Supplementary Information S3 - Model details for simulating a co-evolving resource-consumer metacommunity

3   We model a P patch meta-community where each patch is linked by migration to its neighboring

4   patch. Within each patch, individuals of the consumer species C interact with individuals of

5   the resource species R. We model coevolutionary dynamics in systems where consumers with a

6   given phenotypic value are most effective at exploiting resources with a particular resource trait

7   value, but may be poor at exploiting resources with other trait values (i.e., phentoypic matching

8   - e.g., Nuismer et al. 2007). For instance, an herbivorous insect may evolve specific enzymes

9   permitting it to exploit a novel plant resource, while the plant species may evolve alternative

10   chemical defenses against the herbivore (Rasmann and Agrawal 2011). Alternatively, the ability

11   of a resource to defend itself, and the ability of a consumer to exploit the resource, may itself be a

12   composite trait of many distinct phenotypes (e.g., behavioral as well as morphological defenses),

13   with consumer individuals varying in their ability to exploit different facets of resource defense

14   (e.g., some consumers may be particularly good at identifying resource hiding sites, while others

15   may have greater ability to puncture resource defenses such as shells).

16   In our model, the potential individual fecundity $w_{F,C}(t)$ of an individual consumer varies

17   over time. An individual's breeding value determines the genetic component of this trait.

18   $w_{F,C}(t)$ is also affected by how successfully an individual consumer is able to exploit the resource

19   species. A consumer's ability to successfully exploit the resource, in turn, depends on two

20   quantities: first, the individual's genetically determined exploitation ability, α, and second, the

21   phenotypic distribution of a resource defense trait δ. This adds a further source of genetic

22   variation in individual fecundity, as well as an environmental effect that varies according to the

23   prevailing distribution of the resource's phenotypes. At a given time t, the consumer's fecundity

24   can be given by:

$$w_{F,C}(t) = \xi k \int_{y \in \{\delta\}} \frac{\exp(-(\alpha - y)^2)}{1 + \exp(-(\alpha - y)^2)} dy, \tag{S3-1}$$

25   where ξ is the breeding value characterizing the consumer's baseline fecundity and k scales

26 the effect of the interaction on consumers (it could thus represent, e.g., something like a
27 conversion efficiency). Figure S3-A illustrates the per-capita effect of encounters between a given
28 consumer and resource individual based on their phenotypic values. We note that removing the
29 squared expression inside the exponential would describe a consumer-resource interaction with
30 monotonic arms-race dynamics.

31 The consumer's per-capita mortality rate $w_{M,C}$ is assumed to be constant during an individual
32 consumer's's life; thus, we do not model reduction in survivorship through a failure to acquire
33 resources (e.g., via starvation).

34 Encounters with consumers are assumed to increase the mortality risk of the resource; we
35 describe changes in the resource's mortality rate $w_{M,R}$ to depend on the extent to which the
36 resource's trait is dissimilar to the distribution of consumer exploitation traits:

$$w_{M,R}(t) = \gamma v \int_{x \in \{\alpha\}} \frac{\exp(-(x-\delta)^2)}{1 + \exp(-(x-\delta)^2)} dx, \tag{S3-2}$$

37 where γ is the breeding value characterizing the resource's baseline survivorship and v scales
38 the effect of the interactions on resource mortality.

39 We also model implicit exploitative competition among resource individuals. The outcome
40 of such resource-resource competition determines the distribution of resource fecundities. We
41 assume that the the resource's ability to defend itself against consumers comes at a cost to
42 reproduction. Such a trade-off could arise, for instance, if energetic reserves need to be allocated
43 to producing secondary compounds instead of fruit (e.g., Bazzaz et al. 1987; also Bohannan
44 and Lenski 1997). Changes to resource fecundity are then modeled as:

$$w_{F,R}(t) = w_{F,R}(t)n_i \exp(-\rho\alpha^2), \tag{S3-3}$$

45 where n_i describes the aggregate effect of any encounters a resource individual i may have
46 with other resource individuals, and ρ describes the severity of the trade-off between resource
47 defense and resource fecundity. This entails that greater investment by the resource in any

48   given anti-consumer strategy can entail greater fecundity costs.

49   Eqns. (S3-1 - S3-3) are mathematical abstractions in which a given individual of the

50   focal species is assumed to encounter all possible individuals in the other species. In nature,

51   however, encounters between individuals often result from Poisson processes (e.g., Hassell 1978).

52   Therefore, to capture the effects of contingent interspecific interactions on trait evolution, for

53   a given individual of either species we instead simulate a random subset of possible encounters

54   out of all possible species. The specific life history traits therefore change according to the

55   cumulative interactions an individual experiences during a given time step, rather than summing

56   over all possible interactions.

57   For the simulations of this model reported in the main text, we assumed that the phenotype

58   governing consumer exploitation ability is controlled by three loci which we assume have additive

59   effects on the consumer trait of interest. Similarly, the resource's defensive trait was assumed

60   to be additively controlled by five loci. For both the consumer and resource species, genetic

61   variations in the life history traits at birth were assumed to be minimal.

62   Figure S3-A illustrate how the strength ρ of the tradeoff between resource defense and

63   resource fecundity can govern the eco-evolutionary outcome of consumer-resource coevolution.

64   When the tradeoff is weak, the resource can readily evolve anti-consumer defenses and drive the

65   consumer extinct; when the tradeoff is strong, the resource can ill-afford to invest too heavily

66   in a particular strategy and thus the manner in which it avoids predation shifts, enabling

67   coevolutionary cycling. The consumer can only persist when the tradeoff faced by the resource

68   is weak when there is sufficient migration from patches in which the tradeoff is strong. Figure

69   S3-B show how the extent of migration between patches governs consumer persistence. Figure

70   S3-B shows how when there is limited, the consumer population struggles to persist. However,

71   when cross patch dispersal is relatively high, the inflow of maladapted consumers prevents

72   successful local adaptation and consumer persistence is somewhat more limited. The parameter

73   values used in the simulations of this model employed in the main text are available at `https:`

74   `//github.com/kewok/spegg`.

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(A)   (B)
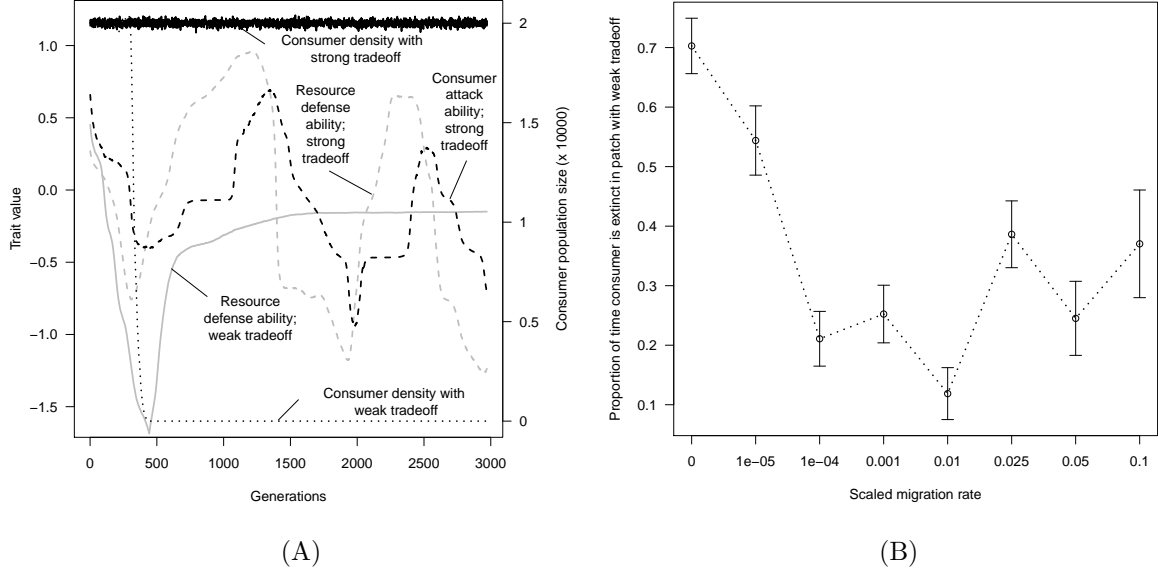
Supplementary Figure S3. (A) Coevolutionary dynamics in a consumer-resource community without migration. The traits affecting inter-specific interactions for the resource are subject to a pleiotropic constraint ρ on fitness, which is modeled as reducing their per-capita fecundity following interactions with intra-specifics (i.e., their competitive ability) depending on how much the resource defense ability trait deviates from zero. The consumer, by contrast, is assumed to face no such constraint. Consumer-resource coevolution is therefore possible only in environments where the tradeoff faced by the resource is strong (black dashed line). (B) The effect of varying the scaled migration rate on consumer persistence, i.e., the proportion of time in which the consumer population is extinct, in the patch with relatively weak constraints on the resource defense trait. A biased island dispersal model is used, in which a proportion π of migrants from each patch ultimately return to their patch of origin. Thus, the values on the abscissa in panel (B) represent the effective migration rate scaled by the propensity of individuals to attempt to leave their home patch. Error bars reflect the standard deviation across 15 replicate simulations.

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