Consumer sexual dimorphism promotes coexistence among competing resources

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Abstract

Within-species variation is a salient feature of natural populations, of substantial importance for species interactions. However, the community consequences of sexual dimorphism, one of the most ubiquitous sources of within-species variance, remains poorly understood. Here, we extend classical models of consumer-resource dynamics to explore the ecological consequences of consumer sexual dimorphism. We show that sexual dimorphism in consumer attack rates on two different resource species promotes coexistence between those resources, mitigating the effects of both apparent competition and direct interspecific competition. Consumer sexual dimorphism can prevent exclusion of a resource with inferior growth rates because reduction in any of the two resources reduces consumer density, generating negative frequency dependence that stabilizes coexistence between resources. Our work highlights ecological sex differences as a potentially key factor governing the assembly of ecological communities, illustrating that the specific source of within-species variance can have important implications for community ecology.

Introduction

Species composition varies substantially across ecological communities, inspiring a rich body of theory and data aimed at identifying the processes that govern community assembly. Resulting models of consumer-resource dynamics yield general conclusions for the circumstances under which competing species can or cannot coexist. This modern coexistence theory tells us that competitive exclusion is expected when competing, or apparently-competing (via shared predation; Holt 1977), species differ substantially in per-capita growth rates and/or when interspecific competition is stronger than intraspecific competition (Chesson 2000). Mechanisms promoting coexistence thus act either to equalize per-capita growth rates or stabilize interactions between species. Many extensions of simple consumer-resource models (summarized in Ellner et al. 2018) have identified features typical of natural populations that affect these two pathways to coexistence.

Within-species variation is one key feature of natural populations that has emerged as a critical contributor to community ecology and species interactions (Bolnick et al. 2011, Start and Gilbert 2017, Des Roches et al. 2018, Start 2018). Phenotypic variation in consumers and/or their resources can either promote or constrain coexistence, under many circumstances yielding different conclusions than would be reached from models ignoring within species variation (Bolnick et al. 2011, Schreiber et al. 2011, Patel and Schreiber 2015, Cortez and Patel 2017). Such variation can arise from evolutionary processes, such as mutation, the maintenance of standing genetic variance (including differences between the sexes), and ontogenetic change, as well as environmental inputs and developmental plasticity. With the possible exception of ontogenetic change, the source of phenotypic variance is rarely considered in ecological models, to the extent that variation is considered at all.

72 Here, we explore the ecological consequences of sexual dimorphism, a central feature of
73 metazoans and many plant populations that has not been fully incorporated into ecological
74 theory. The gamete differences that define the sexes are expected to lead to divergence between
75 males and females in a suite of life history traits (Trivers 1972, Shärer et al. 2012) iconically
76 manifest as striking sexual dimorphism in sexually-selected traits (Darwin 1871, Andersson
77 1994). Although sexual selection and associated mate choice behaviors themselves may have
78 little obvious relevance to interspecific ecological interactions (but see Gomez-Llano et al.
79 2018), the different life histories that define the sexes are often expected lead to different
80 nutritional and resource requirements for males and females (Belovksy 1978, Maklakov et al.
81 2008). As a specific example, in insects, differential contributions of longevity and fecundity to
82 male and female lifetime reproductive success result in different combinations of macronutrients
83 that maximize male and female fitness (Maklakov et al. 2008, Reddiex et al. 2013, Garlapow et
84 al. 2015, Jensen et al. 2015, Camus et al. 2017). Consequently, males and females of many
85 species have evolved divergent resource use, either as an indirect outcome of divergent
86 reproductive roles or through other forms of sex-specific natural selection, resulting in sex-
87 differences in diet composition and often in corresponding trophic morphology (Slatkin 1984,
88 Temeles 1985, Shine 1989, Temeles et al. 2000, De Lisle and Rowe 2015a). Data suggest that
89 these 'ecological' sexual dimorphisms can have substantial consequences for community
90 structure (Fryxell et al. 2015, Pincheira-Donoso et al. 2018, Start and De Lisle 2018). More
91 generally, sex differences may play an important role in the relationship between ecological and
92 evolutionary dynamics (Giery and Layman 2019, Svensson 2019, Fryxell et al. 2019). Sexual
93 dimorphism thus represents a key source of ecologically-relevant variation within species.
94 Critically, this source of intraspecific variation may have different consequences from other

types of variation. Unlike most phenotypes, whose relative abundances can evolve, the ratio of males to females (at birth) is usually genetically fixed at 50:50 (Fisher 1930), though their phenotypes and demography may diverge to have differential ecological impacts. Using a simple model of consumer-resource dynamics, we show that consumer sexual dimorphism has important consequences for coexistence between resources that compete directly or apparently.

Model

Our model represents a simple extension of the classic model of consumer-resource dynamics, in which a consumer species exploits two resources that themselves undergo density-dependent growth (Figure 1). Consumer growth rate is limited only by resource abundance. Our model mainly differs from existing models that do (Schreiber et al. 2011) and do not (e.g. Holt 1977) incorporate within-species variance in that we explicitly model male and female demography, allowing for the possibility that males and females differ in resource-specific attack rates. We can describe the population dynamics of two resources (R_1 and R_2) and consumer males (M) and females (F) using the system of ordinary differential equations:

$$\frac{dR_n}{dt} = r_n R_n \left(1 - \frac{R_n + a_R R_j}{K_n}\right) - a'_{M,n} R_n M - a'_{F,n} R_n F \tag{1a}$$

$$\frac{dM}{dt} = \frac{1}{2} B(M, F, R_1, R_2)\, F - d_M M \tag{2b}$$

$$\frac{dF}{dt} = \frac{1}{2} B(M, F, R_1, R_2)\, F - d_F F \tag{3c}$$

In which M, F, R_n (where n = 1, 2) are the population densities for consumer males, consumer

females, the resources, respectively, $M + F =$ Total Predator population (N) such that $\frac{dN}{dt} = \frac{dM}{dt} + \frac{dF}{dt}$. Each resource n undergoes density-dependent population growth with birth rate r_n towards its carrying capacity K_n, with interspecific competition represented by a_R. For simplicity we assume symmetric competition between the resources. Resources are also regulated by consumers depending on sex-specific attack rates by males $a'_{M,n}$ and by females $a'_{F,n}$. Consumer dynamics are governed by the product of birth rates B and female density, limited by intrinsic mortality d_M and d_F. An appropriate function describing birth rates has been a point of debate for demographers, with the general conclusion being that any function describing birth rates should capture Allee effects likely to limit birth rates in the case of extreme sex ratio skew, with the extreme being that birth rates should be zero when one sex is absent (Caswell and Weeks 1986). Generally, treating birth rates proportional to the harmonic mean density of males and females is agreed as the best approach (Caswell and Weeks 1986, Lindstöm and Kokko 1998). Here, we extend this harmonic mean birth function:

$$B(M, F, R_1, R_2) = 2k \frac{MI_M * FI_F}{MI_M + FI_F} \qquad (2)$$

Where I is the energy intake of a given sex:

$$I_{i=} \sum_{j=1}^{2} a'_{ij} R_j \qquad for\ i = M, F \qquad (3)$$

which couples the dynamics of consumers and resources. In this model the rate of consumer births depends on not just the number of males and females but also on the abundance of both prey and the prey preference of each sex, where MI_M is the number of males who have the energy to reproduce (similarly with females), k is a scaling constant reflecting the number of

133 predator offspring created per prey eaten, and a_{ij} as the attack rate by the *i* predator to the *j*

134 resource. We define the degree of sexual dimorphism, α, such that

$$a'_{M,1} = a'_{F,2} = a'_{max}\left(1 - \frac{\alpha}{2}\right) \quad (4a)$$

135

$$a'_{M,2} = a'_{F,1} = a'_{max}\left(\frac{\alpha}{2}\right) \quad (4b)$$

136

137 where α ranges from zero to one, with α = 1 representing complete sexual monomorphism (both

138 sexes are generalists, attacking each prey at the same rate, $a'_{max}/2$), and α = 0 representing

139 complete sexual dimorphism such that males only attack R_1 and females only attack R_2. For

140 simplicity we assume a symmetric dimorphism in attack rates.

141 We explored deviations from the model in equation 1, including making consumer

142 growth rates a function of only B and d (removing the product with F), relaxing the implicit

143 assumption of monogamy, as well as including a term further penalizing population growth rates

144 under male-biased sex ratio skew (e.g., due to interlocus sexual conflict), which had nearly

145 equivalent effects to introducing simple sex differences in death rate. In all cases qualitative

146 conclusions remain unchanged. In the appendix, we explore the consequences of consumer

147 mating system variation, although report only the simplified cases in the main text as conclusions

148 appear robust to variation in consumer mating system.

149 We were unable to solve the system of equations 1 analytically, and so numerically

150 solved the differential equations using the packages deSolve v 1.21 (Soetgart et al. 2010) and

151 caTools v. 1.17.1.2 (Tuszynski 2019) in R v. 3.5.0 (R Core Team 2018). We iterated through

152 different values of dimorphism (α from 0 to 1 by 0.1), r_1 and r_2 (from 1 to 1.4 by 0.05), d_M and

153 d_F (0.02, 0.024), under three different scenarios of interspecific competition between resource 1

154 and 2: apparent competition, where $a_R = 0$ (see equation 1A), moderate interspecific competition
155 where $a_R = 0.5$, and strong interspecific competition where $a_R = 1$. For each set of parameter
156 values, we ran the numerical solution to equations 1a-c through 10,000 time steps (to ensure the
157 simulation reaches its equilibrium) by increments of 0.1 (to create an accurate discrete model).
158 For each run, we determined the equilibrium abundances of M, F, R_1 and R_2 at t = 10,000. We
159 also calculated the standard deviation of species' abundances in the last 50 time-steps (500 sub
160 time steps); all but 9 (all with sex-biased mortality and direct interspecific competition) of the
161 2244 parameter combinations reached stable equilibrium. Parameters held constant in our
162 numerical solutions were K = 10000, k = 0.0001, and $a'_{max} = 0.0009$. These values were chosen
163 to generate realistic values for the resulting per capita growth rates, and conclusions are not
164 qualitatively changed under deviations from them. The R script to generate all figures and
165 results presented, as well as a file containing numerical solutions to the model, is available in the
166 supplementary material.
167
168 **Results**
169 Exploring the effects of sexual dimorphism on consumer birth rates under the
170 assumptions of equation 2 reveals some important properties of the model. First, because
171 consumer birth rates depend on resource abundance, consumer birth rates decline when density
172 of any single resource declines (Figure 2), even under complete sexual monomorphism.
173 However, introducing sexual dimorphism generates a non-linear relationship between resource
174 abundance and consumer birth rates such that birth rates decline rapidly as a single resource
175 declines in abundance. When dimorphism is complete, birth rates approach zero as abundance of
176 a single resource approaches zero, even if the second resource is abundant (Figure 2). Thus,

sexual dimorphism effectively generates negative frequency dependence such that declining abundance of a single resource is expected to reduce predation pressure via the feedback between resource abundance and consumer population growth rate. Although mating system variation may influence the sex ratio under which birth rates are maximized, these general effects are none the less expected to hold even when the assumption of monogamy is relaxed (see Appendix). Because resource population growth rates are assumed to be dependent in part on consumer density (equation 1A), we may expect such a feedback to generally expand the parameter space under which resources may coexist.

We next explore the temporal dynamics of R_1 and R_2 under three scenarios of apparent competition. When growth rates differ across resources and consumers are sexually monomorphic, the inferior resource rapidly declines to extinction (Figure 3, top panel). This result reflects the classic insight that a resource cannot exist in a community dominated by other resources with superior growth rates in the face of predation (Holt 1977, Holt and Bonsall 2017). When sexes differ in their resource preference completely, such that each sex specializes on a single resource, the inferior resource is maintained and each population in the community cycles to a stable equilibrium (Figure 3, middle panel). This cycling appears to be the result of nonlinearities introduced from both sexual dimorphism and differences in resource growth rates; temporal stability increases in the case of equal growth rates across both resources (Figure 3, bottom panel). These results suggest consumer sexual dimorphism and resource growth rates together determine equilibrium densities of each resource, and we next explore this further by seeking equilibrium solutions to equations 1.

When consumer male and female death rates are equal and resource competition is apparent, increasing consumer sexual dimorphism has the effect of increasing the parameter

space under which resources can coexist. As sexual dimorphism approaches the extreme (each sex uses a different resource), a resource with inferior growth rates can coexist with a superior growing resource under apparent competition (Figure 4A). This effect of dimorphism on coexistence holds under moderate to strong interspecific competition (Figure 4B-C), as well as when the assumption of equal death rates across consumer sexes is relaxed. Introducing sex differences in death rates has predicable effects on resource density, leading to an increase in density of the resource preferred by the sex with higher mortality and an asymmetric response of each resource to varying levels of sexual dimorphism (Figure 5). Allowing for deviations from monogamy (Appendix Figure 1), where consumer birth rates are maximized under sex ratios other than 1:1, and/or incorporating sexual conflict (Appendix Figure 2, 3), where female survival is differentially impacted by sex ratio skew, had similar effects to simply incorporating sex-specific intrinsic mortality (see Appendix).

Sexual dimorphism also effects equilibrium consumer density, leading to a reduction in total density of males and females with increasing sexual dimorphism. However, these changes (Appendix Figure 4A, B) were not as extreme as that seen in equilibrium densities of the two resources, and generally consumer coexistence is expected. When interspecific resource competition equals intraspecific competition ($a_R = 1$), sexually dimorphic consumers cannot exist with resources that differ in growth rate (Appendix Figure 4C), as the superior resource drives extinction of both the inferior resource and, as a result, the consumer. However, the biological relevance of such a scenario, with resource ecological equivalence yet complete consumer dimorphism in attack rates, seems limited.

Discussion

Using a simple model of consumer-resource dynamics we show that consumer sexual dimorphism has substantial consequences for the coexistence of prey that compete directly or apparently. When male and female consumers differ in their resource-specific attack rates, resources that differ in per-capita growth rates can coexist, while competitive exclusion is expected and observed when males and females are monomorphic generalists and resources differ substantially in per capita growth rates. Coexistence occurs when the sexes differ in attack rates because sexual reproduction results in a phenotypic subsidy (Bolnick et al. 2011) in which male and female birth rates are coupled; decreasing abundance of the slower growing resource decreases both consumer male and female birth rates, generating negative frequency dependence that prevents competitive exclusion of the inferior resource. Thus, in this model consumer sexual dimorphism results in a phenotypic subsidy that effectively generates a stabilizing mechanism of coexistence between the resources (Chesson 2000). These results hold whether competition between the resources is completely apparent, occurring only via shared predation (Holt 1977, Holt and Bonsall 2017), or in part direct, indicating that sexual dimorphism may have general stabilizing effects on coexistence between competing species at lower trophic levels whenever consumer birth rates are affected by resource aquistion, and may in part explain the observation that competitive exclusion under apparent competition has only rarely been observed empirically (Schreiber et al. 2011). These results also support conclusions from other food web models suggesting trophic position may impact the observed ecological effects of sexual reproduction (Kawatsu 2018). Importantly, our work also indicates that the specific source of variation may often need to be considered to fully understand the role of within-species variation in community assembly.

245 Although even moderate ecological sexual dimorphism increases the parameter space
246 under which resources coexist, the strongest effects are observed as the consumer population
247 approaches complete sexual dimorphism in attack rates. Cases of such extreme sex differences
248 in diet preference exist (Temeles et al. 2000), although whether they occur with any regularity is
249 unclear. Diet divergence between the sexes, and sexual dimorphisms in trophic morphology, are
250 common (Shine 1989), although overlap in male and female diets can be substantial even in the
251 presence of ecological sex differences (e.g., Stamps et al. 1997, De Lisle and Rowe 2015a). Yet
252 overlap in diet content may be expected even in the case of large differences in attack rates, as
253 diet content is the product of both attack rate and resource abundance. Further, males and
254 females may fail to diverge in diet preference even when optimum diet nutritional content differs
255 across the sexes (Reddiex et al. 2013). These challenges to understanding sex-specific resource
256 acquisition highlight the need for further empirical studies disentangling expressed diet
257 preference, male and female nutritional optima, and the evolution of ecological sexual
258 dimorphism.

259 We have assumed a Fisherian sex ratio, where the primary sex ratio is maintained at a
260 stable 1:1 ratio (Fisher 1930), although our model allows for deviations from a 1:1 operational
261 sex ratio via sex-specific intrinsic mortality. Sex-specific mortality is commonplace in natural
262 populations and can occur for a variety of reasons, such as sex-specific costs of reproduction,
263 predation, or sexual conflict. In our model, sex-specific mortality, as well as variation in
264 consumer mating system (see Appendix) had predictable consequences for resource abundance,
265 leading to increases in the abundance of the resource favored by the sex with higher intrinsic
266 mortality. Nonetheless, the general effects of sexual dimorphism on coexistence hold under sex-

267 biased mortality and departures from monogamy, indicating our general conclusions may also
268 apply to systems with diverse mating systems or where the primary sex ratio deviates from 1:1.
269 Male and female densities were reduced with increasing ecological sexual dimorphism,
270 because consumer births are limited by resource acquisition in both sexes in our model. This
271 suggests that sexually-dimorphic populations may face a higher risk of extinction due to
272 demographic stochasticity. However, it is difficult from our ecological model, that always
273 assumes two resource populations, to fully interpret the consequences of sexual dimorphism on
274 extinction probability. Evolution of sexual dimorphism from a monomorphic ancestor that
275 specializes on a single resource could lead to increased population mean fitness, by increasing
276 the total resource pool available across both sexes (Rand 1952, Selander 1966, Slatkin 1984);
277 such a process represents a form of within-species, between-sex ecological character
278 displacement. More generally, evolution of sexual dimorphism is expected to be critical to
279 population mean fitness whenever optima differ for males and females (Lande 1980), and
280 empirical data suggest sexual dimorphism can be associated with reduced extinction probability
281 at both the macroevolutionary scale and in extant populations (De Lisle and Rowe 2015b).
282 Nonetheless, our results suggest a full understanding of sexual dimorphism's role in population
283 persistence could require integrating theory and data from population/community ecology and
284 evolutionary genetics.
285 Our model generally predicts that ecological sexual dimorphism may promote diversity at
286 lower trophic levels during community assembly. Testing this prediction with correlative data
287 would be possible but challenging. An alternative and non-exclusive hypothesis, that dimorphic
288 predators are more likely to establish in communities with diverse prey assemblages, would also
289 generate such a pattern. Alternatively, experiments that manipulate the expressed dimorphism of

predators and track community dynamics at lower trophic levels are tractable in some systems. Similar experiments have been performed (Fryxell et al. 2015, Start and De Lisle 2018), in which effects of predator sex ratio manipulation on prey communities are assessed in mesocosm designs. Although the results of these experiments do suggest sex differences can have important community consequences, no studies (to our knowledge) have compared communities in which the magnitude of morphological sexual dimorphism is manipulated under a stable sex ratio. Such designs are possible when distributions of male and female phenotypes exhibit substantial variation, and would represent an ideal empirical test of the theoretical results presented here.

Ecological sex differences are commonplace, although the details of their evolutionary drivers and ecological consequences are unclear. Emerging theory and data indicate ecological sex differences may have important consequences for the evolutionary genetics of adaptation (Zajitschek and Connallon 2017), the dynamics of diversification (Bolnick and Doebeli 2003, De Lisle and Rowe 2015b) and community assembly (Fryxell et al. 2015, Pincheira-Donoso et al. 2018, Start and De Lisle 2018). Our work adds to this body of work, indicating that sexual dimorphism can have predictable effects on the structure of ecological communities, by introducing frequency-dependence that stabilizes coexistence between resource species.

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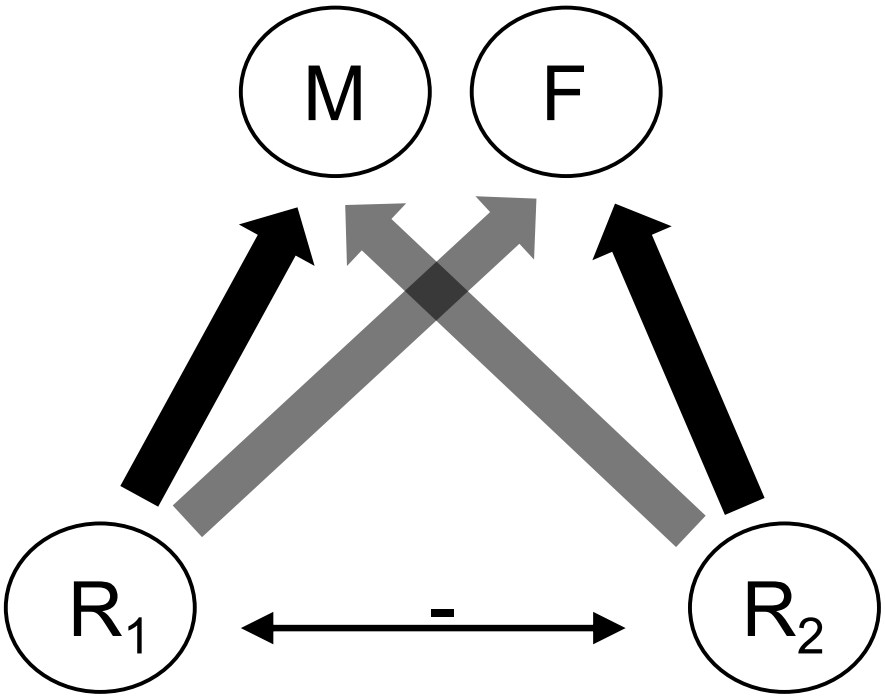
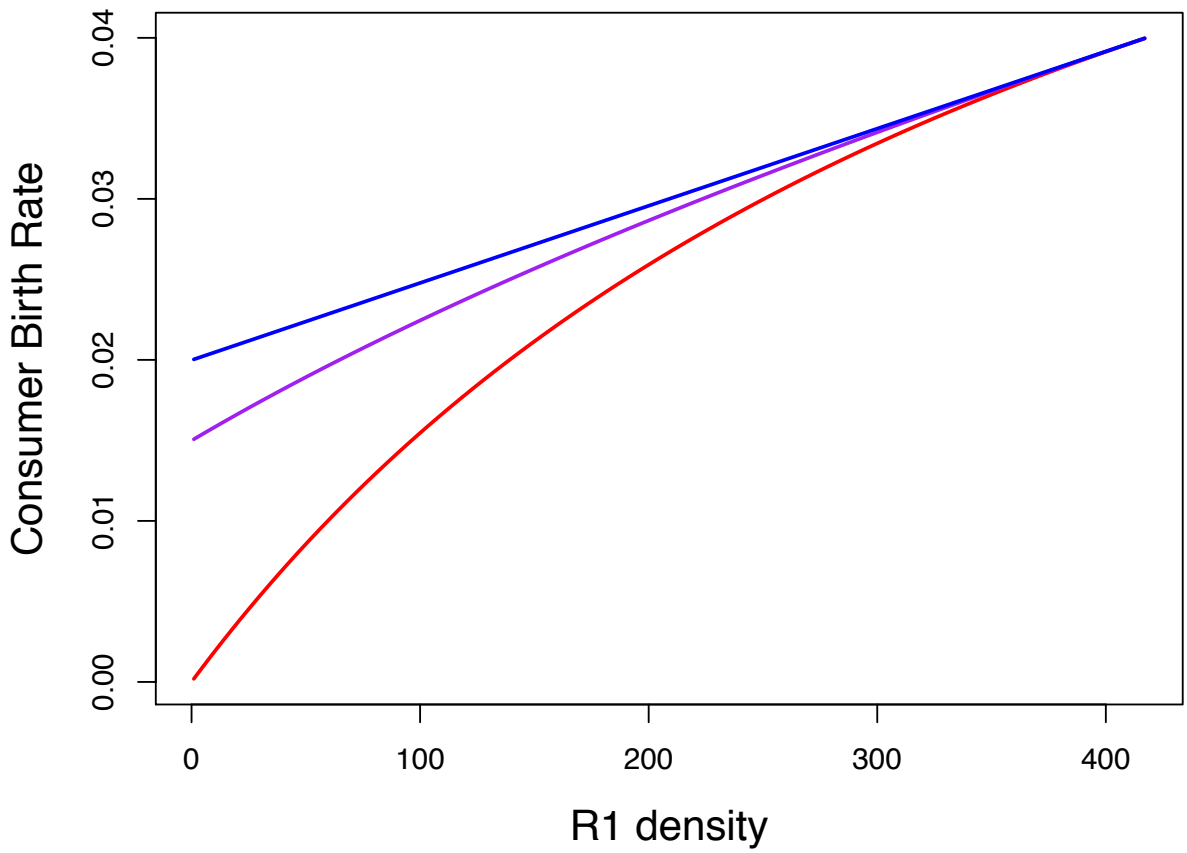


Figure 1. Illustration of the model structure. Males (M) and females (F) of a consumer species exploit two resources (R1 and R2) that may or may not also compete directly (double arrow). Sex-specific attack rates (black arrows) generate sex differences in ecological niche such that males and females preferentially attack R1 and R2, respectively, with varying degrees of overlap (grey arrows). Although males and females may consume different resources, fitness is equal across the sexes and so the dynamics of males, females, resource 1 and resource 2 are coupled.



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322 **Figure 2. Consumer birth rate as a function of Resource 1 density, holding R2 and**

323 **consumer density constant.** Birth rates are reduced with reduced R1 density even when

324 consumers are sexually monomorphic generalists (alpha = 1, blue line) because total resources

325 (R1 plus R2) are reduced. Adding in sexual dimorphism in attack rates generates nonlinearity

326 that leads to rapid reduction in consumer birth rates with decreasing R1 density (alpha = 0.5,

327 purple line, partial overlap between the sexes; alpha = 0, red line, complete sexual dimorphism).

328 Consumer and R2 density were fixed at their equilibrium values obtained as the numerical

329 solutions to equations 1.

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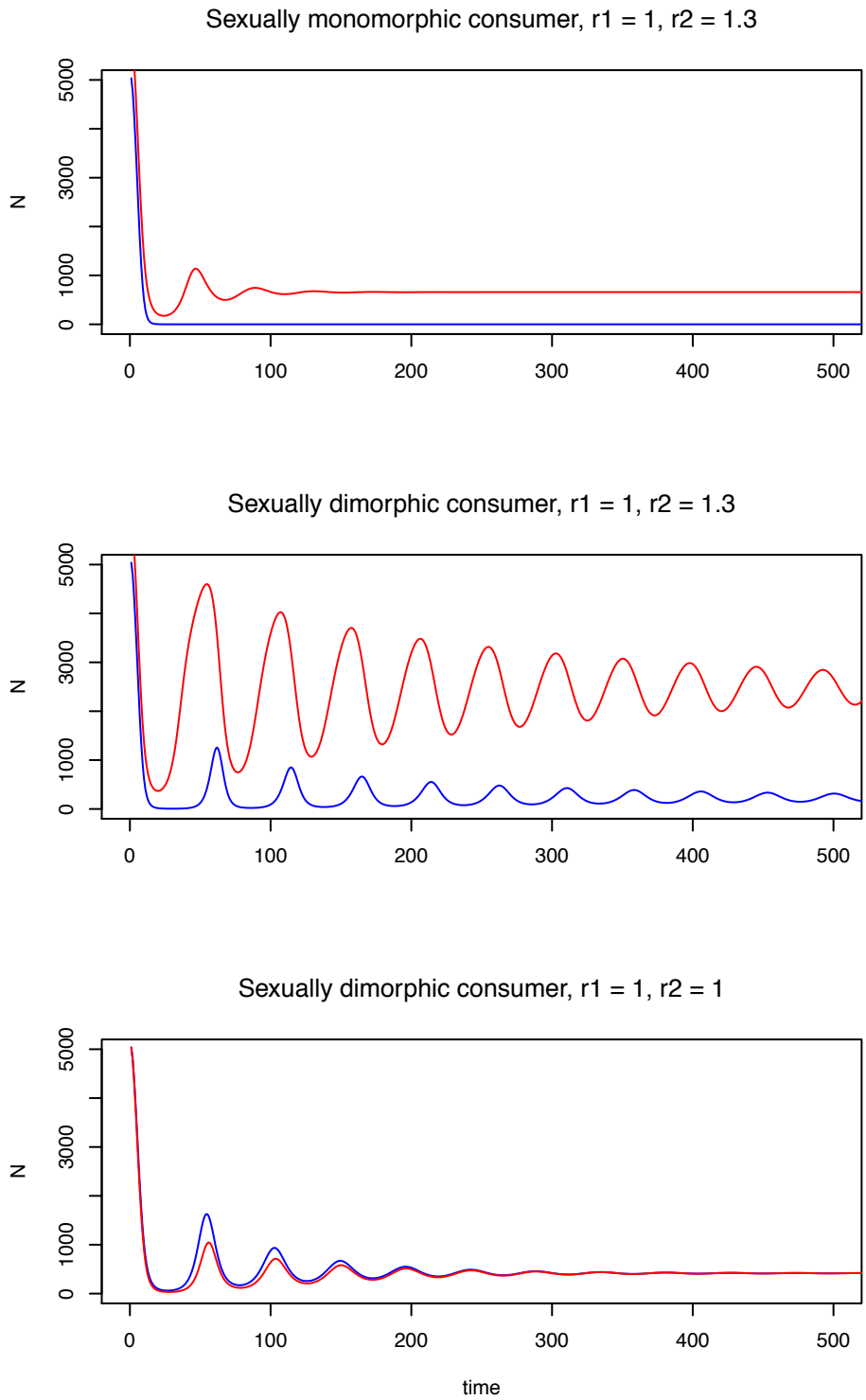
Sexually monomorphic consumer, r1 = 1, r2 = 1.3
N
0
1000
3000
5000
0
100
200
300
400
500
Sexually dimorphic consumer, r1 = 1, r2 = 1.3
N
0
1000
3000
5000
0
100
200
300
400
500
Sexually dimorphic consumer, r1 = 1, r2 = 1
N
0
1000
3000
5000
0
100
200
300
400
500
time

Figure 3. Temporal resource dynamics under three scenarios of apparent competition. In the top panel, differential growth rates across the two resources lead to rapid extinction of resource 1 when consumers are sexually monomorphic. When consumers are completely dimorphic in attack rates, resource 1 can coexist with the superior resource 2, undergoing cyclic dynamics towards equilibrium; middle panel. The bottom panel illustrates dynamics when consumers are completely dimorphic and resources have equal growth rates.

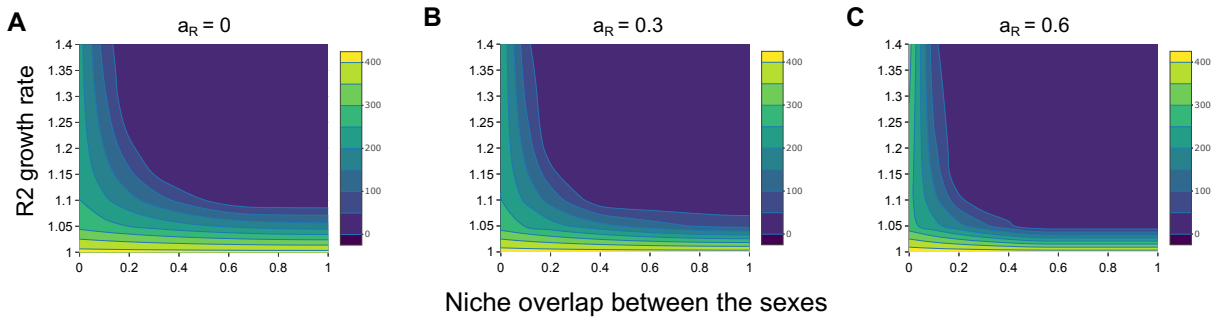

Figure 4. Effects of differential growth rates and consumer sexual dimorphism on resource 1 abundance when consumer mortality is equal across the sexes. Values on z axis are numerical solutions to equation 1 for resource 1 density, with resource 1 growth rate fixed at 1. Competitive exclusion of resource 1 is observed when growth rates differ substantially and consumers are sexually monomorphic (niche overlap = 1). Increasing sexual dimorphism increases the difference in growth rates under which resource 1 can coexist with resource 2. This effect is observed when A) competition between the resources is due only to shared predation, as well as when direct interspecific competition between resource 1 and 2 occurs (B and C).

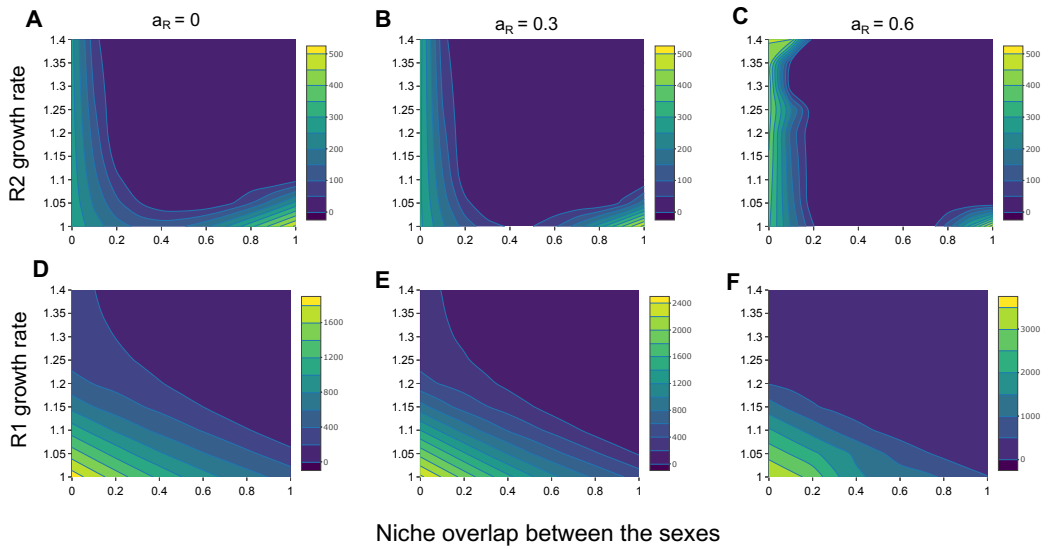

Figure 5. Effects of differential growth rates and consumer sexual dimorphism on resource abundance when mortality is sex-specific (female-biased). Top panels (A-C) are Resource 1 abundance with fixed $r_1 = 1$, bottom panels (D-F) are Resource 2 abundance with fixed $r_2 = 1$. Values on z axis are numerical solutions to equation 1. Introducing sex-biased mortality effectively makes it more difficult for the resource favored by the more abundant sex (in this case, resource 1, preferred by males) to coexist with the resource favored by the rarer sex, as illustrated for resource 1 abundance under varying degrees of direct competition in panels A-B. Differential growth rates have less effect on existence of the resource favored by the rare sex, as illustrated for resource 2 in D-F. In all cases, consumer sexual dimorphism has the effect of promoting coexistence between the two resources. Note differences in z axis scale between top and bottom panels.

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Appendix

Here we relax two assumptions of equations 1 and 2 to explore how various aspects of consumer mating system affect our conclusions. The birth function in equation 2 implies monogamous mating, where each male and female has a single mating partner. We can relax this assumption by including a parameter *h*, termed 'harem size' by demographers (Caswell and Weeks 1986, Lindstöm and Kokko 1998), that reflects departures from monogamy:

$$B(M, F, R_1, R_2) = 2k \frac{MI_M * FI_F}{MI_M + (FI_F) * h^{-1}} \quad (5)$$

In this modified birth function, a value of h = 1 reflects monogamy, while values of h < 1 reflect polyandry and values h >1 reflect polygyny. Whenever h deviates from unity, birth rates, and thus consumer population growth rates, are maximized under a sex ratio skewed towards the sex that is monopolized and limits birth rates more (Caswell and Weeks 1986). Thus, in our model, departures from monogamy have the effect of reducing abundance of the resource favored by the sex that is monopolized (Figure A1), because this resource places a greater limit on consumer

growth rates. None the less, qualitative conclusions on the effects of consumer sexual dimorphism remain unchanged in the face of departures from monogamy.

In many taxa, sexual conflict over optimal mating rate can create scenarios where selection can favor traits in one sex (typically males) that reduce absolute fitness in the other (Arnqvist and Rowe 2005). These sexual conflicts can result in fitness costs borne by females, that are often elevated as competition for mating opportunities increase under sex ratio skew. Equation 1 assumes that equal demographic effects of sex-ratio skew across the sexes, an assumption we can relax by incorporating a term (simplified from a similar term in Rankin and Kokko 2007) into equation 1c:

$$\frac{dF}{dt} = \frac{1}{2}\, B(M, F, R_1, R_2)\, F - d_F F - c\left(\frac{M}{F}\right) \qquad (6)$$

that penalizes female survival under male-biased sex ratios. In this term, the scaling constant c reflects the strength of sexual conflict. Incorporating this sexual conflict term has similar effects to that of sex-biased demography, decreasing the abundance of resource 1 (favored by males) relative to resource 2 (favored by females) (Figure A2, A3); this is unsurprising as the addition of this term generated female biased mortality in the consumer. Thus, variation in consumer mating system has predictable consequences for the relative abundances of each resource.

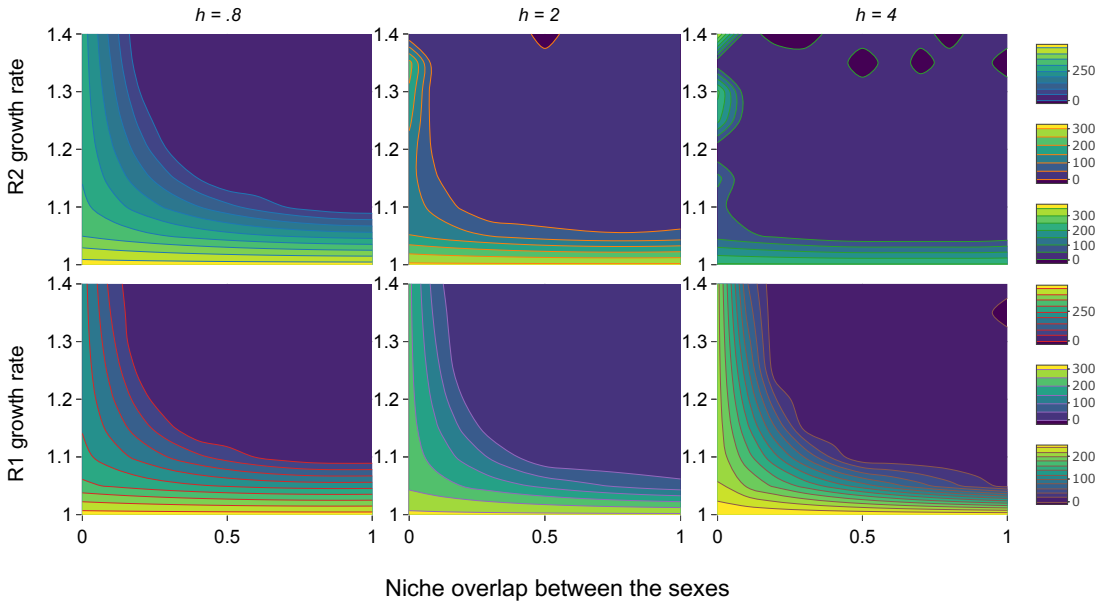

Figure A1. Effects of altering harem size (polyandry vs. polygyny) for resource abundance under apparent competition. Values on z axis are numerical solutions for resource 1 density with resource 1 growth rate fixed at 1 (top panels) or resource 2 density with resource 2 growth rate fixed at 1 (bottom panels). Three different departures from monogamy are illustrated: weak polyandry (left column), and weak and strong polygyny. Increasing sexual dimorphism increases the difference in growth rates under which resources can coexist. a_r was fixed at 0; all other parameter values where as described in the Methods.

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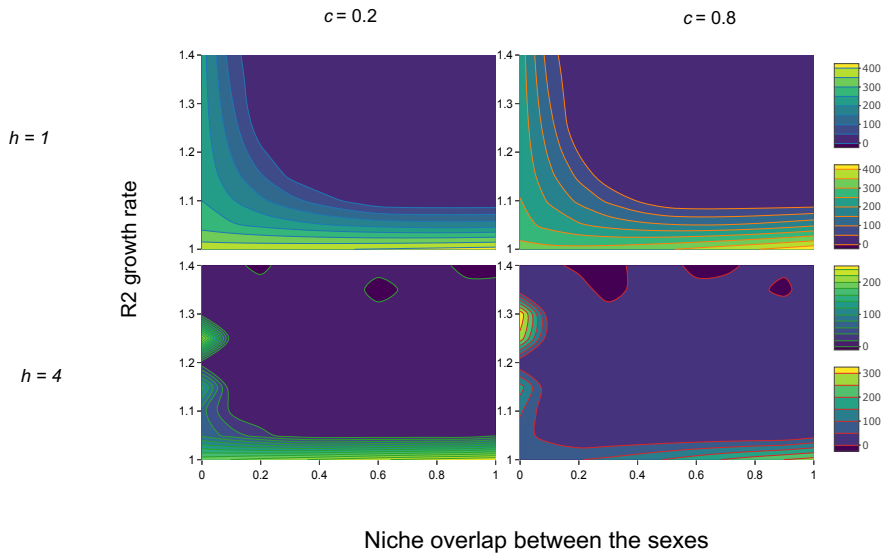

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555 **Figure A2. Effects of sexual antagonism under monogamy and polygyny for resource 1**

556 **abundance.** Values on z axis are numerical solutions for resource 1 density with resource 1

557 growth rate fixed at 1. Two levels of sexual conflict are illustrated in the left and right column.

558 Under monogamy (top panels) introduction of sexual conflict has little effect, although the effect

559 of polygyny (bottom panels) on resource 1 abundance is amplified with the addition of sexual

560 conflict. a_r was fixed at 0; all other parameter values where as described in the Methods.

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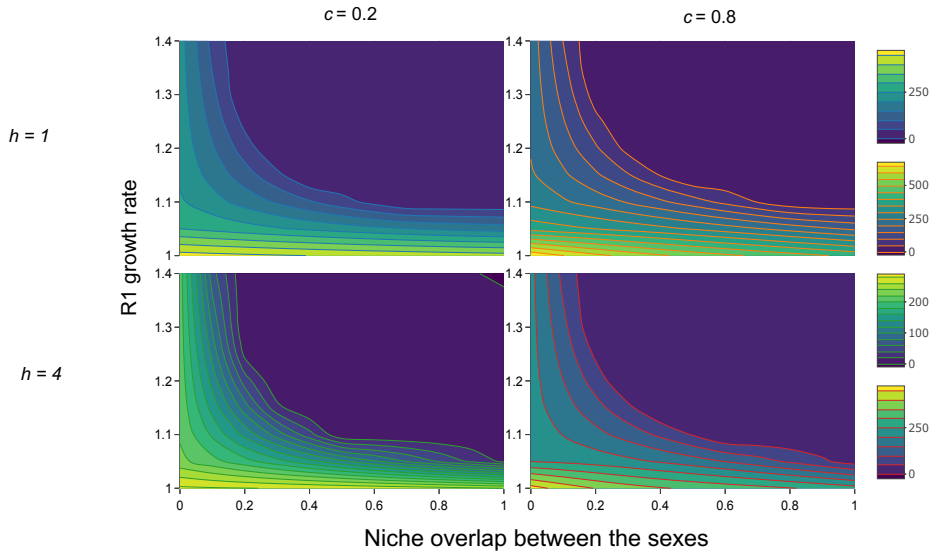

Figure A3. Effects of sexual antagonism under monogamy and polygyny for resource 2 abundance. Values on z axis are numerical solutions for resource 2 density with resource 2 growth rate fixed at 1. Two levels of sexual conflict are illustrated in the left and right column. Sexual conflict has the effect on increasing resource 2 abundance (contrast with Figure A1) as consumer female survival is reduced. a_r was fixed at 0; all other parameter values where as described in the Methods.

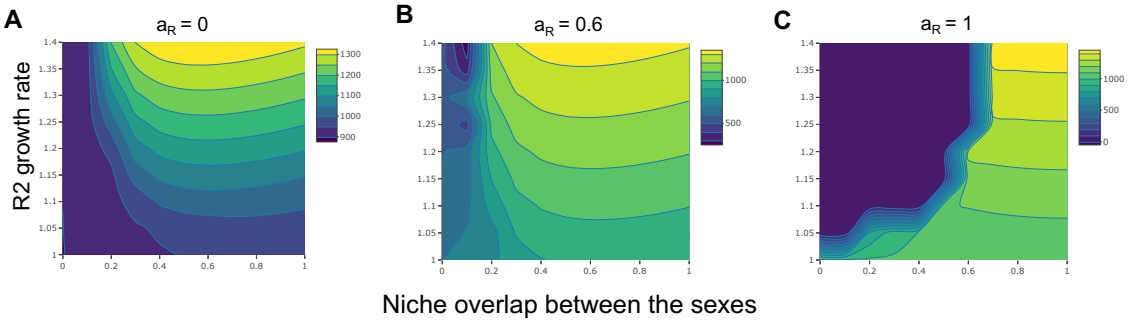

Figure A4. Effects of differential growth rates and consumer sexual dimorphism on consumer abundance. Values on z axis are numerical solutions to equation 1 for female density, with resource 1 growth rate fixed at 1. Consumer density is reduced with increasing sexual dimorphism (reduced niche overlap) under both apparent (A) and interspecific (B) competition between the resources. However, consumer populations are maintained except when interspecific competition between resources is equal to intraspecific competition (C). In this case, sexually-dimorphic consumers cannot exist when resource growth rates differ; competitive exclusion of the inferior resource leads to extinction of both the resource and the consumer. Note differences in z axis scale.