Mammalia, Rodentia)' faeces: first evidence and considerations about their use as track for detecting microplastic pollution	Environmental Science and Pollution Research	Journal article	Europe	Wetland nature reserve	Rodentia	Scat samples	Pollution	Anthropogenic particles/microplastic ingestion	Avoidance
Abdenurm, Cavia & Corriale, 2025	Between walls and wilds: <i>Myocastor coypus</i> Molina, 1782 abundance and occurrence in gated and open communities in Buenos Aires, Argentina	Urban Ecosystems	Journal article	South America	Urban environment	Rodentia	Non invasive signs	Urbanisation	Abundance Occurance	Attractive
Holland, 2006	Bridging aquatic and terrestrial ecosystems: ecology of semiaquatic mammals in southern illinois	Thesis	Dissertation	North America	Mixed (urban, natural, agriculture, wetland)	Carnivora Rodentia Rodentia	Non invasive signs & collated datasets	Anthropogenic disturbance Human disturbance Urbanisation	Presence	Mixed
Charbonnel, 2016	Can Recent Global Changes Explain the Dramatic Range Contraction of an Endangered Semi-Aquatic Mammal	Plos One	Journal article	Europe	Mountainous, low human density	Eulipotyphla	Non invasive signs	Human disturbance Anthropogenic land-use	Presence	Avoidance

	Species in the French Pyrenees?									
LODE, CORMIER & LE JACQUES, 2001	Decline in Endangered Species as an Indication of Anthropogenic Pressures: The Case of European Mink <i>Mustela lutreola</i> Western Population	Environmental Management	Journal article	Europe	Mixed	Carnivora	Collated data (distribution)	Anthropogenic land-use Pollution	Distribution Abundance	Avoidance
Streicher et al., 2022	Diet of a generalist mammalian mesocarnivore in an urban matrix	African Zoology	Short communication (journal article)	Africa	Urban environment	Carnivora	Scat samples	Pollution	Diet	Avoidance
Rheingantz et al., 2016	Differences in activity patterns of the Neotropical otter <i>Lontra longicaudis</i> between rivers of two Brazilian ecoregions	Journal of Tropical Ecology	Short communication (journal article)	South America	Mixed	Carnivora	Camera trapping	Human disturbance	Behaviour (Activity patterns)	Avoidance
Pérez et al., 2020	Distribution and habitat use intensity of the Neotropical Otter ( <i>Lontra longicaudis</i> ) in a Colombian hydroelectric dam	Revista de Biología Tropical	Journal article	South America	Mixed (mostly natural)	Carnivora	Non invasive samples	Dam presence	Distribution Habitat use	Avoidance
Mulu & Ejigu, 2025	Distribution range and human-hippopotamus ( <i>Hippopotamus amphibius</i> ) conflict in the Lake Tana biosphere reserve, Ethiopia	BMC Zoology	Journal article	Africa	Mixed (natural and human settlements)	Artiodactyla	Total counts (transects)	Anthropogenic disturbance Human disturbance	Distribution Habitat use	Avoidance
Jha, 2018	Distribution Status of Smooth Coated Otters ( <i>Lutrogale perscipillata</i> ) and Anthropogenic Factors: A Case Study from Karnali Corridor, Nepal	Thesis	Thesis	Asia	National Park/wildlife reserve	Carnivora	Non invasive signs	Anthropogenic disturbance Human disturbance	Distribution	Avoidance

Ciach, Wrazidto & Fedyń, 2023	Ecosystem engineers enter the city: Habitat characteristics influencing the distribution of Eurasian beavers <i>Castor fiber</i> in a human-transformed landscape	Landscape and urban planning	Journal article	Europe	Urban environment	Rodentia	Non-invasive signs	Anthropogenic land-use Anthropogenic disturbance Urbanisation	Occupancy Habitat use	Mixed
Prieto-Torres & Pinilla-Buitrago, 2017	Estimating the potential distribution and conservation priorities of <i>Chironectes minimus</i> (Zimmermann, 1780) (Didelphimorphia: Didelphidae)	Therya	Journal article	South America	Mixed (inside & outside protected areas)	Didelphimorphia	Collated data	Urbanisation Human disturbance Anthropogenic land-use	<b>(potential)</b> Distribution	Avoidance
Judge, n.d.	Fauna of the Upper Coxs River catchment: An assessment of common freshwater species in a high-demand landscape	Thesis	Research report	Australasia	Mixed	Ornithorhynchidae Rodentia	Observational survey Camera trapping	Anthropogenic land-use	Abundance Presence	Avoidance & neutral
Ramalheira et al., 2021	Giant otter behaviour in a mega-hydroelectric reservoir, Central Amazon, Brazil	Animal Biology	Journal article	South America	Reservoir	Carnivora	Radio-tracking	Dam presence	Behaviour (travelling, foraging, activity patterns)	Neutral
Rahul, 2023	Habitat Assessment and Understanding People's Perception towards Smooth Coated Otters at Ganapathi lake, Sagara Town, Karnataka	Thesis	Thesis	Asia	Urban environment	Carnivora	Non invasive signs	Anthropogenic land-use Human disturbance	Presence	Avoidance Neutral
Cotner & Schooley, 2011	Habitat Occupancy by Riparian Muskrats Reveals Tolerance to Urbanization and Invasive Vegetation	The Journal of Wildlife Management	Journal article	North America	Mixed	Rodentia	Non invasive signs	Urbanisation	Occupancy	Attractive
Palmeirim et al., 2014	Habitat selection for resting sites by the	Studies on Neotropical	Journal article	South America	Mixed	Didelphimorphia	Radio tracking	Anthropogenic disturbance	Habitat preference	Avoidance

	water opossum ( <i>Chironectes minimus</i> ) in the Brazilian Atlantic Forest	Fauna and Environment						Human disturbance		
Gomez et al., 2014	Habitat suitability and anthropogenic correlates of Neotropical river otter ( <i>Lontra longicaudis</i> ) distribution	Journal of Mammology	Journal article	South America	Large wetland	Carnivora	Non invasive signs Camera trapping	Anthropogenic disturbance Human disturbance Pollution	Presence	Avoidance
Saito et al., 2019	How Does the Japanese Water Shrew Chimarrogale platycephalus Cross the Concrete Walls of Check Dams?	Mammal Study	Journal article	Asia	Natural	Eulipotyphla	Radio- tracking	Dam presence	Behaviour (travelling)	Neutral
Biffi, Laffaille, & Buisson, 2017	Influence of environmental factors and biotic interactions on the habitat selection and diet of the Pyrenean desman, <i>Galemys pyrenaicus</i>	Thesis	Thesis	Europe	Mountainous, natural	Eulipotyphla	Non invasive signs	Anthropogenic disturbance Human disturbance	Presence	Avoidance
Almeida & Pereira, 2017	Influence of the water quality on the occurrence of the Neotropical otter ( <i>Lontra longicaudis</i> ) (Olfers, 1818) in a human-altered river basin	Marine and Freshwater Research	Journal article	South America	Urban environment	Carnivora	Non invasive samples	Anthropogenic disturbance	Occurance	Avoidance
Marcelli et al., 2012	Land use drivers of species re-expansion: inferring colonization dynamics in Eurasian otters	Diversity and Distributions	Journal article	Europe	Mixed Nation-wide	Carnivora	Non invasive signs	Anthropogenic land-use Urbanisation	Presence	Avoidance
Biffi, Laffaille, & Buisson, 2019	Local habitat preferences of a semi- aquatic mammal, the	Mammalia	Journal article	Europe	Mountainous (low human density)	Eulipotyphla	Non invasive samples	Anthropogenic disturbance Human disturbance	Presence	Avoidance

	Pyrenean desman <i>Galemys pyrenaicus</i>									
Mendonça & Viera, 2022	Moving far from water: unusual dispersal movement of the water opossum ( <i>Chironectes minimus</i> : Didelphimorphia, Didelphidae) in central Brazil	Biota Neotropica	Short communication (journal article)	South America	Urban environment	Didelphimorphia	Live trapping	Anthropogenic disturbance Anthropogenic land-use	Behaviour (dispersal & movement)	Avoidance
Moun et al., 2024	Multi-scale habitat influences sprainting and group size of a freshwater-obligate smooth-coated otter ( <i>Lutrogale perspicillata</i> ) in Tungabhadra Otter Conservation Reserve, India	Ecological Processes	Journal article	Asia	Protected reserve	Carnivora	Non invasive signs Observation	Anthropogenic land-use Urbanisation Human disturbance Anthropogenic disturbance	Presence	Avoidance
Clavero et al., 2010	Natural, human and spatial constraints to expanding populations of otters in the Iberian Peninsula	Journal of Biogeography	Journal article	Europe	Mixed (low human density)	Carnivora	Non invasive signs	Human disturbance Anthropogenic disturbance Anthropogenic land-use	distribution	Avoidance
Biffi et al., 2017	Novel insights into the diet of the Pyrenean desman ( <i>Galemys pyrenaicus</i> ) using next-generation sequencing molecular analyses	Journal of Mammology	Journal article	Europe	Mountainous	Eulipotyphla	Non invasive samples	Anthropogenic disturbance Human disturbance	Presence Diet	Avoidance
Hoffer, 2016	Occupancy of semi-aquatic mammals in an urban landscape	Thesis	Thesis	North America	Preserve district (mixed)	Carnivora	Non invasive signs	Anthropogenic disturbance Urbanisation Anthropogenic land-use	Presence	Neutral & Avoidance
Emiliano et al., 2020	Patterns of activity rhythms of invasive coypus <i>Myocastor</i>	Mammalian Biology	Journal article	Europe	Mixed	Rodentia	Camera trapping (collated data)	Urbanisation Human disturbance	Behaviour (activity patterns)	Avoidance

	coypus inferred through camera-trapping									
Ratnayaka et al., 2023	Plastic ingestion by fishing cats suggests trophic transfer in urban wetlands	Environmental Pollution	Journal article	South America	Wetland reserve (high urban pressure)	Carnivora	Non invasive samples	Pollution	Plastic ingestion	Neutral
Moun, Ramesh, & Kalle, 2024	Riparian habitat quality and seasonality drives spatiotemporal habitat ecology of sympatric Asian otters in southern Western Ghats	Frontiers in Mammal Science	Journal article	Asia	Mixed	Carnivora	Non invasive signs	Anthropogenic disturbance Anthropogenic land-use	Presence	Avoidance
Weinberger, 2019	Riparian vegetation provides crucial shelter for resting otters in a human-dominated landscape	Mammalian Biology	Journal article	Europe	Mixed	Carnivora	Radio-tracking	Human disturbance Anthropogenic land-use	Habitat preference	Avoidance
Holland et al., 2019	River otter and mink occupancy dynamics in riparian systems	The Journal of Wildlife Management	Journal article	North America	Mixed	Carnivora	Non invasive samples	Urbanisation Anthropogenic land-use	Occupancy	Avoidance (mixed depending on local/landscape scale)
Biffi et al., 2016	Spatial differences across the French Pyrenees in the use of local habitat by the endangered semi-aquatic Pyrenean desman ( <i>Galemys pyrenaicus</i> )	Aquatic conservation: Marine and Freshwater Ecosystems	Journal article	Europe	Mountainous (mixed)	Eulipotyphla	Non invasive signs Non invasive samples	Anthropogenic land-use Urbanisation	Occurrence	Neutral
Hanrahan et al., 2019	Spatial ecology of river otters in a human-modified landscape	Journal of Mammology	Journal article	North America	Mixed	Carnivora	Radio tracking	Urbanisation Anthropogenic land-use	Behaviour (sociality, home range) Habitat preference & selection	Neutral
Barbosa et al., 2001	Spatial, environmental and human influences on the distribution of	Diversity and Distributions	Journal article	Europe	Mixed Nation-wide	Carnivora	Non invasive signs	Urbanisation Human disturbance	Distribution	Avoidance

	otter ( <i>Lutra lutra</i> ) in the Spanish provinces									
Reece, 2020	Species richness and spatial use patterns of medium and large mammals in Majete Wildlife Reserve, Malawi	Thesis	Thesis	Africa	Fenced reserve	Artiodactyla	Camera trapping	Anthropogenic disturbance Human disturbance	Spatial use	Avoidance
Eubanks, 2010	Status and distribution of the state-threatened marsh rice rat ( <i>Oryzomys palustris</i> ) in Illinois	Thesis	Thesis	North America	Mixed	Rodentia	Live trapping	Anthropogenic land-use Anthropogenic disturbance	Presence	Avoidance
Benstead, 2001	Stream community and ecosystem responses to deforestation in eastern Madagascar	Thesis	Dissertation	South America	Mixed (National park & urban)	Afrosoricida	Non invasive samples Radio tracking	Anthropogenic land-use	Density Diet	Neutral
Monadjem et al., 2019	The conservation status of a poorly known range-restricted mammal, the Nimba otter-shrew <i>Micropotamogale lamottei</i>	Mammalia	Journal article	Africa	Mountainous (mixed)	Afrosoricida	Live trapping Radio-tracking	Anthropogenic land-use Anthropogenic disturbance	Presence	Avoidance
Bempah et al., 2022	The direct and indirect effects of damming on the Hippopotamus amphibius population abundance and distribution at Bui National Park, Ghana Launched to accelerate biodiversity conservation	Nature Conservation	Journal article	Africa	National Park	Artiodactyla	Census count	Dam presence	Distribution Abundance	Avoidance
Szumski, 1998	The Effects of Mining Related Metals Contamination on Piscivorous Mammals Along the Upper Clark Fork River, Montana.	Thesis	Dissertation	North America	Mixed	Carnivora	Non invasive signs	Anthropogenic disturbance	Relative abundance	Mixed

Dettori, 2021	The Eurasian otter ( <i>Lutra lutra</i> ) as an environmental bioindicator in relation to exotic invasive species: Giant reed ( <i>Arundo donax</i> ), Red swamp crayfish ( <i>Procambarus clarkii</i> ) and American mink ( <i>Neovison vison</i> )	Thesis	Thesis	Europe	Mixed	Carnivora	Non invasive signs	Human disturbance Urbanisation	Diet	Avoidance
Weinberger, 2016	The Eurasian Otter ( <i>Lutra lutra</i> ) in the Alpine Arc: Resource selection and habitat suitability models	Thesis	Dissertation	Europe	Mixed	Carnivora	Radio-tracking (chapter 2) Collated data (chapter 4)	Human disturbance Anthropogenic land-use	Behaviour (foraging) Occurrence Habitat preference	Avoidance

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