

1 **Factors affecting the prey preferences of jackals (Canidae)**

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33

34 **Abstract**

35 Prey selection by carnivores can be affected by top-down and bottom-up factors. For
36 example, large carnivores may facilitate food resources for mesocarnivores by providing
37 carcasses to scavenge, however mesocarnivores may hunt large prey themselves, and their
38 diets might be affected by prey size and behaviour. We reviewed jackal diet studies and
39 determined how the presence of large carnivores and various bottom-up factors affected
40 jackal prey selection. We found 20 studies of black-backed jackals (*Canis mesomelas*) from
41 43 different times or places, and 13 studies of Eurasian golden jackals (*Canis aureus*) from
42 23 different times or places reporting on 3900 and 2440 dietary records (i.e. scats or stomach
43 contents), respectively. Black-backed jackals significantly preferred small (< 30 kg) ungulate

44 species that hide their young (duiker *Sylvicapra grimmia*, bushbuck *Tragelaphus scriptus* and
45 springbok *Antidorcas marsupialis*), and avoided large (> 120 kg) hider species and follower
46 species of any body size. They had a preferred and accessible prey weight range of 14-26 kg,
47 and a predator to ideal prey mass ratio of 1:3.1. Eurasian golden jackal significantly prefer to
48 prey on brown hare (*Lepus europaeus*; 4 kg), yielding a predator to preferred prey mass ratio
49 of 1:0.6, and a preferred and accessible prey weight range of 0 – 4 kg and 0 – 15 kg,
50 respectively. Prey preferences of jackals differed significantly in the presence of apex
51 predators, but it was not entirely due to carrion availability of larger prey species. Our results
52 show that jackal diets are affected by both top-down and bottom-up factors, because apex
53 predators as well as prey size and birthing behaviour affected prey preferences of jackals. A
54 better understanding of the factors affecting jackal prey preferences, as presented here, could
55 lead to greater acceptance of mesocarnivores and reduced human-wildlife conflict.

56

57 **Introduction**

58 Adequate nutrition affects the fitness of an individual, and is crucial for its survival
59 and reproductive success. Therefore, natural selection should theoretically select for
60 behaviours that augment efficient feeding (Krebs, 1978). Optimal foraging theory states that
61 animals forage in a way that maximizes their net rate of energy intake and subsequently their
62 fitness; resulting in an optimal diet (Pyke, 1984; Pyke et al., 1977). While the evolutionary
63 adaptations of large carnivores to optimal foraging via preferential predation are well studied
64 (Clements et al., 2016; Hayward et al., 2016; Hayward et al., 2014; Krause and Godin, 1995),
65 the optimal foraging strategies of mesocarnivores are poorly known. These might be affected
66 by top-down factors, such as the presence of larger carnivores, as well as bottom-up factors,
67 such as prey size, abundance, behaviour and habitat.

68 Larger carnivores can affect the prey selection of mesocarnivores through competition
69 by: i) direct interference between individuals of the competing species or ii) exploitation of a
70 shared food resource (Linnell and Strand, 2000). Yet, there are also commensal interactions
71 between species where one benefits from the interaction while the other is not affected, such
72 as the provisioning of carcasses for another species to scavenge from (Selva and Fortuna,
73 2007). Each of these top-down interactions may affect the prey preferences of
74 mesocarnivores.

75 Jackals are typical mesocarnivores (5-15 kg) and generally are considered to be
76 opportunistic generalist predators (Giannatos et al., 2010; McKenzie, 1997; Nowak, 1999;
77 Van de Ven et al., 2013), or temporarily food specialists (Fourie et al., 2015; Lanszki et al.,
78 2006) that perform valuable ecosystem services (Ćirović et al., 2016). However extensive
79 research on predator prey preferences illustrates this generalisation is rarely the case, with
80 bottom-up effects also influencing diet (Hayward et al., 2012; Hayward and Kerley, 2005).
81 Side-striped jackals *Canis adustus* are considered omnivorous scavengers, while black-
82 backed *C. mesomelas* and the golden jackals are thought to be more predatory but still
83 omnivorous (scientific names of other species are in Table 1; Nowak, 1999). In Hwange,
84 Zimbabwe, for example, side-striped and black-backed jackals had high dietary overlap
85 (Loveridge and Macdonald, 2003). Jackal dietary flexibility enables them to respond to
86 seasonal or other fluctuations in prey availability (Kaunda and Skinner, 2003). Rodents are a
87 key component of the diets of jackals (Atkinson et al., 2002), but except for special cases
88 (Klare et al., 2010; Lanszki et al., 2006), this reliable source of small packages of high energy
89 yielding prey may not be sufficient for jackals to have evolved to optimally forage upon them
90 as many prey may be required to satisfy the 168-240 g daily dietary requirements of jackals
91 (Mukherjee et al., 2004). The slightly larger Ethiopian wolf's (*Canis simensis*) specialization
92 on rodent prey is thought to reflect the abundance and reliability of these rodents in its

93 Afroalpine habitat, but may also lead to the restricted distribution and population size of this
94 species (Sillero-Zubiri et al., 1995).

95 Foraging group size may affect the predation patterns of jackals as they live in pairs
96 and family groups and have also been observed hunting and foraging in pairs or alone
97 (Lamprecht, 1978; Macdonald, 1979). Similarly, different habitats may affect predation
98 patterns due to different encounter rates. For example, small animals obtain more refuge in
99 areas of dense vegetation, therefore encounter rates between them and jackals would be low
100 (Stokes et al., 2004). Competition between sympatric black-backed and golden jackals (now
101 considered African jackals; Koepfli et al., 2015) in Kenya was predicted to be low due to
102 habitat and diet resource partitioning (Fuller et al., 1989). Similarly, in the Serengeti, black-
103 backed jackals preferred areas of denser vegetation and around the perimeter of the plains
104 whilst golden jackals mostly occurred in the open plains (Wyman, 1967). Black-backed
105 jackals in Hwange displaced side-striped jackals from optimal grassland habitats through
106 their higher levels of aggression, driving them into woodland and scrub (Loveridge and
107 Macdonald, 2002). Prey communities, encounter rates and hunting efficiencies likely differ
108 between habitats. Thus, habitat type is expected to affect jackal diets, although the extent is
109 unknown.

110 Ungulate size and behaviour appears to have a large influence on jackal prey
111 selection. On game farms in South Africa, black-backed jackals had a strong selection for
112 hidiers (Klare et al., 2010), ungulates in which the females give birth away from the herd and
113 hide neonates in vegetation for the first weeks of their lives (Estes, 1999). In contrast, jackals
114 avoided followers (Klare et al., 2010), whose neonates immediately follow the mother after
115 birth, and are sheltered within the herd (Estes, 1999). Similar results were found in eastern
116 Africa, where black-backed and golden jackals were considered to be major predators of
117 gazelles, which are small, hider species, especially during birthing periods (Lamprecht, 1978;

118 Moehlman, 1983; Wyman, 1967). Among hiders, smaller species were more susceptible to
119 jackal predation than larger species (Klare et al., 2010), indicating jackal predation is
120 influenced by ungulate body size. Other factors, such as prey weaponry and aggressive
121 nature, may also influence jackal prey selection due to the greater risk of injury, although this
122 has never been studied in jackals, but is influential in other predators, like cheetahs *Acinonyx*
123 *jubatus* (Clements et al., 2016; Hayward et al., 2006b). In general, the patterns of jackal prey
124 preferences across their range are unknown, and additional factors, such as the presence of
125 large carnivores, might alter the influence of ungulate behaviour on jackal prey preferences.

126 Livestock predation by both black-backed jackals and golden jackals induces conflict
127 with humans, and patterns of such predation are uncertain (Lawson, 1989; McShane and
128 Grettenberger, 1984; Rowe-Rowe, 1975; Yom-Tov et al., 1995). If predation on livestock by
129 jackal occurs, it might be influenced by livestock type and behaviour. For example, the diet
130 of black-backed jackals on small livestock farms in South Africa comprised 25-48% sheep
131 *Ovis aries* across seasons, although jackals did not consume goat *Capra hircus* or cattle *Bos*
132 *taurus* (Kamler et al., 2012). In contrast, golden jackals were found to predate on cattle calves
133 in Israel (Yom-Tov et al., 1995). However, wild prey, including small mammals and
134 ungulates, were consistently selected over sheep in South Africa, indicating that jackals do
135 not preferentially prey upon livestock (Kamler et al., 2012).

136 This study aimed to determine the prey preferences of jackals. As jackals are below
137 the 21.5 kg body mass threshold that dictates preferential predation on large body mass,
138 vertebrate prey (Carbone et al., 1999; Macdonald et al., 2004a), we hypothesised that jackals
139 will be small vertebrate specialists. We investigated the role that apex carnivores, a top-down
140 factor, play in structuring jackal dietary preferences. We also investigated how various
141 bottom-up factors, including prey size, prey behaviour, and habitat, as well as livestock type,
142 affects jackal prey preferences. This provides the ability to predict the diet of jackals

143 (following Hayward et al., 2007) is important due to their potential for human-wildlife
144 conflict via predation on game animals and livestock and also due to their recent range
145 expansion (Rutkowski et al., 2015; Trouwborst et al., 2015).

146

147 **Materials and methods**

148 We recognise that golden jackals have recently been split into a Eurasian *Canis*
149 *aureus* and African *C. anthus* species (Koepfli et al., 2015; Rueness et al., 2011), however
150 few studies are available for the African species. Similarly, there is insufficient dietary
151 information on the side-striped jackal *C. adustus* coupled with prey availability to allow
152 analysis (notwithstanding Atkinson et al., 2002; Loveridge and Macdonald, 2003). Hence,
153 this study explores the prey preferences of black-backed and Eurasian golden jackals (golden
154 jackals hereafter) only.

155 Simple dietary summaries reveal little about animal ecology. Species that occur more
156 prominently in the diet could do so because they are the only species present or the most
157 abundant in the area, or it may be a result of the carnivore selectively preying on that species
158 (Hayward and Kerley, 2005). Hence, prey abundance data are crucial to interpret diet
159 preferences. If a species is killed more frequently than expected based on its availability, it
160 can be assumed that it is preferred, but if it is killed less than expected based on availability,
161 that species is avoided.

162 We obtained data on jackal diet up until March 2015 by searching Google Scholar,
163 Web of Science and grey literature, such as dissertations and reports, using keyword searches
164 for *diet** OR *predation* OR *food* AND *jackal* OR *Canis*. Many studies had useful details on
165 jackal diet yet were excluded from the analysis (Atkinson et al., 2002; Bothma, 1971;
166 Giannatos et al., 2010; Loveridge and Macdonald, 2003; Macdonald et al., 2004b; Markov

167 and Lanszki, 2012; McShane and Grettenberger, 1984; Van de Ven et al., 2013) due to; i)
168 insufficient or no information on prey actual or relative abundance/densities or ii) inability to
169 locate these data from other sources. Continuous observation is generally considered the
170 superior method of determining the diet of predators (Mills, 1992). This type of data is
171 particularly challenging to obtain for smaller predators, such as jackals, which are inherently
172 evasive. Therefore, the studies featured herein relied on scat (n = 64) and stomach content
173 analyses (n = 2; Supplementary Materials). In some cases, this could bias against larger prey
174 species (Mills, 1992), but as studies on both species and sites with/without apex predators
175 were dominated by scat analyses, we do not think this will affect our comparative results.
176 Furthermore, the two stomach content studies were included because they may counter the
177 biases associated with scat analysis (Mills, 1992).

178 There are many indices that researchers have used to define selectivity, however, none
179 is without bias or increasing error with small sample sizes (Chesson, 1978). We used the
180 Jacobs index, which minimizes these biases and relates actual or relative prey abundance to
181 actual or relative diet (Jacobs, 1974), for this study. We used relative frequency of occurrence
182 of prey items in scats as the measure of diet because we were focusing on the numerical
183 preferences of jackals for prey species. We relied on the authors of the studies we used for
184 their estimates of prey abundance, but we acknowledge that the methods used varied and this
185 may be a source of error. Jacobs' index varies between +1 and -1, where +1 shows maximum
186 preference and -1 shows maximum avoidance (Jacobs, 1974). The mean Jacobs index (D) for
187 each prey species was calculated and these values were tested for significant avoidance or
188 preference using t -tests against the mean of 0, where data were normally distributed, or a sign
189 test if not. This type of analysis is not biased by results from one particular area because, for a
190 species to be significantly preferred or avoided, several studies must have produced similar
191 results (Lyngdoh et al., 2014). We determined whether sample size affected our prey

192 preference estimates using regression models of Jacobs' index against sample size for all
193 species with >4 studies where predation for a species was recorded.

194 Jackals are generally thought to eat small to medium-sized prey (Gittleman, 1985;
195 Nowak, 1999) and particularly newborn ungulates (Klare et al., 2010), so we used $\frac{3}{4}$ of mean
196 adult female body mass to account for juveniles and sub-adults killed following previous
197 studies (Jooste et al., 2013; Table 1). Social organisation of prey species, their habitat use
198 and their threat to predators can also affect a predator's ability to capture the prey and prey's
199 ability to detect predators (Hayward and Kerley, 2005). We used a categorical variable of
200 social organisation with 1 relating to solitary individuals, 2 relating to pairs, 3 to small family
201 groups, 4 to small herds (10-50) and 5 to large herds (>50; Table 1). A categorical habitat
202 variable was also used with 1 referring to open grasslands, 2 to savannah or open woodland
203 and 3 to densely vegetated areas. Some species may occur in multiple habitats, in which case
204 an average was used (Table 1). We estimated the likely threat of each prey species based on
205 their possession of weaponry, aggressive nature and body size (where 0 = no likelihood of
206 injury; 1 = potential for injury; 2 = potential for death; Table 1). Birthing strategies of
207 ungulates can be classified into three types: 1) neonate hiders; 2) neonates followers; and 3)
208 unknown (Estes, 1999). Because birthing strategy of ungulates was shown to affect prey
209 preferences by black-backed jackals (Klare et al., 2010), this variable was included in the
210 model for ungulates. Body mass, herd size, habitat use, potential threat and birthing strategy
211 data were taken from Nowak (1999). Some prey species of golden jackal were grouped into
212 categories because the species of cervids, birds or rodents consumed was not always stated.
213 We tested whether these covariates influence jackal prey preferences using generalised linear
214 models with Gaussian distributions and identity link functions on non-correlated variables.
215 We evaluated all possible combinations of models derived from the covariates. Model
216 selection occurred using Akaike's information criterion (AIC) within a maximum likelihood

217 framework (Akaike, 1973, 1974). We used the sum of Akaike's weights (w_i) to determine the
218 relative strength of each covariate with strongly supported models having ΔAIC of < 2
219 (Burnham and Anderson, 1998). We also presented model averaged parameter estimates
220 using the full suite of models. Strongly supported relationships among individual variables
221 were plotted using linear or loess best fit models.

222 At some sites, jackals occur sympatrically with larger carnivores, which may affect
223 their diet via competition, intraguild predation risk or facilitation through jackals scavenging
224 the carcasses of larger carnivore kills. It is difficult to distinguish kills from scavenging and,
225 as were relied on studies using scat and stomach contents, whether they were scavenged or
226 killed is unknown. To overcome this constraint, independent t -tests or Mann-Whitney U-tests
227 were carried out on the Jacobs' index values of each prey species that occurred in sites with
228 and without apex predators to determine whether apex carnivore presence had a significant
229 affect. The presence of one or more of lion *Panthera leo*, leopard *P. pardus*, cheetah, African
230 wild dog *Lycaon pictus*, spotted hyaena *Crocuta crocuta* and/or gray wolf *Canis lupus* was
231 considered as the occurrence of an apex predator, notwithstanding the fact that sometimes
232 jackals dominate interactions with some members of this guild. We used our knowledge of
233 the study sites or the dietary publications themselves to define the presence or absence of
234 apex predators at a site. We calculated the Shannon-Weiner diversity index (H) to compare
235 the prey available at sites with and without apex predators for each jackal species. We also
236 conducted an ANOVA to test whether Jacobs' index values for each species were affected by
237 birthing strategy and the presence/absence of apex predators.

238 We identified the *accessible* prey weight range following the break point analysis
239 using segmented models following Clements et al. (2014). The accessible prey weight range
240 range refers to the size of prey potentially killed by a predator and is most likely to
241 encompass the preferred weight range of earlier prey preference studies (Clements et al.,

2014), which we estimated from loess smoothed plots of mean species Jacobs' index scores against body mass (Hayward et al., 2014). We calculated the *ideal* prey mass as the mean body mass of those species that were significantly preferred. We estimated the body mass of jackals as 7 kg, which was the lower range of adult female body mass (Nowak, 1999) and used this to determine the predator to prey mass ratio by dividing the ideal prey mass of prey by 7.

All analyses were conducted in R (Barton, 2013; R Core Development Team, 2008). Mean (± 1 S.E.) values are presented throughout.

250

251 **Results**

252 We found 20 studies of black-backed jackals from 43 different times or places over a
253 total period of 56 years, and 13 studies of golden jackals from 23 different times or places
254 over 47 years (Supplementary Materials). These reported on 3900 black-backed jackal scats
255 and 2440 golden jackal scats or stomach contents (Supplementary Materials). There was
256 spatial bias in the location of the studies we could use, with no records of black-backed jackal
257 diet studies from the East African sub-population, and no records of golden jackal diets from
258 west Asia and the Middle East (Fig. 1). We were unable to find any dietary studies of side-
259 striped or African golden jackals that included prey abundance data.

260 Out of 23 prey species with >4 records, there was no effect of sample size on the prey
261 preference estimates of black-backed jackals for 20 (Supplementary Material Fig. 1).
262 Bushbuck ($r^2 = 0.16$, $n = 27$, $p = 0.001$) and steenbok ($r^2 = 0.11$, $n = 19$, $p = 0.0497$)
263 exhibited negative relationships largely driven by no records of their predation at higher
264 sample sizes, while common duiker prey preference increased with larger sample size ($r^2 =$
265 0.09 , $n = 20$, $p = 0.046$). There was no effect of sample size on golden jackal prey preference

266 estimates (Supplementary Material Fig. 2). The infrequency of these relationships, the low
267 predictive power of these relationships, and the counterintuitive bias towards no records of
268 predation events at larger sample size give us confidence that our results are not unduly
269 biased by small sample size.

270 The most abundant prey at black-backed jackal study sites were rodents (relative
271 abundance within the prey community = 0.91 ± 0.06 or 91% of the available prey
272 community), impala (0.29 ± 0.06) and hares (0.24 ± 0.24); while small mammals ($0.74 \pm$
273 0.10), chital (0.33 ± 0.09) and cattle (0.18 ± 0.06) had the highest relative abundance at
274 golden jackal study sites (Table 1). Black-backed jackals most frequently consumed birds
275 ($45.4 \pm 11.8\%$ of diet), sheep ($42.7 \pm 4.5\%$) and impala ($26.3 \pm 0.6\%$) where they were killed,
276 while golden jackals primarily consumed small mammals ($76.1 \pm 6.7\%$), chital ($33.4 \pm 8.7\%$)
277 and rodents ($19.9 \pm 13.3\%$; Table 1). Black-backed jackals consumed springhare, hares,
278 birds, rodents, sheep, marine mammals and oribi; and golden jackals consumed sambar, roe
279 and red deer, hares, nilgai, chital and rodents wherever they were sympatric (Table 1). The
280 most frequently consumed items for black-backed jackals were kudu (consumed at 22 sites),
281 bushbuck (18) and warthog (16), while golden jackals mainly consumed small mammals
282 (11), wild boar (11) and pheasant (10; Table 1).

283

284 *Jackal prey preferences*

285 Black-backed jackals significantly prefer to consume birds, common duiker,
286 bushbuck and springbok, and significantly avoid hares, blesbok, kudu, springhares, warthog,
287 buffalo, small mammals, aardwolf, red hartebeest, eland, plains zebra, and wildebeest, and
288 central tendency theory suggests that with a larger sample size they will significantly avoid
289 giraffe, common reedbuck, ostrich, elephant, cattle, tsessebe, goats, sable, nyala, klipspringer

290 and baboon (Table 1; Fig. 2). The mean mass of significantly preferred prey for black-backed
291 jackal is 21.7 ± 3.5 kg (3/4 adult female body mass), yielding a predator to preferred prey
292 mass ratio of 1:3.1.

293 European golden jackal significantly prefer to consume brown hare and significantly
294 avoid cervids in general, and red deer specifically, langur monkeys, pheasant and small
295 mammals (Table 1; Fig. 2). When small mammals and rodents are combined, they are
296 consumed according to their availability ($D = -0.19 \pm 0.12$; $t_{15} = 1.52$, $p = 0.149$). The mean
297 mass of golden jackal preferred prey (3/4 adult female brown hare body mass) is 4 kg,
298 yielding a predator to preferred prey mass ratio of 1:0.6. There is no evidence for a preference
299 for any livestock type by either jackal species (Table 1).

300 Black-backed jackals lived at sites with significantly more prey species present than
301 did golden jackals (9.7 ± 0.8 cf 5.3 ± 0.3 ; $t_{22} = 8.31$, $p < 0.001$), but were more specific in
302 preferentially consuming a significantly lower proportion of those available prey species (24
303 $\pm 4\%$ cf $35 \pm 4\%$; $t_{22} = 3.01$, $p = 0.013$). There was no difference in the number of species
304 consumed or the number preferred between the jackal species (black-backed jackal species
305 consumed = 4.6 ± 0.3 , species preferred = 2.2 ± 0.2 ; golden jackal species consumed = $4.9 \pm$
306 0.3 , preferred = 1.9 ± 0.2 ; Fig. 3). Nonetheless there were highly significant relationships
307 between the number of prey at a site and the number of species consumed and preferred (Fig.
308 3).

309

310 *Factors affecting jackal prey preferences*

311 The generalised linear model of prey preferences by black-backed jackals revealed
312 three models with strong support, and these consisted of prey body mass (twice) and threat
313 (once) as the explanatory variables (Table 2; Fig. 4). These two variables were more than

314 twice as influential in driving black-backed jackal prey preferences as herd size, prey
315 abundance, habitat or prey birthing strategy (Table 2). The segmented model supported this
316 and showed that black-backed jackals have a preferred and accessible prey weight range of
317 14 to 26 kg (Table 3; Fig. 5).

318 Black-backed jackals exhibited different diet preferences in the presence/absence of
319 apex predators. Where apex predators were present, black-backed jackals had significantly
320 greater preference for buffalo ($t_{10} = -2.27, p = 0.047$) and impala ($W_7 = 14, p = 0.045$), and
321 significantly less for bushbuck ($t_{24} = 2.72, p = 0.012$; Fig. 6). This difference was not driven
322 by differences in the relative abundance of prey species at sites with and without apex
323 predators for any species except for impala ($W_7 = 10, p = 0.015$), which were significantly
324 less common at sites with apex predators (14% of the available prey community) than
325 without (50%). Despite this difference in dietary richness when apex predators are present,
326 there is a greater dietary diversity at sites with apex predators ($H' = 0.70$) than without ($H' =$
327 0.42). Overall, there was a significant difference in Jacobs' index between birthing strategies
328 with hiders preferred more than follower species, but there was no significant difference in
329 Jacobs' index between the presence or absence of apex predators (Fig. 6). Black-backed
330 jackals consume prey of similar size at sites with (32.3 ± 4.9 kg) and without apex predators
331 (24.8 ± 7.7 kg; $t_{352} = 0.800, p = 0.423$).

332 The generalised linear model of diet preferences drivers of golden jackals revealed
333 strong support for two models with body mass as the key explanatory variable (Table 2).
334 Body mass was three-times as important in explaining golden jackal diet preferences as any
335 other variable ($\Sigma w_i = 0.54$; Table 2). Jacobs' index values were highest at body masses below
336 4 to 5 kg (Fig. 4). This was confirmed by the segmented models showing strong support for
337 three, four and five break points (Table 3) indicating a preferred prey weight range of 0 – 5
338 kg, and an accessible prey weight range of 0 – 15 kg (Fig. 5).

339 For golden jackals, wild boar were preferred at sites without apex predators and were
340 significantly less preferred where apex predators were present (apex predators present
341 Jacobs' index $D = -0.25$; absent $D = 0.29$; $t_{8.5} = 2.310$, $p = 0.048$). Similarly, pheasants were
342 significantly more avoided in the presence of apex predators (apex present $D = -0.46$, apex
343 absent $D = -0.27$; $t_{1.4} = 0.001$, $p = 0.631$). There was no difference in the relative abundance
344 of these species at sites with and without apex predators ($p > 0.05$).

345

346 **Discussion**

347 Jackals are generally considered to be opportunistic, generalist predators – taking
348 whatever prey is available - however our results show this is not the case as both focal
349 species exhibit distinct preferences for specific species and particular body mass ranges. For
350 black-backed jackals, this preference is not for small vertebrates (as predicted by their body
351 mass being lower than the 21.5 kg limit for obligate large vertebrate predation; Carbone et al.,
352 1999), but rather for smaller ungulates (< 30 kg) including springbok, common duiker and
353 bushbuck, all of which are hider species. This adds weight to single site studies in South
354 Africa that found black-backed jackals preferred species with such birthing behaviour (Klare
355 et al., 2010). However, golden jackals follow predictions more closely with respect to their
356 preference for hares. This optimal foraging on particular species is reinforced by the
357 restriction and similarity in the number of prey species preferred by each jackal species –
358 despite differences in the number available, both species target a limited number of them
359 (Fig. 3). These preferences of jackals are driven mostly by prey body mass (Table 2), a
360 bottom-up factor. The accessible and preferred prey weight range we determined was
361 substantially larger than that reported from individual study sites (e.g., the Serengeti; Sinclair
362 et al., 2003), however is likely to be reinforced if other studies were useable (e.g., Van de

363 Ven et al., 2013). The selection for ungulates may well be driven by predation on newborn
364 young or sick individuals rather than healthy adults (McKenzie, 1997), although we did not
365 find any evidence for this affecting prey preferences and observations of jackals hunting adult
366 ungulates are not uncommon (Kamler et al., 2010; Macdonald, 1979).

367 The broader range of species killed by larger carnivores compared to smaller
368 carnivores like jackal (Radloff and du Toit, 2004; Sinclair et al., 2003), is clear evidence that
369 jackals compete with apex predators to exploit a shared resource. Furthermore, there are
370 numerous records of jackals dying through intraguild predation (Palomares and Caro, 1999).
371 It is therefore not surprising that the presence of apex predators has an impact on the prey
372 preferences of jackals (Fig. 6, Fig. 7). Most researchers espouse the facilitation function of
373 apex predators via provisioning of carcasses to jackals (Van de Ven et al., 2013), however
374 our results illustrate that the situation is more complex. Black-backed jackals prefer buffalo
375 and impala more where apex predators are present, and bushbuck, where they are absent (Fig.
376 6), however this does not appear to be driven by prey body mass as it is not solely large
377 species that are more preferred when jackals are in sympatry with apex predators (Fig. 7).
378 Similarly, wild boar and pheasant are more preferred by golden jackal in the absence of apex
379 predators. This casts doubts on claims that jackals only scavenge larger species (Costa, 1995),
380 as some larger species are consumed only at sites without apex predators present, although
381 we cannot rule out these larger species being sourced from anthropogenic routes (Lanszki et
382 al., 2015). Our results are consistent with previous research, which showed that in the
383 absence of apex carnivores, jackals preyed mostly on small hider ungulates, both newborn
384 and adults (Klare *et al.* 2010). Surprisingly, however, there does not appear to be a
385 generalised provisioning function provided by apex predators related to prey body mass (or
386 carcass mass; Fig. 7), as it is not solely larger prey species that are increasingly preferred in
387 the presence of apex predators (that would indicate this was driven simply by the increased

388 scavenging opportunities and that would be the mechanism). This provisioning service seems
389 driven by the individual characteristics of each prey species and probably their vulnerability
390 to each predator, such that scavenging may occur, but also individual species become
391 increasingly targeted by jackals when they are no longer exploited by apex predators (as
392 shown in Petrunenko et al., 2015). This may relate to a reduction in competition for carcasses
393 arising from naturally occurring mortalities, increased hunting effort undertaken by jackals as
394 solitary jackals can take down prey as large as adult impala (Kamler et al., 2010), shifts in
395 habitat use and behaviour (Tambling et al., 2015) by prey in the presence of apex predators,
396 larger group sizes in the absence of apex predators (a potential driver of their flexible social
397 systems; Macdonald, 1979), a reduction in offtake by apex predators of sick and injured
398 individuals, ungulate social behaviour (solitary vs. herder), or the maternal behaviour of prey
399 species with jackals killing juveniles that lose the protection of mothers killed by apex
400 predators. Thus, while apex predators might fulfil a facilitation role by providing carcasses of
401 large species for jackals to scavenge upon (commensalism), as indicated by the increased use
402 of buffalo when apex predators are present, they may also facilitate jackal predation by
403 removing the protection of adult individuals and thereby leave young vulnerable. The
404 protection of adults does not necessarily have to be via direct aggression towards predators
405 (which is rare), but rather through the increased vigilance they afford (Fitzgibbon, 1993).
406 Alternatively, the presence of apex predators might induce behavioural changes to
407 mesopredators that causes them to hunt different species (Moehrenschrager et al., 2007).

408 Although small mammals comprise the majority of jackal diet, their high relative
409 abundance and low body mass means they are not preferentially preyed upon (Table 1). This
410 is not an artefact of small sample size as over 20 studies reported on small mammals in the
411 diet of jackals and included information on their relative abundance (Table 1). A key property
412 of optimal foraging theory is that prey abundance does not solely control predator

413 consumption of that species, so a predator will not specialize on a less preferred prey
414 regardless of its availability (Pyke et al., 1977). Jackals appear to have evolved to optimally
415 prey upon lagomorphs and small ungulates – indeed it is most likely that it is the young of
416 these ungulates that are consumed rather than adults. Given this, the preferred prey weight
417 range is probably inflated, particularly for black-backed jackals.

418 Although jackals are regularly persecuted for actual or perceived livestock
419 depredation (Gusset et al., 2009; McShane and Grettenberger, 1984; Rowe-Rowe, 1976), we
420 found no evidence that they preferentially preyed upon livestock. All livestock were killed as
421 frequently as expected based on their relative abundance in the prey community (Table 1),
422 suggesting that jackal-pastoralist conflict reduction strategies would be most effective if they
423 concentrated on management strategies for increasing wild prey abundance, protecting
424 livestock rather than persecuting jackals and/or adequately disposing of carcasses. Human
425 persecution could influence the prey preferences of predators by means of increasing the risk-
426 taking behaviour during predation when animals move into novel environments following a
427 perturbation (Tuytens et al., 2000) or by the need to satisfy increased energetic requirements
428 associated with compensatory life history responses (Minnie et al., 2016).

429 The differences in the degree of study among the different jackal species are
430 surprising. While black-backed and Eurasian golden jackals are relatively well studied, we
431 found limited data on side-striped and, less surprisingly, on the newly described African
432 golden jackal. That is not to say dietary studies on these species do not exist, because they do
433 (Atkinson et al., 2002), but rather there were insufficient studies that linked diet to prey
434 abundance to allow the analysis of prey preference. More research is needed on these species
435 and scientists and funding agencies need to recognise that replicated studies are fundamental
436 to our ability to draw broad inferences about the natural world.

437 The resilience of jackal prey preference estimates to the inclusion of small sample
438 sizes is reassuring. We previously tested for differences between prey preference estimates
439 for leopards, and found no effect (Hayward et al., 2006a), and this robustness is reinforced by
440 32 of 35 showing no effect of sample size (Supplementary materials Fig. 1 & 2). Two of the
441 three species that did show an effect of sample size showed that larger sample size was more
442 avoided, which was driven by no records of kills of those species, which seems less likely
443 with larger sample sizes. All species where preference estimates were effected by sample size
444 had sample sizes larger than 38. This has implications for single site and seasonal dietary
445 studies more generally in that even relatively large sample sizes can be biased, however our
446 use of several sites to estimate mean prey preference minimises the impact of a few studies
447 with small sample sizes.

448 The determination of prey preferences of jackals identifies the key prey resources they
449 have evolved to optimally forage upon, illustrates the ecological flexibility jackals exhibit in
450 the absence of apex predators, and shows the diversity of facilitation services these larger
451 species offer. Thus, we provide a more nuanced understanding of the interactions between
452 apex and mesocarnivores and illustrate the behavioural flexibility of jackals where they can
453 switch between wolf-like (ungulate) and fox-like (small mammal) predation patterns. The
454 preference values for the prey of each jackal species can be used in many ways, including
455 dietary or home range prediction (Hayward et al., 2009; Hayward et al., 2007). Finally, we
456 show that both top-down and bottom-up forces affect jackal prey preferences. Undoubtedly,
457 the effects of top-down and bottom-up forces on jackal prey preferences vary with intensity
458 across sites, and probably are dependent on jackal density, large carnivore density and
459 diversity, prey density and diversity, levels of human persecution, and habitat. Black-backed
460 and golden jackals appear to have evolved to exploit different resources through their distinct
461 feeding habitats. Future research should investigate how these specific factors influence

462 jackal prey preferences under various conditions, thereby leading to a more comprehensive
463 understanding of how top-down and bottom-up forces shape jackal prey preferences.

464

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468

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657

Tables

Table 1. Preference status (P/A; where – denotes significantly avoided, + significantly preferred, and ~ killed in accordance with relative abundance), mean Jacobs's index value of each jackal prey species, number of studies recording it as potential prey ($n_{present}$) and actual prey (n_{kill}), preference test statistics via either t -tests or sign tests, mean proportional abundance and kills of each prey species, body mass (three-quarters of adult female), and categories of herd size, main habitat, potential threat to black-backed and Eurasian golden jackals, and ungulate birthing behaviour (H – hider; F – follower; O - other) of black-backed jackal prey. Scientific names are based on the IUCN Red List. Species names with (no kills) refers to data where studies with no kills of this species were reported. An asterisk (*) refers to species likely to be significantly avoided with a larger sample size.

Species	Scientific name	P/A	Jacobs' index (+/- S.E.)	$n_{present}$	n_{kill}	t/Sign test	d.f.	p	Abundance	Kills	Body mass (kg)	Herd size / Habitat / Threat / Birthing
a) Black-backed jackal												
Aardwolf	<i>Proteles cristatus</i>	-	-0.78 +/- 0.22	9	1	1	9	0.04	0.01 +/- 0.00	0.01 +/- 0.01	6	2 / 2 / 0 / O
Baboon	<i>Papio spp.</i>		-1 +/- 0	2	0				0.01 +/- 0.01	0 +/- 0	12	5 / 2 / 2 / O
Birds		+	0.83 +/- 0.15	4	4	5.66	3	0.01	0.07 +/- 0.05	0.45 +/- 0.12	1	5 / 1 / 0 / O
Blesbok	<i>Damaliscus dorcas phillipsi</i>	-	-0.56 +/- 0.13	16	9	-4	15	0.001	0.04 +/- 0.01	0.01 +/- 0.00	53	3 / 1 / 1 / F
Bontebok	<i>Damaliscus dorcas dorcus</i>		-1	1	0				0.01	0 +/- 0		
Buffalo	<i>Syncerus caffer</i>	-	-0.74 +/- 0.12	16	5	-6.01	15	<0.001	0.05 +/- 0.01	0.02 +/- 0.01	432	5 / 2 / 2 / F
Bushbuck	<i>Tragelaphus scriptus</i>	~	-0.06 +/- 0.15	27	18	-0.403	26	0.69	0.04 +/- 0.01	0.13 +/- 0.04	23	1 / 3 / 1 / H
Bushbuck (no kills)		+	0.41 +/- 0.10	18	18	4.23	17	<0.001				
Bushpig	<i>Potamochoerus larvatus</i>	~	-0.06 +/- 0.55	4	2	2	4	1	0.01 +/- 0.01	0.02 +/- 0.02	46	3 / 3 / 1 / O

Cattle	<i>Bos taurus</i>	~*	-1 +/- 0	4	0	0	4	0.125	0.03	0 +/- 0	235	3 / 1.5 / 2 / H
Dogfish			-0.67 +/- 0.33	2	1				0.02 +/- 0.01	0.01 +/- 0.01	0.66	5 / 1 / 0 / O
Duiker, blue	<i>Cephalophus monticola</i>		-1	1	0				0.01	0		
Duiker, common	<i>Sylvicapra grimmia</i>	~	-0.09 +/- 0.18	20	12	12	20	0.503	0.02 +/- 0.01	0.05 +/- 0.02	16	1 / 2.5 / 1 / H
Duiker, common (no kills)		+	0.51 +/- 0.12	12	12	4.15	11	0.002	0.01	0		
Eland	<i>Tragelaphus oryx</i>	-	-0.82 +/- 0.09	24	5	5	24	0.007	0.11 +/- 0.02	0.02 +/- 0.02	345	5 / 2 / 2 / H
Elephant	<i>Loxodonta africana</i>	~*	-1	4	0	0	4	0.125	0.02	0 +/- 0		
Gemsbok	<i>Oryx gazella</i>	~	-0.36 +/- 0.15	14	9	9	14	0.424	0.04 +/- 0.01	0.04 +/- 0.01	158	4 / 1 / 2 / H
Giraffe	<i>Giraffa camelopardalis</i>	-	-1 +/- 0	12	0	0	12	<0.001	0.03 +/- 0.01	0 +/- 0	550	3 / 2 / 2 / H
Goat	<i>Capra hircus</i>	~*	-1 +/- 0	3	0	0	3	0.25	0.06	0 +/- 0	45	3 / 1.5 / 1 / H
Grysbok, Cape	<i>Raphicerus melanotis</i>		0 +/- 1	2	1				0.01 +/- 0.01	0.01 +/- 0.01	7	1 / 2.5 / 0 / H
Grysbok, Sharpe's	<i>Raphicerus sharpei</i>		0.79	1	1				0.001	0.01		
Hare, Cape	<i>Lepus capensis</i>	-	-0.55 +/- 0.06	3	3	-6.161	2	0.025	0.18	0.06 +/- 0.01	4	1 / 1.5 / 0 / O
Hare, scrub	<i>Lepus saxatilis</i>		-0.63 +/- 0.37	2	1				0.07 +/- 0.04	0.01 +/- 0.01	4	1 / 1.5 / 0 / O
Hares		-	-0.42 +/- 0.13	8	8	-	7	0.039	0.24 +/- 0.03	0.12 +/- 0.02	4	1 / 1.5 / 0 / O
Hartebeest, red	<i>Alcephalus busephalus</i>	-	-0.78 +/- 0.10	21	5	2	21	<0.001	0.07 +/- 0.01	0.02 +/- 0.01	95	4 / 1.5 / 1 / H
Hippopotamus	<i>Hippopotamus amphibius</i>		-1	1	0				0	0		
Impala	<i>Aepyceros melampus</i>	~	-0.24 +/- 0.20	17	14	6	17	0.332	0.29 +/- 0.06	0.26 +/- 0.10	30	4 / 2 / 1 / H
Klipspringer	<i>Oreotragus oreotragus</i>		-1 +/- 0	2	0				0.01 +/- 0.01	0 +/- 0	10	2.5 / 3 / 0 / H
Kudu	<i>Tragelaphus strepsiceros</i>	-	-0.59 +/- 0.09	31	22	5	31	<0.001	0.23 +/- 0.04	0.07 +/- 0.02	135	3 / 2 / 2 / H
Lagomorphs		-	-0.48 +/- 0.09			-5.28	12	<0.001				
Lechwe	<i>Kobus leche</i>		-1	1	0				0.001	0		
Livestock		~	-0.61 +/- 0.20			1	10	0.343				
Mussels			-0.60	1	1				0.05	0.01		
Nyala	<i>Tragelaphus angasi</i>		-1 +/- 0	2	0				0.01 +/- 0.00	0 +/- 0	47	3 / 2 / 2 / H
Oribi	<i>Ourebia ourebi</i>		0.20 +/- 0.69	2	2				0.06 +/- 0.06	0.03 +/- 0.01	14	2 / 1 / 1 / H
Ostrich	<i>Struthio camelus</i>	~*	-1 +/- 0	4	0	0	4	0.125	0.01 +/- 0.00	0 +/- 0	70	3 / 1.5 / 2 / O

Reedbuck, common	<i>Redunca arundinum</i>	~*	-1 +/- 0	5	0				0.01 +/- 0.00	0 +/- 0	32	3 / 3 / 1 / H
Reedbuck, mountain	<i>Redunca fulvorifula</i>	~	-0.67 +/- 0.33	3	1	3	1	1	0.07 +/- 0.04	0.05 +/- 0.05	23	3 / 3 / 1 / H
Rhebuck, grey	<i>Pelea capreolus</i>		0.33	1	1				0.23	0.37		
Roan	<i>Hippotragus equinus</i>		-1	1	0				0.01	0		
Rodents		~*	-0.97 +/- 0.03	4	4	0	4	0.125	0.91 +/- 0.06	0.08 +/- 0.02	0.02	5 / 1.5 / 0 / O
Sable	<i>Hippotragus niger</i>		-1 +/- 0	2	0				0.01 +/- 0.00	0 +/- 0	180	4 / 2 / 2 / H
Seal/dolphin			0.85 +/- 0.05	2	2				0.02 +/- 0.00	0.20 +/- 0.06		
Sheep	<i>Ovis aries</i>	~	0.29 +/- 0.09	3	3	3.40	2	0.077	0.29	0.43 +/- 0.04	23	5 / 1.5 / 0 / F
Small mammals		-	-0.74 +/- 0.06			-12	14	<0.001			0.03	
Springbok	<i>Antidorcas marsupialis</i>	~	-0.24 +/- 0.14	24	15	11	24	0.839	0.11 +/- 0.03	0.12 +/- 0.03	26	5 / 1 / 1 / H
Springbok (no kills)		+	0.22 +/- 0.09	15	15	2.34	14	0.035	0.17 +/- 0.04	0.20 +/- 0.04		
Springhare	<i>Pedetes capensis</i>	-	-0.65 +/- 0.07	11	11	-9.79	10	<0.001	0.22 +/- 0.03	0.06 +/- 0.01	2	1 / 2 / 0 / H
Steenbok	<i>Raphicerus campestris</i>	~	-0.14 +/- 0.18	19	14	7	19	0.359	0.10 +/- 0.03	0.04 +/- 0.01	8	1.5 / 1.5 / 0 / H
Suids		-	-0.64 +/- 0.10			4	37	<0.001				
Tsessebe	<i>Damaliscus lunatus</i>	~*	-1 +/- 0	3	0				0.01 +/- 0.00	0 +/- 0	90	3 / 2 / 1 / H-F
Warthog	<i>Phacochoerus africanus</i>	-	-0.70 +/- 0.08	32	16	3	32	<0.001	0.14 +/- 0.03	0.03 +/- 0.01	45	3 / 2 / 2 / O
Waterbuck	<i>Kobus ellipsiprymnus</i>	~	-0.49 +/- 0.26	8	3	3	8	0.727	0.01 +/- 0.00	0.01 +/- 0.01	188	3.5 / 2 / 2 / H
Wildebeest, black	<i>Connochaetes gnou</i>	-	-1 +/- 0	13	0	0	13	<0.001	0.02 +/- 0.00	0 +/- 0	100	4 / 1 / 1 / F
Wildebeest, blue	<i>Connochaetes taurinus</i>	-	-0.92 +/- 0.06	11	2	0	11	<0.001	0.13 +/- 0.02	0.01 +/- 0.00	135	5 / 1 / 1 / F
Zebra, mountain	<i>Equus zebra</i>		-1	1	0				0	0		
Zebra, plains	<i>Equus quagga</i>	-	-0.88 +/- 0.05	17	6	0	17	<0.001	0.08 +/- 0.02	0.01 +/- 0.00	175	3 / 2 / 2 / F

b) Eurasian golden jackal

Badger	<i>Meles meles</i>		-0.33 +/- 0.50	3	1	-0.661	2	0.576	0.01 +/- 0.01	0.01 +/- 0.01	10	1 / 2
Birds			-0.41 +/- 0.11									
Blackbuck	<i>Antilope cervicapra</i>		-0.02 +/- 0.98	2	1				0.02 +/- 0.01	0.19 +/- 0.19	28	4 / 1
Cattle	<i>Bos taurus</i>		-0.34 +/- 0.28	5	4	-1.233	4	0.285	0.28 +/- 0.06	0.18 +/- 0.06	235	3 / 1.5
Deer spp.		-	-0.57 +/- 0.04	3	3	-13.84	2	0.005	0.21 +/- 0.11	0.07 +/- 0.05		
Deer, chital	<i>Axis axis</i>		-0.14 +/- 0.14	5	5	-0.985	4	0.380	0.38 +/- 0.08	0.33 +/- 0.09	30	4 / 1.5

Deer, fallow/roe			-0.25 +- 0.10	3	3	-2.541	2	0.126	0.03 +- 0.01	0.02 +- 0.01	22.5	3 / 2
Deer, fallow/roe/red			0.20 +- 0.10	4	4	2.020	3	0.137	0.02 +- 0.01	0.03 +- 0.01		
Deer, red	<i>Cervus elaphus</i>	-	-0.76 +- 0.07	3	3	-11.26	3	0.001	0.02 +- 0.01	0.04 +- 0.02	130	3 / 3
Deer, roe	<i>Capreolus capreolus</i>		-0.39 +- 0.32	5	5	-1.200	4	0.296	0.03 +- 0.01	0.06 +- 0.01	15	3 / 2
Deer, sambar	<i>Rusa unicolor</i>		-0.31 +- 0.13	6	6	-2.368	5	0.064	0.11 +- 0.02	0.07 +- 0.03	200	3.5 / 2
Donkey	<i>Equus asinus</i>		-1 +- 0						0.08	0.01	160	3 / 1
Gaur	<i>Bos gaurus</i>		-0.92						0.15	0.01	650	3 / 3
Goat	<i>Capra hircus</i>		-0.44						0.08	0.03	24	4 / 1
Hare	<i>Lepus spp.</i>		0.29 +- 0.37	3	3	0.783	2	0.515	0.11 +- 0.09	0.09 +- 0.03	4	1 / 1
Hare, brown	<i>Lepus europaeus</i>	+	0.44 +- 0.12	5	5	3.516	4	0.025	0.01 +- 0.01	0.01 +- 0.01	4	1 / 1
Horse	<i>Equus ferus</i>		-1						0.02	0.01		
Invertebrates			-0.85									
Lagomorphs			0.38 +- 0.14				8	0.688				
Livestock			-0.49 +- 0.18				10	0.289				
Monkey, langur	<i>Semnopithecus entellus</i>	-	-0.66 +- 0.18	4	3	-3.742	3	0.033	0.17 +- 0.10	0.03 +- 0.01	5	5 / 2
Mule			-1 +- 0	1	0				0.02	0.01	190	1 / 1
Nilgai	<i>Boselaphus tragcamelus</i>		0.18 +- 0.32	5	5		5	1.000	0.09 +- 0.03	0.17 +- 0.10	169	4 / 2
Pheasant	<i>Chrysolophus spp.</i>	-	-0.58 +- 0.10	13	10	-5.680	12	<0.001	0.04 +- 0.02	0.05 +- 0.02	5	2 / 2
Rodent			0.36 +- 0.13	3	3	2.880	2	0.103	0.09 +- 0.06	0.20 +- 0.13	0.3	1 / 2
Sheep	<i>Ovis aries</i>		-0.26						0.62	0.73		
Small mammals		-	-0.31 +- 0.12	13	11	-2.533	12	0.026	0.68 +- 0.07	0.76 +- 0.07	0.025	1 / 2
Tahr, Nilgiri	<i>Nilgiritragus hylocrius</i>		-0.99	1	1				0.74	0.01	80	4 / 2
Ungulates			-0.14 +- 0.10			-1.419	30	0.166				
Wild boar	<i>Sus scrofa</i>		-0.06 +- 0.14	18	11	-0.390	17	0.701	0.06 +- 0.02	0.09 +- 0.03	47	3 / 2.5

Table 2. Model selection statistics for the top ten models of the drivers of prey selection in a) black-backed and b) Eurasian golden jackals.

Intercept	Abundance	Body mass	Habitat	Herd size	Threat	Birthing strategy	d.f.	AIC _c	ΔAIC _c	Akaike's weight
<i>Black-backed jackal</i>										
-0.322					-0.215		3.0	57.757	0.000	0.149
-0.424		-0.001					3.0	58.043	0.285	0.130
-0.332		-0.001			-0.138		4.0	59.219	1.462	0.072
-0.271	-0.322				-0.233		4.0	59.839	2.082	0.053
-0.267				-0.021	-0.203		4.0	60.112	2.355	0.046
-0.306			-0.009		-0.214		4.0	60.242	2.485	0.043
-0.357		-0.001		-0.023			4.0	60.365	2.608	0.041
-0.542							2.0	60.382	2.625	0.040
-0.406	-0.151	-0.001					4.0	60.439	2.681	0.039
-0.366		-0.001	-0.032				4.0	60.465	2.708	0.039
Sum of Akaike's weights (w_i)	0.240	0.500	0.220	0.240	0.560	0.060				
Model-averaged parameter estimates	-0.052	-0.001	-0.006	-0.006	-0.110	0.446				
<i>Eurasian golden jackal</i>										
-0.091		-0.002					3.0	24.890	0.000	0.320
-0.246							2.0	25.516	0.626	0.234
-0.102				-0.056			3.0	27.937	3.047	0.070
0.062		-0.002	-0.086				4.0	27.978	3.088	0.068
-0.036		-0.002		-0.023			4.0	28.153	3.263	0.063
-0.067	-0.161	-0.002					4.0	28.155	3.265	0.063
-0.132			-0.065				3.0	28.300	3.410	0.058
-0.237	-0.071						3.0	28.415	3.525	0.055
-0.040			-0.041	-0.052			4.0	31.249	6.359	0.013
-0.089	-0.087			-0.056			4.0	31.275	6.385	0.013
Sum of Akaike's weights (w_i)	0.160	0.540	0.170	0.180						
Model-averaged parameter estimates	-0.019	-0.001	-0.013	-0.007						

Table 3. Model selection statistics for the segmented model to determine preferred and accessible prey weight ranges of a) black-backed and b) Eurasian golden jackals following Clements *et al.* (2014). Breakpoints refer to the number of slope changes within the segmented model and they are ranked according to Akaike's weights.

Breakpoints	AIC_c	ΔAIC_c
a) Black-backed jackal		
2	45.564	0
4	47.581	2.017
3	47.795	2.231
5	47.795	2.231
1	77.110	31.55
b) Eurasian golden jackal		
3	21.588	0
4	23.467	1.879
5	23.467	1.879
2	28.280	6.692
1	28.98	7.388

Figures

Fig. 1. Distribution map of the jackals with the locations of study sites that provided data on jackal diet and prey availability that were used in this study. Note that the distribution maps come from the IUCN Red List that have not yet been updated to reflect the two species of golden jackal (Jhala and Moehlman, 2008), however the African distribution of golden jackal reflects that of *Canis anthus* while the Eurasian distribution reflects that of *C. aureus*.

Fig. 2. Prey preferences of a) black-backed and b) golden jackals according to Jacobs' index. Black bars represent significantly preferred species and white bars significantly avoided species. Species in grey are consumed in accordance with their relative abundance.

Fig. 3. Relationships between the number of prey species present at a site and a) the number preferred and b) the number killed. There was no significant difference in the number of species killed or preferred between each jackal species ($t_{22} < 0.67$, $p > 0.40$ for both).

Fig. 4. Relationships between the most strongly supported variables explaining prey selection in a) black-backed jackals and b) Eurasian golden jackals based on the generalised linear modelling (Table 2). The insets show the loess smooth relationship over a subset of prey body masses. Grey shading represented the 95 percentile confidence interval.

Fig. 5. Segmented models of the preferred and accessible weight ranges of a) black-backed and b) Eurasian golden jackals. The x-axis shows the rank of species body mass and

the actual body mass this refers to the actual body mass at the segmented model breakpoints.

Fig. 6. The effect of the presence of apex predators on the prey selection by black-backed jackals. Stars show species with significant differences in prey selection (Jacobs' index) at sites with and without apex predators present. A two-way ANOVA revealed there was a significant difference in Jacobs' index values between birth strategies ($F_{1, 30} = 10.110, p = 0.003$), but not in the effect of apex predators ($F_{1, 30} = 0.056, p = 0.815$) or the interaction term ($F_{1, 30} = 0.129, p = 0.722$).

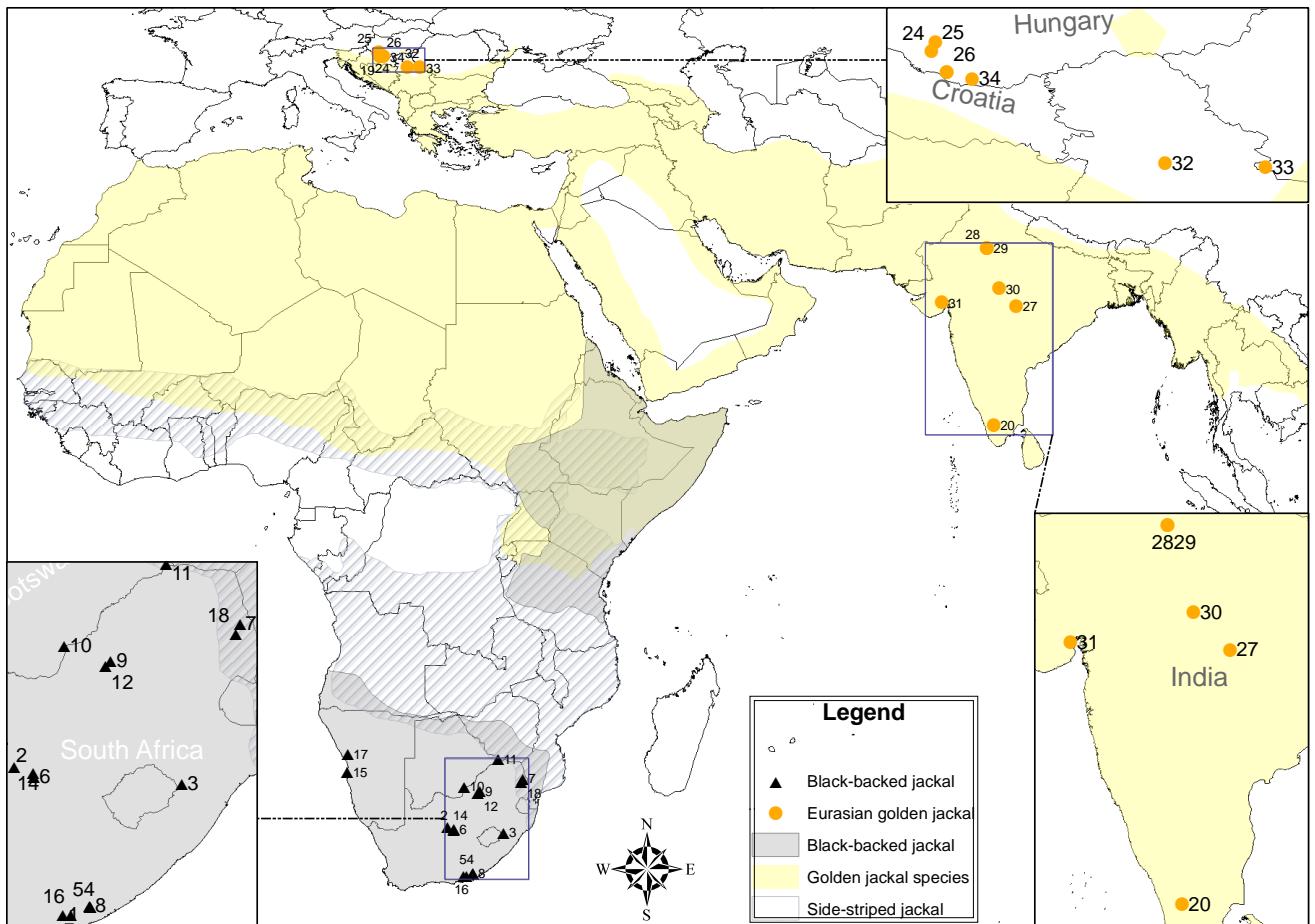


Fig. 1

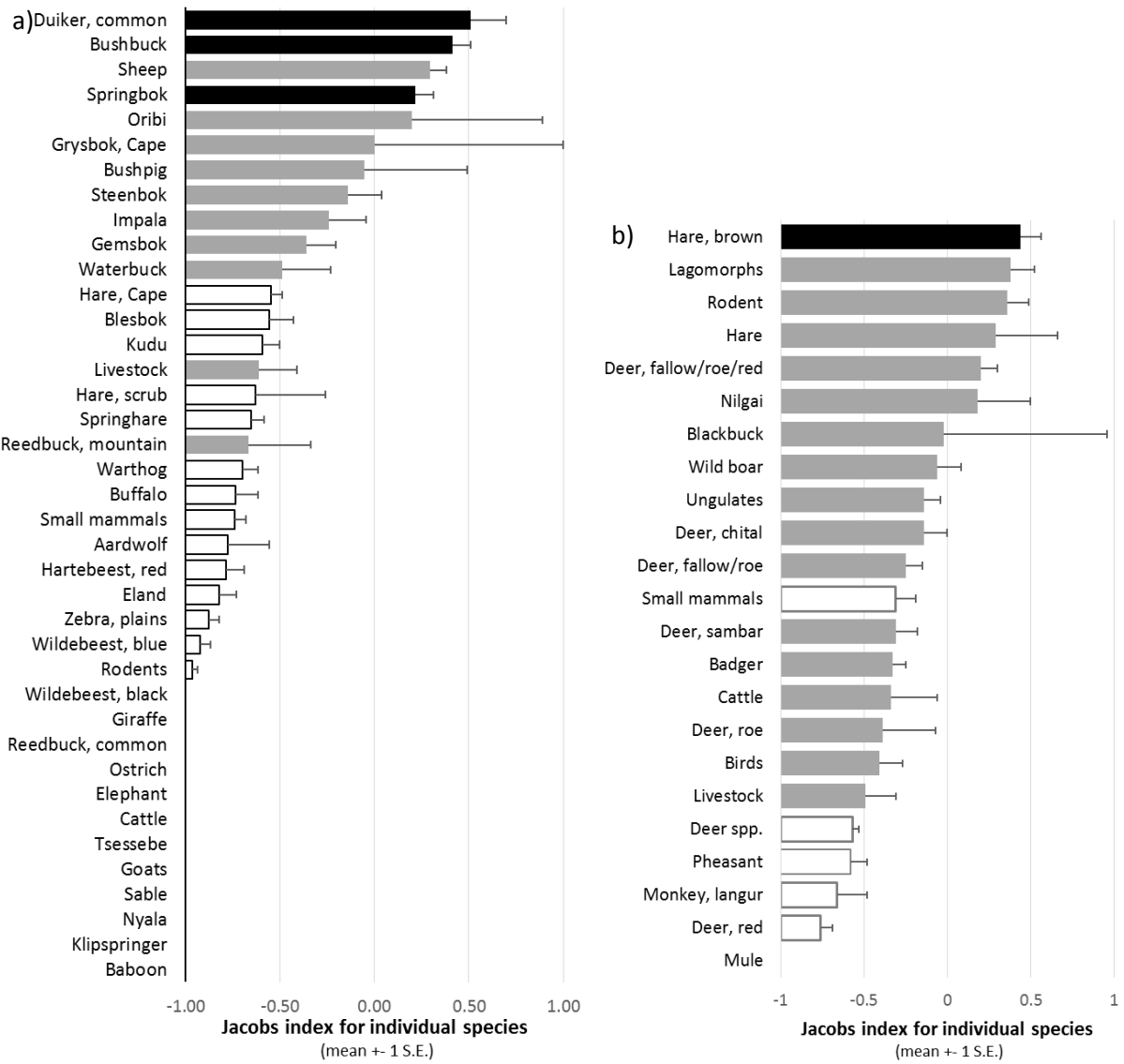


Fig. 2

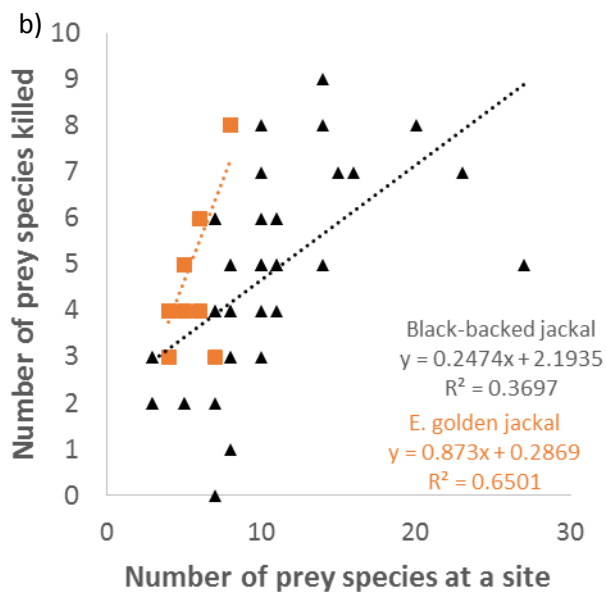
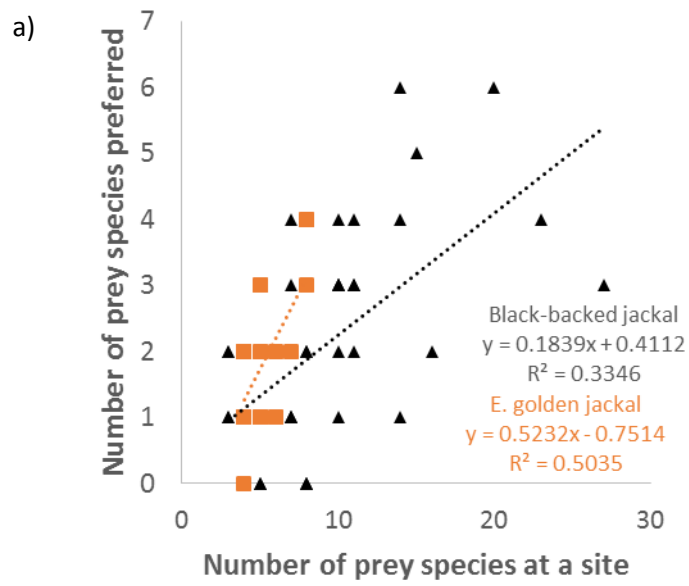


Fig. 3

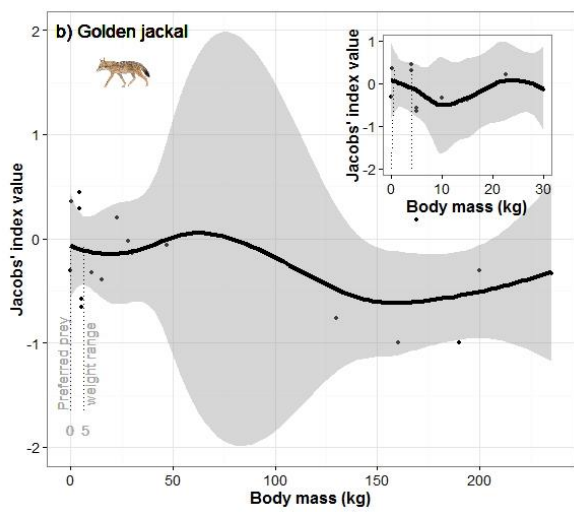
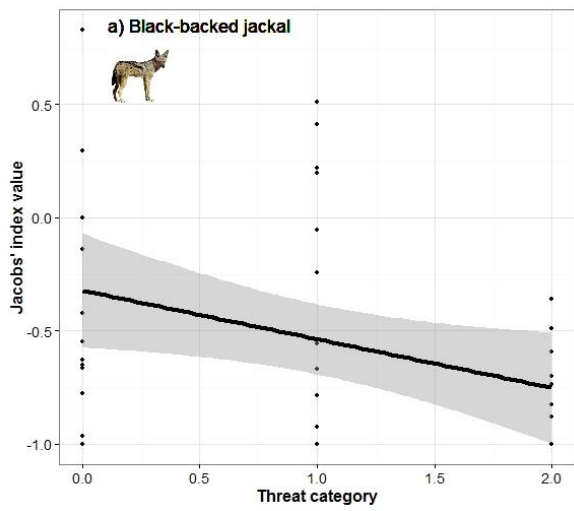
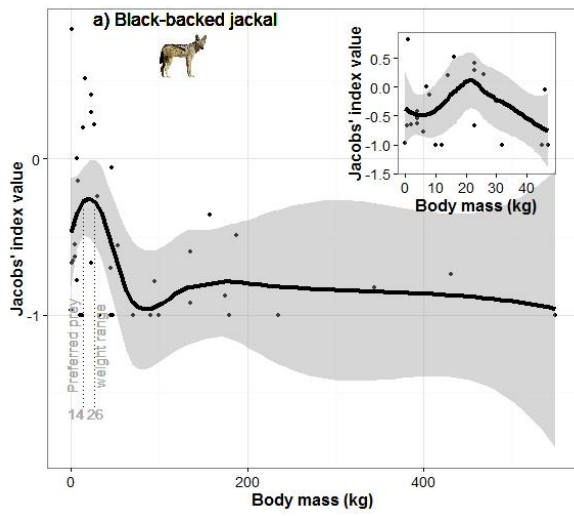


Fig. 4

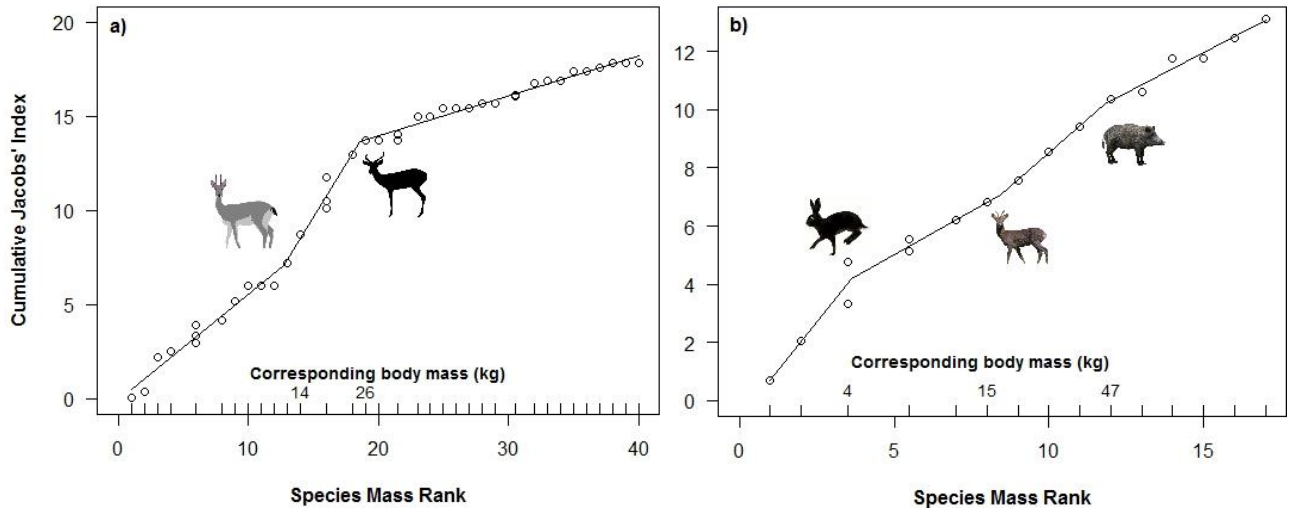


Fig. 5

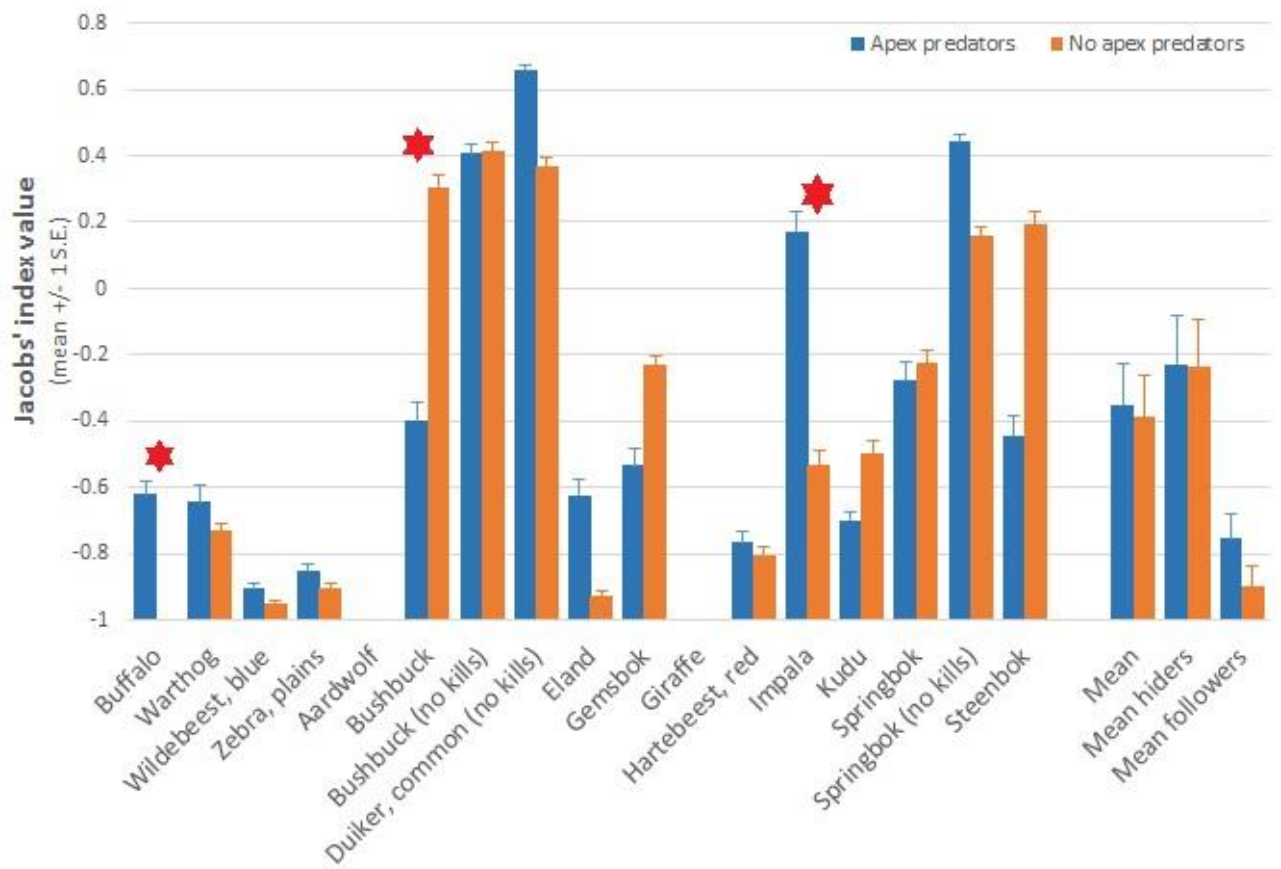


Fig. 6