

1 Conservation gone to the dogs: when canids rule the beach in small 2 coastal reserves.

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16

17 **ABSTRACT**

18 On most developed coastlines, dunes backing ocean beaches constitute an urbanised
19 landscape mosaic containing remnant pockets of small conservation areas. Urbanised
20 beaches are also prime sites for domestic dogs, known to be environmentally harmful in
21 many other settings. It is unknown, however, whether small, protected parcels of dune are
22 adequate for biological conservation and whether dogs compromise their functional
23 conservation objectives. Here we examine, for two small (2 km ocean boundary) reserves in
24 Eastern Australia abutting an urban area, whether such small reserves can continue to
25 function as effective conservation instruments on ocean beaches, using scavenger community
26 composition and efficiency to assess ecosystem function. Two non-native species of canids -
27 domestic dogs (*Canis lupus familiaris*) and red foxes (*Vulpes vulpes*) - were ubiquitous and
28 numerous inside conservation areas, to the point of having become the most abundant
29 vertebrate scavengers at the beach-dune interface, outcompeting native scavengers for wave-
30 cast carrion. Dogs and foxes have effectively supplanted raptors, normally abundant on non-
31 urban beaches in the region, and other avian scavengers, as the principal consumers of
32 animal carcasses both inside the declared reserves and at the urban beach. Whilst the
33 ecological threats posed by foxes are widely and intensively addressed in Australia in the
34 form of fox-control programs, dog controls are less common and stringent. Our data
35 emphasize, however, that managing domestic dogs may be required to the same extent in
36 order to maintain key forms and functions in coastal reserves situated close to urban areas.

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38 **Keywords:** sandy shores; conservation; scavengers; invasive species; domestic dogs; apex
39 predators; red foxes; reserves

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41

42 **1. Introduction**

43

44 Conservation planning and practice usually operate based on spatial patterns of features,
45 whilst conserving processes is much more rarely practiced (Klein et al. 2009). Considering
46 processes in conservation is however, important, chiefly because biodiversity features are
47 generated and maintained by processes (Pressey and Bottrill 2009), and because processes
48 connect populations, food webs and habitats across ecosystem boundaries (Schlacher and
49 Connolly 2009).

50

51 Arguably, biological transformation of organic matter is one of *the* pivotal processes in most
52 ecosystems. Scavengers that consume animal carcasses are central to this function (Barton et
53 al. 2013; Wilson and Wolkovich 2011), including the processing and translocation of marine
54 necromass on ocean shores (Schlacher et al. 2013b; Schlacher et al. 2013c).

55

56 Conservation reserves are the principal tool for protecting and managing biodiversity and
57 ecological processes (Margules and Pressey 2000). Whilst conservation practitioners regularly
58 invest in a diverse portfolio of activities aimed at protecting natural features and functions
59 (e.g. controlling invasive species, fire management, re-vegetation; Wilson et al. 2007), the
60 acquisition, or designation, of land and sea to create reserves remains the chief tool in most
61 conservation programs (Pressey and Bottrill 2009; Pressey et al. 2007). Many of these
62 conservation programs increasingly have to address threats associated with urban expansion
63 (Noriega et al. 2012; Sushinsky et al. 2013).

64

65 Ocean beaches are focal points for urban expansion. The attractiveness of beaches is
66 frequently the *raison de etre* for widespread habitat loss and transformation in the coastal
67 fringe, driven by extensive land conversion through housing developments and associated
68 infrastructure (McLachlan et al. 2013; Noriega et al. 2012). Dunes backing beaches represent
69 real estate of immense monetary value and new developments outside traditional coastal
70 cities often centre on attractive ocean beaches (Nordstrom et al. 2011). These large-scale
71 transformations of the coastal landscape, particularly of sandy shorelines, propagate to

72 widespread ecological changes that can have serious ramifications for biodiversity and key
73 ecological processes (Schlacher et al. 2014).

74

75 Biodiversity conservation in urban areas and at the urban fringe provides large social and
76 health benefits to residents (Sushinsky et al. 2013). Conservation planning is possible in areas
77 earmarked for urban expansion (Bekessy et al. 2012), but is very rarely practiced on sandy
78 beaches (Harris et al. 2013). Instead, management of sandy shorelines usually seeks to
79 enhance recreational opportunities and to maximise economic values (e.g. housing, tourism,
80 mining; Nordstrom 2000; Schlacher et al. 2007). This emphasis on social and economic issues
81 has shaped many sandy coastlines into mosaics where the expansion of human land uses has
82 limited and constrained conservation areas to small reserves (Lucrezi et al. 2009). It is
83 unrealistic to expect that the dominance of humans, their activities and impacts will diminish
84 in coastal landscapes formed by sandy beaches. It is, however, realistic, and of importance to
85 conservation, to ask whether small remnant reserves on sandy coastlines can function as
86 effective conservation instruments – this is one of the questions addressed in this paper.

87

88 Free-ranging domestic animals that encroach on conservation areas can significantly reduce
89 the effective area protected (Wierzbowska et al. 2012), with multiple ecological impacts that
90 compromise conservation efforts attributed to dogs (Hughes and Macdonald 2013; Silva-
91 Rodríguez and Sieving 2012; Weston and Stankowich 2014). Because beaches are prime
92 recreational sites for dog owners and their animals, we also ask whether dogs can
93 significantly alter a key ecological process on marine shorelines inside and outside reserves:
94 consumption and translocation of marine animal carcasses cast ashore.

95

96 **2. Materials and Methods**

97 **2.1. Metrics**

98 We used two complementary classes of scavenging metrics to test for reserve effects on
99 sandy beaches in a partly urbanised landscape: i) characteristics of the scavenger guild (i.e.,
100 abundance, distribution, diversity and species composition of carrion consumers; identity of
101 species feeding first at carcass), and ii) quantitative measures of carrion consumption
102 efficiency (i.e., time to carcass detection and removal, fraction of carcasses removed;
103 Schlacher et al. in press). The expectations were that the scavenger guild in reserves would

104 comprise more raptors that would consume carrion more quickly and completely. Conversely,
105 urban beaches were expected to support scavengers usually associated with human
106 settlements (e.g. crows, gulls, foxes) that may also differ in how efficient they consume
107 beach-cast carrion (sensu Huijbers et al. 2013).

108

109 **2.2 Study area**

110 The effects of small coastal reserves on beach scavenging were measured in southeast
111 Queensland on the east coast of Australia (Fig. 1). This is one of Australia's fastest-growing
112 regions, where much of the population growth and ongoing urbanisation is concentrated in
113 a narrow coastal strip (Noriega et al. 2012). Development is usually aggregated on dunes
114 landwards of ocean beaches, having led to a situation where most coastal dunes have been
115 converted to housing and infrastructure (Lucrezi et al. 2010). Coastal dunes without houses
116 remain only in the form of a few small landscape fragments interspersed between urban
117 areas; several of these fragments have, however, been assigned formal conservation status in
118 the region. (<http://www.nprsr.qld.gov.au/parks/noosa/about.html>.)

119

120 We studied two conservation areas separated by an urbanised stretch of dunes located on
121 the Sunshine Coast (Fig. 1). These reserves, whilst small in extent, represent the only
122 remaining coastal dune fragments assigned formal conservation status outside of larger
123 national parks in the region. The reserves cover 1.8 and 2.1 km of shoreline and are
124 separated by a 5km stretch of developed beach (Fig. 1). As measures of urbanisation we
125 counted, using Google Earth, the number of dwellings and the number of beach access paths
126 crossing the dunes. The spatial unit for these counts were contiguous 0.5 x 0.5 km quadrats
127 aligned parallel to the shore, with the ocean-facing edge of each quadrat positioned at the
128 dune-beach edge.

129

130 **2.3 Field methods**

131 Carrion consumers were sampled using motion-triggered cameras (ScoutGuard SG560Z-8M
132 with digital passive infrared sensors) baited with two fish carcasses each (sea mullet, *Mugil*
133 *cephalus*, a species commonly found in the surf-zone of tropical to temperate beaches
134 worldwide). Cameras were placed at the seaward edge of the dunes where marine carrion

135 naturally accumulates. Deployments were made within 2 h of sunrise and retrieved after 24 h
136 following methods detailed in Huijbers et al (2013).

137

138 We sampled scavengers every 7 days for 13 consecutive weeks from 03 June to 26 August
139 2013, yielding a total of 757 valid records of feeding from 164 successful camera
140 deployments. Forty-four camera deployments were compromised, 19 from reserves and 25
141 from the urban beach. The main reasons for deployment failure were, in descending order
142 frequency: theft, vandalism, removal of fish, malfunction of the camera, and inimical weather
143 factors.

144

145 The locations of camera sites along the shore followed a stratified random design. The
146 coastline in each sector was first divided into equal-length segments, followed by random
147 positioning of deployment sites within individual segments (constrained to fall within 200m
148 of the centre of segments to achieve adequate dispersion); mean distances between sites
149 was 551 m (se 141 m, min. 136 m, max. 858 m). Eight sites were located inside reserves and
150 eight sites outside the reserves on the urban beach (Fig. 1).

151

152 **2.4. Data analyses**

153 Multivariate variation in the species composition of the scavenger assemblages was spatially
154 partitioned with Permutational Multivariate Analysis of Variance (PERMANOVA; Anderson
155 2001), containing the fixed factor '*Reserve*' and the random factor '*Site*' (nested within
156 '*Reserve*'). The same design structure was used for spatial contrasts analysed with
157 Generalized Linear Models for the univariate metrics of scavenging (i.e., time to carcass
158 detection, time to removal of carcass, carcasses removed); models for carcass removal (a
159 binary outcome) used logit-link functions (Quinn and Keough 2002).

160

161 We modelled times to carcass detection and removal (continuous) and the probability of
162 complete carcass removal (binary; defined as an individual fish carcasses being no longer
163 present on the beach after 24 h) in response to several human and biological factors.

164 Saturated Generalized Linear Models (GLZ) contained two human predictor variables, '*houses*'
165 and '*tracks*' (i.e. beach access paths cut through the dunes, connecting the beach with roads,
166 houses and carparks), and nine biological predictors in the form of presence records for a

167 scavenger species in individual camera deployments i.e. 'fox' [red fox, *Vulpes vulpes*], 'dog'
168 [*Canis lupus familiaris*], 'brahminy kite' [*Haliastur indus*], 'torresian crow' [*Corvus orru*], white-
169 bellied sea eagle' [*Haliaeetus leucogaster*], 'white-faced heron' [*Egretta novaehollandiae*], 'rat'
170 [*Rattus* spp.], 'silver gull' [*Chroicocephalus novaehollandiae*], and 'whistling kite' [*Haliastur*
171 *sphenurus*]) Model performance was evaluated using the corrected Akaike Information
172 Criterion (AICc) based on all possible combinations of variables used in model building
173 (Burnham et al. 2011; Symonds and Moussalli 2011). A multi-model inference approach was
174 employed to assess the contributions of individual variables based on their summed Akaike
175 weights (Anderson 2008); summed AICc weights (w_+) provide relative probabilities of
176 variable importance, with variables < 0.3 likely to be of minor or no importance (Burnham
177 and Anderson 2002).

178
179

180 **3. Results**

181 **3.1. The scavenger guild**

182 Dogs, none of which was a native dingo, and torresian crows were the most abundant beach
183 scavengers, recorded in 100 of 164 camera deployments (61 %, Table 1). Three other
184 scavenger species (brahminy kites, red foxes, silver gulls) occurred at moderate to low
185 frequencies of 12 - 21%, whilst all remaining scavengers (whistling kites, white-faced herons,
186 white-bellied sea eagles, rats, cats) were rare, occurring in 2 to 6 deployments only (Table 1).

187

188 The structure of the scavenger assemblage was very similar (Bray-Curtis similarity = 71 %)
189 between beach sectors inside and outside of the small coastal reserves (Table 1; Fig. 2). We
190 detected only a weak (ANOSIM, $R = 0.09$; PERMANOVA, $P = 0.09$) separation of scavenger
191 guild composition between beaches fronting conservation areas and beaches fronting urban
192 areas: both harboured a closely-matched suite of carrion consumers at comparable
193 frequencies (Table 1, Fig. 2).

194

195 Remarkably, domestic dogs occurred, on average, at the same frequency inside the reserves
196 as they did outside (Fig. 3). Birds of prey were generally rare and there was no distinct
197 pattern suggesting significantly higher frequencies of any raptor species inside the reserves.

198 Somewhat paradoxically, in the southern coastal reserve, dogs were recorded at
199 extraordinary high frequency, scavenging on fish carcasses in up to 92% of samples, the
200 highest incidence of scavenging of any one species recorded throughout the study area (Figs.
201 1, 3 & 4).

202

203 Dogs outperformed all other native scavengers in detecting fish carcasses. Dogs were the
204 first scavenger species to feed on fish carcasses on the beach more often than any other
205 species. Out of 164 successful experimental camera deployments, dogs fed first on the
206 carrion 69 times (42%), followed by torresian crows ($n = 58$), then brahminy kites ($n = 14$); all
207 other species detected fish carrion in fewer than seven cases. In terms of the frequency of
208 first encounters per site, dogs most often arrived - as the first scavenger species - at the
209 carrion in nine out of 16 sites (56%), and were second at the carcass in a further four sites. At
210 every site, dogs were amongst the top three species that most often detected a carcass first.

211

212 Mainly because dogs dominated carrion detection throughout the study area, we detected
213 only a weak spatial separation of assemblages based on the composition of species feeding
214 first at carcasses inside and outside of reserves (ANOSIM, $R = 0.12$; PERMANOVA, $P = 0.10$).

215 A higher proportion of carcasses was detected by dogs inside the reserves (48%) than in
216 urban areas (35%), perhaps because most owners unleash their dogs on the beach inside the
217 reserves. Brahminy kites accounted for 14% of first carcass detections in urban areas, but for
218 only 3% inside reserves; all other species showed comparable, and generally low, carrion
219 detection frequencies irrespective of location (Table 1).

220

221 **3.2 Scavenging metrics**

222 Scavengers arrived at carcasses slightly quicker inside the reserves (3.12 ± 0.43 h) than
223 outside (3.75 ± 0.61 h), but means did not differ significantly (GLM, $P = 0.58$). Time to
224 removal of carcasses was highly variable. Although scavengers took, on average, two hours
225 longer to remove carcasses from urban beaches than from beaches bordering conservation
226 reserves, means of removal times did not differ significantly between reserves and urban
227 beaches (reserves: 7.76 ± 0.61 h, urban: 9.99 ± 0.93 h; GLM, $P = 0.23$).

228

229 Of the 328 fish carcasses that we had experimentally deployed, 308 (94%) were completely
230 scavenged (i.e., removed from the beach) within 24 hours. All but five fish, of 174 deployed
231 inside reserves, were removed by scavengers, yielding a 97% scavenging efficiency. By
232 comparison, on urban beaches, overall scavenging efficiency was lower at 90% (139 of 154
233 fish removed). Thus, although carcass removal rates were high in both sectors, the
234 probability of a fish being completely scavenged was significantly (logistic GLZ, $P = 0.014$)
235 higher inside reserves (95CI of pred. removal prob.: 0.93 - 0.99) than on the urban beach
236 (95CI of pred. removal prob.: 0.84 - 0.94, Fig. 4).

237

238 **3.3. Factors shaping scavenging attributes**

239 Scavengers arrived quickest at carcasses in the southern reserve and in the centre of the
240 urban beach. Conversely, carcass detection times were longer at the edges of the urban
241 beach and in the northern conservation area (Fig. 4). Time to contact was best predicted by
242 the presence of crows, dogs and brahminy kites - species that generally detected carrion
243 rapidly after experimental placement. Foxes took markedly longer to detect carrion, most
244 likely a consequence of their nocturnal foraging behaviour (Table 2). The density of houses
245 and tracks were weak predictors of detection time (Table 2).

246

247 All fish were removed by scavengers from the beach at the southern and northern edges of
248 the study area, whereas scavenging efficiency was lower (~80%) at a number of urban sites
249 (Fig. 4). Housing density was the most important predictor of the probability that an entire
250 carcass became scavenged (i.e., removed within 24 h from the beach), with fewer carcasses
251 removed from beach sites that were backed by more houses (Table 2). Foxes, which were
252 captured on cameras more often in the southern conservation reserve – where carcass
253 removal was 100% at three out of four sites inside that reserve - had a positive effect on
254 removal rates, whereas dogs had the opposite effect (Table 2).

255

256 For those carcasses detected by scavengers, time to complete removal was generally
257 shortest at the edges of the study area (Fig. 4). Foxes, which forage nocturnally, were the
258 most important predictor of carcass removal time; foxes generally arrived at carrion much
259 later, but then they scavenged most of the carcasses not previously detected or completely

260 consumed, by diurnal scavengers. A broad suite of other scavengers (rats, white-bellied sea
261 eagles, dogs, and brahminy kites) also affected removal times of carcasses (Table 2).

262

263 Across all three metrics of scavenging efficiency that we modelled (i.e., detection time,
264 removal rate, removal time), the presence of foxes was the most important predictor. Foxes
265 were included in the best model for every predictor and ranked first (time to removal) and
266 second (detection time and removal rate) based on variable weights (Table 2). Dogs ranked
267 second in terms as predictors of scavenging efficiency (Table 2). Thus, an invasive mammal
268 (red fox) and a domestic mammal (dog) explained a large proportion of scavenging patterns
269 on beaches, whereas houses and tracks (essentially proxies for a location effect with respect
270 to urban and conservation areas) were less influential predictors (Table 2).

271

272



273 **4. Discussion**

274 **4.1. Functional reserve performance**

275 Ecosystems globally lose habitat to agriculture, forestry, industry, mining, and expanding
276 human settlements. Conservation areas are often, but not always, effective responses to
277 these threats (Pressey and Bottrill 2009). Significant proximate threats, that continue to
278 transform beaches and coastal dunes worldwide, include extensive habitat conversions by
279 urban development, intensive recreation and tourism, the use of off-road vehicles, and
280 impacts from non-native animals, which can be domestic, invasive, and/or feral (Defeo et al.
281 2009; Schlacher et al. 2007). Conservation areas are, however, uncommon for beaches or
282 seldom effective where they do exist (Harris et al. 2014; Schlacher et al. 2014; Schlacher et al.
283 2013a).

284

285 Here we present data showing that a core ecological function – removal of wave-cast animal
286 carcasses – has switched from native raptors to non-native mammalian carnivores in a beach
287 and dune reserve invaded by domestic dogs and non-native red foxes. By comparison, on
288 regional beaches where these two mammalian species are much less abundant, a large part
289 of scavenging is done by raptors (Huijbers et al. in press; Huijbers et al. 2013). This
290 functional replacement can theoretically be reversed, as reduction or elimination of both
291 foxes and dogs is well within the practicable bounds of active wildlife management (e.g.
292 baiting, shooting), especially in reserves (Dowling and Weston 1999; Kinnear et al. 2002).
293 Arguably, carcass removal continues inside the coastal reserves, suggesting that net
294 ecological function is maintained despite an abundance of dogs and foxes. Whilst dogs and
295 foxes can indeed be efficient consumers of carrion on beaches, their scavenging activity
296 cannot be considered truly functionally equivalent because of the numerous, often massive,
297 deleterious impacts that both foxes and dogs cause to native wildlife in coastal areas of
298 Australia (Schlacher et al. 2014; Weston et al. 2014b).

299

300 **4.2. Foxes and dogs on beaches: ecological implications**

301 Most fundamentally, the role of reserves is to separate elements of biodiversity and
302 ecological function from the processes that threaten their existence in the wild (Sarkar et al.

303 2006). The presence of foxes and the large numbers of domestic dogs that we recorded
304 within reserves run, however, counter to conservation objectives.

305

306 The red fox is a non-native carnivore in Australia, being a formidable exotic species,
307 widespread and abundant across the continent (Letnic et al. 2012). The red fox was
308 introduced in the 1850s and only became established in the 1870s, well after the colonies
309 ceased to be penal settlements. Indeed, it was introduced for the recreational benefit of the
310 squattocracy – a class whose association with the penal colonies was by that stage quite
311 distant.

312

313 Red foxes are generalist predators, consuming, often as cursorial hunters, a broad spectrum
314 of prey items (Mitchell and Banks 2005). Foxes make extensive use of sandy beaches in
315 Australia (Meek and Saunders 2000), and in coastal populations the catholic diet of foxes
316 encompasses carrion that is scavenged from the strandline (Huijbers et al. 2013). Foxes have
317 supplanted similar-sized endemic carnivores in many regions of Australia and now constitute
318 a serious threat to biodiversity, including extirpation of many native vertebrates (McKenzie et
319 al. 2007). Thus, 'fox control' is a widespread management practice in Australia and
320 eradication programs that use a variety of methods (e.g. leg-hold trapping, baiting, hunting,
321 spotlighting, den searches) are carried out by several levels of government (Rout et al. 2013).
322 The local government authority also attempts to control fox populations (both inside and
323 outside the reserve), but our data show that foxes continue to be present throughout the
324 study area, including regular observations of scavenging activity inside reserves (Fig. 1).

325

326 In Australia there is a dog for every six people (Hughes and Macdonald 2013). Dogs have
327 numerous destructive impacts on wildlife (reviewed by Hughes and Macdonald 2013;
328 Weston and Stankowich 2014; Young et al. 2011). On the particular beach sites studied here,
329 dogs have effectively supplanted wild scavengers, particularly raptors, which are the principal
330 diurnal scavengers on other, less urbanised, beaches in the region. Impacts on native wildlife
331 are likely to be in the form of competition for food (i.e., removal of marine carrion washed up
332 naturally on beaches by dogs).

333

334 While our results were unexpected, dogs have previously been implicated as scavengers
335 Castle et al. (2013) providing some rather dramatic, and unexpected, supporting evidence
336 that domestic dogs can be scavengers of dead fish on beaches. Castle et al. (2013) report
337 that red tides along the Texas coasts caused the death of numerous fish that washed ashore
338 on the beaches, and following this carrion pulse, several coyotes and dogs died or had to be
339 euthanized. The likely cause of the canids' deaths was poisoning by presumptive ingestion of
340 toxic dead fish (Castle et al. 2013).

341

342 Animals exposed to carnivores react to predation risks by altering distributions, behaviours
343 or temporal use patterns of landscape elements and resources (Kloppers et al. 2005). It is
344 plausible that dogs also have non-lethal impacts on birds on beaches, possibly via fear-
345 mediated effects. Silva-Rodriguez and Sieving (2012) show that dogs, via predation and non-
346 lethal harassment, shape the landscape-scale distribution of endangered prey species. Thus,
347 when dogs are present on beaches, birds may perceive a 'landscape of fear' (Brown et al.
348 1999; Laundré et al. 2001), possibly contributing to the low scavenging rates by birds
349 recorded in this setting.

350

351 Beyond the scavenger system, effects of dogs in beach and dune ecosystems are likely to be
352 more numerous and severe than consumption of carrion resources, particularly in terms of
353 the impacts of dogs on nesting birds and turtles (Baudains and Lloyd 2007; Burger and
354 Gochfeld 2013; Weston and Elgar 2005). These putative effects remain to be quantified for
355 the reserve in question.

356

357 **4.3. Dog management on beaches**

358 Managing dogs on beaches is a complex and often highly politically issue (Miller et al. 2014;
359 Williams et al. 2009). Fundamentally, because people hold diverse and opposing views about
360 dogs in the environment, managing dogs is often about managing people, their
361 expectations, behaviours, and attitudes (Holmberg 2013). Most coastal managers have to
362 address competing issues, and managing dogs on beaches can therefore be considered not
363 to be fundamentally different from managing beaches and dunes for other types of uses
364 (Dugan et al. 2010; Schlacher et al. 2006). However, major differences are that the presence
365 of dogs is often incompatible with conservation objectives (Weston and Stankowich 2014;

366 Young et al. 2011), and that environmental impacts attributable to dogs are more severe
367 than those resulting from other recreational activities, except the highly destructive
368 consequences of driving off-road vehicles (Schlacher et al. 2013d; Weston et al. 2014b).

369

370 Zoning of beaches for different forms of dog use (e.g. off-leash, on-leash always, on-leash
371 temporary) is widely practiced, but compliance with leasing regulations is often low and dog
372 zoning is rarely done for conservation objectives. Dogs can be a public health issue (e.g. risk
373 of infections and bites; Kennedy and Collignon 2008). Zoning tries to reduce this risk by
374 excluding dogs from popular swimming areas or regulating for them to be leashed there at
375 all times. Dogs are allowed off the leash on the fringes or outside of recreation nodes; this
376 practice concentrates dogs in parks and nature reserves where conflicts with wildlife become
377 amplified (cf. Fig. 1). This type of zoning partly explains the prevalence of dogs reported by
378 us inside the reserves bordering urban beaches: dogs spill over into conservation areas in
379 large numbers as a result of being banned in urban nodes, and because dog walkers seek
380 more 'natural' environs for their canine's leisure activities where they can let their dogs run
381 free (see also (Maguire et al. 2013). Thus, current practices in urban planning may have
382 paradoxical outcomes for wildlife, concentrating dogs in conservation areas. This situation –
383 dogs being quasi ubiquitous in public green spaces and becoming concentrated in reserves
384 – is not uncommon elsewhere (Weston et al. 2014a). It calls for land-use planning decisions
385 to more clearly articulate the precise objectives of green spaces (e.g. dog recreation, wildlife
386 conservation, non-dog recreation), and to avoid mixing of use types that are inherently
387 incompatible (e.g. free-ranging dog exercise areas versus bird habitats).

388

389 If we accept that dogs can in certain situations create a landscape of fear (plausible but not
390 demonstrated at our study site), dogs may have unusual applications in wildlife management.
391 For example, dogs could be used to control the distribution of wildlife species conflicting
392 with human interests (e.g., displacing or changing the behaviour of herbivores in agricultural
393 areas or forestry plantations; Cromsigt et al. 2013; Miller et al. 2001). This thought-provoking
394 logic for morphing dogs into a management tool to intentionally displace animals applies -
395 in reverse - in a conservation context: dogs should, logically, be displaced from nature
396 reserves to avoid the displacement of native wildlife from reserves.

397

398 **5. Conclusions**

399 Reserves – designed to separate wildlife from human pressures – are a pivotal instrument in
400 biological conservation (Huijbers et al. 2014). We asked the general question whether small
401 reserves established for sandy beaches and coastal dunes can maintain ecological function,
402 where function was defined as the removal of wave-cast marine animal carcasses from the
403 shore by vertebrate scavengers. Carcass consumption was rapid and near-complete both
404 inside and outside reserves. However, this ecological function was fulfilled by invasive red
405 foxes and domestic dogs who dominated the scavenger guilds, a situation quite distinct
406 from raptor-dominated scavenging in larger reserves backed by less urbanised areas in the
407 region. Because dogs and red foxes severely impact native wildlife in Australia, biological
408 efficiency in terms of carcass removal does not constitute ecological equivalency because it
409 comes at a high environmental cost. Thus, controlling dogs and foxes in coastal reserves and
410 elsewhere is critical to maintain ecosystem function. Dog management in particular, calls for
411 fresh approaches that better address multiple expectations of society whilst recognising the
412 incompatibility of coastal wildlife and canids.

413

414

415 **6. Acknowledgements**

416 This study was partly funded by a grant from the local government authority, Sunshine Coast
417 Council, to TAS.

418

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578 **Table 1**

579 Comparison (based on SIMPER analysis) between urban beaches and reserves for A - species detected
 580 first at carcasses, and B - all species detected as interacting with carcasses during a 24 hour
 581 deployment period of baited camera traps. Bold values denote higher frequency of occurrence in
 582 either the reserves or urban sites.
 583

A – species first detecting a carcass

Species	Reserves (proportion of camera deployments)	Urban (proportion of camera deployments)	Diss/SD	Contrib%
Dog	48%	35%	1.13	20.36
Brahminy kite	3%	14%	0.94	18.78
Silver gull	7%	1%	0.98	13.99
Whistling kite	0%	5%	0.98	12.35
Fox	5%	4%	0.95	12.14
Torresian crow	36%	35%	1.28	11.23
White-faced heron	0%	5%	0.53	8.32
White-bellied sea eagle	1%	0%	0.37	2.83

B – all species interacting with carcass during deployment

Species	Reserves (proportion of samples)	Urban (proportion of samples)	Diss/SD	Contrib%
Red fox	22%	21%	1.30	16.75
Brahminy kite	20%	23%	1.38	15.78
Silver gull	13%	12%	1.27	14.80
Whistling kite	1%	6%	1.21	11.79
Dog	64%	57%	1.55	10.39
White-faced heron	0%	6%	0.73	8.42
Rat	3%	0%	0.76	6.67
White-bellied sea eagle	3%	1%	0.66	6.03
Torresian crow	60%	62%	1.02	4.96

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589 **Table 2**

590 Contributions of variables to GLZ models used to predict three metrics of scavenging efficiency: 1)
 591 time between carcass placement and the first scavenger species arriving at a carcass (*'Time to*
 592 *Detection'*), 2) the proportion of fish carcasses removed (*'Carcasses removed'*), and 3) the time
 593 between carcass deployment and its removal (*'Time to Removal'*).

594 Variable contributions are assessed in a multi-model inference approach using cumulative weights,
 595 $w+(j)$. Variables in bold, and marked with *, are included in the best (i.e. lowest AICc) model for a
 596 particular metric. Variables are ordered by their mean rank across the three metrics of scavenging.

597

Predictor Variable	1 - Time to detection		2 - Carcasses removed		3 - Time to removal	
	$w+(j)$	'best' model	$w+(j)$	'best' model	$w+(j)$	'best' model
Red fox	0.99	*	0.58	*	1.00	*
Dog	0.94	*	0.45	*	0.71	*
Brahminy kite	0.82	*	0.47	*	0.59	*
Tracks	0.51		0.34		0.92	*
Torresian crow	0.99	*	0.34		0.37	
Houses	0.35		0.88	*	0.40	
White-bellied sea eagle	0.41		0.35		0.78	*
White-faced heron	0.41		0.50		0.30	
Rat	0.33		0.31		0.99	*
Silver gull	0.42		0.27		0.44	
Whistling kite	0.42		0.26		0.26	

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602 **Figure Captions**

603

604 **Fig. 1** Location of the study sites in Eastern Australia, comprising two small coastal conservation
605 reserves (green triangles) to the north and south of an urban beach (red circles). Scavengers were
606 surveyed with camera traps baited with fish at the dune-beach interface to mimic the stranding of
607 marine animal carcasses on the upper part of the sandy shore. Animal symbols (foxes and dogs)
608 represent the frequency at which each of these two carnivores was recorded in repeated camera
609 surveys. The labels 'dog', 'crow' and 'brahminy kite' denote which species was most often the first
610 scavenger to feed at the fish carcasses.

611

612 **Fig. 2** Ordination diagrams (PCO – Principal Coordinate Analysis) illustrating variation in species
613 composition of the scavenger assemblages based on a) species that detected carcasses first, and b)
614 the full suite of species feeding at carcasses over the deployment period.

615

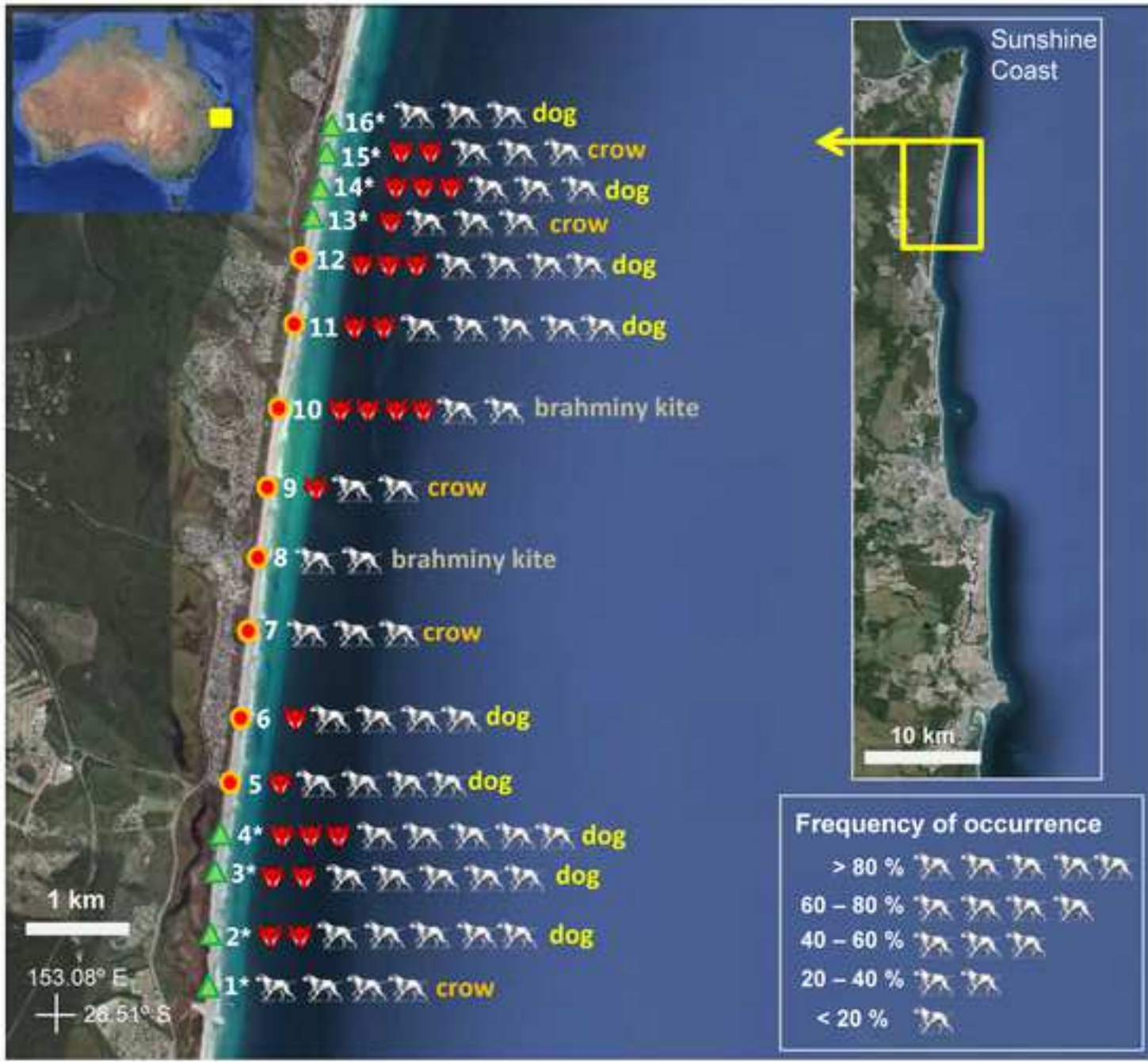
616 **Fig. 3** Spatial patterns in beach land-use (top) and in the abundance of vertebrate scavengers (b-g)
617 that forage at the interface between the dunes and the sandy shore. Abundance estimates for
618 vertebrate scavengers are derived from repeated camera-trap surveys using experimentally-placed
619 fish carcasses, at eight sites located in two small coastal reserves (green triangles) and eight sites
620 fronting an urban beach (red circles). Bars on the right margin of each panel represent the 95%
621 confidence intervals for abundance estimates inside (green) and outside (red) reserves.

622

623 **Fig. 4** Spatial variation in scavenging as measured by three complementary metrics: a) time elapsed
624 before scavengers make contact with a deployed carcass, b) the fraction of carcasses completely
625 scavenged (i.e., removed from the site by a scavenger within 24 hours), and c) time elapsed between
626 carcass deposition and removal.

627

Figure 1
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▲ Conservation Reserves ● Urban Beaches

Figure 2

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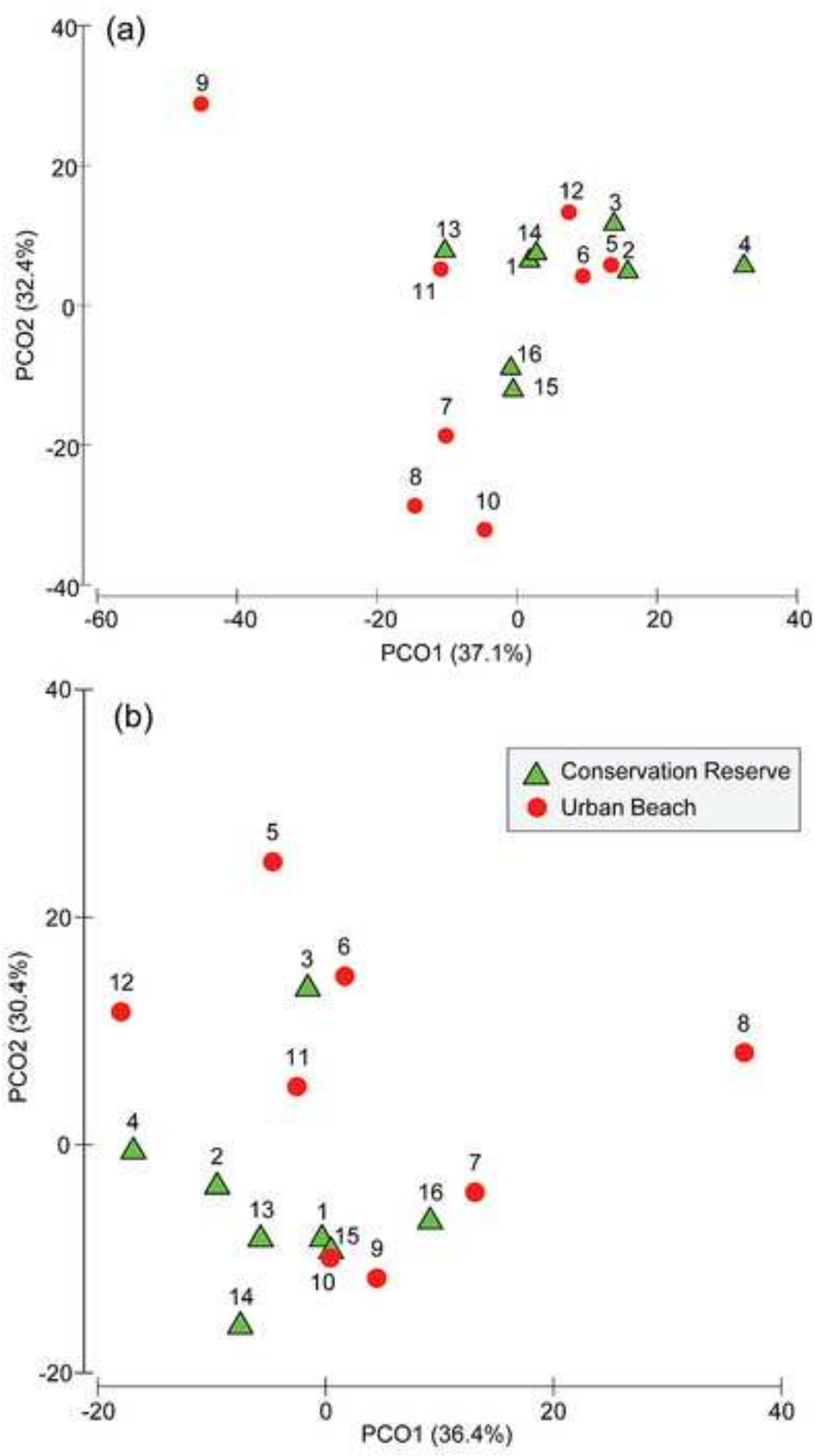


Figure 3

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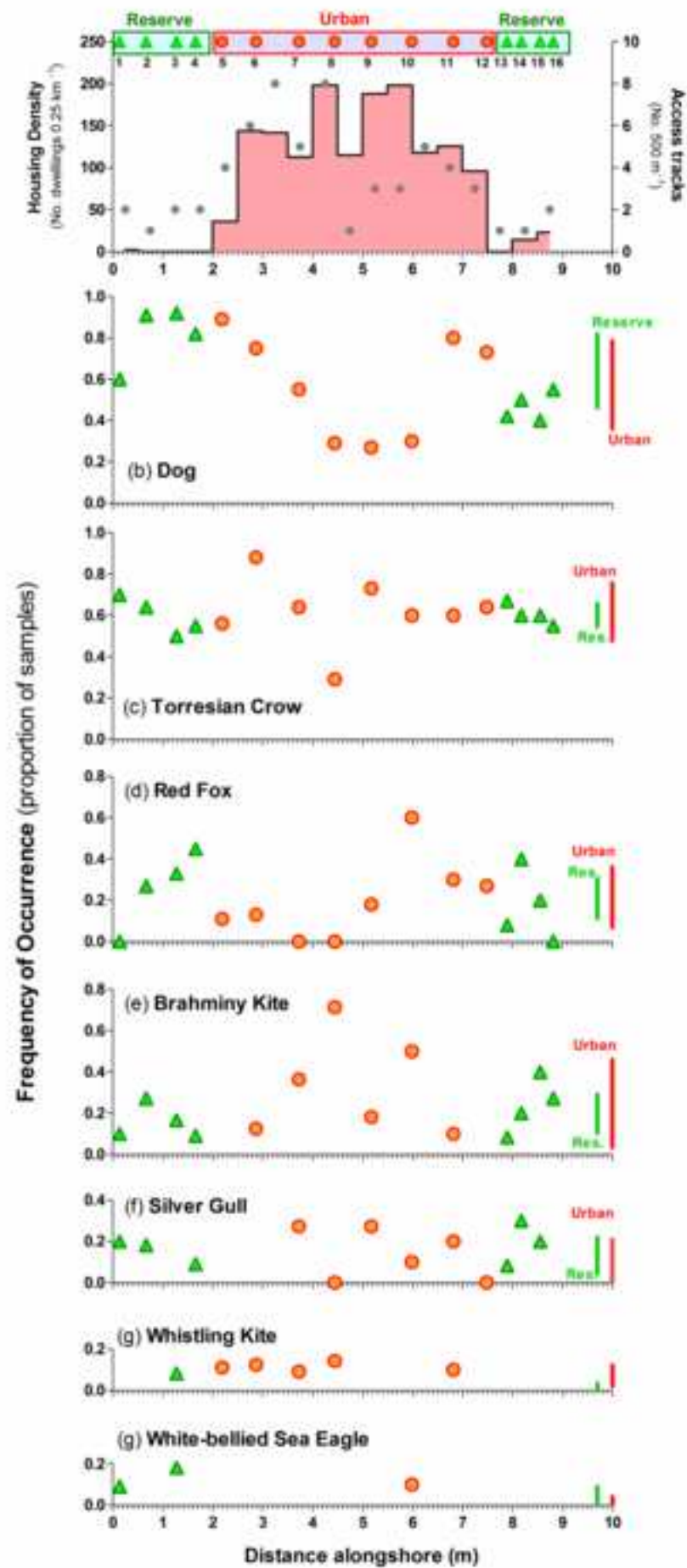


Figure 4

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