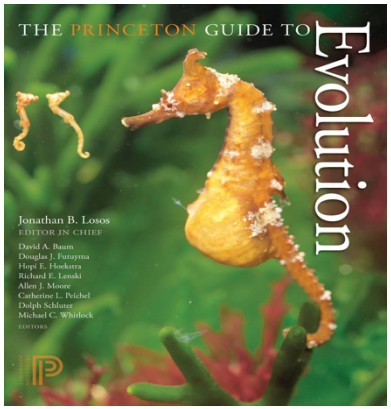
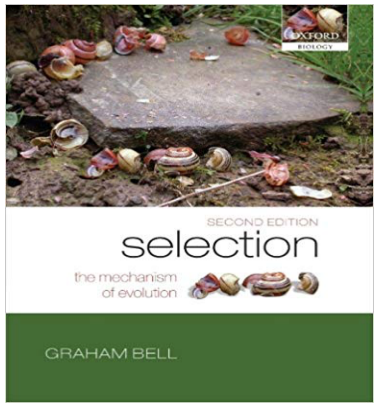
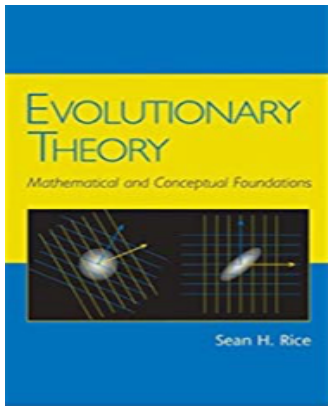
Let the concept of *eco-evolutionary feedbacks* be functional!

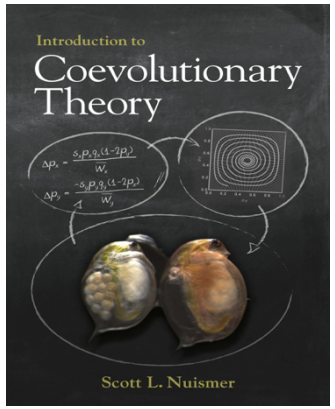
Blake Matthews
Eawag, Switzerland

[Feedbacks are] "*One of the chief themes of scientific understanding*"
Judson 1980, MacArthur Fellow ("Genius grant")







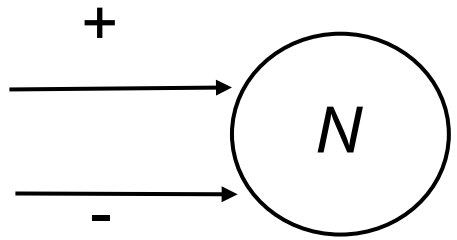


FEEDBACK - the modification of a process by its results or effects.

ECOLOGICAL FEEDBACK - the modification of an ecological process by its results or effects.

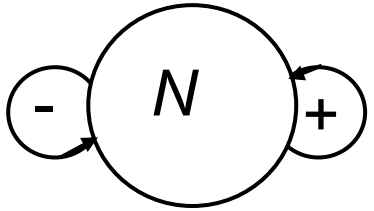
NO FEEDBACK

$$\frac{dN(t)}{dt} = B(t) - D(t)$$

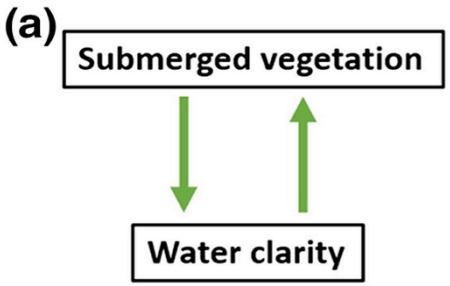


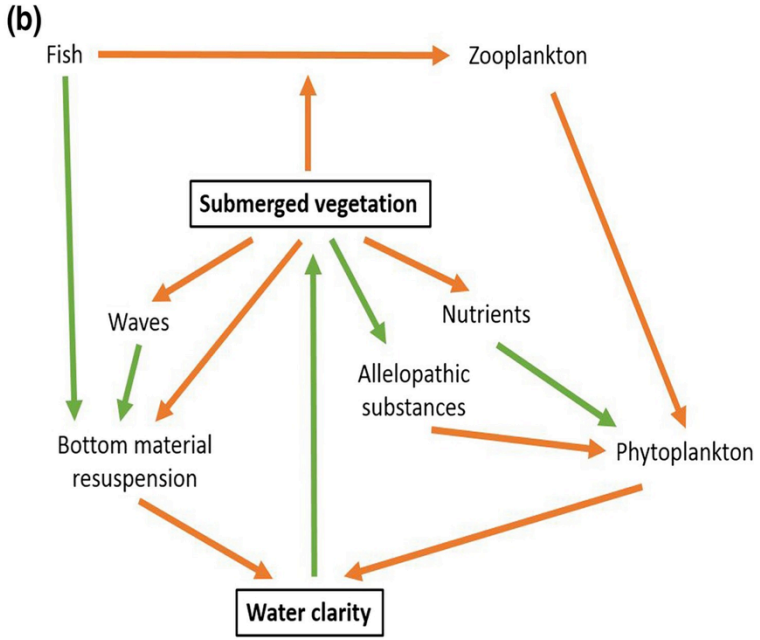
FEEDBACK

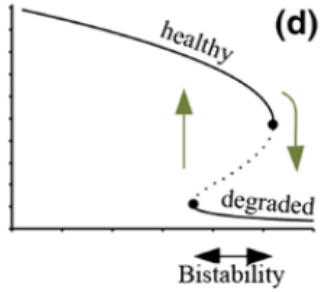
$$\frac{dN(t)}{dt} = (b - d)N(t)$$



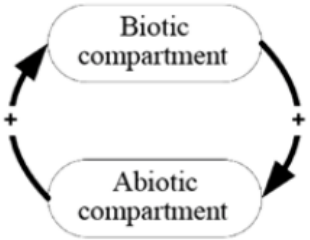
Ecosystem ecology feedbacks







Discontinuous transition (catastrophic)



Strong feedback loop

Functional Ecology

British Ecological Society

Functional Ecology 2016, **30**, 88–97

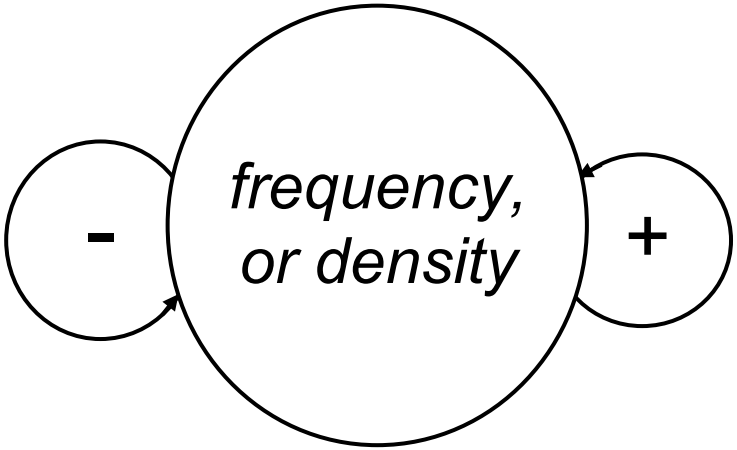
doi: 10.1111/1365-2435.12601

MECHANISMS AND CONSEQUENCES OF FACILITATION IN PLANT COMMUNITIES

When can positive interactions cause alternative stable states in ecosystems?

Sonia Kéfi*,[1], Milena Holmgren[2] and Marten Scheffer[3]

EVOLUTIONARY FEEDBACK - the modification of an evolutionary process by its results or effects.



Evolutionary equilibria
Population regulation
Homeostasis

Runaway evolution
Inbreeding tolerance
Evolution of cooperation
Niche construction
Parental care

"a runaway process can grind to a halt because positive feedback might eventually turn negative owing to some feature of the biological interaction" (Lehtonen and Kokko 2012)

Positive feedbacks in evolutionary biology

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B

Phil. Trans. R. Soc. B (2012) **367**, 211–221
doi:10.1098/rstb.2011.0177

Research

Positive feedback and alternative stable states in inbreeding, cooperation, sex roles and other evolutionary processes

Jussi Lehtonen and Hanna Kokko*

Division of Ecology, Evolution and Genetics, Research School of Biology, Australian National University, Canberra, Australian Capital Territory 0200, Australia

ELSEVIER

Opinion *TRENDS in Ecology and Evolution* Vol.19 No.12 December 2004

Full text provided by www.sciencedirec SCIENCE DIRECT

Vicious circles: positive feedback in major evolutionary and ecological transitions

Bernard J. Crespi

Behavioural Ecology Research Group, Department of Biosciences, Simon Fraser University, Burnaby BC, Canada, V5A 1S6

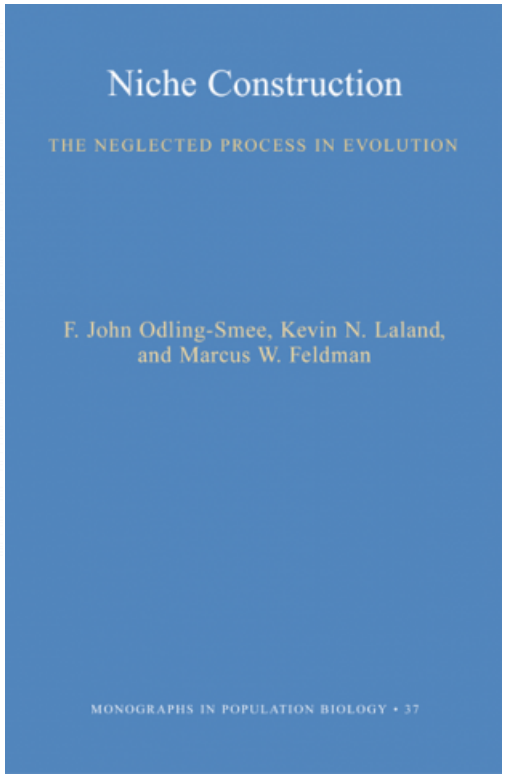
Feedback Theory and Darwinian Evolution

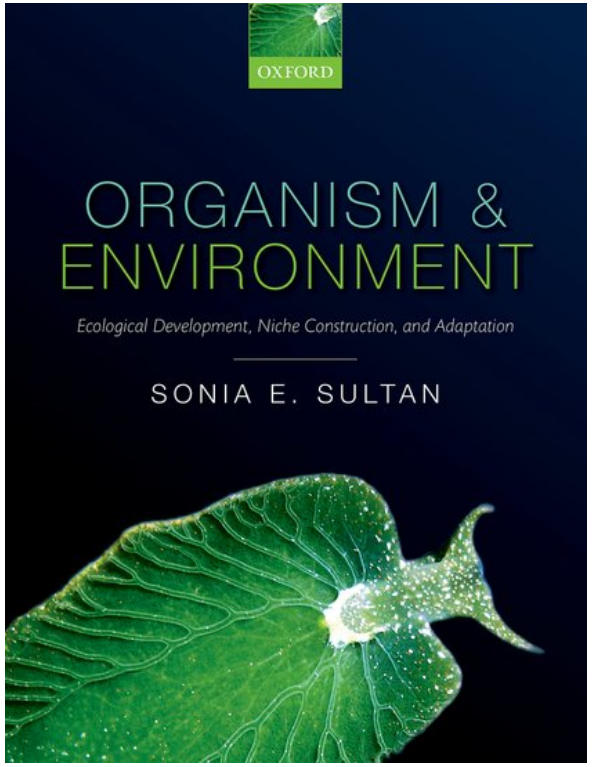
DOUGLAS S. ROBERTSON

15 *Pavilion Drive, Gaithersburg, MD* 20878, *U.S.A.*

(*Received on* 9 *September* 1990, *Accepted in revised form on* 6 *June* 1991)

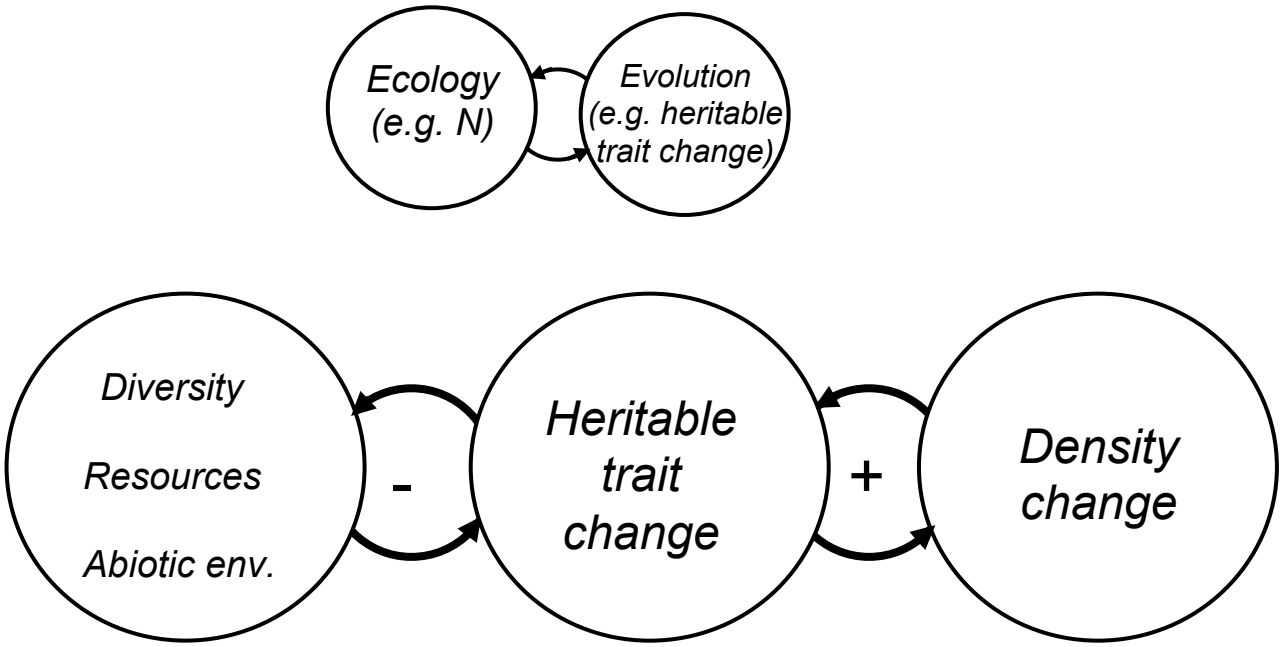
Feedback loops can have a significant impact on biological systems that are evolving under Darwinian natural selection. Many of the striking and sometimes bizarre patterns that characterize the evolution of such systems have simple, natural explanations that involve the effects of feedback loops. The two fundamental types of feedback loops, positive and negative, have effects that are radically different: negative feedback tends to produce stability and resistance to change; positive feedback produces instability and even catastrophe. Both types of feedback loops are important in biological systems, and both can produce chaos, whose mathematical complexity often produces strange, beautiful and totally unexpected patterns that have only begun to be explored using the computational capabilities of modern electronic computers. An understanding of the patterns that can result from the effects of feedback loops can produce important new insights into the patterns that mark the evolutionary development of biological systems.





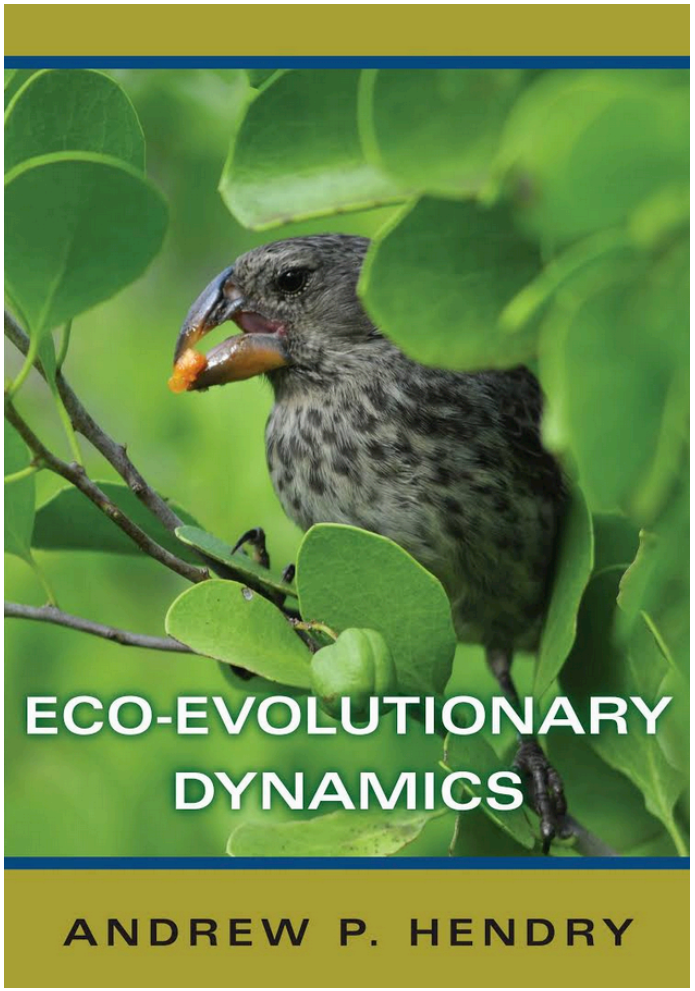
FEEDBACK - the modification of a process by its results or effects.

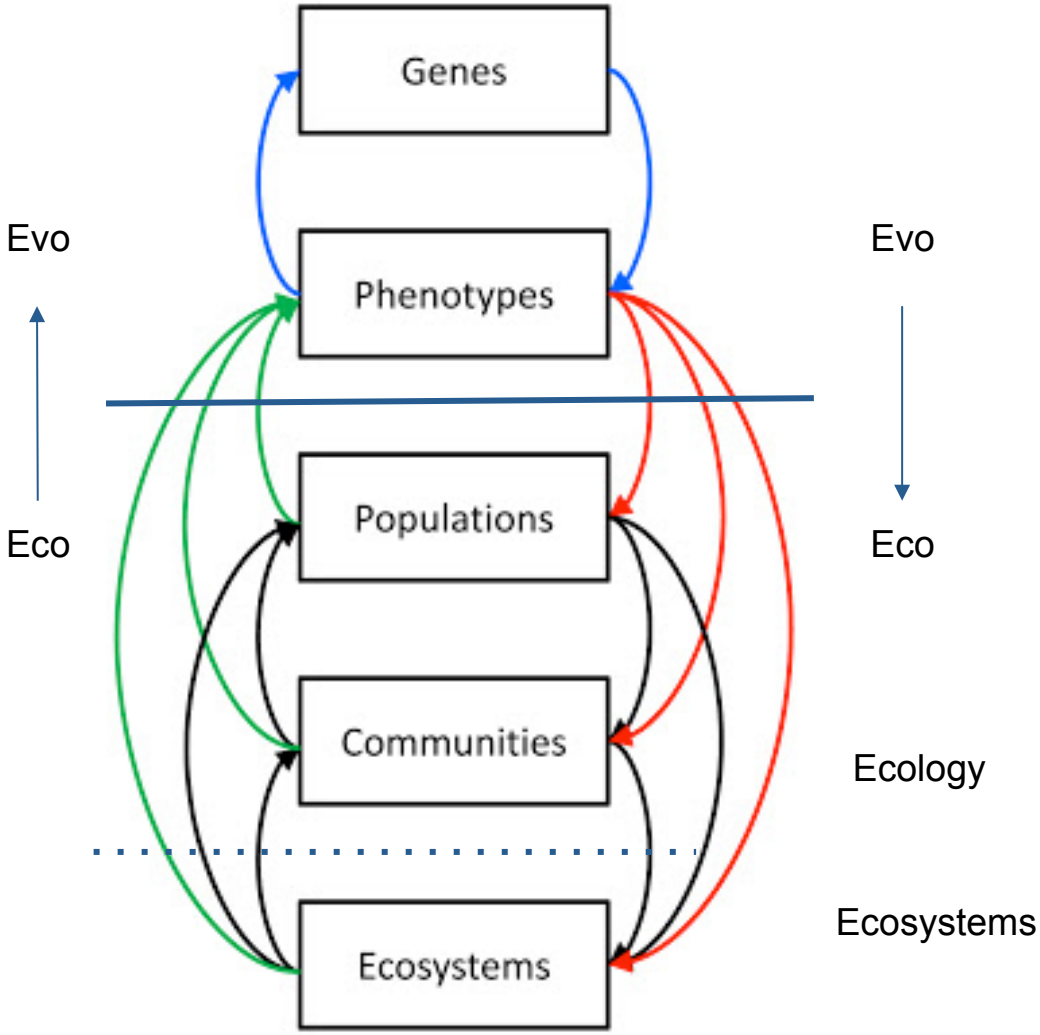
ECO-EVOLUTIONARY FEEDBACK - Ecological and evolutionary change reciprocally influence each other through the same *(or different)* traits and ecological variables



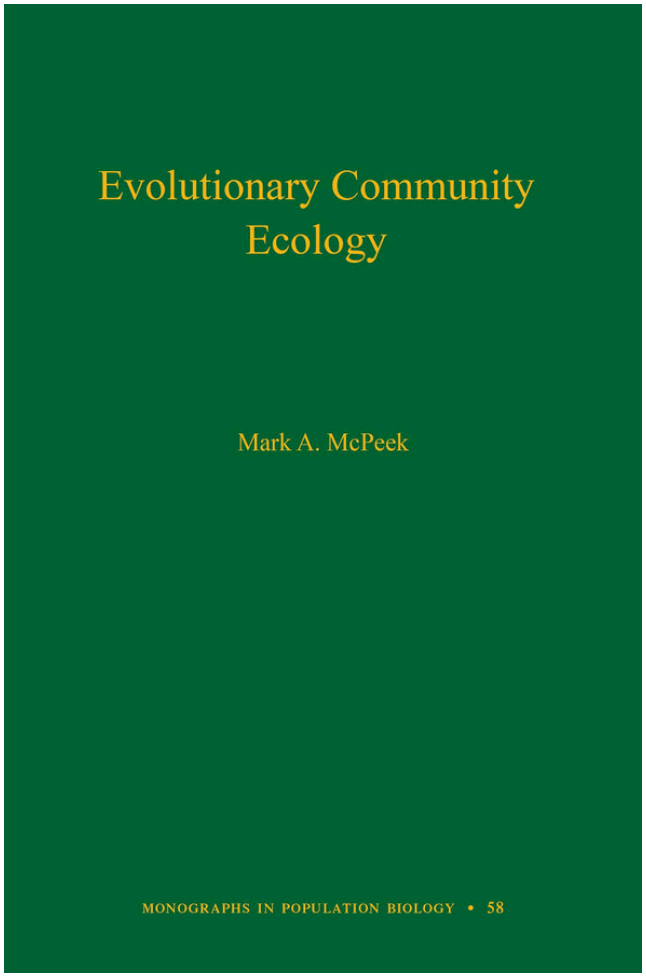
A conceptual model of feedbacks between ecology and evolution

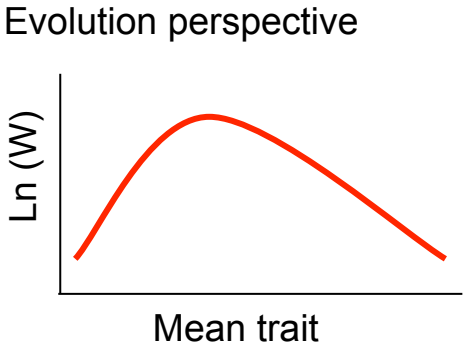
Eco-evolutionary feedback (narrow sense) - “Ecological and evolutionary change reciprocally influence each other through the same traits and ecological variables”

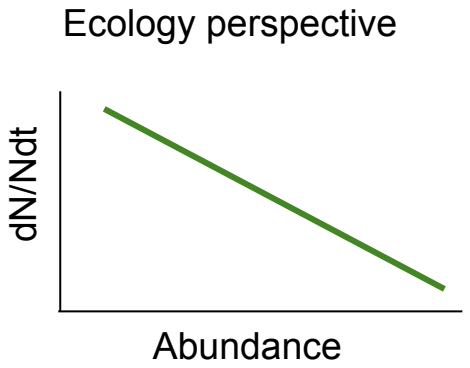


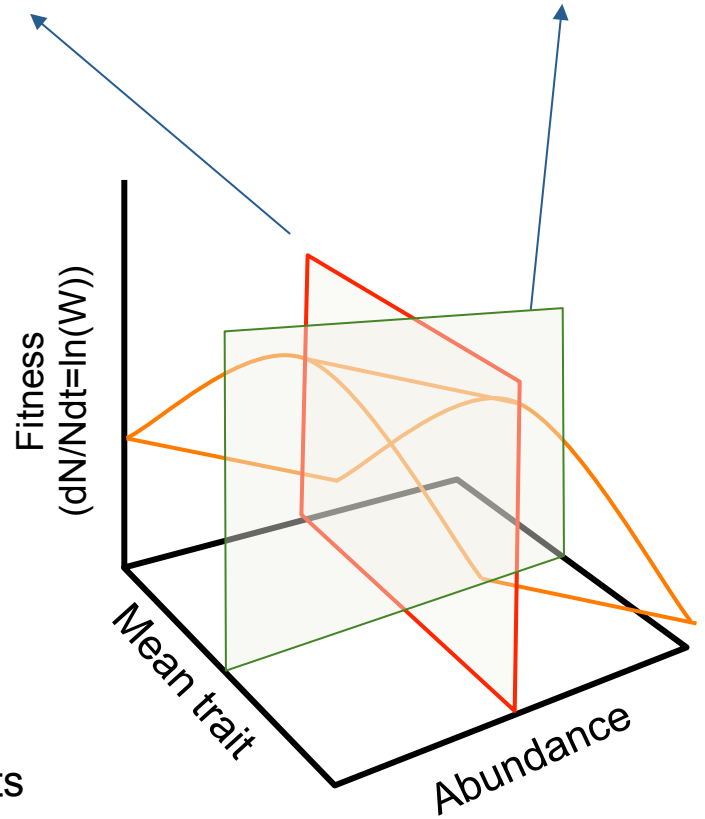


Analytical models of feedback between ecology and evolution









Absolute fitness is an ecological property.

The outcome of coevolutionary interactions among species is determined by the balances that are struck among the fitness components and the selection gradients experienced by each species

Feedbacks in evolutionary ecology

VOL. 191, NO. 1 THE AMERICAN NATURALIST JANUARY 2018

SYNTHESIS

Theoretical Approaches in Evolutionary Ecology: Environmental Feedback as a Unifying Perspective

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Submitted March 2, 2017; Accepted August 11, 2017; Electronically published November 3, 2017

Online enhancements: videos.

ABSTRACT: Evolutionary biology and ecology have a strong theoretical underpinning, and this has fostered a variety of modeling approaches. A major challenge of this theoretical work has been to unravel the tangled feedback loop between ecology and evolution. This has prompted the development of two main classes of models. While quantitative genetics models jointly consider the ecological and evolutionary dynamics of a focal population, a separation of timescales between ecology and evolution is assumed by evolutionary game theory, adaptive dynamics, and inclusive fitness theory. As a result, theoretical evolutionary ecology tends to be divided among different schools of thought, with different toolboxes and motivations. My aim in this synthesis is to highlight the connections between these different approaches and clarify the current state of theory in evolutionary ecology. Central to this approach is to make explicit the dependence on environmental dynamics of the population and evolutionary dynamics, thereby materializing the eco-evolutionary feed-

Introduction

Evolution is rooted in ecology (Hutchinson 1965; McPeek 2017). Natural selection and genetic drift, the two forces that sort genetic variation, are fundamentally ecological

External environmental variables

$$(n, f, \mathbf{e})$$

$$\frac{d\mathbf{e}}{dt} = \mathcal{D}(\mathbf{E})$$

population growth rate

$$\frac{dn}{dt} = \bar{r}(\mathbf{E})n$$

Population abundance

Population genetics

$$\frac{df_i}{dt} = f_i(r_i(\mathbf{E} - \bar{r}(\mathbf{E}))$$

Frequency of types

types

Moving from theory to empirical tests....

"...there is no escaping the complex problem of jointly tracking the entangled dynamics of the trait distribution and the environmental variables."
(Lion 2018, AmNat)

Agenda for empiricists:

- identify the evolving traits of interest (both response and effect traits)
- determine their genetic basis
- quantify trait variation and rates of evolution in natural populations
- experimentally test how various ecological factors (i.e. agents of selection) affect trait evolution (e.g. selection gradients)
  - organism density and trait distributions
  - environmental conditions modified by organisms (traits, densities, higher order species interactions)
- test importance of such reciprocal interactions in natural populations

Experimental tests: a tale of three (fishy) feedbacks

Current Biology
Report

Experimental Evidence of an Eco-evolutionary Feedback during Adaptive Divergence

Blake Matthews,[1,*] Thierry Aebischer,[2,3,6] Karen E. Sullam,[1,4] Bänz Lundsgaard-Hansen,[2] and Ole Seehausen[2,5]
[1]Aquatic Ecology Department, Center for Ecology, Evolution, and Biogeochemistry, Eawag, 6047 Kastanienbaum, Switzerland
[2]Fish Ecology and Evolution Department, Center for Ecology, Evolution, and Biogeochemistry, Eawag, 6047 Kastanienbaum, Switzerland
[3]Department of Biology, University of Fribourg, 1700 Fribourg, Switzerland
[4]Zoological Institute, University of Basel, 4051 Basel, Switzerland
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*Correspondence: blake.matthews@eawag.ch
http://dx.doi.org/10.1016/j.cub.2015.11.070

Experimental evidence that parasites drive eco-evolutionary feedbacks

Franziska S. Brunner[a,1,2], Jaime M. Anaya-Rojas[b,c,1], Blake Matthews[b,3], and Christophe Eizaguirre[a,3]

[a]School of Biological and Chemical Sciences, Queen Mary University of London, London E1 4NS, United Kingdom; [b]Aquatic Ecology Department, Eawag, Swiss Federal Institute of Aquatic Research and Technology, 6047 Kastanienbaum, Switzerland; and [c]Division of Aquatic Ecology and Macroevolution, Institute of Ecology and Evolution, University of Bern, 3012 Bern, Switzerland

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nature ecology & evolution

ARTICLES

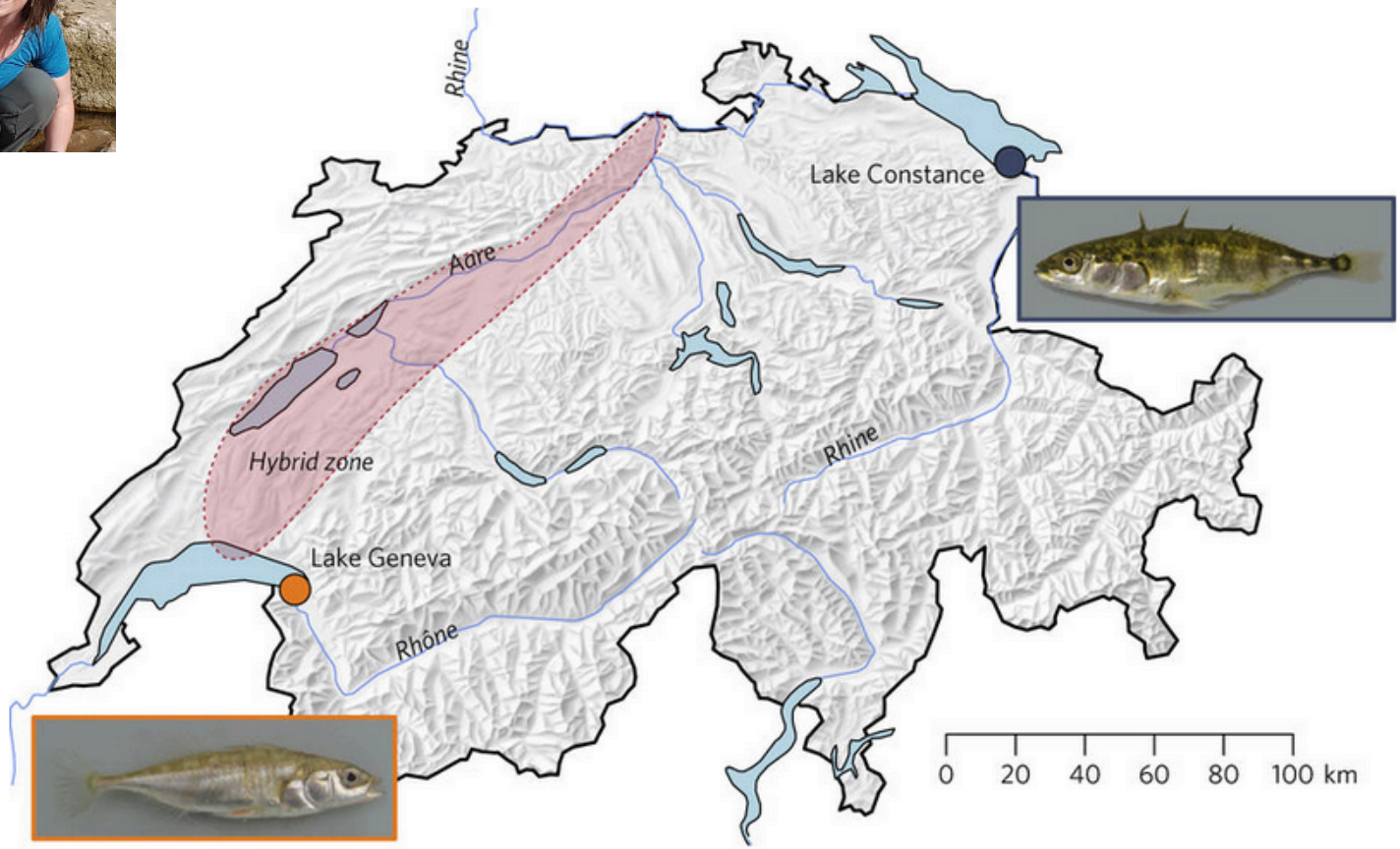
DOI: 10.1038/s41559-017-0308-2

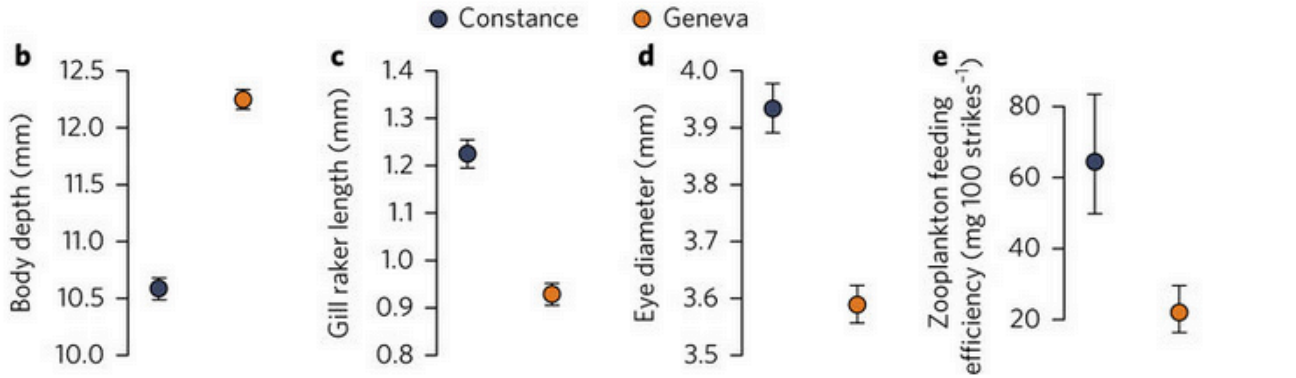
Transgenerational selection driven by divergent ecological impacts of hybridizing lineages

Rebecca J. Best[1,2,3*], Jaime M. Anaya-Rojas[1,2,4,5], Miguel C. Leal[2], Dominik W. Schmid[1], Ole Seehausen[2,4] and Blake Matthews[1]

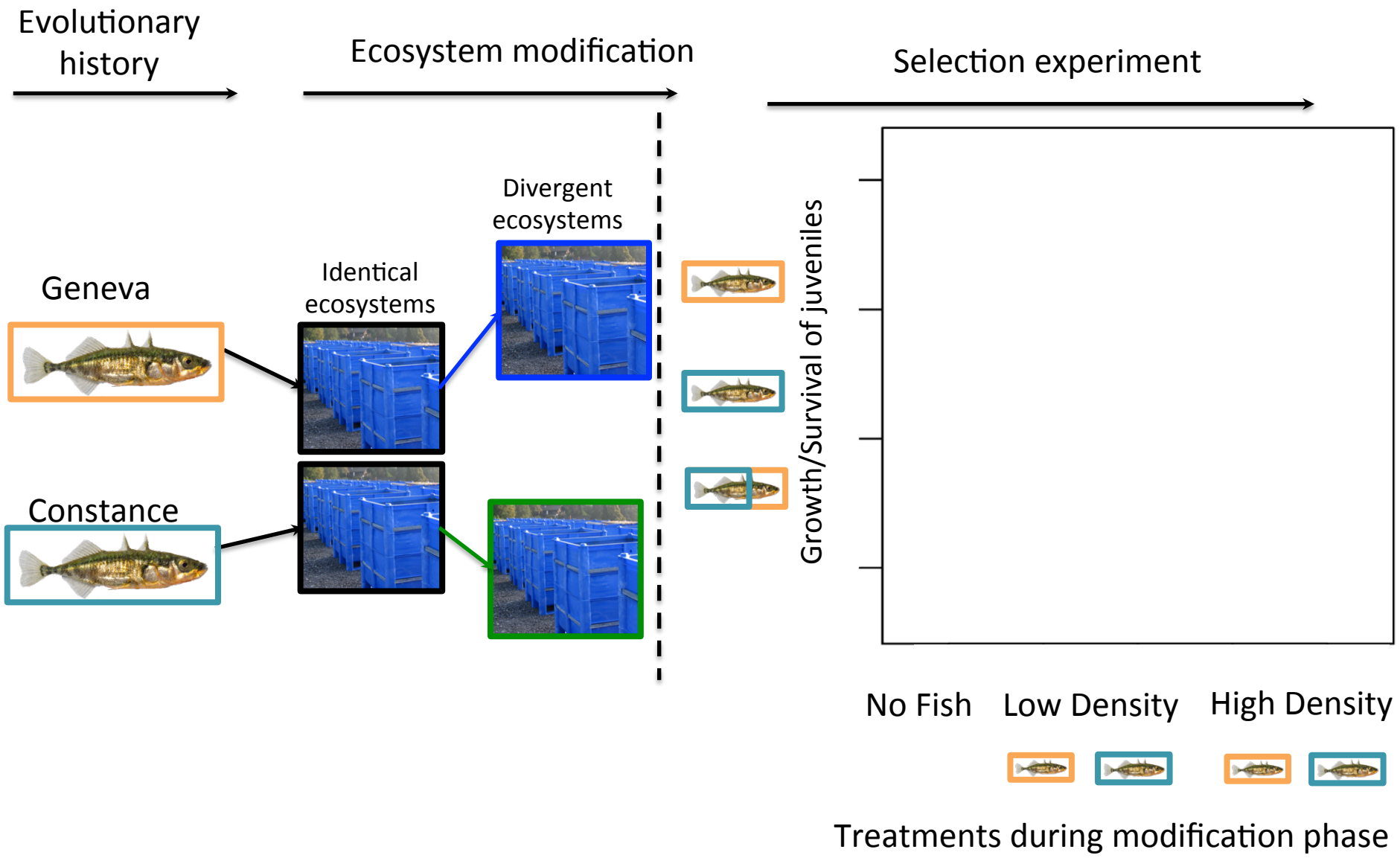
THE MODEL ORGANISM

(Stickleback)

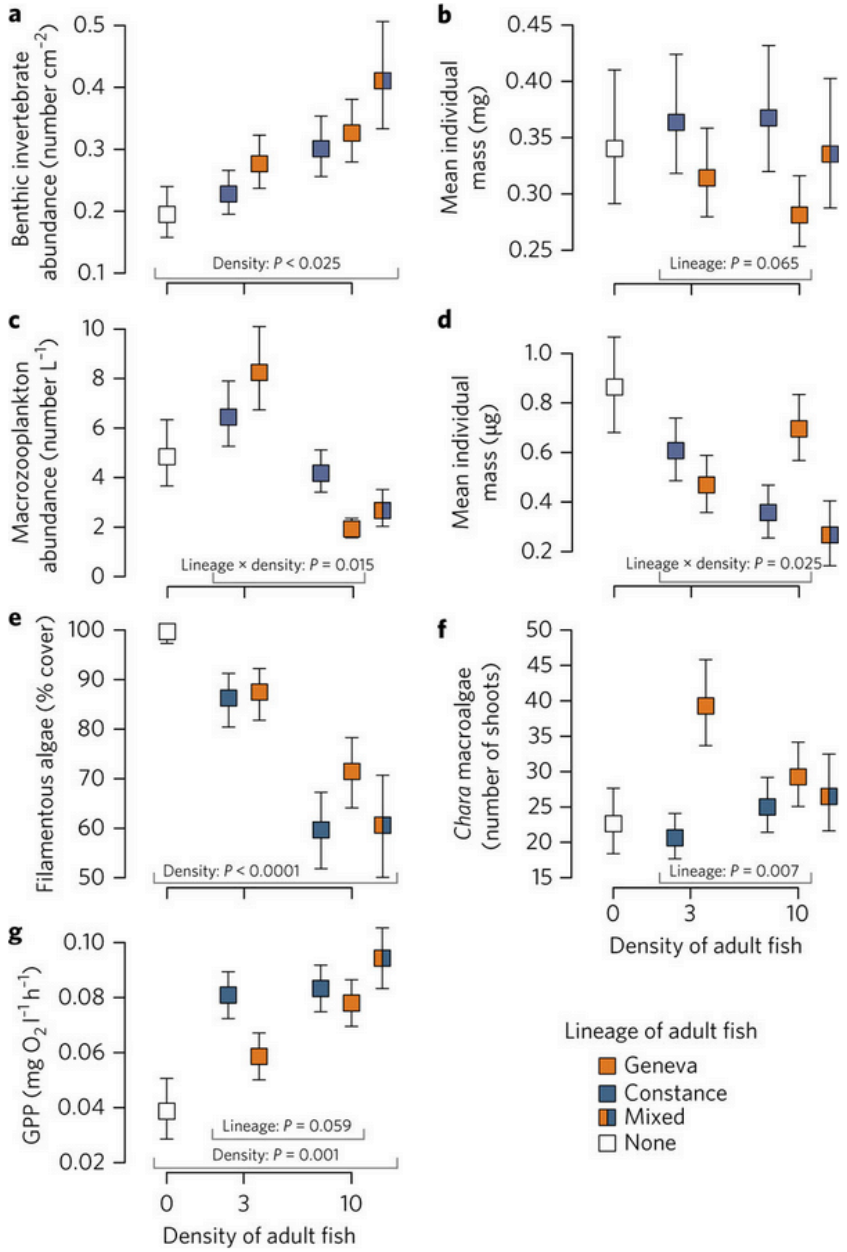

Rhine
Lake Constance
Aare
Hybrid zone
Rhine
Lake Geneva
Rhône
0 20 40 60 80 100 km


Constance
Geneva
b
Body depth (mm)
12.5
12.0
11.5
11.0
10.5
10.0
c
Gill raker length (mm)
1.4
1.3
1.2
1.1
1.0
0.9
0.8
d
Eye diameter (mm)
4.0
3.9
3.8
3.7
3.6
3.5
e
Zooplankton feeding efficiency (mg 100 strikes^{-1})
80
60
40
20

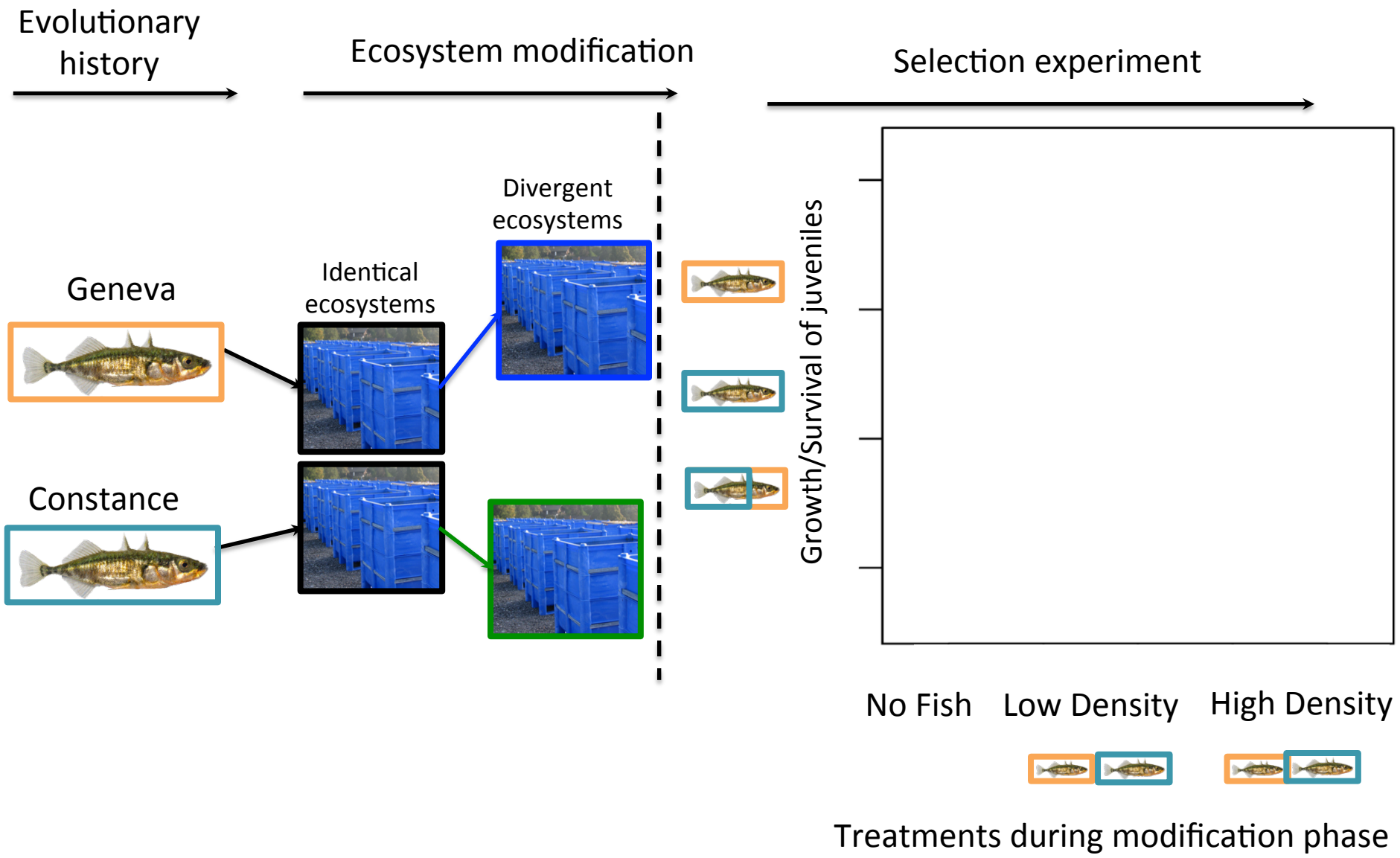
Do ecosystem effects of adults modify selection pressures on juveniles?



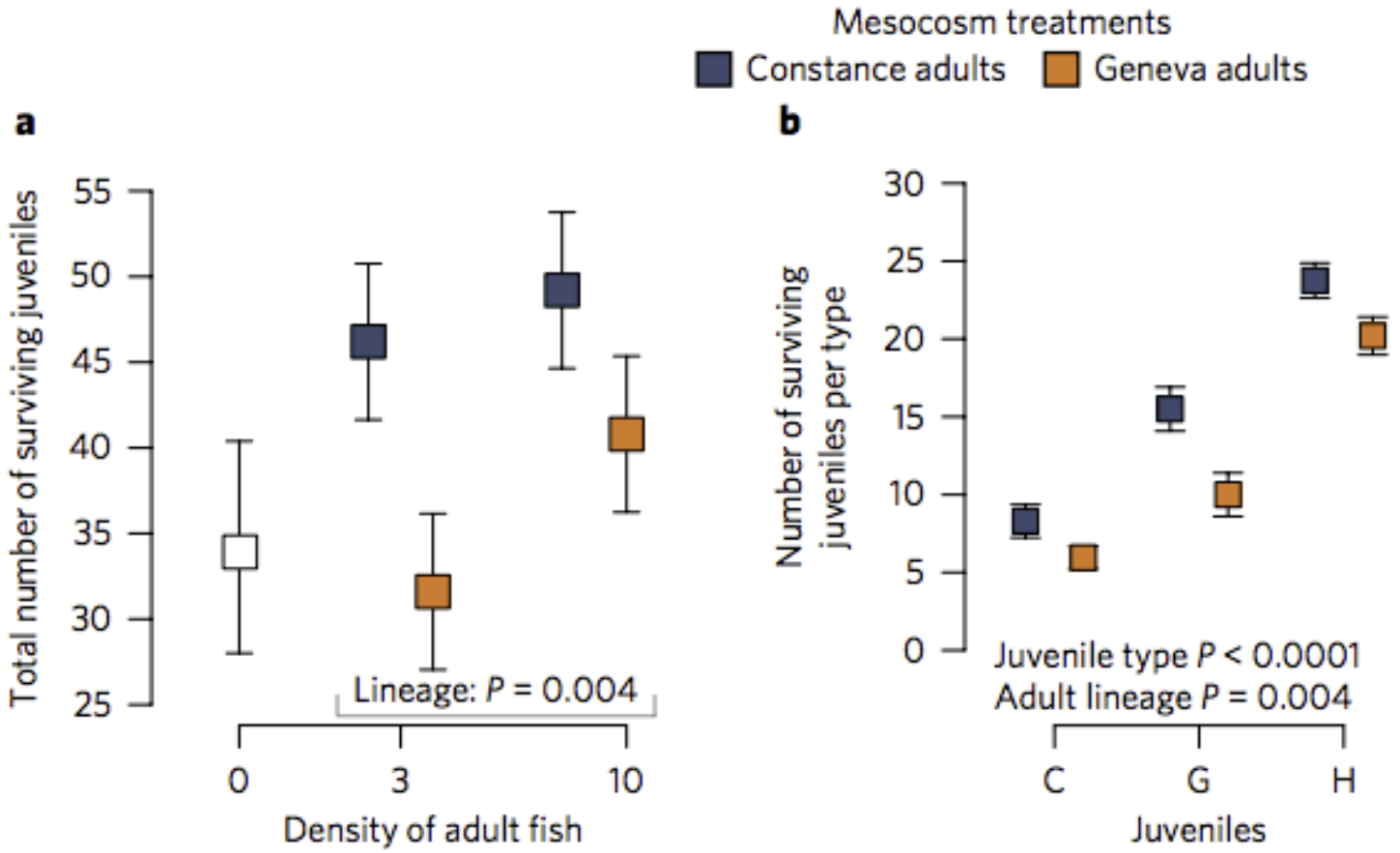
Ecological effects of density and lineage



Do ecosystem effects of adults modify selection pressures on juveniles?

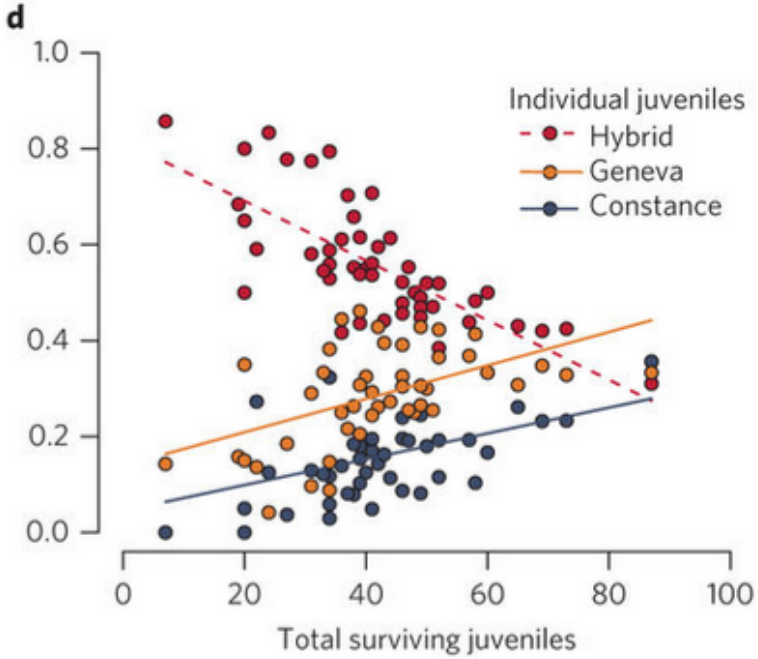


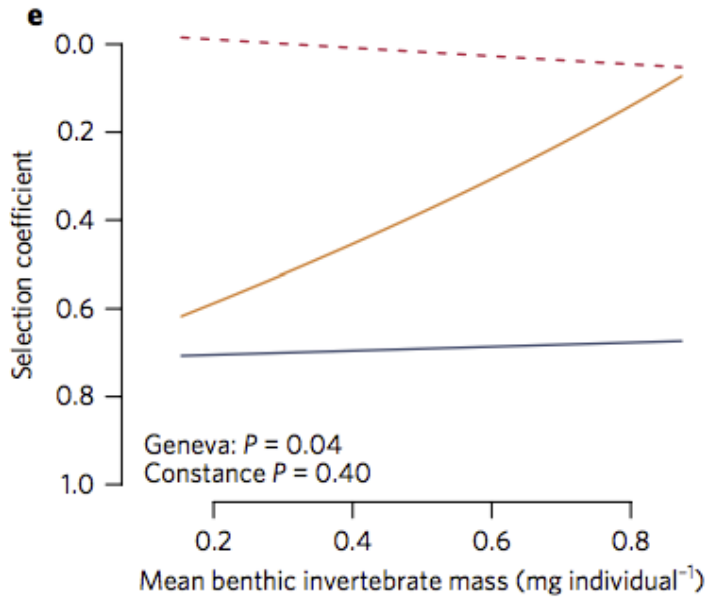
Survival of juveniles depended more on lineage than density of adults



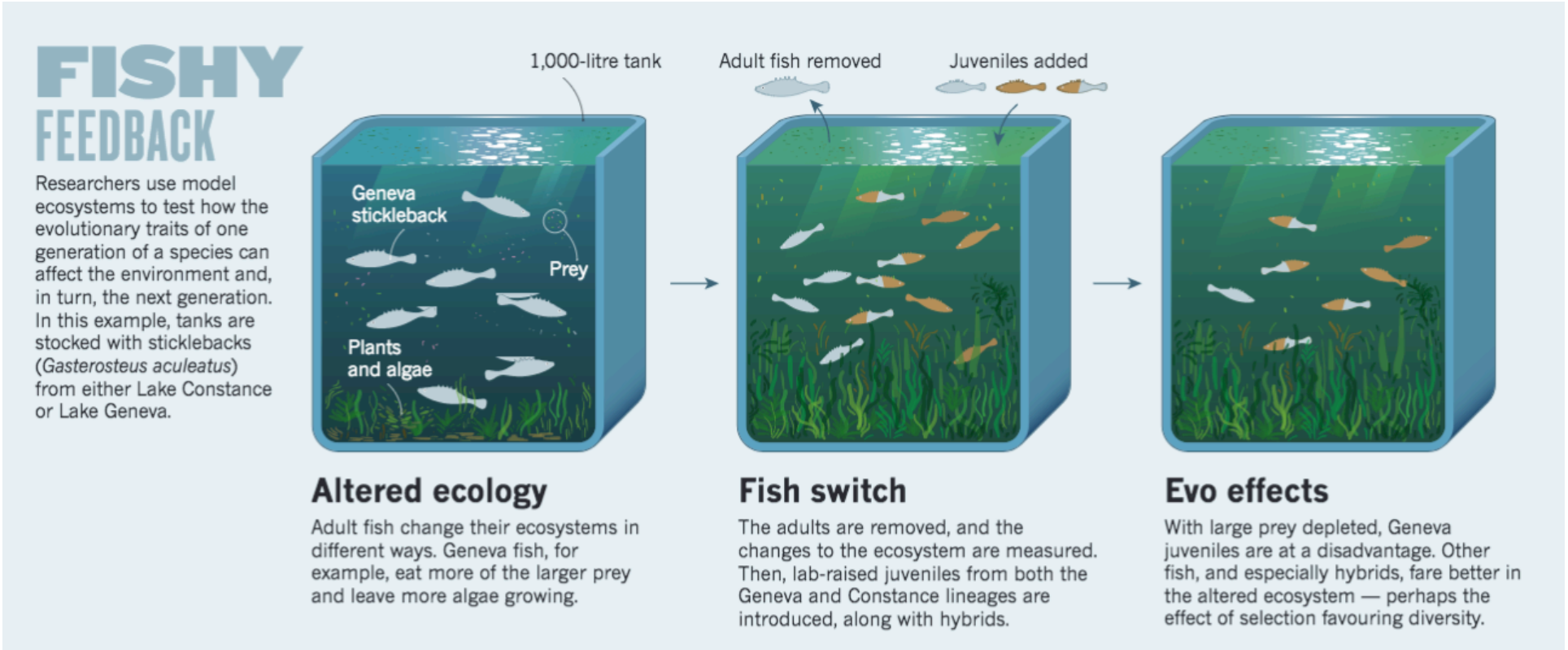
Hybrid performance was environment independent

Proportion of surviving juveniles (out of 99)

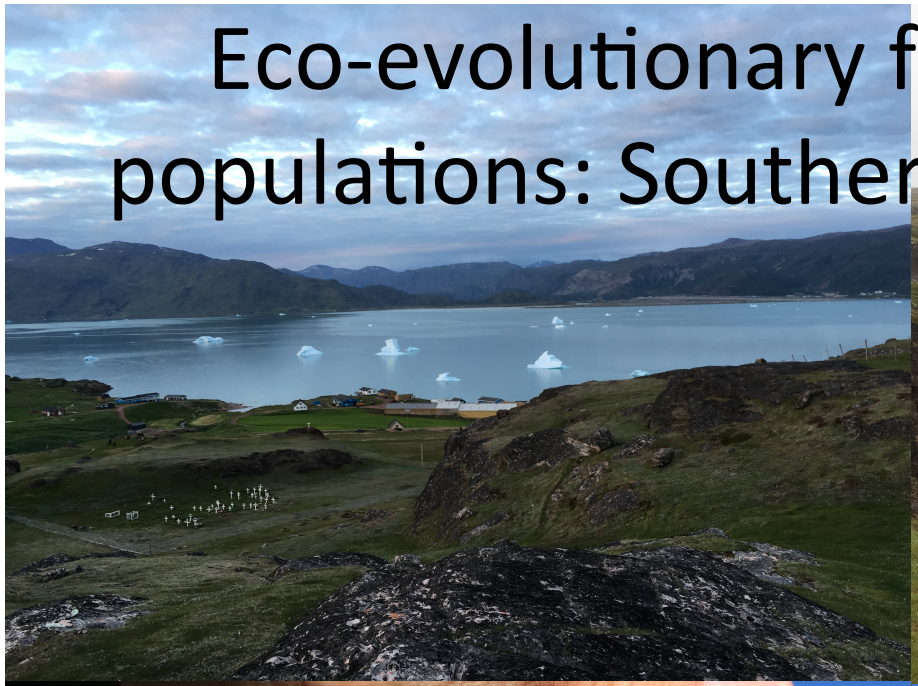




Some experimental evidence of eco-evo feedbacks (likely mediated via effects on prey community composition)



Eco-evolutionary feedbacks in natural populations: Southern Greenland (2018-…)



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Miguel Leal

Daniel Steiner

eawag aquatic research

FNSNF Swiss National Science Foundation

CONCEPTS & SYNTHESIS
EMPHASIZING NEW IDEAS TO STIMULATE RESEARCH IN ECOLOGY

Ecological Monographs, 84(2), 2014, pp. 245–263

Under niche construction: an operational bridge between ecology, evolution, and ecosystem science

Blake Matthews,[1,8] Luc De Meester,[2] Clive G. Jones,[3] Bas W. Ibelings,[4] Tjeerd J. Bouma,[5] Visa Nuutinen,[6] Johan van de Koppel,[5] and John Odling-Smee[7]

[1]*EAWAG, Aquatic Ecology Department, Center for Ecology, Evolution and Biogeochemistry, Kastanienbaum 6047 Switzerland*
[2]*Laboratory of Ecology, Evolution and Conservation, University of Leuven, 3000 Leuven, Belgium*
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[7]*Mansfield College, University of Oxford, Oxford OX13TF United Kingdom*

Abstract. All living organisms modify their biotic and abiotic environment. Niche construction theory posits that organism-mediated modifications to the environment can change selection pressures and influence the evolutionary trajectories of natural populations.

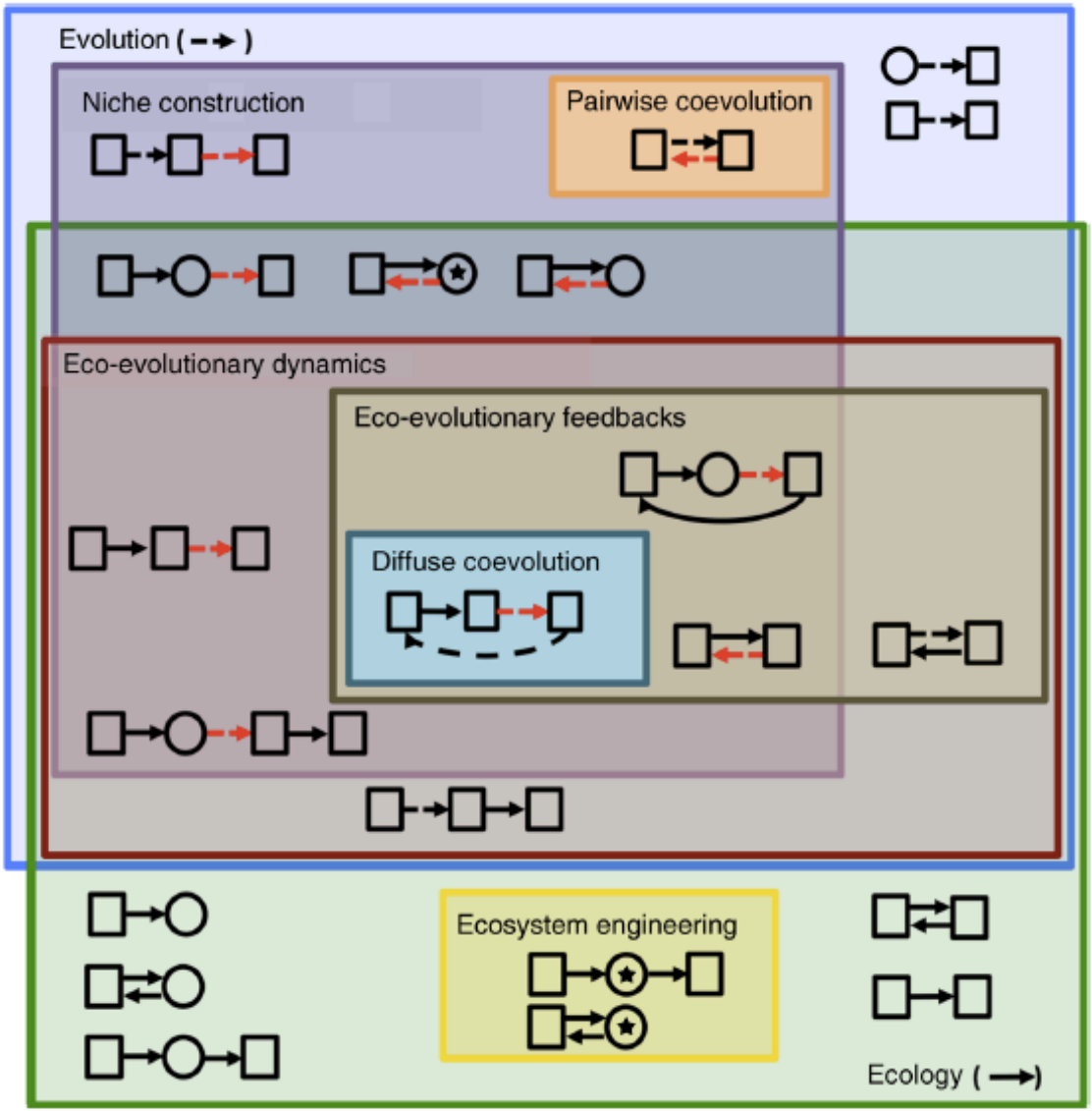

FIG. 1. A Venn diagram showing which modules of biotic (square) and abiotic (circles) entities, which are connected by evolutionary (dashed lines) and non-evolutionary effects (solid lines), are associated with different major concepts in ecology and evolution (bounded by labeled shaded boxes). Non-evolutionary effects include organism-mediated effects on both biotic and abiotic conditions (e.g., ecological effects shown in Fig. 2A), and evolutionary effects include evolutionary responses to selection. The stars denote effects on the physical state of the abiotic environment, to distinguish ecosystem engineering (yellow box) from effects on other abiotic conditions (e.g., the chemical environment). The minimum condition for evolution by niche construction to occur is to have a pathway that starts and ends with an organism (i.e., a niche constructor and a recipient of niche construction), and has at least two connections with an evolutionary effect beyond the first connection. Starting from the left of each pathway the red dashed arrow defines where evolution by niche construction has occurred.