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Title:

Surrogate species vs. landscape metric: Does presence of a raptor species explains diversity of multiple taxa more than patch area?

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23
24

Abstract

Prioritizing conservation areas is a central theme in conservation biology. The use of surrogate species and landscape metrics to identify areas with high conservation value is common. However, few studies have examined the relative efficacy of these two surrogates. In this study, we compared the efficacy of the presence/absence (PA) of a top predator (Eastern Marsh Harrier, *Circus spilonotus*) and wetland patch area on species richness, total abundance, and community composition of birds, plants, and small mammals, but species richness and community composition only for plants, in a fragmented wetland landscape. Although harrier PA was an effective indicator of the distribution of birds, it had no significant efficacy on the distributions of plants and small mammals. Patch area was more effective indicator of the distributions of plants and small mammals. These results suggest that surrogate species can be more effective indicators than landscape surrogates when there are ecological linkages between surrogate species and the focal taxa (e.g., similarity of habitat requirements between surrogate species and focal taxa or hetero-specific attraction). On the other hand, landscape surrogates would be useful when ecological knowledge about the relationships is limited.

Keywords

Biodiversity conservation, Fragmented landscape, Multiple taxa, Patch area, Surrogate

45 species, Wetland.

46

Introduction

Biodiversity has rapidly been declining in recent decades at a global scale (Cardinale et al. 2012) due to the worldwide loss of natural habitat and fragmentation of remaining habitats (Fahrig 2003). Prioritizing conservation areas is now a central theme in conservation biology. The use of surrogate species such as top predators, keystone species, and umbrella species to identify areas of high conservation value is a common practice in conservation prioritization because it is difficult to build conservation plans based on habitat requirements of all species in the target ecosystem (Wilcox 1984). This approach has attracted considerable attention (e.g., Di Minin and Moilanen 2014), as it can raise environmental awareness (Leader-Williams and Dublin 2000) and generate good financial support for conservation programs (Caro and O'Doherty 1999). However, the surrogate species approach tends to carry inconsistent outcomes and often lacks an ecological rationale (e.g., Cabeza et al. 2008). Nonetheless, some studies have suggested that there are species that promote the survival of many associated species in the community (e.g., Pakkala et al. 2006; Mönkkönen et al. 2007), and that some species/species groups can be used as indicators of community composition in fragmented landscapes because communities tend to be nested with progressive fragmentation (Sætersdal and Gjerde 2011; Larsen et al. 2012). Therefore, it may be possible to select useful surrogate species by considering their ecological roles and focal landscape type.

67 The use of landscape metrics (e.g., patch area, shape, and connectivity) to
68 identify areas with high conservation value has also received considerable attention,
69 along with remarkable technical improvements in remote sensing in recent years (e.g.,
70 Faith 2003; Hortal et al. 2009). Such an approach has several advantages for
71 conservation prioritization. For example, landscape metrics can be relatively easily
72 measured on a large scale for any places for which satellite or aerial images are
73 available (Banks-Leite et al. 2011). However, the efficacy of the landscape surrogate
74 approach has not been validated with biological data in the field (but see Banks-Leite et
75 al. 2011; Barton et al. 2014) although several studies have looked at correlations (and
76 causality) between landscape metrics and biodiversity metrics (e.g., Oja et al. 2005;
77 Goetz et al. 2010). In addition, landscape surrogates may not be effective for raising
78 financial support and environmental awareness.
79 Particular surrogate species/species groups are never associated with the species
80 richness and community composition of all taxonomic groups present (Niemi and
81 McDonald 2004; Sattler et al. 2014). Similarly, responses to landscape metrics vary
82 among species/taxonomic groups (e.g., Davis 2004; Barbaro et al. 2005). Therefore,
83 taxonomic groups expected to be protected based on species/landscape surrogate
84 approaches would be limited. In other words, the efficacy of these approaches may
85 differ among taxa. To evaluate the effectiveness of each approach for protecting
86 biodiversity, a comparison between species and landscape surrogate approaches across

87 multiple taxa is needed. Nevertheless, only a few studies have examined the relative
88 efficacy of these two approaches (but see Bräuniger et al. 2010; Banks-Leite et al. 2011;
89 Lindenmayer et al. 2014).
90 In this study, we examined the relative efficacy of the presence/absence (PA) of
91 surrogate species and landscape surrogates on the species richness, total abundance, and
92 community composition of birds, plants, and small mammals, but species richness and
93 community composition only for plants, in wetland fragments. We used the Eastern
94 Marsh Harrier, *Circus spilonotus*, which is an avian top predator, as a surrogate species.
95 This is because raptor species have been used as presumed indicator species of species
96 richness and the abundance of some taxonomic groups such as birds and plants (e.g.,
97 Sergio et al. 2005; Burgas et al. 2014). We used wetland patch area as a landscape
98 surrogate because patch area is the most basic landscape metric that affects species
99 richness, abundance, and community composition of various taxa (e.g., Krauss et al.
100 2004; Yamaura et al. 2008; Hu et al. 2011). We used birds and plants as focal taxa.
101 These are widely used for biodiversity assessments because of the rich body of
102 knowledge on their ecology, and their species richness is positively correlated with that
103 of other taxa in many cases (Gardner et al. 2008; Kessler et al. 2011). We also used
104 small mammals as additional target taxon because of the likely existence of
105 predator-prey interactions between the marsh harrier and small mammals (Morioka et al.
106 1995). Specifically, we tested the following two hypotheses. The first is that harrier PA

is an effective indicator of the distribution of other wetland birds and small mammals, but not of the distribution of wetland plants. This is because the harrier has similar habitat requirements to other wetland birds, the harrier can be an important cue in the habitat selection of other bird species (i.e., hetero-specific attraction) (e.g., Mönkkönen et al. 2007), and the harrier mainly preys on small mammals (Simmons 2000). The second hypothesis is that patch area is broadly associated with biodiversity metrics across three taxonomic groups. Wetland ecosystems are one of the most endangered ecosystems due to clearance for prime agricultural land and industrial areas (Dudgeon et al. 2006). However, the effectiveness of surrogate approaches for biodiversity conservation has not been demonstrated in wetland ecosystems (but see Brose 2008; Ormerod et al. 2010).

Materials and methods

Study area and its wetland

The study area is located in the Iburi region, central Hokkaido, northern Japan (Fig. 1). Although there were huge expanses of wetlands in this region in the early 1900s, more than 90% of those wetlands have been lost due to the development of agricultural lands and urbanization. Currently, the wetlands in this area consist of patches of various sizes (Fig. 1). All wetland patches in this region are dominated by common reed *Phragmites australis* that may include subdominant sedge (*Carex* spp.) and *Juncus* spp.,

127 *Phynchospora* spp., and *Eleocharis* spp communities.

128

129 Measuring wetland patch areas

130 We defined continuities of reed, sedge, and rush communities as “wetland patches.”

131 We treated these vegetation cover types, surrounded by other landscape features (e.g.,

132 forest, river, and road) of more than 50 meters, as separate wetland patches. Areas of

133 all patches were calculated using ArcMap 10.0 (ESRI 2011) from aerial photographs

134 taken in 2002. The study area had a total of 97 wetland patches.

135

136 Survey of surrogate species

137 We used the Eastern Marsh Harrier as a surrogate species for the following reasons.

138 First, the Marsh Harrier is easily detected because it is a medium-sized raptor that

139 occurs in open habitats. Second, its ecology and natural history are well-known (e.g.,

140 Simmons 2000). Third, avian surrogate species are better associated with species

141 richness and the abundance of co-occurring species than are mammalian surrogate

142 species (Branton and Richardson 2011). Finally, the presence of breeding raptors is an

143 important cue in the habitat selection of various bird species (e.g., Mönkkönen et al.

144 2007). These criteria are needed for effective use of the surrogate species approach

145 (Caro and O’Doherty 1999). In the study region, the harriers prey on small- or

146 medium-sized birds and mammals (Morioka et al. 1995), arrive in late March, which is

147 earlier than most migratory wetland bird species (M. Senzaki unpublished data), and
148 breed from early April to early August on a reed-bed in wetland patches. This species is
149 listed as Endangered by the 4th Red List of Threatened Birds of Japan (Japan Wildlife
150 Research Center 2002).
151 We investigated whether each of the 97 patches in the study area was used by
152 harriers as breeding patches from early April to early June in 2012. We established 46
153 observation points across the study area and conducted observation surveys, in which
154 we stayed for 2 h to locate harriers at each observation point. We observed up to 10
155 wetland patches at an observation point. Each wetland patch was observed up to three
156 times on different dates (i.e., totally up to 6 h), if we could not detect harriers during
157 the first or second observation periods. Since we were not able to fully observe some
158 wetland patches from the single observation points, we observed such patches from
159 multiple observation points. When we observed any breeding behavior of marsh
160 harriers (i.e., nest building, feeding of chicks), we treated those habitats as breeding
161 patches. We identified 21 such patches from among the 97 wetland patches.
162
163 Surveys of birds, plants, and small mammals
164 We selected a total of 32 patches of various size (4.3–100.8 ha) to quantify the
165 densities of birds, plants, and small mammals. We conducted surveys for birds, plants,
166 and small mammals at 30, 32, and 20 patches, respectively. Marsh harriers bred at half

of the total number of sites for each taxonomic group (i.e., 15, 16, and 10 patches, respectively). There was no relationship between the PA of the harrier and the log-transformed patch areas for birds (ANOVA, $F_{(1, 28)} = 2.43$, $p = 0.13$), plants (ANOVA, $F_{(1, 30)} = 1.58$, $p = 0.22$), or small mammals (ANOVA, $F_{(1, 18)} = 1.48$, $p = 0.24$) (Fig. 5).

We conducted daytime and nighttime bird surveys from early June to early July in 2012 (25 patches) and 2013 (5 patches). For daytime surveys, we set up a 300 m census route on a reed-bed in each wetland patch. Then we walked slowly along the route, and recorded all birds seen or heard within 50 m of either side of each route. We completed the surveys between 0400 to 0900 h on clear days when diurnal birds were most active. For nighttime surveys, we conducted unlimited-radius point counts that consisted of a 30-min passive listening period at the center of a census route used in the diurnal surveys. We recorded the number of individuals of all birds heard simultaneously at each survey point. We completed the surveys between 2000 to 0200 h in fair weather conditions (no rain or strong wind). Both daytime and nighttime surveys in each patch were conducted two times on different dates in the same year. We conducted separate plant surveys for three dominant plant communities from late July to early September in 2012 (26 patches) and 2013 (6 patches). We defined vegetation cover dominated by the common reed as a “reed community.” We also defined vegetation cover dominated by sedges (*Carex* spp.) of approximately 1.0 m in

187 height as a “sedge community,” and that dominated by rushes (*Juncus* spp.,
188 *Phynchospora* spp., and *Eleocharis* spp.) of approximately 0.5 m in height as a “rush
189 community.” If there were any community groups in the wetland patches, we
190 established two 2 m × 2 m quadrats in each community and recorded all vascular plant
191 species in each quadrat. We also measured the cover of each species within each
192 quadrat. We did not conduct surveys in cases where the area of each community was
193 too small to survey (<8 m^2 in a patch). We examined whether each plant community
194 existed in each patch using aerial photographs and field surveys. As a result, we
195 conducted surveys in 32 patches for the reed community, 22 patches for the sedge
196 community (13 patches with harriers and 11 patches without harriers), and 14 patches
197 for the rush community (six patches with harriers and eight patches without harriers).
198 There were no relationships between the PA of the harrier and log-transformed patch
199 area in the reed community (ANOVA, $F_{(1, 30)} = 1.58$, $p = 0.22$), sedge community
200 (ANOVA, $F_{(1, 20)} = 0.73$, $p = 0.40$), or rush community (ANOVA, $F_{(1, 12)} = 2.67$,
201 $p = 0.13$) (Fig. 5).
202 Small mammal surveys were conducted from late June to late July in 2013. We
203 used a live-trapping method, which is the most common method used to study small
204 mammals (Michel et al., 2006). We established two 90-m-long parallel trap-lines that
205 were placed 50 m apart in reed-beds in each wetland patch. Ten Sherman traps (7.6 cm
206 × 8.9 cm × 22.8 cm, H. B. Sherman Trap) were placed sequentially every 10 m along

each trap-line, hence 20 traps were placed in each patch. Traps were baited with oatmeal. Three visits were made at dawn, 24, 48, and 72 h after installation. Individuals captured on the first and second visits were temporarily marked (color mark on the tail or abdomen) and then released.

To avoid pseudoreplication, we spaced the sampling sites between patches at least 500 m apart. For birds and plants, we grouped all species recorded into wetland species (i.e., species that breed in wetland) and species that prefer other habitat types following the literature (Umezawa et al. 2009; The Ornithological Society of Japan 2012). For small mammals, this grouping was omitted because no species that prefer other habitats were recorded. Finally, we obtained a total number of species (i.e., species richness) for wetland birds, plants, and small mammals and total abundance for wetland birds and small mammals at each sampling site. We defined total abundances as the sum of the maximum number of individuals of each wetland species at each sampling site. Non-wetland species (i.e., species that breed in other habitats) were excluded from the above calculations for the following two reasons. First, we were interested in the conservation of wetland species because wetland species have a higher conservation profile than non-wetland species in our study area. Second, although wetlands often provide important resources for non-wetland species, they cannot be conserved by protecting the harrier or wetland because their breeding habitat is not protected.

227

228 Statistical analysis

229 We used a generalized linear model (GLM) with a Poisson error and a log link function
230 to examine the effectiveness of the PA of the marsh harrier and patch area on the species
231 richness and abundance of the three target taxa. For wetland plants, abundance was not
232 calculated. Explanatory variables were PA of the mash harrier and log-transformed
233 patch areas.

234 We conducted principal component analysis (PCA) to examine the community
235 composition of wetland patches for birds, small mammals, and each of the three plant
236 communities separately, using the abundance of each species for wetland birds and
237 small mammals and coverage of each species for wetland plants. We used the first two
238 principal axes as the indices of community composition. We used a generalized linear
239 model (GLM) with a Gaussian error with each of two axes as a response variable, and
240 the PA of the mash harrier and log-transformed patch area as two explanatory variables.

241 We constructed regression models for combinations of all possible explanatory
242 variables and ranked them by Akaike's information criterion for small sample situations
243 (AICc). Models with a ΔAICc ($\Delta AICc_i = AICc_i - AICc_{min,}$ where $AICc_i$ and $AICc_{min}$ is
244 the AICc value for model$_i$ and the AICc value of the best model in the model subset,
245 respectively) smaller than 2 have substantial support (Burnham and Anderson 2002).
246 We performed model averaging when there were several models with a ΔAICc smaller

247 than 2. We interpreted parameters in averaged models at the 5% significance level and
248 10% marginal significance level. In addition, for all focal taxa, we performed Pearson
249 correlation analysis between species richness and abundance (except for plants),
250 between species richness and the first two axes of the PCA, and between abundance and
251 the first two axes of the PCA (except for plants). All analyses were conducted using R
252 software (ver. 2.15.3 R Core Team 2013).
253
254 **Results**
255 We recorded a total of 733 individuals of 13 wetland bird species, 117 wetland plant
256 species (70 species in the reed community [n = 32], 77 species in the sedge community
257 [n = 22], and 66 species in the rush community [n = 14]), and 102 individuals
258 (excluding recaptures) of 6 wetland small mammal species.
259 For wetland birds, the PA of the harrier was significantly associated with
260 species richness, total abundance, and the first two axes of the PCA (Fig. 2; Table 1).
261 For wetland plants, patch area was significantly associated with the species richness of
262 the reed and rush communities (Fig. 3; Table 1), and had marginally significant
263 associations with the first axis of the rush community and the second axis of the reed
264 community (Fig. 3). For small mammals, no covariate was associated with species
265 richness (Figs. 2, 3; Table 1). Total abundance was significantly associated with patch

266 area (Fig. 3; Table 1). Both the PA of the harrier and patch area had little association
267 with the first two axes of the PCA (Figs. 2, 3; Table 1).
268 For wetland birds, species richness was positively correlated with abundance
269 and the first axis of PCA, and negatively correlated with the second axis of PCA
270 (Table 2). Total abundance was positively correlated with the first axis of PCA (Table
271 2). For wetland plants and small mammals, there were no consistent correlations
272 among species richness, total abundance (for small mammals only), and the first two
273 axes of PCA (Table 2).
274
275 **Discussion**
276 As predicted, we found strong relationships between the PA of the harrier and species
277 richness, total abundance, and community composition of wetland birds (Fig. 2; Table
278 1). These results imply that the habitat requirements of the marsh harrier are similar to
279 those of many wetland bird species, in line with a previous study (Sattler et al. 2014).
280 For example, the harrier often breeds in a reed-bed with a high groundwater level
281 (Morioka et al. 1995; M. Senzaki unpublished data), which is also suitable breeding
282 habitat for wetland specialists such as the Water Rail (*Rallus aquaticus*), Baillon's Crake
283 (*Porzana pusilla*), and Eurasian Bittern (*Botaurus stellaris*); such habitat may be
284 protected from terrestrial mammalian predators. However, another possible explanation
285 of our results is that the presence of the harrier may be a cue for habitat selection of

286 other wetland birds (heterospecific attraction). The effects of predators on their potential
287 prey species are not always only negative (i.e., predation risk) but may also be positive
288 (i.e., protection benefits). In fact, several studies have shown that the abundances of
289 various potential prey species decrease with distance from avian predator nests (e.g.,
290 Pakkala et al. 2006; Mönkkönen et al. 2007). In our study region, the marsh harrier
291 arrives earlier at the breeding site than most migratory wetland bird species (M. Senzaki
292 unpublished data). Therefore, wetland birds arriving later may select the breeding site
293 depending on the presence of harriers as an important cue. In addition, for wetland birds,
294 there were significant correlations among species richness, abundance, and the first two
295 axes of PCA (Table 2). We also found strong relations between these variables and the
296 PA of the harrier (Fig. 2; Table 1). These relationships indicate that wetland bird
297 assemblages in the study area are determined by the ecological conditions and that the
298 PA of the harrier reflects these communities/conditions (Niemi and McDonald 2004;
299 Sætersdal and Gjerde 2011).

300 On the other hand, harrier PA was not a good indicator for wetland plants and
301 especially for small mammals regardless of the likely existence of predator-prey
302 interactions between the marsh harrier and small mammals (Fig. 2; Table 1). These
303 results are likely because there are no or only weak ecological links between the harrier
304 and these taxonomic groups, or because the factors that affect the habitat selection of
305 each taxon differ. For example, in this study area, the Marsh Harrier rarely forages in

306 the breeding wetland patches (i.e., they have foraging habitats separate from nesting
307 wetland patches) (M. Senzaki personal observation), and so the Marsh Harrier may
308 select breeding wetland patches independently of the abundance of small mammals in
309 the wetland patches. In addition, the amount of leaf litter and nitrogen content of the soil
310 may affect the species richness, abundance, and community composition of wetland
311 plants and small mammals (Foster and Gross 1998; Odachi et al. 2009; Loydi et al.
312 2013), while the Marsh Harrier selects breeding patches independently of these factors.
313 Studies have shown that patch area is a key factor that can explain the species
314 richness, total abundance, and community composition of various taxa (e.g., Krauss et
315 al. 2004; Hu et al. 2011). However, patch area was not a perfect indicator of these
316 parameters in our study, although it was a relatively better indicator than harrier PA for
317 plants and small mammals (Table 1; Fig. 3). These results indicate that it is difficult to
318 extract critical landscape metrics related to species richness, abundance, and community
319 composition of focal taxa (Holland et al. 2004). For example, the key factors affecting
320 species richness, total abundance, and community composition within each plant
321 community may not be related to the extent of wetland vegetation cover (i.e., wetland
322 patch area), but rather the cover of each plant community. Moreover, there may be a
323 difference between vegetation cover and actual available area for small mammals
324 because it is difficult to quantitatively assess submerged area of vegetation cover using
325 aerial photographs and/or satellite images.

Numerous studies have criticized the use of surrogate species to identify areas of high conservation value (e.g., Cabeza et al. 2008), however, our results suggest that this approach can be useful when habitat requirements of surrogate species are similar to those of the focal taxa and when there are ecological reasons for why the PA of surrogate species is an effective indicator of the focal taxa. Therefore, this approach would be more effective than landscape surrogate approaches when there is prior knowledge on the focal taxa, communities, and ecosystems of the area under consideration. On the other hand, several studies have indicated that landscape surrogate approaches are simpler, cheaper, and more useful than surrogate species approaches (e.g., Banks-Leite et al. 2011; Barton et al. 2014). Our results also show that the overall performance of patch area for multiple taxa is higher than that of the presence/absence of harrier. In addition, if more complicated landscape metrics other than patch area (e.g., connectivity, habitat shape, and habitat amounts) are incorporated, the performance of landscape surrogate approaches may be improved. A number of studies have successfully modeled species distribution over various taxonomic groups using multiple landscape metrics (e.g., Oja et al. 2005; Goetz et al. 2010). Therefore, landscape surrogates may be more effective when there is not enough knowledge on the relationships between surrogate species and focal taxa (Ferrier 2002). Alternatively, because species and landscape surrogates are not mutually exclusive, the combination of these two surrogates is a promising option that may deliver more effective conservation

346 output across multiple taxonomic groups rather than focusing on a single surrogate (Di
347 Minin and Moilanen 2014). For example, in our study area, although a single surrogate
348 approach (i.e., harrier PA or Patch area) was effective at protecting a particular
349 taxonomic group (Table 1; Figs 2 and 3), prioritizing larger wetland patches with
350 harriers was the most practical and effective strategy for conserving many wetland
351 species across multiple taxonomic groups. However, variation in such combination
352 approaches is rarely tested and needs further work.
353
354
355

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494
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496 **Table**

497 **Table 1** Parameters (β) and unconditional SE in each averaged models. Unselected

498 parameters in each averaged model are not shown. Single and double asterisks indicate

499 marginal significance ($p < 0.10$) and significance ($p < 0.05$), respectively.

500

Response variable	Variables	β	SE	p
Birds				
Species richness	Intercept	1.78	0.11	< 0.001**
	Presence of raptor	0.32	0.14	0.02**
Abundance	Intercept	3.06	0.06	< 0.001**
	Presence of raptor	0.26	0.07	< 0.001**
Composition_PC1[a]	Intercept	-0.66	0.36	0.08*
	Presence of raptor	1.31	0.51	0.02**
Composition_PC2[b]	Intercept	0.56	0.36	0.13
	Presence of raptor	-1.12	0.51	0.04**
Plants				
Reed community				
Species richness	Intercept	1.83	0.18	< 0.001**
	Patch area	0.15	0.07	0.03**
Composition_PC1[a]	Intercept	-0.29	0.81	0.72
	Presence of raptor	1.49	1.21	0.24
Composition_PC2[b]	Intercept	-1.40	1.51	0.36
	Patch area	0.89	0.48	0.08*
Sedge community				
Species richness	Intercept	2.48	0.20	< 0.001**
	Presence of raptor	-0.21	0.12	0.11
	Patch area	0.10	0.07	0.21
Composition_PC1[a]	Intercept	-0.71	1.07	0.52
	Presence of raptor	2.20	1.28	0.10
Composition_PC2[b]	Intercept	-1.03	1.80	0.58
	Patch area	0.90	0.66	0.20
Rush community				
Species richness	Intercept	2.16	0.31	< 0.001**
	Patch area	0.18	0.08	0.047**
Composition_PC1[a]	Intercept	2.90	3.28	0.40
	Patch area	-1.83	0.93	0.08*

Composition_PC2[b]	Intercept	0.43	1.04	0.70
	Presence of raptor	-2.44	1.56	0.16
Small-mammals				
Species richness	Intercept	0.87	0.39	< 0.05**
	Patch area	-0.17	0.20	0.44
Abundance	Intercept	2.78	0.36	< 0.001**
	Patch area	-0.43	0.14	< 0.01**
Composition_PC1[a]	Intercept	-0.23	0.68	0.75
	Patch area	0.30	0.34	0.41
Composition_PC2[b]	Intercept	0.51	0.86	0.57
	Patch area	-0.44	0.32	0.19

501 [a] Axis 1 by principal component analysis. [b] Axis 2 by principal component analysis.

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Figure captions

Fig. 1

Map of wetland patches (*green*) in Hokkaido, northern Japan.

Fig. 2

Association of harrier PA (presence/absence of the marsh harrier) with (a) species richness, total abundance, and the first two axes of the PCA of wetland birds, (b) species richness and the first two axes of the PCA of the wetland plants, and (c) species richness, total abundance, and the first two axes of the PCA of wetland small mammals. Asterisks indicate significance below 5%.

Fig. 3

Association of patch area with (a) species richness, total abundance, and the first two axes of the PCA of wetland birds, (b) species richness and the first two axes of the PCA of the wetland plants, and (c) species richness, total abundance, and the first two axes of the PCA of wetland small mammals. Solid and dashed lines indicate significance below 5 and 10%, respectively.

Figures

Figure. 1

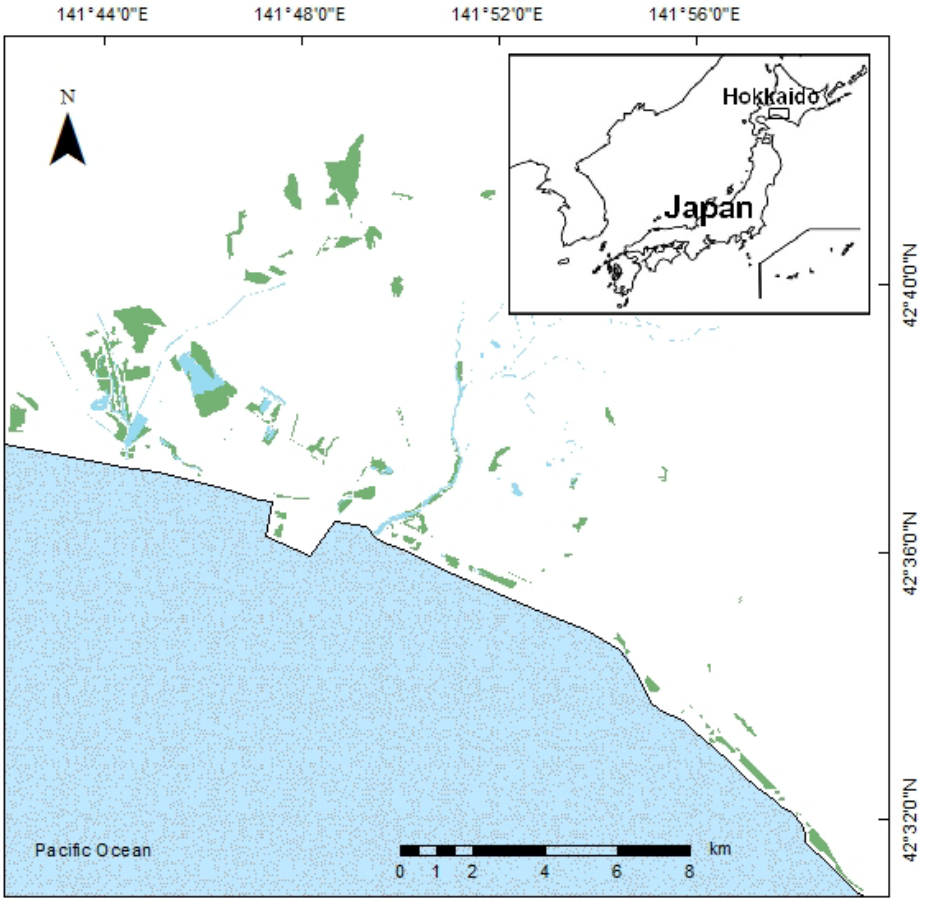


Figure 2

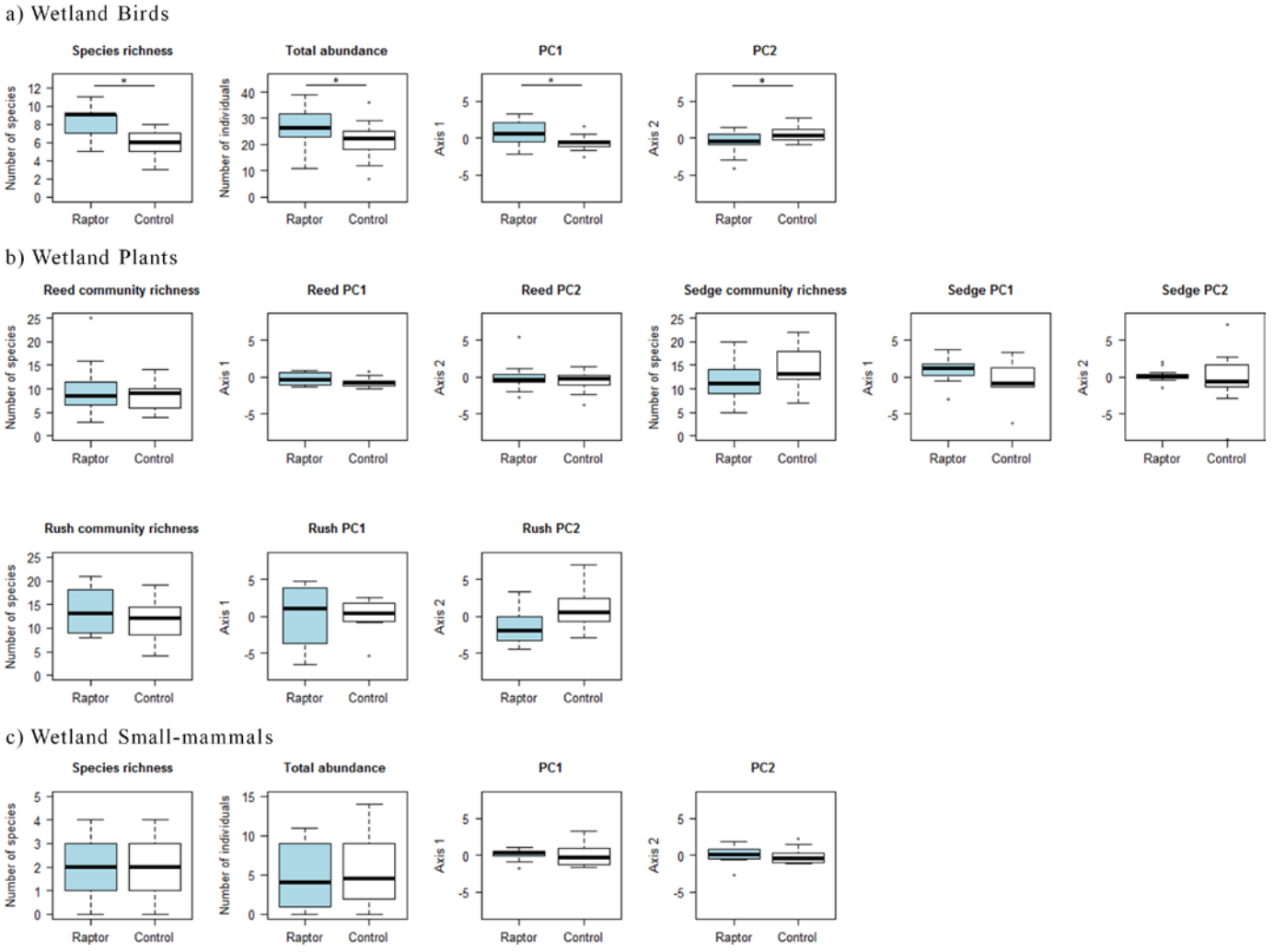
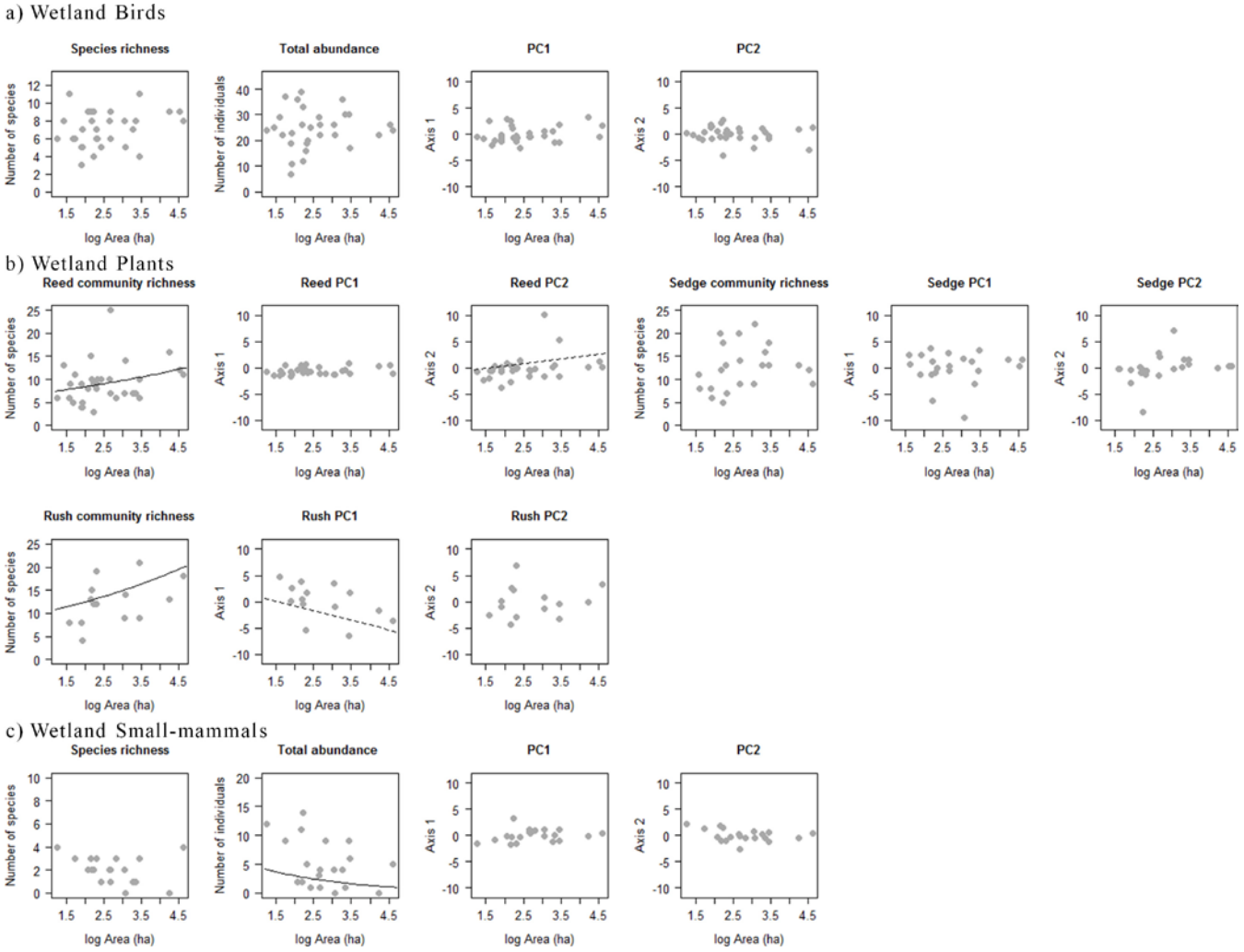

a) Wetland Birds
Species richness
Total abundance
PC1
PC2
Number of species
Number of individuals
Axis 1
Axis 2
Raptor
Control
b) Wetland Plants
Reed community richness
Reed PC1
Reed PC2
Sedge community richness
Sedge PC1
Sedge PC2
Rush community richness
Rush PC1
Rush PC2
c) Wetland Small-mammals
Species richness
Total abundance
PC1
PC2

Figure 3


a) Wetland Birds
Species richness
Total abundance
PC1
PC2
Number of species
Number of individuals
Axis 1
Axis 2
log Area (ha)
b) Wetland Plants
Reed community richness
Reed PC1
Reed PC2
Sedge community richness
Sedge PC1
Sedge PC2
Rush community richness
Rush PC1
Rush PC2
c) Wetland Small-mammals
Species richness
Total abundance
PC1
PC2

Appendices

Table 2 Results of Pearson's correlation tests. Asterisks show significant correlations: * - *P-value* < 0.05; ** - *P-value* < 0.01.

a) Birds

	Bird_richness	Bird_abundance
Bird_abundance	0.64*	
Bird_PC1	0.67**	0.37*
Bird_PC2	-0.40*	-0.35

b) Plants

Reed		Sedge		Rush	
	Reed_richness		Sedge_richness		Rush_richness
Reed_PC1	0.72**	Sedge_PC1	-0.39	Rush_PC1	-0.82**
Reed_PC2	-0.17	Sedge_PC2	-0.23	Rush_PC2	-0.01

c) Small-mammals

	Mammal_richness	Mammal_abundance
Mammal_abundance	0.70**	
Mammal_PC1	-0.15	0.12
Mammal_PC2	0.36	0.64**

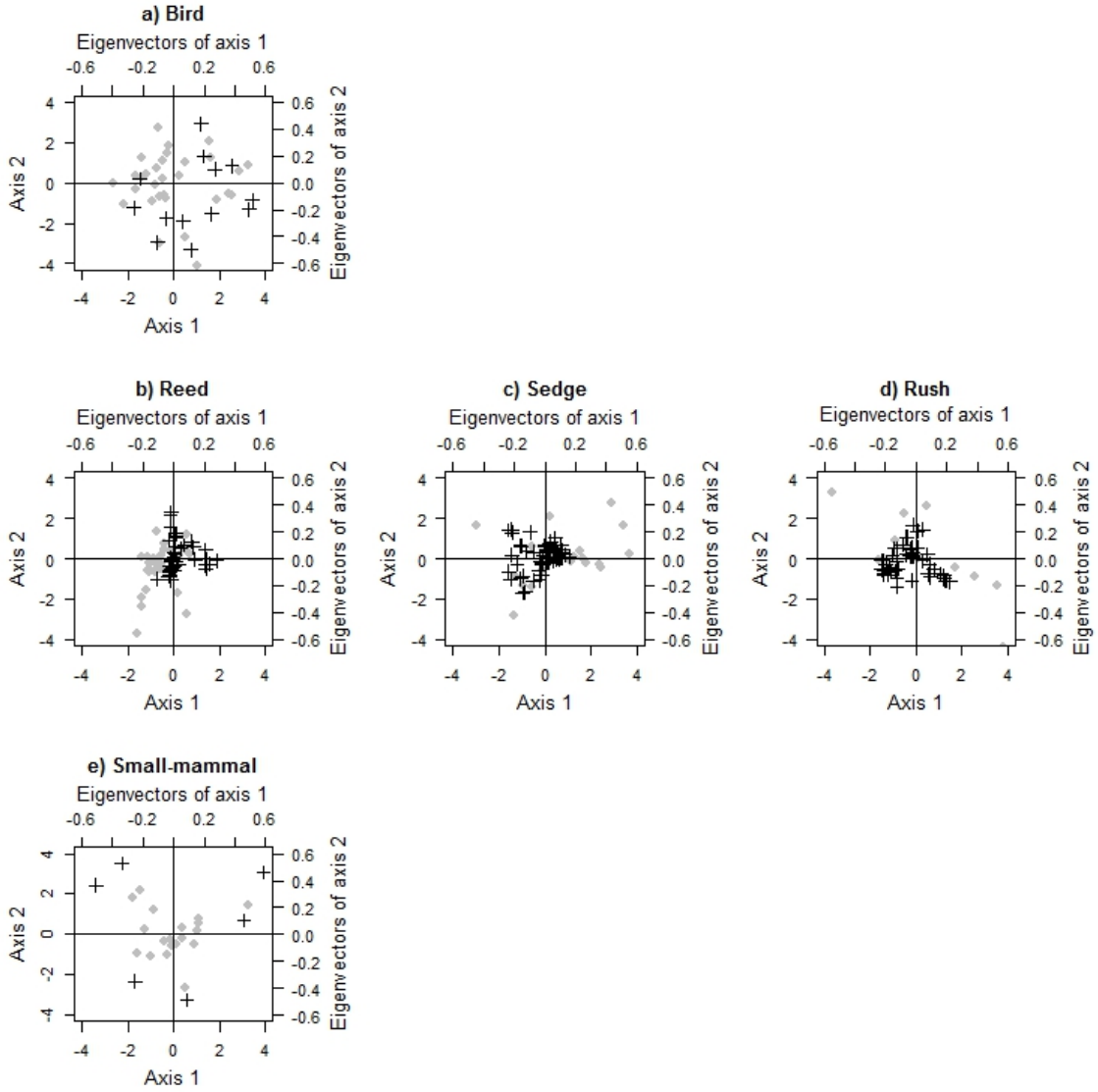
538 **Table 3** Results of model selection. "Weight" indicates "Akaike weight".

Response variable	Variablrs	Rank	ΔAICc	Weight
Birds				
Species richness	Raptor	1	0.00	0.62
	Raptor + Patch	2	2.34	0.19
		3	3.17	0.13
	Patch	4	4.44	0.07
Abundance	Raptor	1	0.00	0.76
	Raptor + Patch	2	2.35	0.23
		3	9.53	0.01
	Patch	4	11.45	0.00
Composition_PC1a	Raptor	1	0	0.65
	Raptor + Patch	2	2.31	0.20
		3	3.91	0.09
	Patch	4	4.91	0.06
Composition_PC2b	Raptor	1	0	0.59
		2	2.31	0.19
	Raptor + Patch	3	2.64	0.16
	Patch	4	4.2	0.07
Plants				
Reed community				
Species richness	Patch	1	0.00	0.55
	Raptor + Patch	2	2.01	0.20
		3	2.54	0.15
	Raptor	4	3.45	0.10
Composition_PC1a		1	0	0.46
	Raptor	2	0.86	0.30
	Patch	3	2.24	0.15
	Raptor + Patch	4	3.45	0.08
Composition_PC2b	Patch	1	0	0.47
		2	1.01	0.29
	Raptor + Patch	3	2.22	0.16
	Raptor	4	3.42	0.09
Sedge community				
Species richness	Raptor	1	0.00	0.30

		2	0.11	0.29
	Raptor + Patch	3	0.44	0.24
	Patch	4	1.24	0.16
Composition_PC1a	Raptor	1	0	0.44
		2	0.36	0.37
	Raptor + Patch	3	2.97	0.10
	Patch	4	3.05	0.10
Composition_PC2b		1	0	0.47
	Patch	2	0.73	0.33
	Raptor	3	2.52	0.13
	Raptor + Patch	4	3.72	0.07
Rush community				
Species richness	Patch	1	0	0.58
		2	1.97	0.22
	Raptor + Patch	3	3.3	0.11
	Raptor	4	3.59	0.10
Composition_PC1a	Patch	1	0	0.47
		2	0.61	0.35
	Raptor + Patch	3	2.88	0.11
	Raptor	4	3.92	0.07
Composition_PC2b		1	0.00	0.45
	Raptor	2	0.69	0.32
	Raptor + Patch	3	2.42	0.13
	Patch	4	3.01	0.10
Small-mammals				
Species richness		1	0.00	0.56
	Patch	2	1.80	0.23
	Raptor	3	2.48	0.16
	Raptor + Patch	4	4.54	0.06
Abundance	Patch	1	0.00	0.78
	Raptor + Patch	2	2.75	0.20
		3	8.32	0.01
	Raptor	4	9.82	0.01
Composition_PC1a		1	0	0.58
	Patch	2	1.95	0.22

	Raptor	3	2.71	0.15
	Raptor + Patch	4	5.11	0.045
Composition_PC2b		1	0	0.47
	Patch	2	0.71	0.33
	Raptor	3	2.77	0.12
	Raptor + Patch	4	3.52	0.081

[a] Axis 1 by principal component analysis. [b] Axis 2 by principal component analysis.



543

544 **Fig. 4**

545 Results of principal components analysis (PCA). The grey circles indicate site scores

546 and plus signs the eigenvector of each species.

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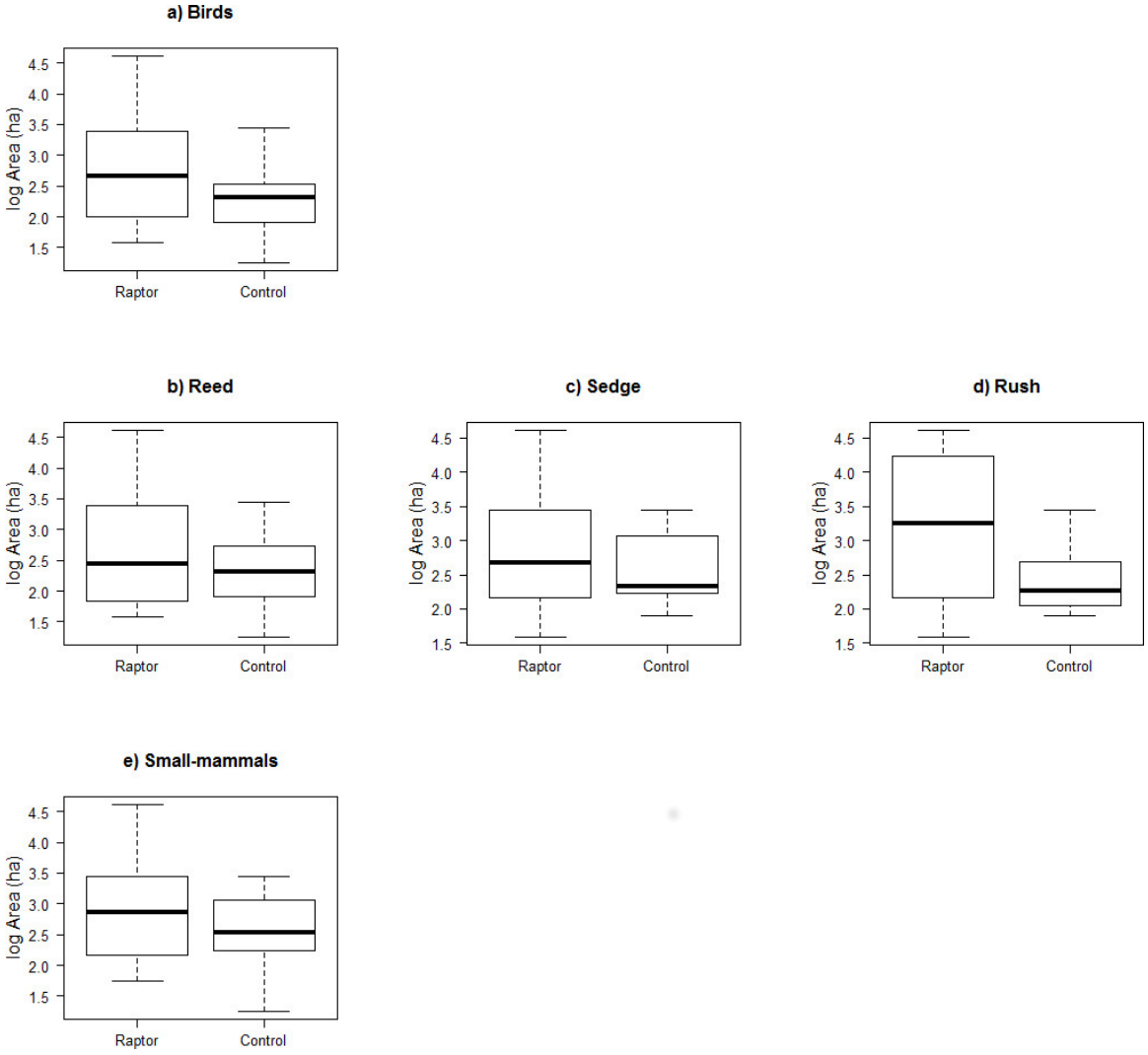

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549 **Fig. 5**

550 Relationships between the harrier PA and the log-transformed patch area (ha) for birds,

551 plants (reed, sedge, and rush communities), and small mammals.

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