1   **Title:** Maintenance of community function through compensation breaks down over time in a

2   desert rodent community

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7   **Original submission:** This submission analyzes long-term data on rodent community abundance

8   and energy use from the Portal Project. Sections of this timeseries have been analyzed in

9   numerous other publications, but this is the first to analyze data from 2007-2020 on

10   compensation on experimental and control plots.

11   **No prior publication:** This submission is posted as a preprint on bioRxiv at

12   https://www.biorxiv.org/content/10.1101/2021.10.01.462799v1.

13   **Animal welfare:** Rodent censuses were conducted with IACUC approval, most recently under

14   protocol 201808839_01 at the University of Florida.

15   **Open research:** All data and code to reproduce these analyses are archived on Zenodo at

16   https://doi.org/10.5281/zenodo.5544361 and https://doi.org/10.5281/zenodo.5539880.

17   **Analytic methods:** All analyses were conducted in R version 4.0.3.

18 **Abstract**

19 Understanding the ecological processes that maintain community function in systems

20 experiencing species loss, and how these processes change over time, is key to understanding the

21 relationship between community structure and function and predicting how communities may

22 respond to perturbations in the Anthropocene. Using a 30-year experiment on desert rodents, we

23 show that the impact of species loss on community-level energy use has changed repeatedly and

24 dramatically over time, due to 1) the addition of new species to the community, and 2) a

25 reduction in functional redundancy among the same set of species. Although strong

26 compensation, initially driven by the dispersal of functionally redundant species to the local

27 community, occurred in this system from 1997-2010, since 2010, compensation has broken

28 down due to decreasing functional overlap within the same set of species. Simultaneously, long-

29 term changes in sitewide community composition due to niche complementarity have decoupled

30 the dynamics of compensation from the overall impact of species loss on community-level

31 energy use. Shifting, context-dependent compensatory dynamics, such as those demonstrated

32 here, highlight the importance of explicitly long-term, metacommunity, and eco-evolutionary

33 perspectives on the link between species-level fluctuations and community function in a

34 changing world.

35 **Key words:** community function, compensation, zero-sum dynamic, environmental fluctuations,

36 functional redundancy

Introduction

Determining the extent to which community-level properties are affected by species loss, and how and why this changes over time, is key for understanding how communities are structured and how community function may respond to future perturbations (Gonzalez and Loreau 2009). When species are lost from a community, their contributions to community function (e.g. total productivity or resource use) are also directly lost. Community function may be maintained, however, if in the new community context, species that remain perform similar functions to the species that were lost, and compensate for the decline in function directly caused by species loss - i.e., functional redundancy (Walker 1992, 1995; Ernest and Brown 2001; Rosenfeld 2002; Gonzalez and Loreau 2009). When compensation via functional redundancy occurs among consumers with a common resource base, it is consistent with a zero-sum competitive dynamic, in which resources not used by one species are readily absorbed by competitors, and any increases in the abundance of one species must come at the direct expense of others (Van Valen 1973; Ernest et al. 2008).

Because the response of system-level function to species loss is partially determined by the degree of functional redundancy in a community, processes that cause functional redundancy to change over time can have important consequences for the long-term maintenance of ecosystem function. Colonization events may buffer community function against species loss, if a community gains species that perform similar functions to the species that were lost (Ernest and Brown 2001; Leibold et al. 2017). The ability of colonization to supply functionally redundant species depends on the species (and traits) present in the broader metacommunity, and on the rate of dispersal supplying appropriate species to local communities (Leibold et al. 2017).

59   Even without the addition of new species and traits, however, functional redundancy

60   within a consistent set of coexisting species may fluctuate over time. While, in theory, functional

61   redundancy may occur via the special case of complete niche neutrality (e.g. Hubbell 2001), it

62   may also occur in niche-structured systems that contain species that share some traits but differ

63   along other niche axes (Thibault et al. 2010). In these systems, if similar, but non-identical,

64   species respond to environmental change in similar ways, functional overlap can be maintained

65   or even strengthened. However, if niche differences cause species to respond differently to

66   changing conditions, the degree of functional overlap between those species may decline,

67   resulting in a breakdown in compensation (Loreau 2004; Fetzer et al. 2015). Over time, as

68   metacommunity dynamics and changing environmental conditions modulate functional

69   redundancy within a community, the extent to which community function is robust to species

70   loss - and the strength of zero-sum competition - may also be dynamic and context-dependent.

71   Despite logical conceptual support, and evidence from experimental microcosms (Fetzer

72   et al. 2015), there is little empirical documentation of how, and through which mechanisms,

73   temporal changes in functional redundancy modulate the effect of species loss on ecosystem

74   function in natural assemblages. Although relatively plentiful, observational data cannot

75   unambiguously detect compensation through functional redundancy, and even short-term

76   experiments may not be sufficient to capture temporal variation in compensation (Ernest and

77   Brown 2001; Houlahan et al. 2007). In contrast, long-term manipulative experiments are

78   uniquely suited to address this question. In long-term experiments in which key species are

79   removed from a community over an extended period of time, the impact of species loss on

80   community function can be directly quantified by comparing community function between

81   complete and manipulated assemblages. As metacommunity dynamics and environmental

82 conditions shift over time, long-term monitoring can reveal how these processes contribute to

83 changes in functional redundancy and ecosystem function across different time periods. Due to

84 the financial and logistical resources required to maintain and monitor whole-community

85 manipulations over long timescales, these experiments are rare in natural systems representative

86 of realistic evolutionary, geographic, and environmental constraints (Hughes et al. 2017).

87   Here, we use a 30-year experiment on desert rodents to investigate how shifts in

88 functional redundancy alter the effect of species loss on community function over time. In this

89 study, kangaroo rats (*Dipodomys* spp.), the largest and competitively dominant species in the

90 rodent community, have been removed from a subset of experimental plots to explore how the

91 loss of key species affects community function, measured as community-level metabolic flux

92 ("total energy use", or *Etot*) or total biomass (Ernest et al. 2019). For systems of consumers with

93 a shared resource base, such as this community of granivorous rodents, *Etot* reflects the total

94 amount of resources being processed by an assemblage, and total biomass directly reflects

95 standing biomass. Both are important metrics of community function (Lawton 1994; Ernest and

96 Brown 2001). Long-term monitoring of this experiment has documented repeated shifts in the

97 habitat and species composition of this system, resulting in distinct time periods characterized by

98 different habitat conditions and configurations of the rodent community (Christensen et al.

99 2018). Abrupt reorganization events in community composition occurred in 1997 and in 2010,

100 associated with the establishment and subsequent decline of the pocket mouse *Chaetodipus*

101 *baileyi*. *C. baileyi* is similar in size, and presumably other traits, to kangaroo rats, and its

102 establishment in 1996-97 drove a pronounced increase in compensation due to functional

103 redundancy between *C. baileyi* and kangaroo rats (Ernest and Brown 2001; Thibault et al. 2010).

104 Over the course of this experiment, shifting environmental conditions have caused the habitat at

105   the study site to transition from desert grassland to scrub, driving a shift in baseline rodent

106   community composition away from kangaroo rats and favoring other, smaller, granivores

107   (Brown et al. 1997; Ernest et al. 2008). By making comparisons across these time periods, we

108   explored how shifts in community composition and functional overlap among the same species

109   have contributed to long-term changes in the effect of species loss on community function.

110   **Methods**

111   *The Portal Project*

112   The Portal Project consists of a set of 24 fenced experimental plots located approximately

113   7 miles east of Portal, AZ, USA, on unceded land of the Chiricahua Apache. Beginning in 1977,

114   kangaroo rats (*Dipodomys spectabilis, D. merriami,* and *D. ordii*) have been experimentally

115   excluded from a subset of these plots (exclosures), while all other rodents are allowed access

116   through small holes cut in the plot fencing. Control plots, with larger holes, are accessible to all

117   rodents, including kangaroo rats. Rodents on all plots are censused via monthly bouts of live-

118   trapping. Each individual captured is identified to species and weighed. For additional details on

119   the site and methodology of the Portal Project, see Ernest et al. (2019).

120   *Data*

121   We used data for control and exclosure plots from February 1988 until January 2020. The

122   experimental treatments for some plots have changed over time, and we used the subset of plots

123   that have had the same treatments for the longest period of time (Ernest et al. 2019). Four control

124   plots, and five exclosure plots, met these criteria. In order to achieve a balanced sample, we

125   randomly selected four exclosure plots for analysis. We divided the timeseries into three time

126   periods defined by major transitions in the rodent community surrounding the establishment and

127   decline of *C. baileyi* (Ernest and Brown 2001; Christensen et al. 2018). The first time period

128   (February 1988-June 1997) precedes *C. baileyi*'s establishment at site. We defined *C. baileyi*'s

129   establishment date as the first census period in which *C. baileyi* was captured on all exclosure

130   plots (following Bledsoe and Ernest, 2019). During the second time period (July 1997-January

131   2010), *C. baileyi* was abundant on both exclosure and control plots. This time period ended with

132   a reorganization event in which *C. balieyi* became scarce sitewide. We used January 2010, the

133   midpoint of the 95% credible interval for the date of this reorganization event as estimated in

134   Christensen et al. (2018), as the end date for this time period. The last time period spans from

135   Feburary 2010-January 2020. For each individual rodent captured, we estimated the individual-

136   level metabolic rate using the scaling relationship between individual body mass and metabolic

137   rate $b = 5.69 * (m^{0.75})$, where *m* is body mass in grams and *b* is metabolic rate (for details, see

138   White et al. 2004). We calculated treatment and species-level energy use as the sum of the

139   appropriate individuals' metabolic rates, and total biomass as the sum of individuals' body mass

140   measurements.

141   *Statistical analysis of rodent community energy use and biomass*

142   Here, we describe analyses for energy use. For biomass, we repeated these analyses

143   substituting biomass values for energy use throughout. For all variables, we combined data for

144   all plots within a treatment in each monthly census period and calculated treatment-level means.

145   This is necessary to calculate compensation, and we treated other variables in the same way to

146   maintain consistency. A provisional plot-level analysis yielded qualitatively equivalent results

147   (Appendix S1). To measure the overall impact of kangaroo rat removal on *Etot*, we calculated a

148   "total energy ratio" as the ratio of treatment-level *Etot* for kangaroo-rat exclosure plots relative to

149   unmanipulated control plots, i.e. $Etot_E/Etot_C$ where $Etot_E$ and $Etot_C$ are total energy use on

150   exclosures and controls, respectively (Thibault et al 2010; Bledsoe and Ernest 2019). This ratio is

151   distinct from compensation, which we defined as the proportion of the energy made available by

152   kangaroo rat removal taken up via compensatory increases in energy use by small granivores (all

153   granivores other than kangaroo rats; *Baiomys taylori, C. baileyi, Chaetodipus hispidus,*

154   *Chaetodipus intermedius, Chaetodipus penicillatus, Perognathus flavus, Peromyscus eremicus,*

155   *Peromyscus leucopus, Peromyscus maniculatus, Reithrodontomys fulvescens, Reithrodontomys*

156   *megalotis,* and *Reithrodontomys montanus*). We calculated this as $(SG_E - SG_C)/KR_C$, where SG_E

157   and SG_C are the amount of energy used by small granivores (SG) on exclosure and control plots,

158   respectively, and KR_C is the amount of energy used by kangaroo rats (KR) on control plots

159   (Ernest and Brown 2001). To compare these variables across time periods, we used generalized

160   least squares models (GLS; the R package *nlme*; Pinheiro et al. 2020) of the form (SG_E –

161    $SG_C)/KR_C$ ~ *time period*, for compensation, and $Etot_E/Etot_C$ ~ *time period*, for the total energy

162   ratio. We included a continuous-time autoregressive temporal autocorrelation term to account for

163   temporal autocorrelation between values from monthly census periods within each multi-year

164   time period (for details of model selection, see Appendix S2). To evaluate change in baseline

165   community composition over time, we calculated the proportion of treatment-level energy use

166   accounted for by kangaroo rats on control plots in each census period ($KR_C/Etot_C$). Proportional

167   energy use is bounded 0-1 and is therefore not appropriate for GLS, so we compared values

168   across time periods using a binomial generalized linear model (GLM) of the form $KR_C/Etot_C$ ~

169   *time period*. Finally, we calculated the proportional energy use accounted for by *C. baileyi* (CB)

170   on exclosure and control plots in each census period ($CB_E/Etot_E$ and $CB_C/Etot_C$, respectively). *C.*

171   *baileyi* was not present at the site prior to 1996, and we restricted the analysis of *C. baileyi*

172   proportional energy use to the second two time periods. We compared *C. baileyi* proportional

173   energy use over time and across treatments using a binomial GLM of the form $CB_E/Etot_E$ ~ *time*

174   *period + treatment*. For all models, we calculated estimated means and 95% confidence or

175   credible intervals for time-period (and, for *C. baileyi*, treatment) level values, and contrasts

176   between time periods (and, for *C. baileyi*, treatments), using the R package *emmeans* (Lenth

177   2021). Analyses were conducted in R 4.0.3 (R Core Team 2020). Data and code are archived at

178   https://doi.org/10.5281/zenodo.5544361 and https://doi.org/10.5281/zenodo.5539880.

179   **Results**

180   The impact of kangaroo rat removal on community function has changed repeatedly

181   over time, through a combination of abrupt shifts in compensation associated with *C. baileyi*, and

182   long-term changes in baseline community composition sitewide (Figure 1). These dynamics are

183   qualitatively identical whether function is measured as total energy use (Figure 1; Appendix S2)

184   or total biomass (Appendix S3). The first shift coincided with *C. baileyi*'s establishment in the

185   community beginning in 1996-97 (Figure 1D). *C. baileyi* rapidly became dominant on exclosure

186   plots and dramatically increased compensation (Figure 1B). From 1997-2010, small granivores

187   compensated for an average of 58% of kangaroo rat energy use on control plots (95% interval

188   48-67%), an increase from an average of 18% from 1988-1997 (95% interval 8-29%; contrast *p*

189   < 0.001; for complete results of all models, see Appendix S2) from 1997-2010. With *C. baileyi*'s

190   addition to the community, the total energy ratio (on exclosures relative to controls; Figure 1A)

191   increased from 30% (20-40%) to 71% (62-79%, contrast *p* < 0.014). In the second shift,

192   beginning around 2010, *C. baileyi*'s abundance sitewide dropped precipitously (Figure 1D). *C.*

193   *baileyi*'s proportional energy use dropped from an average of 72% (65-80%) to 26% (18-35%,

194   contrast *p* < 0.001) on exclosure plots, and from 11% (6-16%) to essentially 0 on control plots

195   (contrast *p* < 0.001). Other species of small granivore did not make compensatory gains to offset

196   the decline in *C. baileyi* (Figure 1B). As a result, compensation declined from an average of 58%

197   (48-67%) to 28% (17-38%, contrast $p = 0.002$), a level not significantly different from the 18%

198   (8-29%, contrast $p = .44$) observed prior to *C. baileyi*'s establishment at the site. Somewhat

199   paradoxically, while the total energy ratio also dropped following *C. baileyi*'s decline, from an

200   average of 71% (62-79%) from 1997-2010 to 50% (40-60%, contrast $p = 0.0056$) from 2010-

201   2020, it remained higher than its average of 30% (20-40%, contrast $p = 0.0144$) from 1988-1997

202   (Figure 1A). Over the course of the experiment, community composition shifted sitewide. In

203   later years, kangaroo rats accounted for a lower proportion of baseline *Etot* than they did at the

204   beginning of the study (Figure 1C). From 1988-1997, kangaroo rats accounted for 92% (87-97%)

205   of *Etot* on controls; after 1997, this dropped to an average of approximately 70% (1988-1997

206   compared to later time periods, both $p = .0004$; 1997-2010 and 2020-2020 not significantly

207   different, $p = .976$). Because the proportion of *Etot* directly lost to kangaroo rat removal was

208   smaller from 2010-2020 than from 1988-1997, the total energy ratio was higher from 2010-2020

209   than it was from 1988-1997 - even though there was not a detectable difference between the two

210   time periods in the proportion of lost energy being offset through compensation.

211   **Discussion**

212   The dynamics of rodent community energy use at Portal illustrate that the role of

213   functional redundancy in buffering community function against species loss fluctuates over time,

214   due to changes in both species composition and in the degree of functional overlap among the

215   same species. The 1997 increase in compensation, driven by *C. baileyi*'s establishment at the

216   site, was a clear and compelling instance of colonization from the regional species pool

217   overcoming limitations on functional redundancy (Ernest and Brown 2001; Leibold et al 2017).

218   Although the small granivore species originally present in the community did not possess the

219   traits necessary to compensate for kangaroo rats, *C. baileyi* supplied those traits and

220   substantially, but incompletely, restored community function. In contrast, following the

221   community reorganization event in 2010, *C. baileyi* remained present in the community, but

222   ceased to operate as a partial functional replacement for kangaroo rats. This is consistent with

223   fluctuating conditions modulating functional redundancy between similar, but non-identical,

224   competitors. Kangaroo rats and *C. baileyi* are relatively similar in size and are demonstrably

225   capable of using similar resources. However, *C. baileyi* prefers different, shrubbier microhabitats

226   than kangaroo rats, and the two groups have been observed to replace each other in adjacent

227   habitats (Ernest and Brown 2001). We suggest that this study site, which has historically been

228   dominated by kangaroo rats, constitutes marginal habitat for *C. baileyi*, and that, while

229   conditions from 1997-2010 aligned sufficiently with *C. baileyi*'s requirements to create

230   appreciable functional redundancy between kangaroo rats and *C. baileyi*, conditions since have

231   caused this redundancy to break down. *C. baileyi*'s decline occurred immediately following a

232   period of low plant productivity and low rodent abundance community-wide, and in the decade

233   following, the site experienced two long and severe droughts (Appendix S4; Christensen et al.

234   2018). These extreme conditions may themselves have limited *C. baileyi's* fitness at the site, or

235   the community-wide low abundance event may have temporarily overcome incumbency effects

236   and triggered a community shift tracking longer-term habitat trends (Thibault and Brown 2008;

237   Christensen et al. 2018). Regardless of the proximate cause of *C. baileyi*'s decline, the fact that

238   *C. baileyi* remains in the community, but no longer compensates for kangaroo rats, illustrates

239   that changing conditions can have profound effects on community function by modulating the

240   degree of functional redundancy within a consistent set of species.

241   While changes in compensation have contributed to changes in community function in

242   this system, changes in compensation alone do not fully account for the long-term changes in the

243 overall impact of kangaroo rat removal on *Etot*. Since 2010, although the ratio of *Etot* on

244 exclosure plots relative to control plots declined coinciding with the breakdown in compensation

245 associated with *C. baileyi*, it remained higher than the levels observed prior to 1997 (Figure 1A).

246 This difference between the first and last time periods cannot be explained by an increase in

247 compensation, as compensation from 2010-2020 was not greater than pre-1997 levels (Figure

248 1B). Rather, the increase in *Etot* on exclosure plots relative to control plots was the result of a

249 long-term decrease in the contribution of kangaroo rats to *Etot* sitewide. Because kangaroo rats

250 accounted for a smaller proportion of *Etot* on control plots from 2010-2020 than they did prior to

251 1997, their removal had a smaller impact on community function – even though there was not an

252 increase in the degree to which small granivores compensated for their absence. In fact, the

253 comparable levels of compensation achieved in the decades preceding and following *C. baileyi*'s

254 dominance at the site suggest a relatively stable, and limited, degree of functional overlap

255 between kangaroo rats and the original small granivores (i.e., excluding *C. bailyei*). Niche

256 complementarity, combined with changing habitat conditions, may partially explain this

257 phenomenon. It is well-documented that, while kangaroo rats readily forage in open

258 microhabitats where predation risk can be relatively high, smaller granivores preferentially

259 forage in sheltered microhabitats as an antipredator tactic (Kelt 2011). Over the course of this

260 experiment, the habitat at this study site has transitioned from an arid grassland to a shrubland

261 (Brown et al. 1997). As sheltered microhabitats became more widespread, small granivores may

262 have gained access to a larger proportion of resources and increased their share of *Etot* sitewide.

263 However, kangaroo rats may have continued to use resources in open areas, which would have

264 remained inaccessible to smaller granivores even on exclosure plots. The long-term reduction in

265 the impact of kangaroo rat removal on community function, driven by niche complementarity

266   and consistent niche partitioning, contrasts with the temporary compensatory dynamic driven by

267   functional redundancy with *C. baileyi*. Although changes in the overall effect of species loss are

268   sometimes treated interchangeably with compensation (e.g. Ernest and Brown 2001 compared to

269   Thibault et al. 2010), it is important to recognize that multiple distinct pathways modulate the

270   long-term impacts of species loss on community function. Particularly in strongly niche-

271   structured systems, complementarity effects and fluctuations in functional redundancy may occur

272   simultaneously, with complex and counterintuitive impacts on community function.

273   Overall, the decadal-scale changes in energy use among the Portal rodents underscore the

274   importance of long-term metacommunity dynamics to the maintenance of community function

275   following species loss (see Leibold et al. 2017). Although a single colonization event may allow

276   for temporary compensation via functional redundancy, as conditions shift, species that once

277   compensated may no longer perform that function (see also Isbell et al. 2011). Particularly if

278   limiting similarity prevents similar competitors from specializing on precisely the same habitats

279   (Rosenfeld 2002), temporary, context-dependent compensation may be common. To maintain

280   compensation over time, multiple colonization events, supplying species that are functionally

281   redundant under different conditions, may be required. Depending on dispersal rates, and the

282   diversity and composition of regional species pools, this may be unlikely or even impossible. At

283   Portal, dispersal limitation introduced a 20-year delay in the compensatory response driven by *C.*

284   *baileyi*. Theoretically, a new species capable of compensating for kangaroo rats, and better-

285   suited to conditions at the site since 2010, could restore compensation under present conditions –

286   but it is unclear whether this species exists or if it can disperse to this site. As ecosystems

287   globally undergo reductions in habitat connectivity and regional beta diversity, and enter novel

288 climatic spaces, maintenance of community function via functional redundancy may grow

289 increasingly rare and fragile (Dornelas et al. 2014; Williams and Jackson 2007).

290 Finally, the long-term variability in functional redundancy documented here adds

291 important nuance to our understanding of how zero-sum dynamics operate in natural

292 assemblages. Theories invoking zero-sum dynamics, and tests for compensatory dynamics in

293 empirical data, often treat a zero-sum dynamic as a strong and temporally consistent constraint

294 (Hubbell 2001; Houlahan et al. 2007). In this framing, any resources made available via species

295 loss should immediately be taken up by other species. This is not consistent with the dynamics

296 that occur at Portal, which has seen extended periods of time when resources are available on

297 exclosure plots but are not used. Rather, these results are more consistent with a zero-sum

298 constraint operating at metacommunity or evolutionary scales (Van Valen 1973; Terry and Rowe

299 2015; Leibold et al. 2017). Over short timescales, or within a closed local assemblage, niche

300 differences may weaken zero-sum effects, especially under fluctuating conditions. However,

301 over larger temporal and spatial scales, dispersal or evolution may supply new species equipped

302 to use available resources - via either functional redundancy, or niche complementarity allowing

303 them to exploit novel niches. A long-term, metacommunity, and even macroevolutionary

304 approach may be necessary to fully understand how zero-sum constraints, functional

305 redundancy, and niche complementarity contribute to the maintenance of community-level

306 function in the face of species extinctions and changing conditions over time.

307 **Acknowledgements**

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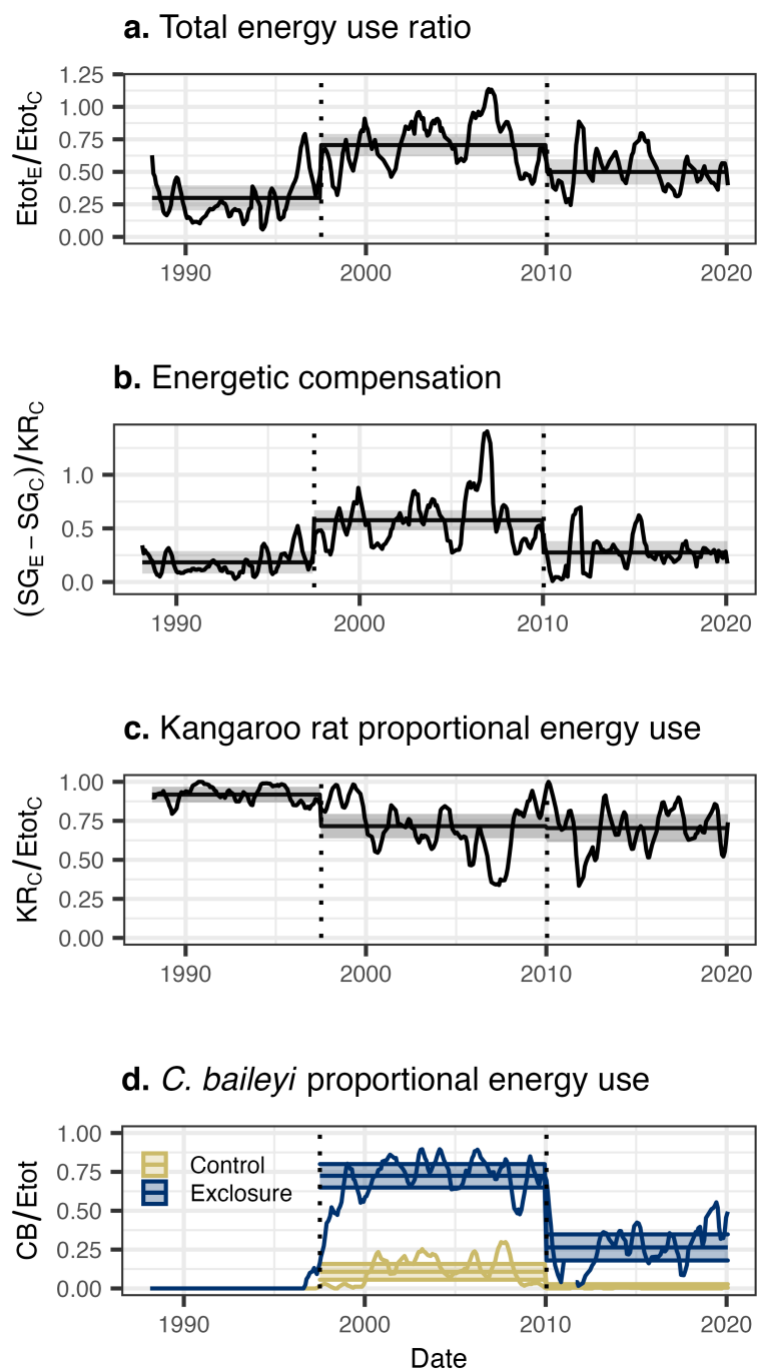334   Goheen. 2008. "Zero Sum, the Niche, and Metacommunities: Long-Term Dynamics of

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403 **Figure legends**

404 **Figure 1.** Dynamics of energy use and rodent community composition over time. Lines represent

405 the ratio of total energy use on exclosure plots to control plots (a), 6-month moving averages of

406 energetic compensation (b), and the share of community energy use accounted for by kangaroo

407 rats on control plots (c), and by *C. baileyi* (d), on control (gold) and exclosure (blue) plots.

408 Dotted vertical lines mark the boundaries between time periods used for statistical analysis.

409 Horizontal lines are time-period estimates from generalized least squares (a, b) and generalized

410 linear (c, d) models, and the semitransparent envelopes mark the 95% confidence or credible

411 intervals.

412

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414

415

416 **Figures**

a. Total energy use ratio

b. Energetic compensation

c. Kangaroo rat proportional energy use

d. *C. baileyi* proportional energy use

417

418

Appendix S1 - Plot-level analysis

Supplemental information for "Maintenance of community function through compensation

breaks down over time in a desert rodent community", by Renata M. Diaz and S. K. Morgan

Ernest, in Ecology.

Fully annotated code and RMarkdown documents to reproduce these analyses are available at

https://doi.org/10.5281/zenodo.5544361 and https://doi.org/10.5281/zenodo.5539880.

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456

457

458 **Explanation**

459 In order to calculate energetic compensation and the total energy ratio, we require an estimate for

460 the baseline values of total energy use, kangaroo rat energy use, and small granivore energy use

461 on control plots. Estimating these baselines requires aggregating over between-plot variability

462 among the control plots. For consistency, in the main analysis, we also aggregate across the

463 exclosure plots and focus on treatment-level means throughout. Here, we explore the effect of

464 between-plot variability on our analyses, to the extent possible. We used treatment-level means

465 across control plots to calculate energetic compensation and the total energy ratio, but calculated

466 these quantities separately for each exclosure plot, and conducted analyses including a random

467 effect of plot. We also conducted analyses of *Dipodomys* and *C. baileyi* proportional energy use

468 using plot-level data, again including plot as a random effect. Results were qualitatively the same

469 as using treatment-level means.

470

471   **Compensation**

472   *Model specification and selection*

473   We fit linear mixed-effects models (using the lme function in the R package nlme; Pinheiro et

474   al. 2021) of the form compensation ~ time period with a random effect of plot and temporal

475   autocorrelation structure to account for autocorrelation between monthly census periods within

476   each time period. We compared these to models without the autocorrelation structure, without

477   the random effect, and without the term for time period. The best-fitting model included terms

478   for time period, random effect of plot, and autocorrelation.

479   **Table S1. Model comparison for compensation.**

Model.specification	AIC
intercept + timeperiod + plot (random effect) + autocorrelation	1360.207
intercept + timeperiod + plot (random effect)	1680.916
intercept + timeperiod + autocorrelation	1409.830
intercept + plot (random effect) + autocorrelation	1408.362
intercept + plot (random effect)	1879.126
intercept	2036.371

480   *Results*

481   **Table S2. Coefficients from linear mixed-effects model for compensation**

482   Note that "oera" is the variable name for the term for time period in these analyses.

	Value	Std.Error	DF	t-value	p-value
(Intercept)	0.3451282	0.1048354	1362	3.292096	0.0010199

oera.L	0.0653090	0.0373313	1362	1.749446	0.0804392
oera.Q	-0.2845830	0.0341063	1362	-8.343990	0.0000000

Table S3. Estimates from linear mixed-effects model for compensation

Timeperiod	emmean	SE	df	lower.CL	upper.CL
1988-1997	0.1827673	0.1091842	3	-0.1647055	0.5302400
1997-2010	0.5774892	0.1078860	3	0.2341478	0.9208306
2010-2020	0.2751282	0.1093969	3	-0.0730215	0.6232779

Table S4. Contrasts from linear mixed-effects model for compensation

Comparison	estimate	SE	df	t.ratio	p.value
1988-1997 - 1997-2010	-0.3947220	0.0491845	1362	-8.025330	0.0000
1988-1997 - 2010-2020	-0.0923609	0.0527944	1362	-1.749446	0.1873
1997-2010 - 2010-2020	0.3023610	0.0496411	1362	6.090948	0.0000

486 **Total energy use**

487 *Model specification and selection*

488 As for compensation, we fit linear mixed-effects models fitting *total_energy_ratio ~ time period*

489 with a random effect of plot and a temporal autocorrelation term to account for autocorrelation

490 between monthly census periods within each timeperiod. We compared these to models without

491 the autocorrelation term, without the random effect, and without the term for time period. The

492 best-fitting model included terms for time period, random effect of plot, and autocorrelation.

493 **Table S5. Model comparison for total energy ratio.**

Model.specification	AIC
intercept + timeperiod + plot (random effect) + autocorrelation	474.8558
intercept + timeperiod + plot (random effect)	924.1830
intercept + timeperiod + autocorrelation	507.7842
intercept + plot (random effect) + autocorrelation	543.5425
intercept + plot (random effect)	1266.2097
intercept	1382.7469

494 *Results*

495 **Table S6. Coefficients from linear mixed-effects model on total energy ratio**

496 Note that "oera" is the variable name for the term for time period in these analyses.

	Value	Std.Error	DF	t-value	p-value
(Intercept)	0.5018200	0.0709701	1362	7.070865	0.0e+00
oera.L	0.1454309	0.0301324	1362	4.826392	1.5e-06

oera.Q   -0.2545852   0.0273660   1362   -9.302977   0.0e+00

497 Table S7. Estimates from linear mixed-effects model on total energy ratio

Timeperiod	emmean	SE	df	lower.CL	upper.CL
1988-1997	0.2950508	0.0751321	3	0.0559470	0.5341547
1997-2010	0.7096879	0.0738511	3	0.4746606	0.9447151
2010-2020	0.5007212	0.0752881	3	0.2611207	0.7403216

498 Table S8. Contrasts from linear mixed-effects model on total energy ratio

Comparison	estimate	SE	df	t.ratio	p.value
1988-1997 - 1997-2010	-0.4146370	0.0395736	1362	-10.477622	0.0e+00
1988-1997 - 2010-2020	-0.2056703	0.0426137	1362	-4.826392	4.6e-06
1997-2010 - 2010-2020	0.2089667	0.0398571	1362	5.242901	5.0e-07

499

500 **Kangaroo rat proportional energy use**

501 *Model specification and selection*

502 To compare proportional energy use across time periods, we used binomial generalized linear

503 mixed models (using the glmer function in the R package lme4; Bates et al. 2015), which

504 allowed us to include a random effect of plot.

505 For *Dipodomys* proportional energy use, we compared models with and without the random

506 effect of plot and with and without a term for timeperiod. The best-fitting model included terms

507 for timeperiod and a random effect of plot.

508 **Table S9. Model comparison for Dipodomys proportional energy use.**

Model.specification	AIC
intercept + timeperiod + plot (random effect)	1040.861
intercept + plot (random effect)	1162.470
intercept + timeperiod	1108.490
intercept	1208.081

509 *Results*

510 **Table S10. Coefficients from GLMER on Dipodomys energy use.**

511 Note that "oera" is the variable name for the term for time period in these analyses.

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	2.181163	0.1305753	16.704251	0
oera.L	-1.946096	0.2664545	-7.303670	0
oera.Q	1.124620	0.1769225	6.356572	0

512 **Table S11. Estimates from GLMER on Dipodomys energy use.**

513 Note that estimates are back-transformed onto the response scale, for interpretability.

Timeperiod	prob	SE	df	asymp.LCL	asymp.UCL
1988-1997	0.9823009	0.0062020	Inf	0.9701452	0.9944566
1997-2010	0.7795273	0.0183934	Inf	0.7434769	0.8155777
2010-2020	0.7797464	0.0208516	Inf	0.7388780	0.8206149

514 **Table S12. Contrasts from GLMER on Dipodomys energy use.**

515 Contrasts are performed on the link (logit) scale.

Comparison	estimate	SE	df	z.ratio	p.value
1988-1997 - 1997-2010	0.2027736	0.0194108	Inf	10.4464200	0
1988-1997 - 2010-2020	0.2025545	0.0217545	Inf	9.3109407	0
1997-2010 - 2010-2020	-0.0002191	0.0278048	Inf	-0.0078811	1

516

517 **C. baileyi proportional energy use**

518 *Model specification and selection*

519 As for kangaroo rat proportional energy use, we used a binomial generalized linear mixed effects

520 model to compare *C. baileyi* proportional energy use across time periods. Because *C. baileyi*

521 occurs on both control and exclosure plots, we investigated whether the dynamics of *C. baileyi*'s

522 proportional energy use differed between treatment types. We compared models incorporating

523 separate slopes, separate intercepts, or no terms for treatment modulating the change in *C. baileyi*

524 proportional energy use across time periods, i.e. comparing the full set of models:

525 • *cbaileyi_proportional_energy_use ~ timeperiod + treatment + timeperiod:treatment*

526 • *cbaileyi_proportional_energy_use ~ timeperiod + treatment*

527 • *cbaileyi_proportional_energy_use ~ timeperiod*

528 We also tested a null (intercept-only) model of no change across time periods:

529 • *cbaileyi_proportional_energy_use ~ 1*

530 We compared all of these models with and without a random effect of plot.

531 We found that the best-fitting model incorporated a random effect of plot, and fixed effects for

532 time period and for treatment, but no interaction between them

533 (*cbaileyi_proportional_energy_use ~ timeperiod + treatment*). We therefore proceeded with this

534 model.

535 **Table S13. Model comparison for C. baileyi proportional energy use.**

Model.specification	AIC
intercept + timeperiod + treatment + timeperiod:treatment + plot (random effect)	1021.318
intercept + timeperiod + treatment + plot (random effect)	1020.263
intercept + timeperiod + plot (random effect)	1042.758

intercept + plot (random effect)	1321.149
intercept + timeperiod + treatment + timeperiod:treatment	1166.653
intercept + timeperiod + treatment	1162.901
intercept + timeperiod	1869.097
intercept	2036.489

536 *Results*

Table S14. Coefficients from GLMER on C. baileyi energy use

538 Note that "oera" is the variable name for the term for time period in these analyses, and

539 "oplottype" refers to experimental treatment.

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-2.443643	0.2067789	-11.81766	0
oera.L	-1.866286	0.1530068	-12.19740	0
oplottype.L	3.265183	0.2913472	11.20719	0

Table S15. Estimates from GLMER on C. baileyi energy use

541 Note that estimates are back-transformed onto the response scale, for interpretability.

Timeperiod	Treatment	prob	SE	df	asymp.LCL	asymp.UCL
1997-2010	Control	0.0312856	0.0116044	Inf	0.0085414	0.0540297
1997-2010	Exclosure	0.7658194	0.0392864	Inf	0.6888195	0.8428193
2010-2020	Control	0.0023009	0.0008486	Inf	0.0006378	0.0039641
2010-2020	Exclosure	0.1893142	0.0364430	Inf	0.1178872	0.2607412

542 **Table S16. Contrasts from GLMER on C. baileyi energy use.**

543 Contrasts are performed on the link (logit) scale.

Comparison	Treatment	estimate	SE	df	z.ratio	p.value
1997-2010 - 2010-2020	Control	2.639326	0.2163843	Inf	12.1974	0
1997-2010 - 2010-2020	Exclosure	2.639326	0.2163843	Inf	12.1974	0

544

545 **References**

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554

555 **Appendix S2 - Full analytical methods and model results**

556 *Supplemental information for "Maintenance of community function through compensation*

557 *breaks down over time in a desert rodent community", by Renata M. Diaz and S. K. Morgan*

558 *Ernest, in Ecology.*

559 Fully annotated code and RMarkdown documents to reproduce these analyses are available at

560 https://doi.org/10.5281/zenodo.5544361 and https://doi.org/10.5281/zenodo.5539880.

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584

585 **Compensation**

586 We fit a generalized least squares (of the form *compensation ~ timeperiod*; note that

587 "timeperiod" is coded as "oera" throughout) using the gls function from the R package nlme

588 (Pinheiro et al. 2021). Because values from monthly censuses within each time period are subject

589 to temporal autocorrelation, we included a continuous autoregressive temporal autocorrelation

590 structure of order 1 (using the CORCAR1 function). We compared this model to models fit

591 without the autocorrelation structure and without the time period term using AIC. The model

592 with both the time period term and the autocorrelation structure was the best-fitting model via

593 AIC, and we used this model to calculate estimates and contrasts using the package emmeans

594 (Lenth 2021).

595 **Table S1. Model comparison for compensation.**

Model.specification	AIC
intercept + timeperiod + autocorrelation	69.85023
intercept + autocorrelation	84.74902
intercept + timeperiod	157.09726
intercept	252.74534

596 **Table S2. Coefficients from GLS for compensation**

597 Note that "oera" is the variable name for the term for time period in these analyses.

	Value	Std.Error	t-value	p-value
(Intercept)	0.3450313	0.0294996	11.696141	0.0000000
oera.L	0.0647933	0.0524103	1.236269	0.2172146

oera.Q   -0.2833553   0.0477359   -5.935890   0.0000000

Table S3. Estimates from GLS for compensation

Timeperiod	emmean	SE	df	lower.CL	upper.CL
1988-1997	0.1835362	0.0520378	44.11081	0.0786683	0.2884041
1997-2010	0.5763899	0.0462641	47.37851	0.4833383	0.6694416
2010-2020	0.2751677	0.0528010	46.75897	0.1689314	0.3814041

Table S4. Contrasts from GLS for compensation

Comparison	estimate	SE	df	t.ratio	p.value
1988-1997 - 1997-2010	-0.3928537	0.0689413	47.89422	-5.698378	0.0000
1988-1997 - 2010-2020	-0.0916315	0.0741194	45.51740	-1.236269	0.4383
1997-2010 - 2010-2020	0.3012222	0.0694989	49.52957	4.334200	0.0002

601 **Total energy use ratio**

602 As for compensation, we fit a generalized least squares of the form *total_energy_ratio ~*

603 *timeperiod*, accounting for temporal autocorrelation between monthly censuses within each time

604 period using a continuous autoregressive autocorrelation structure of order 1. We compared this

605 model to models fit without the timeperiod term and/or autocorrelation structure, and found the

606 full (timeperiod plus autocorrelation) model had the best performance via AIC. We used this

607 model for estimates and contrasts.

608 **Table S5. Model comparison for total energy ratio.**

Model.specification	AIC
intercept + timeperiod + autocorrelation	-132.92138
intercept + autocorrelation	-118.15000
intercept + timeperiod	13.29396
intercept	156.85988

609 **Table S6. Coefficients from GLS on total energy ratio**

610 Note that "oera" is the variable name for the term for time period in these analyses.

	Value	Std.Error	t-value	p-value
(Intercept)	0.5016731	0.0271176	18.499880	0.0000000
oera.L	0.1413504	0.0477646	2.959316	0.0033001
oera.Q	-0.2503659	0.0429312	-5.831790	0.0000000

611 **Table S7. Estimates from GLS on total energy ratio**

Timeperiod	emmean	SE	df	lower.CL	upper.CL

1988-1997	0.2995118	0.0475806	36.19943	0.2030323	0.3959913
1997-2010	0.7060960	0.0419773	38.51943	0.6211550	0.7910369
2010-2020	0.4994115	0.0480066	37.62774	0.4021956	0.5966274

Table S8. Contrasts from GLS on total energy ratio

Comparison	estimate	SE	df	t.ratio	p.value
1988-1997 - 1997-2010	-0.4065842	0.0623398	40.51631	-6.522060	0.0000
1988-1997 - 2010-2020	-0.1998997	0.0675493	37.12310	-2.959316	0.0144
1997-2010 - 2010-2020	0.2066845	0.0626456	41.44768	3.299267	0.0056

613

614 **Kangaroo rat (Dipodomys) proportional energy use**

615 Proportional energy use is bounded 0-1 and cannot be fit with generalized least squares. We

616 therefore used a binomial generalized linear model of the form

617 *dipodomys_proportional_energy_use ~ timeperiod*. We compared a model fit with a timeperiod

618 term to an intercept-only (null) model using AIC, and found the timeperiod term improved

619 model fit. We used this model for estimates and contrasts.

620 Note that we were unable to incorporate temporal autocorrelation into generalized linear models,

621 and we prioritized fitting models of the appropirate family over accounting for autocorrelation.

622 Due to the pronounced differences between time periods for these variables, we were

623 comfortable proceeding without explicitly accounting for autocorrelation.

624 **Table S9. Model comparison for Dipodomys proportional energy use.**

Model.specification	AIC
intercept + timeperiod	258.3581
intercept	280.8497

625 **Table S10. Coefficients from GLM on Dipodomys energy use.**

626 Note that "oera" is the variable name for the term for time period in these analyses. Coefficients

627 are given on the link (logit) scale.

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.4032480	0.1503201	9.335068	0.0000000
oera.L	-1.1000833	0.2871738	-3.830723	0.0001278
oera.Q	0.5855493	0.2304516	2.540878	0.0110574

628 **Table S11. Estimates from GLM on Dipodomys energy use.**

629 Note that estimates are back-transformed onto the response scale, for interpretability.

Timeperiod	prob	SE	df	asymp.LCL	asymp.UCL
1988-1997	0.9183528	0.0256462	Inf	0.8680872	0.9686183
1997-2010	0.7160901	0.0398537	Inf	0.6379782	0.7942020
2010-2020	0.7035835	0.0456677	Inf	0.6140765	0.7930905

630 **Table S12. Contrasts from GLM on Dipodomys energy use.**

631 Contrasts are performed on the link (logit) scale.

contrast	estimate	SE	df	z.ratio	p.value
a_pre_pb - b_pre_reorg	1.4950249	0.3942281	Inf	3.7922836	0.0004
a_pre_pb - c_post_reorg	1.5557527	0.4061251	Inf	3.8307227	0.0004
b_pre_reorg - c_post_reorg	0.0607279	0.2938992	Inf	0.2066282	0.9767

632

633 **C. baileyi proportional energy use**

634 As for kangaroo rat proportional energy use, we used a binomial generalized linear model to

635 compare *C. baileyi* proportional energy use across time periods. Because *C. baileyi* occurs on

636 both control and exclosure plots, we investigated whether the dynamics of *C. baileyi*'s

637 proportional energy use differed between treatment types. We compared models incorporating

638 separate slopes, separate intercepts, or no terms for treatment modulating the change in *C. baileyi*

639 proportional energy use across time periods, i.e. comparing the full set of models:

640 • *cbaileyi_proportional_energy_use ~ timeperiod + treatment + timeperiod:treatment*

641 • *cbaileyi_proportional_energy_use ~ timeperiod + treatment*

642 • *cbaileyi_proportional_energy_use ~ timeperiod*

643 We also tested a null (intercept-only) model of no change across time periods:

644 • *cbaileyi_proportional_energy_use ~ 1*

645 We found that the best-fitting model incorporated effects for time period and for treatment, but

646 no interaction between them (*cbaileyi_proportional_energy_use ~ timeperiod + treatment*). We

647 therefore proceeded with this model.

648 **Table S13. Model comparison for C. baileyi proportional energy use.**

Model.specification	AIC
intercept + timeperiod + treatment + timeperiod:treatment	237.7643
intercept + timeperiod + treatment	231.0963
intercept + timeperiod	460.8477
intercept	541.3799

649 **Table S14. Coefficients from GLM on C. baileyi energy use**

650 Note that "oera" is the variable name for the term for time period in these analyses, and

651 "oplottype" refers to treatment. Coefficients are given on the link (logit) scale.

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-1.574028	0.1670168	-9.424368	0
oera.L	-1.409273	0.2010398	-7.009921	0
oplottype.L	2.184896	0.2267112	9.637355	0

652 **Table S15. Estimates from GLM on C. baileyi energy use**

653 Note that estimates are back-transformed onto the response scale, for interpretability.

Timeperiod	Treatment	prob	SE	df	asymp.LCL	asymp.UCL
1997-2010	Control	0.1069314	0.0258894	Inf	0.0561890	0.1576737
1997-2010	Exclosure	0.7246076	0.0385129	Inf	0.6491236	0.8000915
2010-2020	Control	0.0160560	0.0058224	Inf	0.0046444	0.0274676
2010-2020	Exclosure	0.2639419	0.0428458	Inf	0.1799657	0.3479181

654 **Table S16. Contrasts from GLM on C. baileyi energy use.**

655 Contrasts are performed on the link (logit) scale.

Comparison	Treatment	estimate	SE	df	z.ratio	p.value
1997-2010 - 2010-2020	Control	1.993013	0.2843132	Inf	7.009921	0
1997-2010 - 2010-2020	Exclosure	1.993013	0.2843132	Inf	7.009921	0

656

657 **References**

658 Lenth, Russell V. (2021). emmeans: *Estimated Marginal Means, aka Least-Squares Means.* R

659 package version 1.7.0. <URL: https://CRAN.R-project.org/package=emmeans>

660 Pinheiro J, Bates D, DebRoy S, Sarkar D, R Core Team (2021). *nlme: Linear and Nonlinear*

661 *Mixed Effects Models*. R package version 3.1-153, <URL: https://CRAN.R-

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663

Appendix S3 - Biomass analysis

664

665 *Supplemental information for "Maintenance of community function through compensation*

666 *breaks down over time in a desert rodent community", by Renata M. Diaz and S. K. Morgan*

667 *Ernest, in Ecology.*

668 Fully annotated code and RMarkdown documents to reproduce these analyses are available at

669 https://doi.org/10.5281/zenodo.5544361 and https://doi.org/10.5281/zenodo.5539880.

670 All statistical methods for biomass are identical to the ones for energy use (Appendix S1).

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696

697 **Compensation**

698 We fit a generalized least squares (of the form *compensation ~ timeperiod*; note that

699 "timeperiod" is coded as "oera" throughout) using the gls function from the R package nlme

700 (Pinheiro et al. 2021). Because values from monthly censuses within each time period are subject

701 to temporal autocorrelation, we included a continuous autoregressive temporal autocorrelation

702 structure of order 1 (using the CORCAR1 function). We compared this model to models fit

703 without the autocorrelation structure and without the time period term using AIC. The model

704 with both the time period term and the autocorrelation structure was the best-fitting model via

705 AIC, and we used this model to calculate estimates and contrasts using the package emmeans

706 (Lenth 2021).

707 **Table S1. Model comparison for compensation.**

Model.specification	AIC
intercept + timeperiod + autocorrelation	-17.623354
intercept + autocorrelation	-3.297103
intercept + timeperiod	92.184205
intercept	207.804481

708 **Table S2. Coefficients from GLS for compensation**

709 Note that "oera" is the variable name for the term for time period in these analyses.

	Value	Std.Error	t-value	p-value
(Intercept)	0.3081443	0.0290539	10.605950	0.0000000
oera.L	0.0711412	0.0514131	1.383719	0.1673549
oera.Q	-0.2799121	0.0465252	-6.016352	0.0000000

710 **Table S3. Estimates from GLS for compensation**

Timeperiod	emmean	SE	df	lower.CL	upper.CL
1988-1997	0.1435663	0.0511419	39.28312	0.0401458	0.2469867
1997-2010	0.5366915	0.0452745	41.91562	0.4453185	0.6280646
2010-2020	0.2441751	0.0517205	41.17937	0.1397373	0.3486130

711 **Table S4. Contrasts from GLS for compensation**

Comparison	estimate	SE	df	t.ratio	p.value
1988-1997 - 1997-2010	-0.3931253	0.0673811	43.22895	-5.834358	0.0000
1988-1997 - 2010-2020	-0.1006089	0.0727090	40.36882	-1.383719	0.3588
1997-2010 - 2010-2020	0.2925164	0.0678003	44.43055	4.314383	0.0003

712

713 **Total biomass ratio**

714 As for compensation, we fit a generalized least squares of the form *total_biomass_ratio* ~

715 *timeperiod*, accounting for temporal autocorrelation between monthly censuses within each time

716 period using a continuous autoregressive autocorrelation structure of order 1. We compared this

717 model to models fit without the timeperiod term and/or autocorrelation structure, and found the

718 full (timeperiod plus autocorrelation) model had the best performance via AIC. We used this

719 model for estimates and contrasts.

720 **Table S5. Model comparison for total biomass ratio.**

Model.specification	AIC
intercept + timeperiod + autocorrelation	-176.57761
intercept + autocorrelation	-162.61339
intercept + timeperiod	-15.98438
intercept	146.61442

721 **Table S6. Coefficients from GLS on total biomass ratio**

722 Note that "oera" is the variable name for the term for time period in these analyses.

	Value	Std.Error	t-value	p-value
(Intercept)	0.4553971	0.0272418	16.716827	0.0000000
oera.L	0.1454493	0.0477989	3.042941	0.0025257
oera.Q	-0.2531409	0.0427343	-5.923594	0.0000000

723 **Table S7. Estimates from GLS on total biomass ratio**

Timeperiod	emmean	SE	df	lower.CL	upper.CL

1988-1997	0.2492046	0.0476584	33.82432	0.1523326	0.3460765
1997-2010	0.6620857	0.0419515	35.98516	0.5770030	0.7471684
2010-2020	0.4549009	0.0480215	34.98703	0.3574107	0.5523911

724 Table S8. Contrasts from GLS on total biomass ratio

Comparison	estimate	SE	df	t.ratio	p.value
1988-1997 - 1997-2010	-0.4128811	0.0621739	38.42746	-6.640747	0.0000
1988-1997 - 2010-2020	-0.2056963	0.0675979	34.67694	-3.042941	0.0121
1997-2010 - 2010-2020	0.2071848	0.0624325	39.20390	3.318542	0.0054

725

726 **Kangaroo rat (Dipodomys) proportional biomass**

727 Proportional biomass is bounded 0-1 and cannot be fit with generalized least squares. We

728 therefore used a binomial generalized linear model with no temporal autocorrelation term, of the

729 form *dipodomys_proportional_biomass ~ timeperiod*. We compared a model fit with a

730 timeperiod term to an intercept-only (null) model using AIC, and found the timeperiod term

731 improved model fit. We used this model for estimates and contrasts.

732 **Table S9. Model comparison for Dipodomys proportional biomass.**

Model.specification	AIC
intercept + timeperiod	215.2069
intercept	227.9608

733 **Table S10. Coefficients from GLM on Dipodomys biomass.**

734 Note that "oera" is the variable name for the term for time period in these analyses. Coefficients

735 are given on the link (logit) scale.

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.6149566	0.1644937	9.817741	0.0000000
oera.L	-1.1672395	0.3180813	-3.669626	0.0002429
oera.Q	0.6619048	0.2473324	2.676175	0.0074468

736 **Table S11. Estimates from GLM on Dipodomys biomass.**

737 Note that estimates are back-transformed onto the response scale, for interpretability.

Timeperiod	prob	SE	df	asymp.LCL	asymp.UCL
1988-1997	0.9376458	0.0226460	Inf	0.8932605	0.9820310

1997-2010	0.7454543	0.0385025	Inf	0.6699909	0.8209177
2010-2020	0.7426552	0.0437171	Inf	0.6569713	0.8283392

738 **Table S12. Contrasts from GLM on Dipodomys biomass.**

739 Contrasts are performed on the link (logit) scale.

contrast	estimate	SE	df	z.ratio	p.value
a_pre_pb - b_pre_reorg	1.6360275	0.4372643	Inf	3.741508	0.0005
a_pre_pb - c_post_reorg	1.6507259	0.4498349	Inf	3.669626	0.0007
b_pre_reorg - c_post_reorg	0.0146984	0.3057707	Inf	0.048070	0.9987

740

741 **C. baileyi proportional biomass**

742 *Model specification and selection*

743 As for kangaroo rat proportional biomass, we used a binomial generalized linear model to

744 compare *C. baileyi* proportional biomass across time periods. Because *C. baileyi* occurs on both

745 control and exclosure plots, we investigated whether the dynamics of *C. baileyi*'s proportional

746 biomass differed between treatment types. We compared models incorporating separate slopes,

747 separate intercepts, or no terms for treatment modulating the change in *C. baileyi* proportional

748 biomass across time periods, i.e. comparing the full set of models:

749 • *cbaileyi_proportional_biomass ~ timeperiod + treatment + timeperiod:treatment*
750 • *cbaileyi_proportional_biomass ~ timeperiod + treatment*
751 • *cbaileyi_proportional_biomass ~ timeperiod*
752 We also tested a null (intercept-only) model of no change across time periods:

753 • *cbaileyi_proportional_biomass ~ 1*
754 We found that the best-fitting model incorporated effects for time period and for treatment, but

755 no interaction between them (*cbaileyi_proportional_biomass ~ timeperiod + treatment*). We

756 therefore proceeded with this model.

757 **Table S13. Model comparison for C. baileyi proportional biomass.**

Model.specification	AIC
intercept + timeperiod + treatment + timeperiod:treatment	237.6847
intercept + timeperiod + treatment	231.2374
intercept + timeperiod	466.4937
intercept + treatment	346.2154
intercept	543.7811

758   **Table S14. Coefficients from GLM on C. baileyi biomass.**

759   Note that "oera" is the variable name for the term for time period in these analyses, and

760   "oplottype" refers to treatment. Coefficients are given on the link (logit) scale.

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-1.538798	0.1671239	-9.207525	0
oera.L	-1.403286	0.2006948	-6.992140	0
oplottype.L	2.270657	0.2298594	9.878462	0

761   **Table S15. Estimates from GLM on C. baileyi biomass**

762   Note that estimates are back-transformed onto the response scale, for interpretability.

Timeperiod	Treatment	prob	SE	df	asymp.LCL	asymp.UCL
1997-2010	Control	0.1041331	0.0255800	Inf	0.0539971	0.1542691
1997-2010	Exclosure	0.7425132	0.0376727	Inf	0.6686761	0.8163504
2010-2020	Control	0.0157248	0.0057341	Inf	0.0044861	0.0269634
2010-2020	Exclosure	0.2838438	0.0439192	Inf	0.1977637	0.3699240

763   **Table S16. Contrasts from GLM on C. baileyi biomass.**

764   Contrasts are performed on the link (logit) scale.

Comparison	Treatment	estimate	SE	df	z.ratio	p.value
1997-2010 - 2010-2020	Control	1.984546	0.2838253	Inf	6.99214	0
1997-2010 - 2010-2020	Exclosure	1.984546	0.2838253	Inf	6.99214	0

765

766 **Figure S1. Biomass results**

A. Total biomass ratio

B. Biomass compensation

C. Kangaroo rat proportional biomass

D. *C. baileyi* proportional biomass
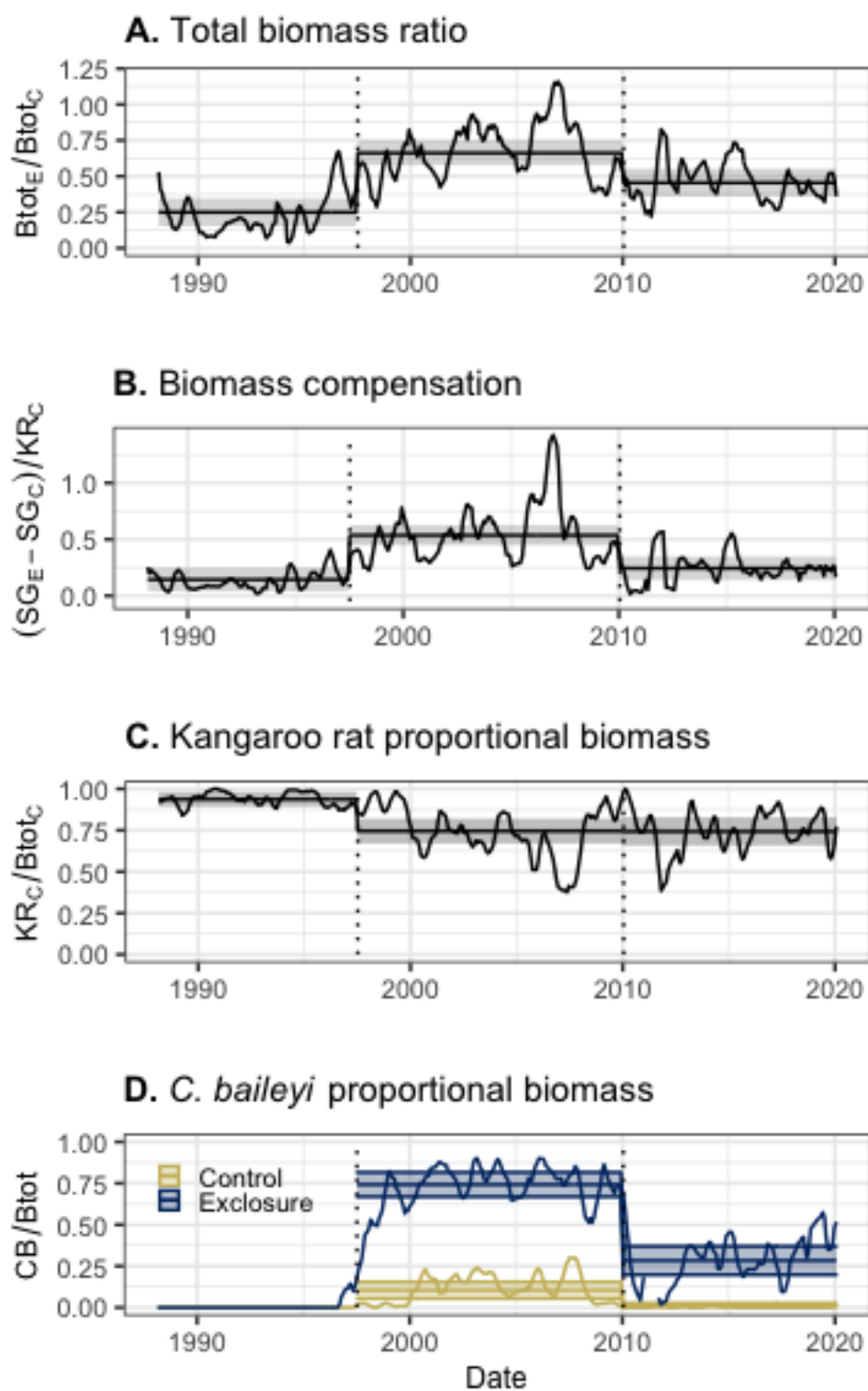
767

768 **Figure S1 Legend.**

769 Dynamics of biomass and rodent community composition over time. Lines represent the ratio of

770 biomass on exclosure plots to control plots (a), 6-month moving averages of biomass

771 compensation (b), and the share of community-wide biomass accounted for by kangaroo rats on

772 control plots (c), and by C. baileyi (d), on control (gold) and exclosure (blue) plots. Dotted

773 vertical lines mark the boundaries between time periods used for statistical analysis. Horizontal

774 lines are time-period estimates from generalized least squares (a, b) and generalized linear (c, d)

775 models, and the semitransparent envelopes mark the 95% confidence or credible intervals.

776

777 **References**

778 Lenth, Russell V. (2021). emmeans: *Estimated Marginal Means, aka Least-Squares Means.* R

779 package version 1.7.0. <URL: https://CRAN.R-project.org/package=emmeans>

780 Pinheiro J, Bates D, DebRoy S, Sarkar D, R Core Team (2021). *nlme: Linear and Nonlinear*

781 *Mixed Effects Models*. R package version 3.1-153, <URL: https://CRAN.R-

782 project.org/package=nlme>.

783

Appendix S4 - Covariates of rodent community change

Supplemental information for "Maintenance of community function through compensation

breaks down over time in a desert rodent community", by Renata M. Diaz and S. K. Morgan

Ernest, in Ecology.

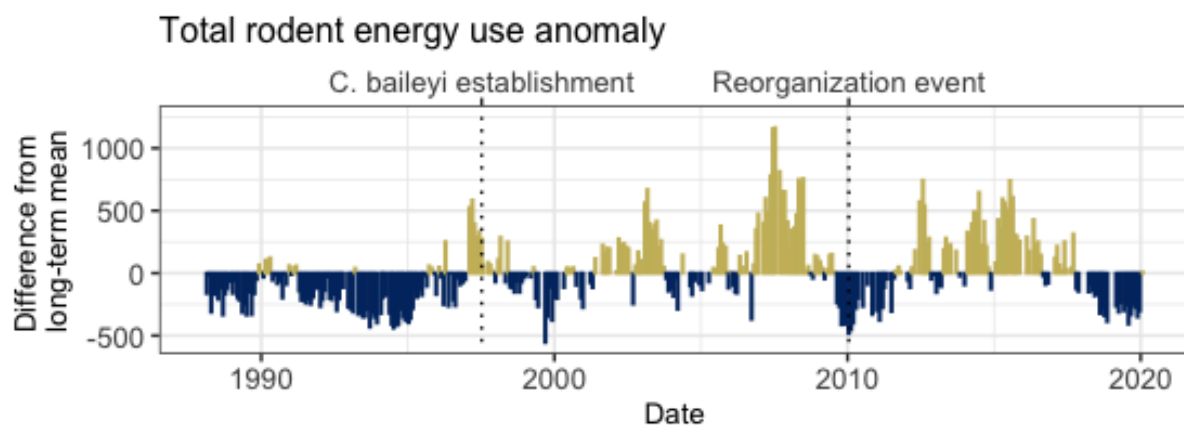Fully annotated code and RMarkdown documents to reproduce these analyses are available at

https://doi.org/10.5281/zenodo.5544361 and https://doi.org/10.5281/zenodo.5539880.
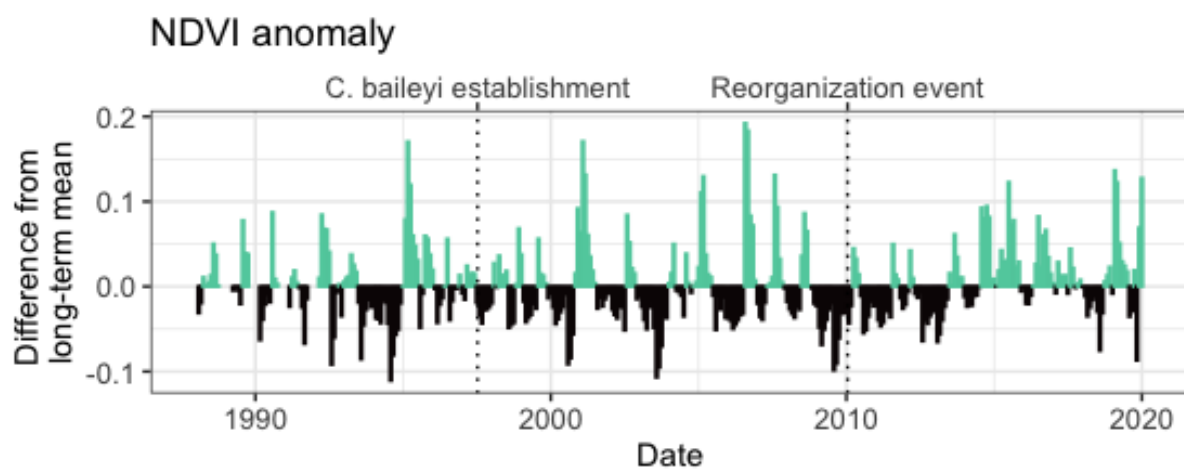
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Appendix S4 Figure S1 - Covariates of rodent community change

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797

798   **Legend**
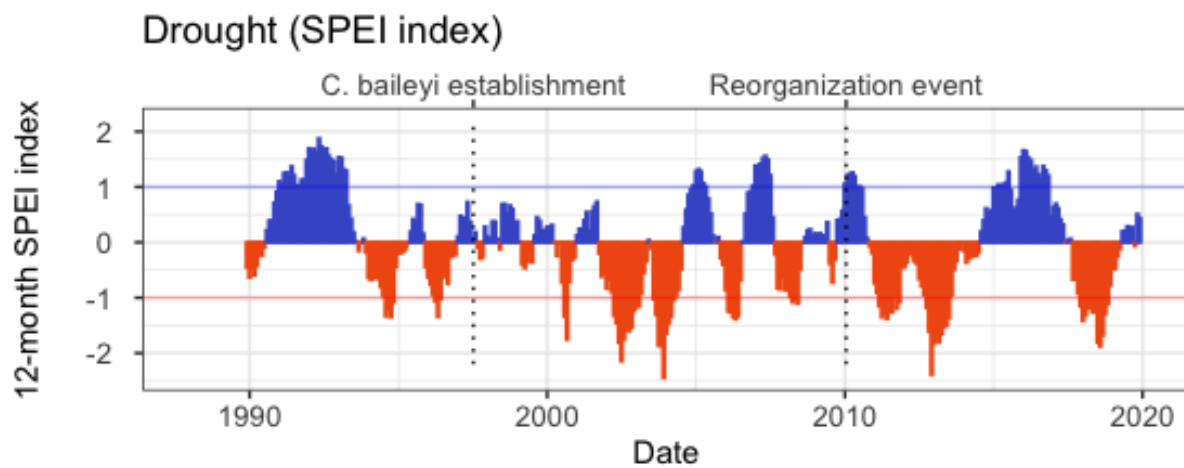
799   *Figure S1*. Changes in overall community energy use (A), NDVI (B), and local climate (C)

800   surrounding the 2010 shift in rodent community composition. As documented in Christensen et

801   al. (2018), the 2010 transition followed a period of low abundance community-wide (A) and low

802   plant productivity (B). Since 2010, the site has experienced two periods of drought (C)

803   interspersed with an unusually wet period.

804   Total rodent energy use (A) is calculated as the total energy use of all granviores on control plots

805   ($Etot_C$) in each census period. The anomaly (shown) is calculated as the difference between the

806   total energy use in each census period and the long-term mean of total energy use. Vertical

807   dashed lines mark the dates of major transitions in the rodent community. NDVI anomaly (B) is

808   calculated as the difference between monthly NDVI and the long-term mean for that month.

809   NDVI data were obtained from Landsat 5, 7, and 8 using the ndvi function in the R package

810   portalr (Maesk et al. 2006; Vermote et al. 2016; Christensen et al. 2019). Drought (C) was

811   calculated using a 12-month Standardized Precipitation Evapotranspiraiton index (SPEI) for all

812   months from 1989-2020, using the Thornthwaite method to estimate potential evapotranspiration

813   (using the R package SPEI, Beguería and Vicente-Serrano 2017; Slette et al. 2019; Cárdenas et

814   al. 2021). Values greater than 0 (blue) indicate wetter than average conditions, and values less

815   than 0 (red) indicate drier conditions. Values between -1 and 1 (horizontal lines) are considered

816   within normal variability for a system, while values < -1 constitute drought (Slette et al. 2019).

817

818   **References**

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