

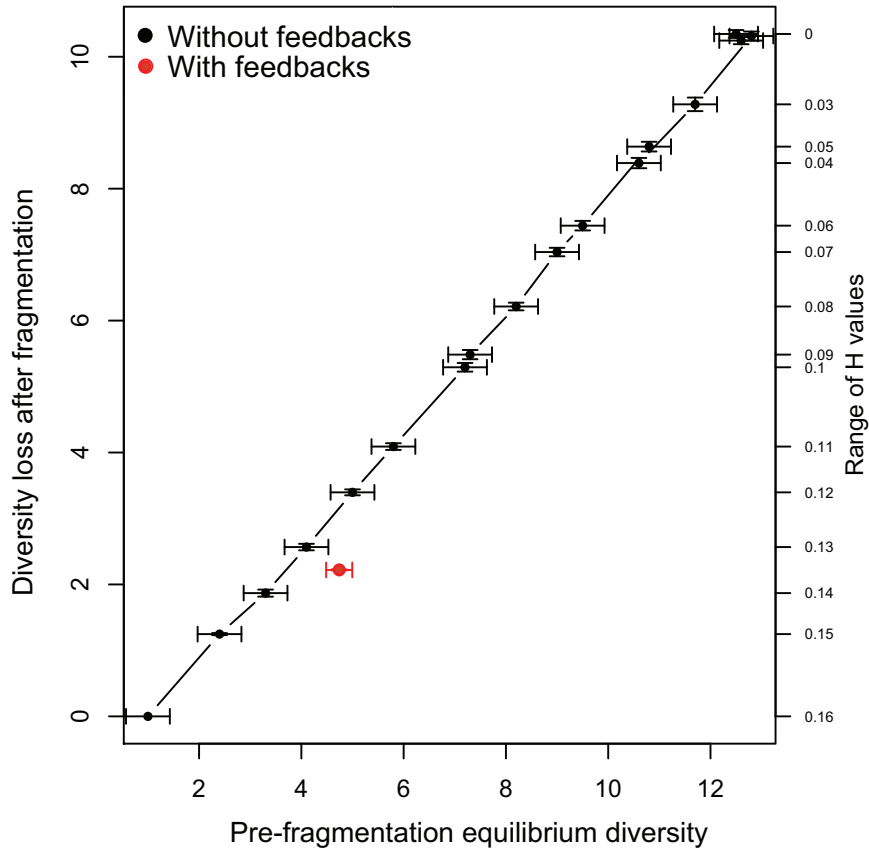
Ecography

**ECOG-01027**

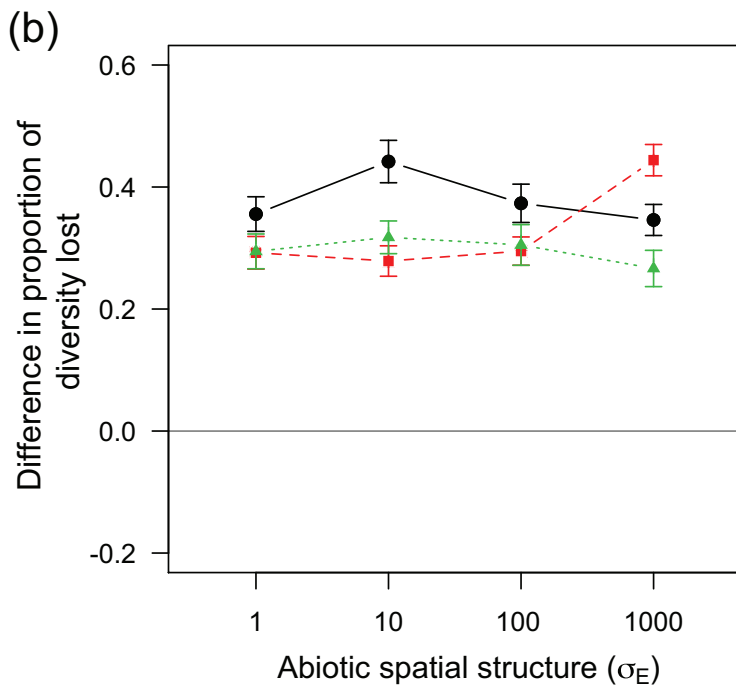
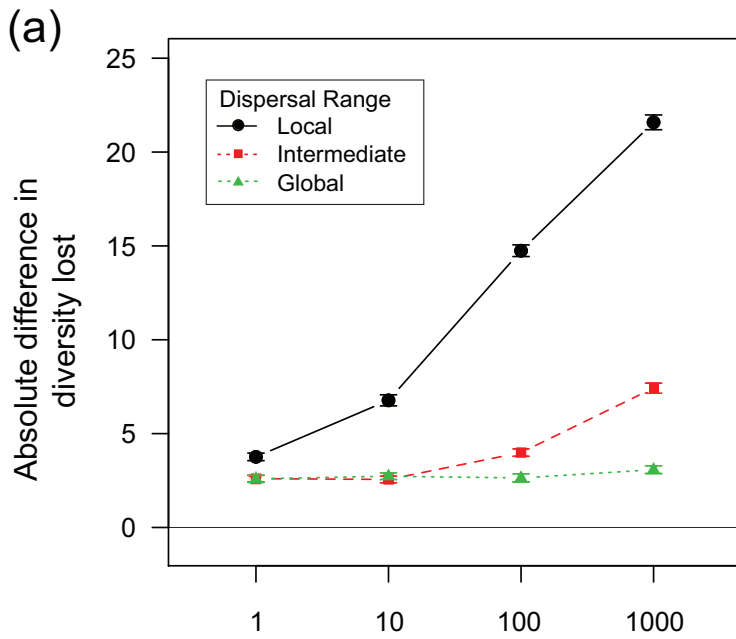
Zee, P. C. and Fukami, T. 2014. Complex organism-environment feedbacks buffer species diversity against habitat fragmentation. – *Ecography* doi: 10.1111/ecog.01027

**Supplementary material**

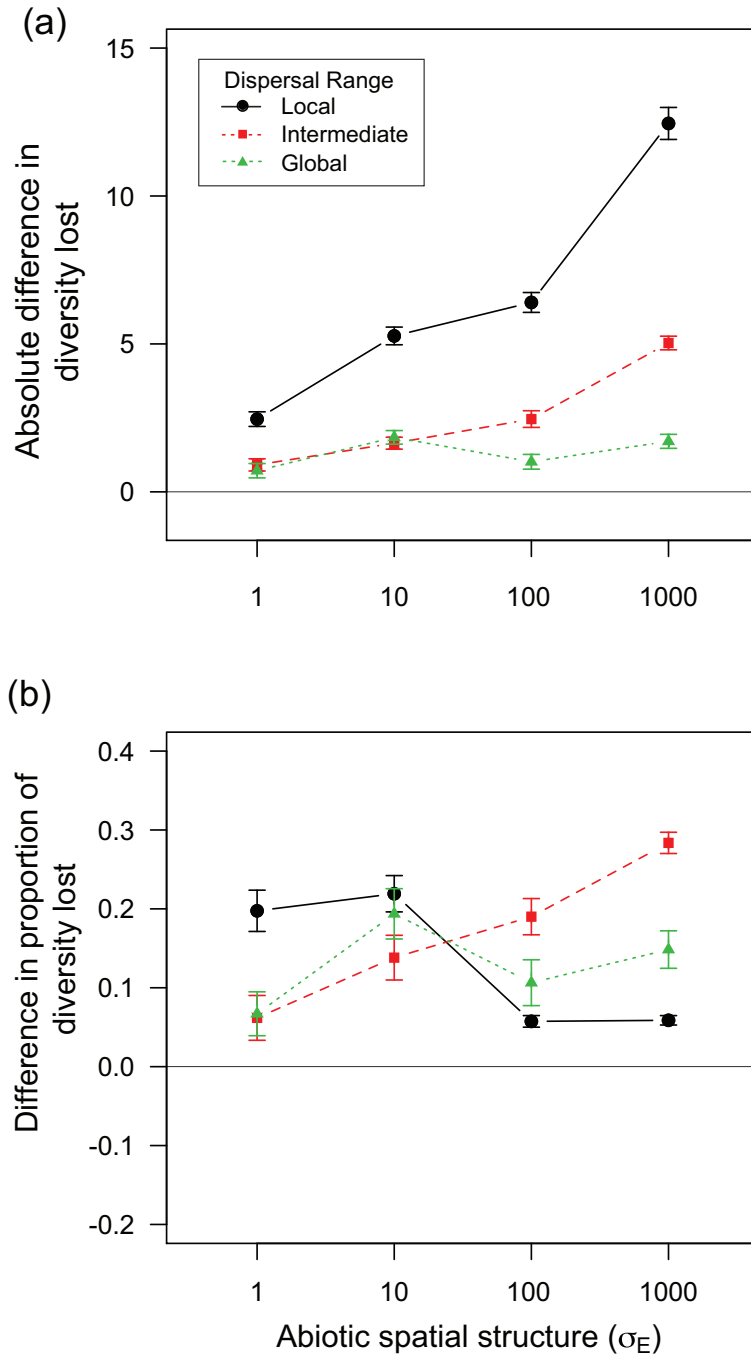
## Appendix 1



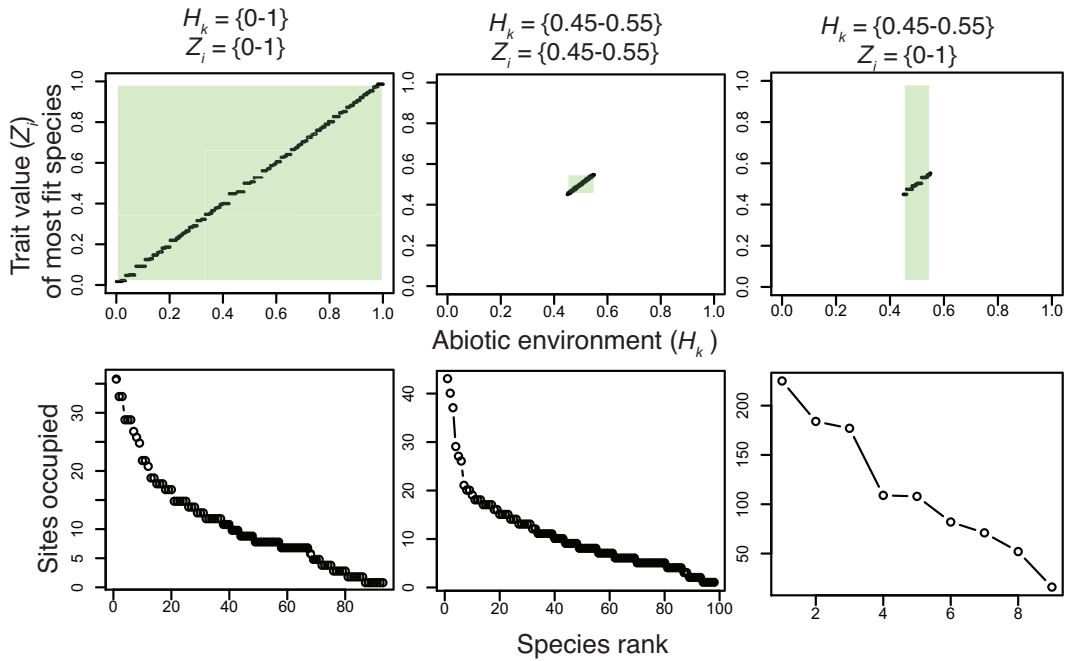
**Figure A1. Feedbacks buffer species diversity.** To examine the buffering effect of feedbacks further, we ran additional simulation to generate comparable pre-fragmentation equilibrium diversity (by narrowing the range of abiotic  $H$  values). The diversity loss without feedbacks (black points) was greater than the diversity loss with feedbacks (red points) for the same level of pre-fragmentation equilibrium diversity (roughly 4.5 species, in this example).



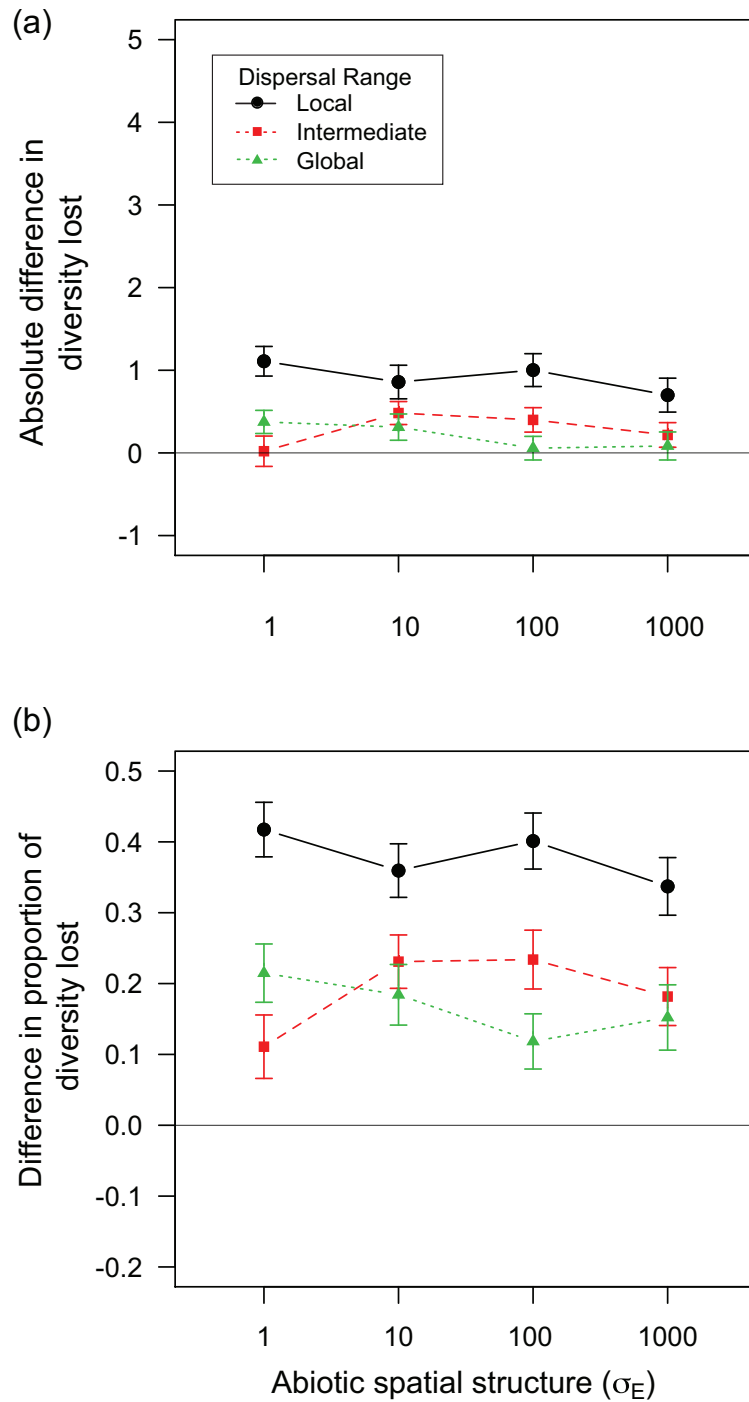
**Figure A2. Buffering effects of complex feedbacks with reduce niche differentiation** (i.e.,  $H_k = \{0.45-0.55\}$ ;  $Z_i = \{0.45-0.55\}$ ). In this scenario the magnitude of the absolute buffering effect is the greatest, as a result of higher pre-fragmentation diversities. (a) Absolute buffering effect. (b) Proportional buffering effect. Error bars represent standard errors.



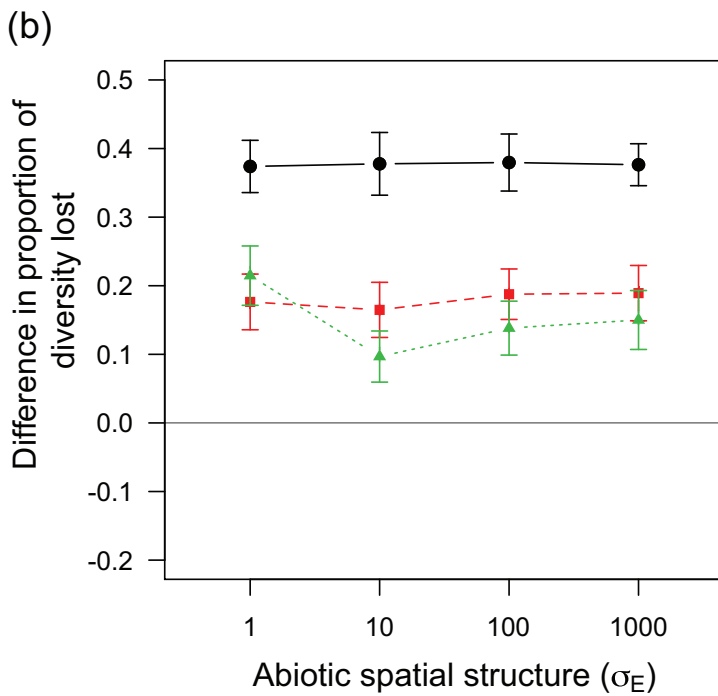
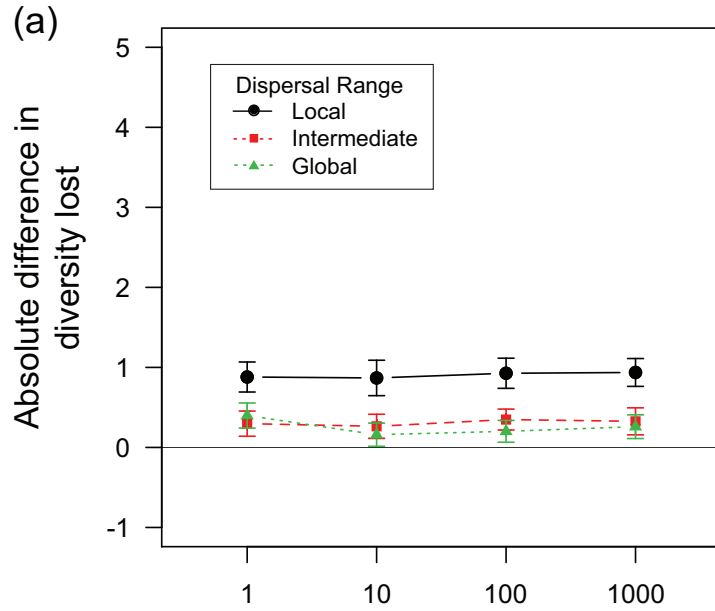
**Figure A3. Buffering effects of complex feedbacks with extreme fitness differences** (i.e.,  $H_k = \{0 - 1\}$ ;  $Z_i = \{0 - 1\}$ ). In this scenario the magnitude of the absolute buffering effect is also greater, as a result of higher pre-fragmentation diversities. (a) Absolute buffering effect. (b) Proportional buffering effect. Error bars represent standard errors.



**Figure A4: Ranges of abiotic values and species trait values determine the possible number and abundance distribution of species before fragmentation.** Each column shows a representative example of under a combination of ranges of abiotic values and species trait values, as labeled. The top row shows the trait values for the most fit species across the range of abiotic values on the landscape ( $H_k$ ), in the absence of complex feedbacks. Green shaded areas of the upper panels show the range joint range of  $H_k$  and  $Z_i$  values. The bottom panels show the number of sites on the landscape occupied by each of the species, sorted by decreasing abundance rank. Note, the ranges of x- and y-axes vary across bottom panels reflecting the differences in potential pre-fragmentation diversity.



**Figure A5. Buffering effects of complex feedbacks with ecological neutrality** (i.e.,  $H_k = \{0.45 - 0.55\}$ ; all  $Z_i = 0.5$ ). When species are competitively neutral with other, there was a buffering effect that increased as dispersal was more local. However, there was no influence of the abiotic spatial structure. (a) Absolute buffering effect. (b) Proportional buffering effect. Error bars represent standard errors.



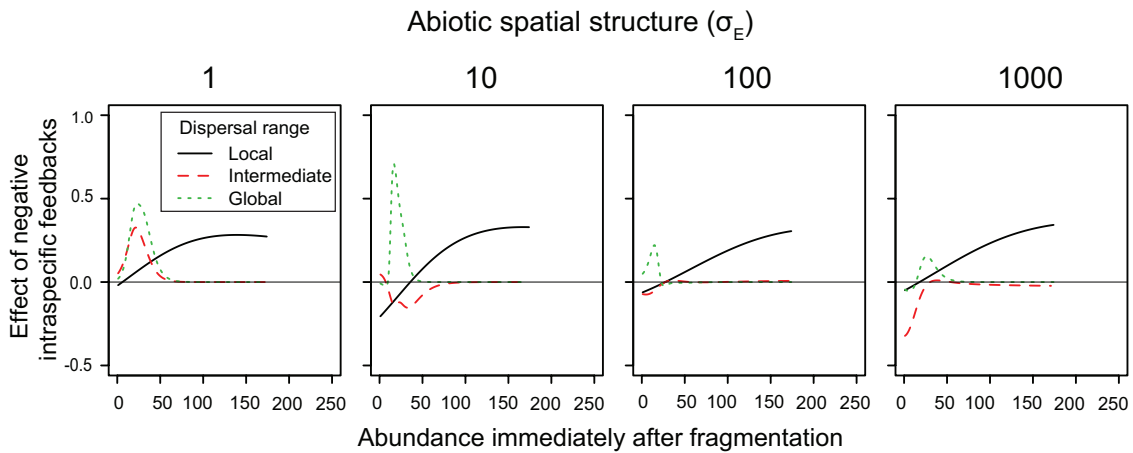
**Figure A6. Buffering effects of complex feedbacks with ecological neutrality on a highly heterogeneous landscape** (i.e.,  $H_k = \{0 -1\}$ ; all  $Z_i = 0.5$ ). When species are competitively neutral with other, there was a buffering effect that increased as dispersal was more local. However, there was no influence of the abiotic spatial structure. (a) Absolute buffering effect. (b) Proportional buffering effect. Error bars represent standard errors.



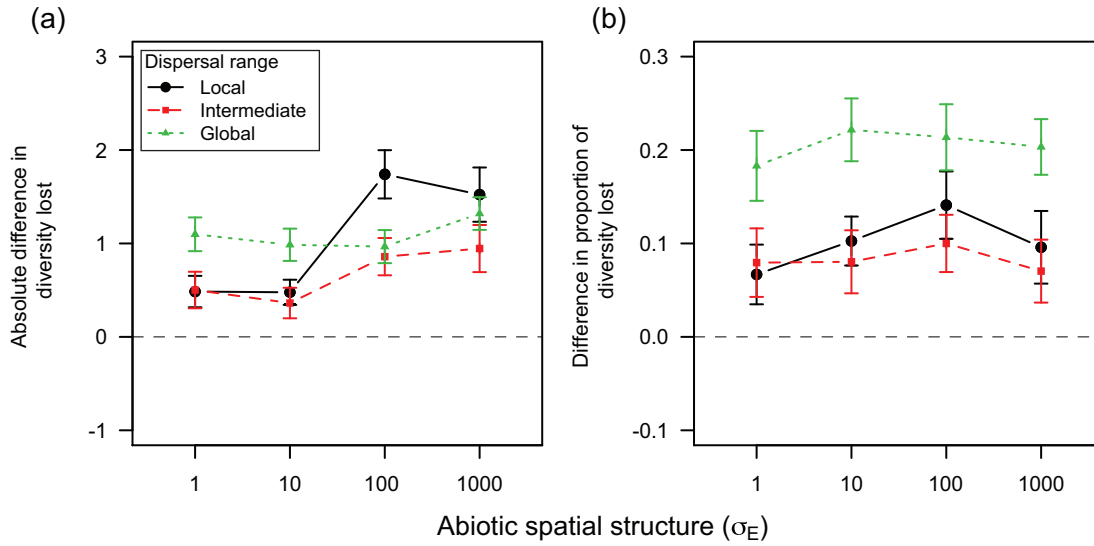








**Figure A13. Negative intraspecific feedbacks facilitate species persistence.** Each curve shows the difference in the probability of eventual extinction between simulations with the complex feedback and mixed feedback regimes. The key distinction is that the complex feedback regime has strictly negative intraspecific feedbacks. In general, these negative intraspecific feedbacks decrease the probability of extinction for a given abundance.



**Figure A14. The buffering effect was significantly positive in landscapes with contiguous, non-fragmented habitat loss.** The buffering effect of complex feedbacks is always significantly positive in both the absolute number of species (a) and the proportion of species (b), though there is variation in the strength depending on dispersal distance and structure of abiotic variation. Black, red, and green symbols and solid, dashed and dotted lines represent local, intermediate, and global dispersal regimes, respectively. Error bars represent standard errors.

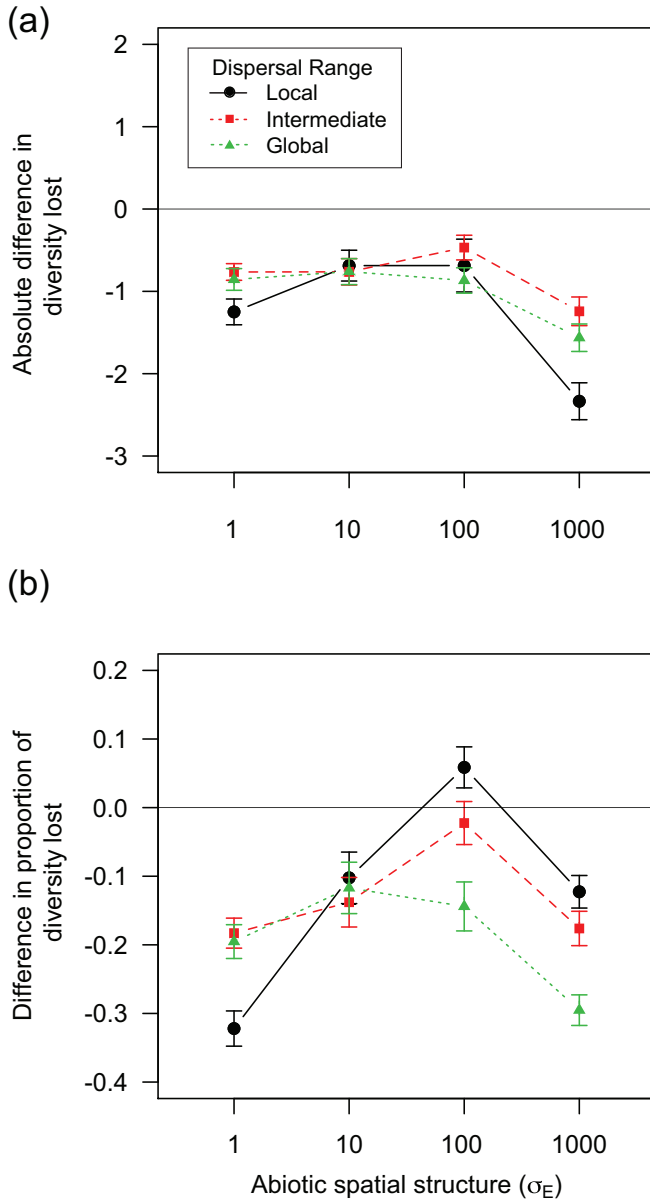
## Appendix 2

Our main conclusion that complex organism-environment feedbacks buffer species diversity against habitat fragmentation appears fairly robust across a range of parameter values, with respect to whether species are ecologically neutral or show fitness differences among them (Supplementary material Appendix 1, Figs. A2-A6). However, there are scenarios where exceptions to this main conclusion exist, and here we highlight some of those exceptions.

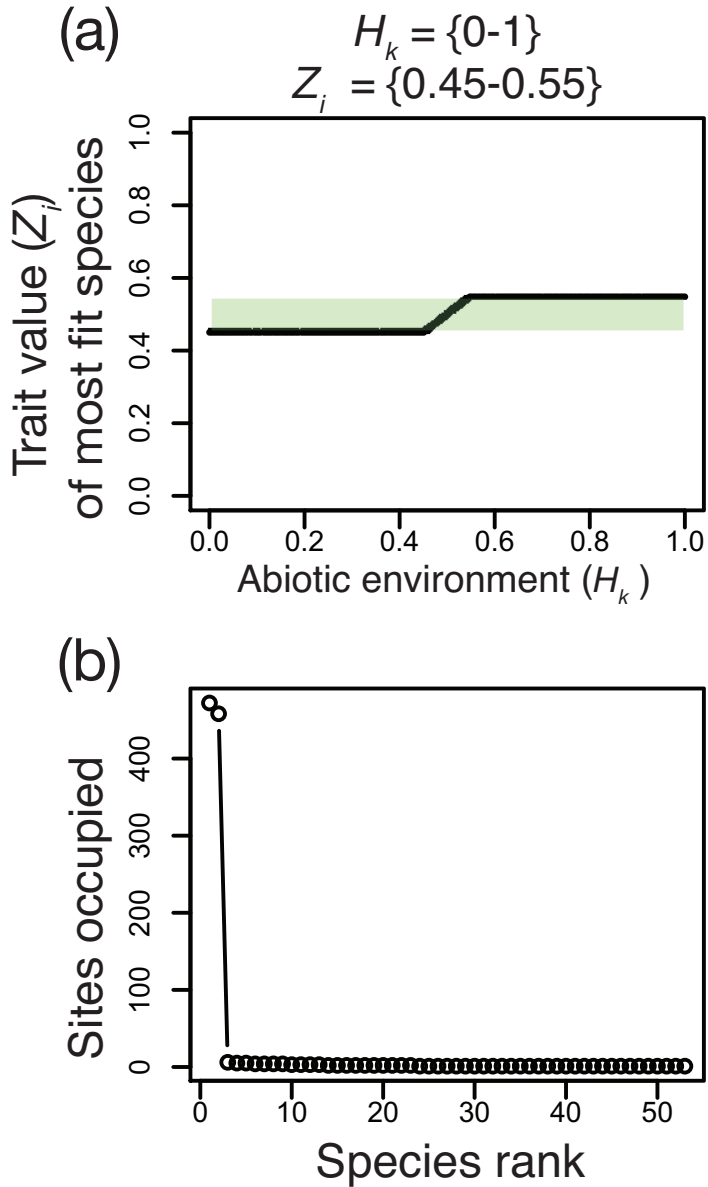
When there is a wide range of abiotic variation (e.g.,  $H_k = \{0-1\}$ ), but a small range of species trait values (e.g.,  $Z_i = 0.45-0.55$ ), the two most extreme species ( $Z_i = 0.45$  and  $Z_i = 0.55$ ) are competitive dominants across a large proportion of the landscape (all sites where  $H_k \leq 0.45$  and  $H_k \geq 0.55$ ) (Supplementary material Appendix 2, Fig. A7). This leads to low species diversity before fragmentation. However, when there are complex feedbacks, more species can coexist prior to fragmentation because the feedbacks generate environmental heterogeneity necessary for coexistence. Following fragmentation, a number of these coexisting species go extinct, leading to more species going extinct in simulations with complex feedbacks. This scenario leads to complex feedbacks increasing the number of species lost following fragmentation (Supplementary material Appendix 2, Fig. A7).

When there is no abiotic variation in the landscape (i.e., all  $H_k = 0.5$ ), but species differ in their traits, one species (the species with its  $Z_i$  value closest to 0.5) monopolize all sites.

With complex feedbacks, however, other species coexist prior to fragmentation, and then a subset of them go extinct following fragmentation. In contrast to when there are competitive differences among species (both extreme and modest), when species are competitively neutral on a homogeneous landscape, complex feedbacks generate a buffering effect following fragmentation (Supplementary material Appendix 2, Fig. A9). This is because, under ecological neutrality, a higher number of species coexist even on a homogeneous landscape, compared to scenarios where a competitive dominant exists.



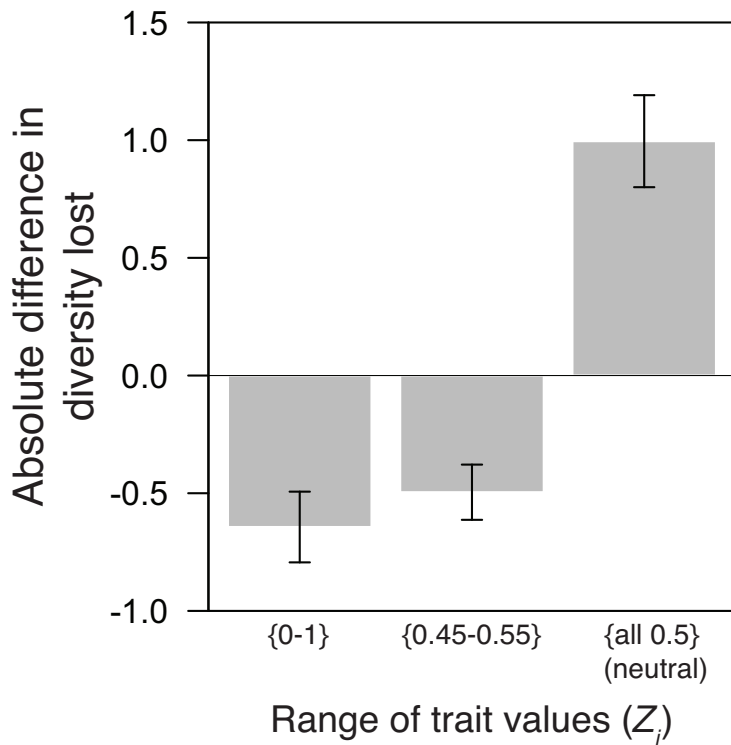
**Figure A7.** When there were modest fitness differences on landscapes with high abiotic variation (i.e.,  $H_k = \{0-1\}$  and  $Z_i = \{0.45-0.55\}$ ), complex feedbacks do not buffer against diversity loss following fragmentation. (a) Absolute buffering effect. (b) Proportional buffering effect. Error bars represent standard errors.



**Figure A8. Ranges of abiotic values and species trait values determine the possible number and abundance distribution of species before fragmentation.** (a) Trait values for the most competitive species across the range of abiotic values on the landscape ( $H_k$ ), in the absence of feedbacks. The green shaded area marks the joint range of  $H_k$  and  $Z_i$  values in the simulation. (b) Rank-abundance curve for these most competitive species, showing the number of sites on the landscape occupied by each of the species. In this



case, the majority of species occupy only a single site, and two species dominate the landscape.



**Figure A9.** When there is no abiotic variation in the landscape ( $H_k$  is 0.5 for all sites), there was no buffering effect of complex feedbacks when the differences species competitive abilities are wide ( $Z_i = \{0-1\}$ ) or narrower ( $Z_i = \{0.45-0.55\}$ ). However, in the neutral case (all species  $Z_i = 0.5$ ), there was a buffering effect. Error bars represent standard errors.