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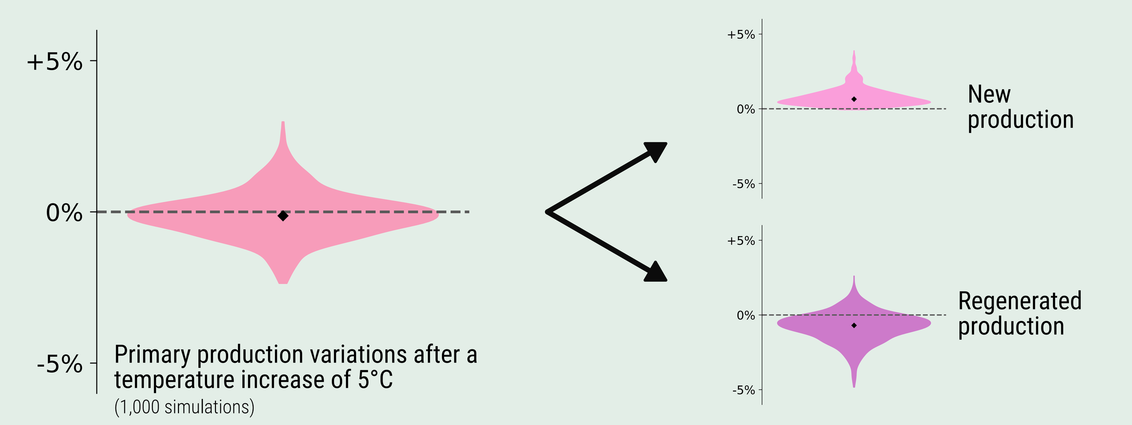
Eco-evolutionary Responses of the Microbial Loop to Surface Ocean Warming and Consequences for Primary Production

Philippe Cherabier[1], Régis Ferrière[1,2,3]

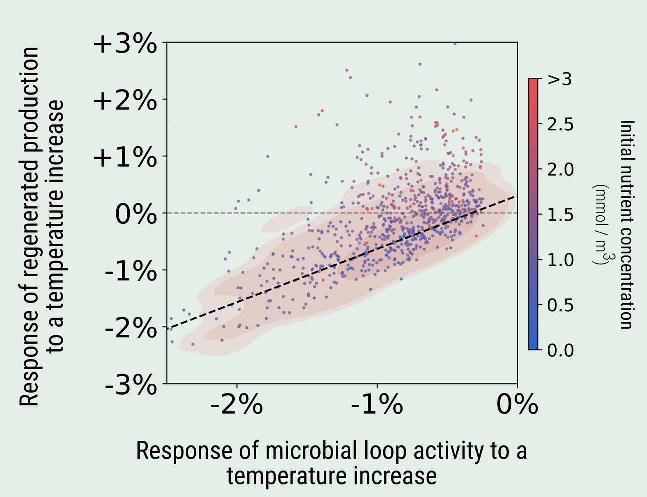
[1]Institut de Biologie de l'Ecole Normale Supérieure (IBENS), Paris. [2]Department of Ecology & Evolutionary Biology, University of Arizona, Tucson. [3]International Research Laboratory for Interdisciplinary Global Environmental Studies (iGLOBES), Tucson

Ecophysiological response of primary production to a temperature increase

A rise in temperature changes individual metabolisms, which changes the fluxes of nitrogen between compartments. These changes make the **ecophysiological response** of the system, i.e. in which no adaptation through selection takes place. We find that the ecophysiological response of **primary production** can either be **positive** or **negative**:

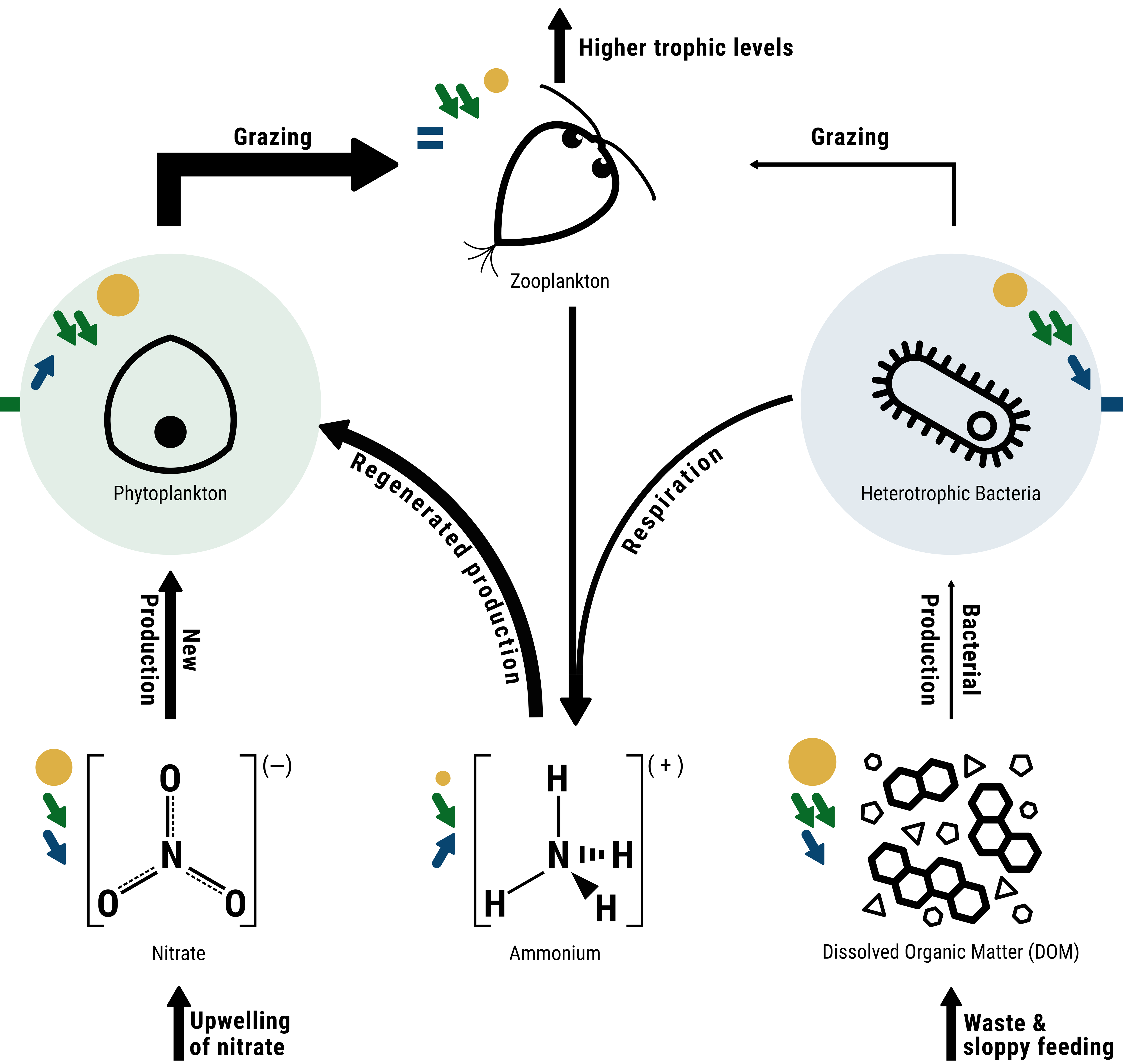


The direction of change depends on the balance between new and regenerated production: negative when the decrease in regenerated production is larger than the increase in new production, and positive otherwise.



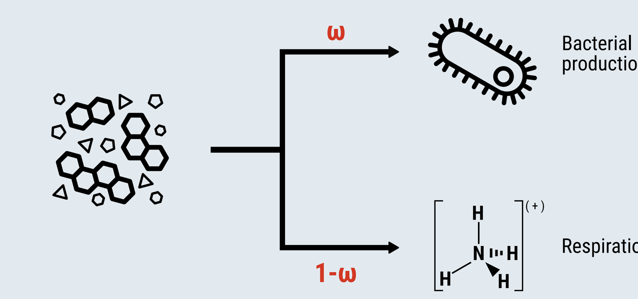
A strong decrease in regenerated production is more likely in nutrient-poor regions (blue dots) than in nutrient-rich regions (red dots). In nutrient-poor regions, a decrease in regenerated production is directly correlated with a decrease in microbial loop activity (the red region represents the density of resampled set of simulations in nutrient-poor ecosystems).

In nutrient-poor ecosystems, the main component of primary production is regenerated production. We conclude that **in oligotrophic regions of a warming ocean, the future of primary production depends on the activity of the microbial loop.**



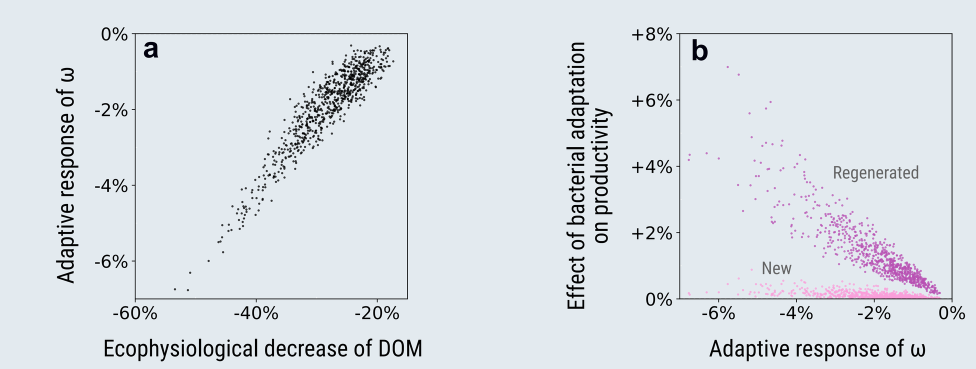
Effect of bacterial adaptation on ecosystem productivity

Changes in the ecological equilibrium brought by sea-surface warming induce a pressure on heterotrophic bacteria to adapt. We focus on the adaptation of **bacterial growth efficiency** (BGE). This trait is a critical determinant of nutrient fluxes in the ecosystem and microbial loop efficiency. BGE is defined as the fraction ω of resource consumed allocated to growth, the rest being respired (with uptake rates depending on the fraction 1-ω respired):

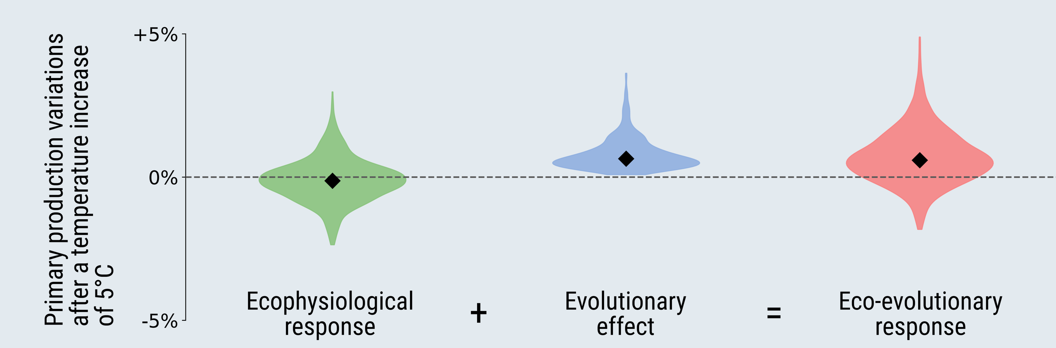


We derive the invasion fitness of a new trait value over the resident from the ecological equilibrium, and find that the resulting **selection gradient** is the sum of two opposing pressures: the pressure for a more efficient growth (the **yield pressure**) which favors higher values of ω, and the pressure for a more effective resource acquisition (the **acquisition pressure**), which favors lower values.

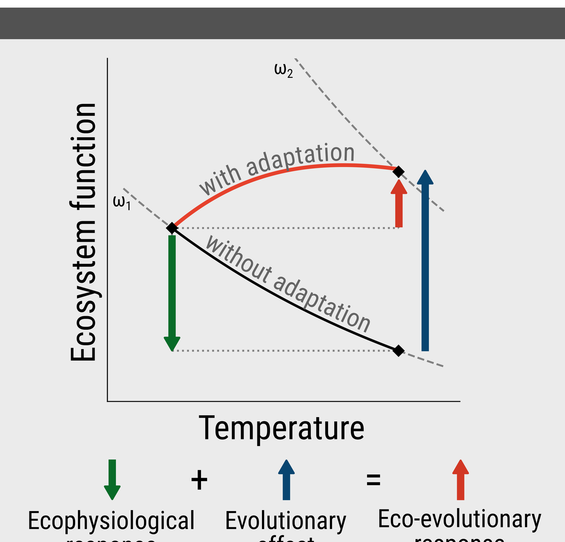
Sea-surface warming leads to a strong decrease in dissolved organic matter. This increases the acquisition pressure more than the yield pressure, resulting in a decrease in BGE (**a**). This decrease ripples through the ecosystem, leading to an increase in both new and regenerated production (**b**):



In nutrient-poor environments, the effect of bacterial adaptation can even compensate the decrease of primary production induced by warming. This shows the importance of evolutionary adaptation and eco-evolutionary feedback to understand and predict the future of primary production.



Method



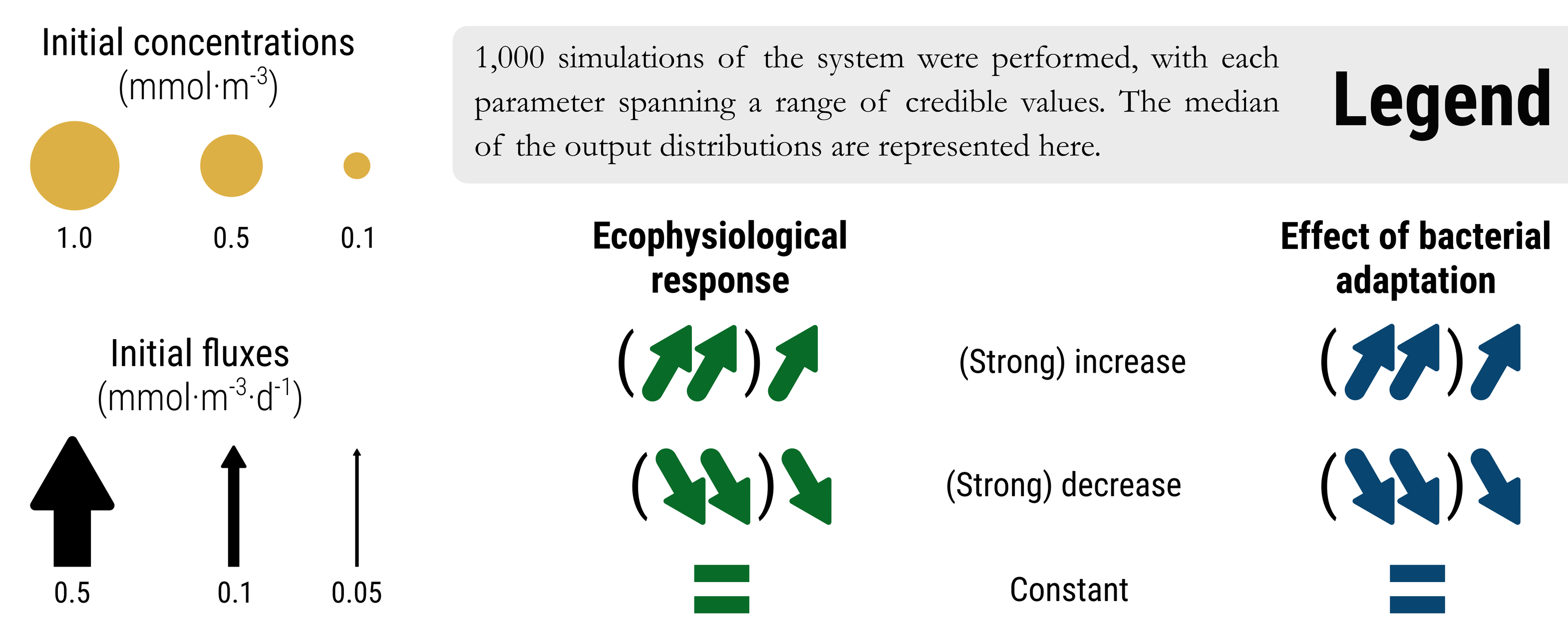
Here we develop a theoretical eco-evolutionary model to predict the **ecophysiological response** of a sea-surface ecosystem to a temperature increase at ecological equilibrium, and how this response drives the adaptation of bacterial growth efficiency ω from ω_1 to ω_2 using adaptive dynamics.

How this adaptation then changes the balance of nutrient fluxes in the system makes up the **evolutionary effect**, leading to variations in key functions of the ecosystem such as primary production.

Together, ecophysiological response and evolutionary effect combine to form the **eco-evolutionary response** of the ecosystem.

Legend

1,000 simulations of the system were performed, with each parameter spanning a range of credible values. The median of the output distributions are represented here.



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