
EVOLUTION, FUNCTIONAL DIVERSITY, REGIME SHIFTS, HYSTERESIS, AND NONLINEARITY; ECOSYSTEM RESPONSES TO ENVIRONMENTAL CHANGE.

A PREPRINT

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Abstract

To be completed

Keywords Biodiversity · Evolution · Hysteresis · Alternate stable states · Environmental change · Regime shift · Threshold · Ecosystem · Cyanobacteria · Sulphur bacteria

```
library(tidyverse)
```

```
## -- Attaching packages ----- tidyverse 1.3.0 --
```

```
## v ggplot2 3.3.3    v purrr  0.3.4
## v tibble  3.1.0    v dplyr  1.0.5
## v tidyr   1.1.2    v stringr 1.4.0
## v readr   1.4.0    v forcats 0.5.0
```

```
## -- Conflicts ----- tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()
```

```
library(microxanox)
library(patchwork)
library(here)
```

```
## here() starts at /Users/owenpetchey/Desktop/microxanox/diversity_envresp1
source(here("simulations/r_functions/various_useful_functions.r"))
```

1 Introduction

Types of ecosystem responses to environmental change. What and why. Importance of non-linearity and hysteresis. Feedbacks, diversity / evolution. Includes graphical hypotheses. What is the relative importance of feedbacks (composition) and diversity / evolution.

Ceulemans, R., Wojcik, L.A. & Gaedke, U. (2021). Functional diversity alters the effects of a pulse perturbation on the dynamics of tritrophic food webs. *bioRxiv*, 2021.03.22.436420.

(Dakos et al. 2019)

Anoxic-oxic ecosystem shifts as a case study. Contemporary relevance. Intermediate complexity of system... diagram of system, including some panels of subsystems showing some of the positive feedbacks. Central role of inhibition / tolerance. Also showing responses to changes in oxygen diffusivity (justify from Bush et al this as a key environmental driver).

Empirical evidence of variation in organismal tolerance. Across species and evolution experiments. (Schoeffler et al. 2019)

Recent experimental evolution studies have demonstrated considerable increases in tolerance. For example, the sulphur bacteria *Desulfovibrio vulgaris* evolved a 32-fold increase in oxygen tolerance (Schoeffler et al. 2019). Furthermore, the evolved strains were capable of oxygen respiration that permits growth. Genome re-sequencing revealed that few mutations were involved. Additionally, the cyanobacterium *Microcystis aeruginosa* evolved a four-fold higher sulphide tolerance via rare spontaneous mutations (Martín-Clemente et al. 2019). In that study, populations with higher genetic variation and those experiencing slower environmental change (an increase in sulphide concentration) were more likely to persist at high sulphide concentration.

(Rolfe et al. 1978) - Factors related to the oxygen tolerance of anaerobic bacteria. (Ramel et al. 2015) - "they were able to grow but the final biomasses and the growth yield were lower than that obtained under anaerobic conditions," "Determination of the molar growth yields on lactate suggested that a part of the energy gained from lactate oxidation was derived toward cells protection/repairing against oxidative conditions rather than biosynthesis" (Hamilton et al. 2018) - "Cyanobacterial photosynthesis under sulfidic conditions: insights from the isolate *Leptolyngbya* sp. strain hensonii"

Physiological tolerances to environmental conditions, including interspecific variation in tolerance and evolution of tolerance, are a key component of the engineering of ecosystem for determining their stability (Minervini et al. 2014)(Gómez-Gras et al. 2019)(Cuenca Cambroneró et al. 2018)(Vos et al. 2017)(Evans & Wallenstein 2014)(Rolfe et al. 1978)(Knoll & Bauld 1989)(Girvan et al. 2005).

Questions: - How does variation organismal tolerances affect response

Approach: - Modelling the system with ODEs. - Diversity manipulation (can be considered selection among strains, or selection among species). - Do not include mutation.

2 Methods

2.1 The model

Bush et al (2017) contains an excellent description of the model of the ecosystem. Here we only describe the extensions needed for modelling multiple strains/taxa per functional group.

2.2 Measurement of non-linearity and hysteresis

Take from Garnier et al.

Rate-independent hysteresis, because we are considering only stable states, and not rate-dependent hysteresis, which can occur when a lag in the system response to an environmental response causes a difference between the observed system state at time t and the stable state for the environmental conditions present at time t .

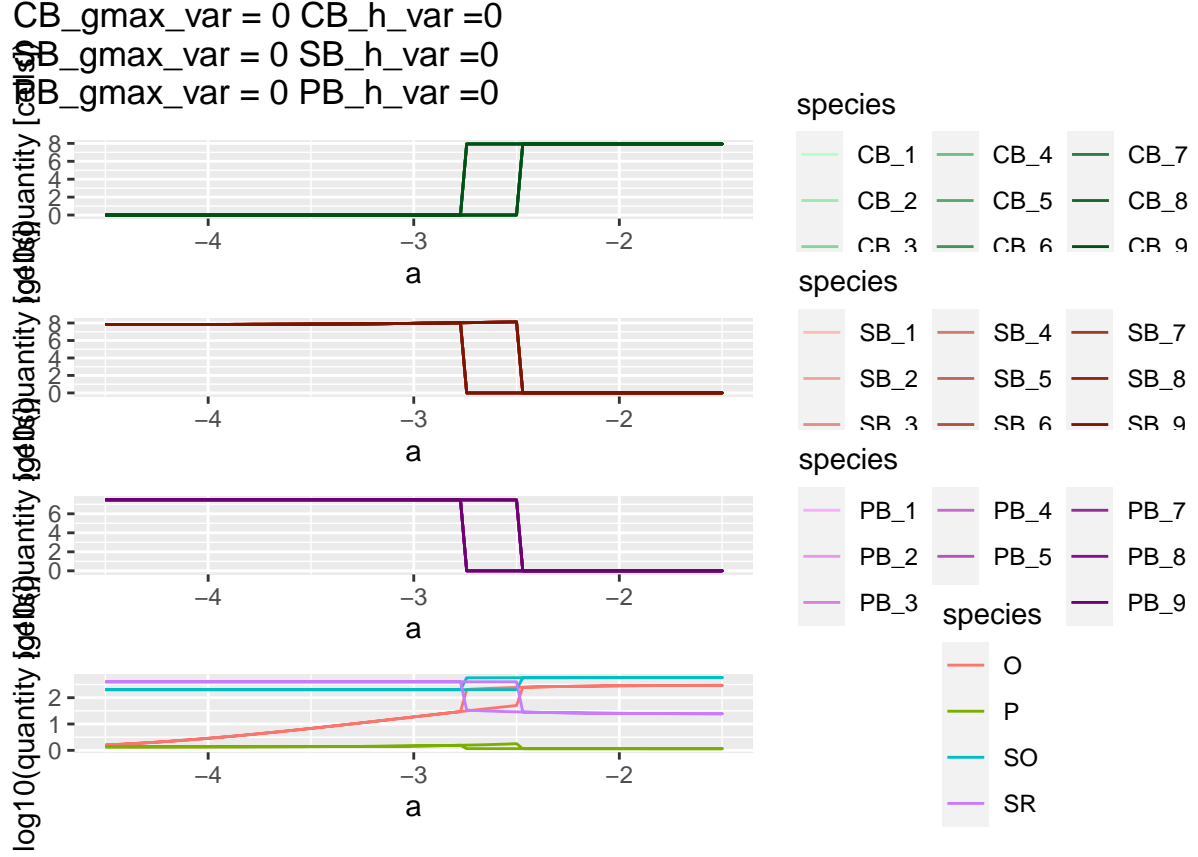


Figure 1: your caption

2.3 Implementation

R package.

3 Results

3.1 Figure: Stable states with and without variation.

,

3.2 Figure: hysteresis, shift point, nonlinearity, as var increases.

```
ss_sim_data <- readRDS(here("simulations/sim_data/ss_res_3.RDS"))

ss_sim_data <- ss_sim_data %>%
  group_by(CB_var_gmax_s, CB_var_h_s,
           SB_var_gmax_s, SB_var_h_s,
           PB_var_gmax_s, PB_var_h_s) %>%
  do(stability_measures = get_stability_measures(.$ss_res[[1]]))
results <- unnest(ss_sim_data, cols = c(stability_measures))

results %>%
  filter(Species == "O") %>%
  ggplot(aes(x = CB_var_gmax_s, y = hyst_range)) +
  geom_point()
```

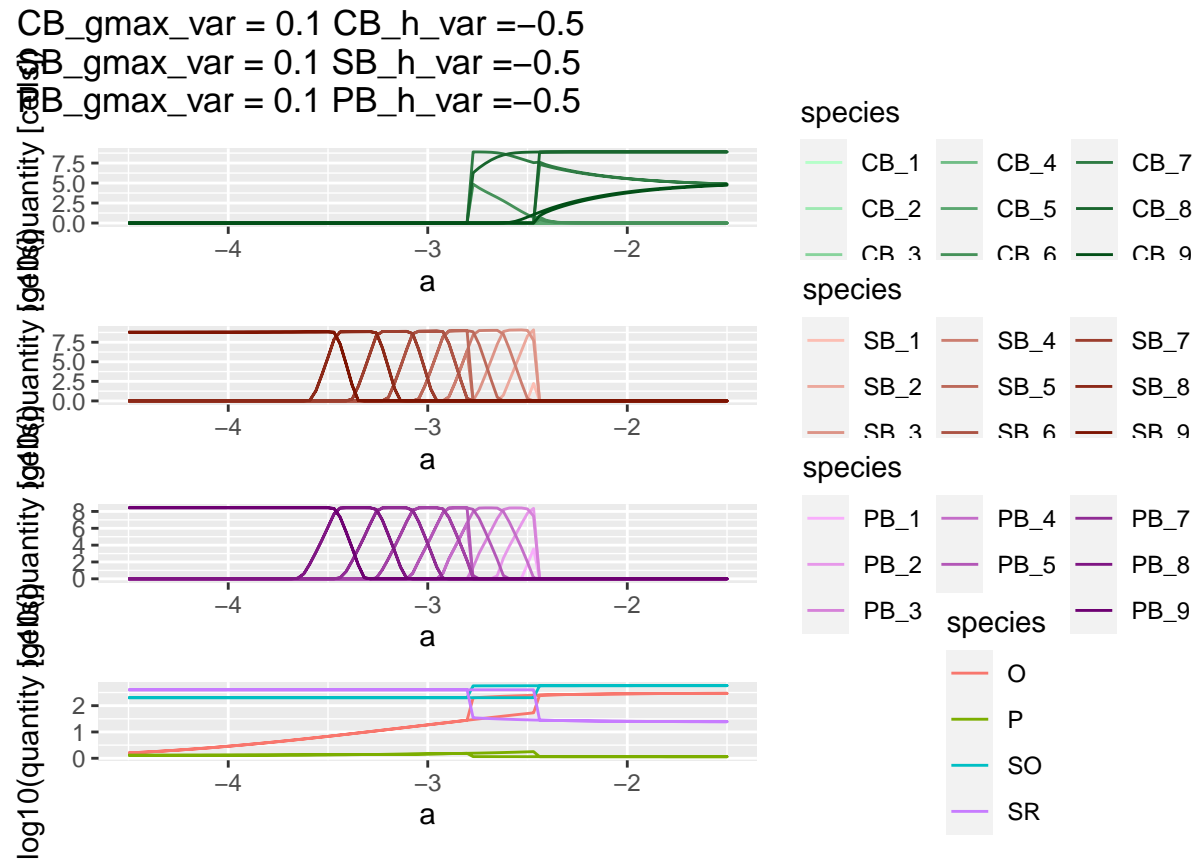
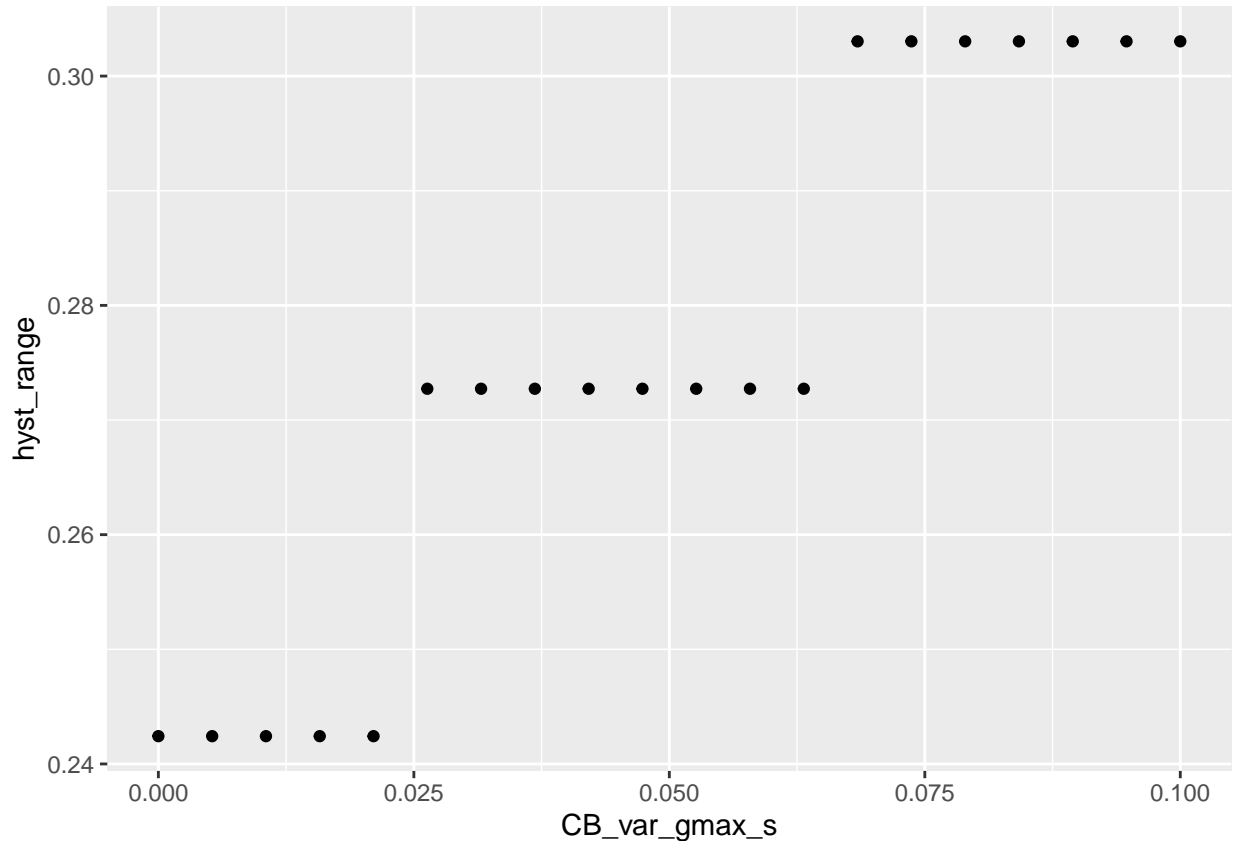


Figure 2: your caption



3.3 Figure: Temporal switches

To be added. Need to go both ways (oxic to anoxic, and anoxic to oxic).

4 Discussion

<https://onlinelibrary.wiley.com/doi/10.1111/gcb.15662?af=R>

5 Acknowledgements

SNF URPP

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