Population ecology: Theory, methods, lenses

Dr. Bill Fagan

Population Ecology & Spatial Ecology

A) Core principles of population growth

B) Spatial problems and methods for modeling them

C) Integrodifference equations as a robust platform

Population Ecology & Spatial Ecology

A) Core principles of population growth

B) Spatial problems and methods for modeling them

C) Integrodifference equations as a robust platform

Socio – Environmental Issues:

1. Fisheries
2. Invasive Species
3. Biological Control
4. Ecological Footprints
5. Critical Patch Size / Reserve Design

A) Core principles of population growth

Berryman: On principles, laws, and theory in population ecology. Oikos. 2003

1) Exponential population growth as a null baseline. What causes deviations from that ?

The Basics of Discrete Time Models

Have Form $$N_{t+1} = f\left[N_t, N_{t-1}, N_{t-2}, \ldots\right]$$

where N is the thing you are measuring

and t is an index representing blocks of time.

Constant time step = 1 unit (year, month, day, second)

→ Time is discrete, #'s need not be

In many cases

$$N_{t+1} = f\left[N_t\right]$$ Reduced Form

Status next time step depends <u>only</u> on where system is now.

$\Rightarrow$ history is unimportant

Alternatively: $N_{t+1} = f[N_t, N_{t-1}, N_{t-2}...]$ history is important

$\Rightarrow$ wide applicability

1) Many ecological phenomenon change discretely

- insects don't hatch out all day long, only in morning
- rodents are less mobile near full moon
- seeds germinate in spring

2) Data were collected at discrete times ⟨ daily censuses, yearly censuses

The Simplest Discrete Time Model

$$N_{t+1} = \lambda N_t$$ "Geometric" Growth Equation

N Thing we are counting (e.g., Panda Bears)

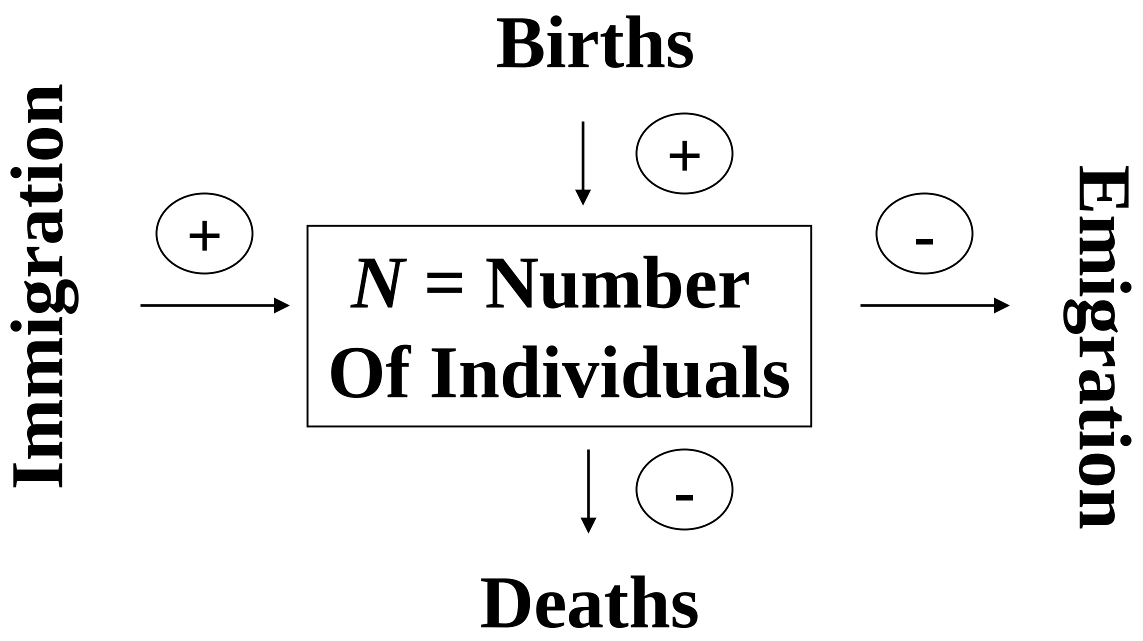
t Time index

Δt "Time Step" or "Time Interval"

λ "Population Multiplier"
"Geometric per capita rate of growth"
"Discrete per capita rate of growth"
"Lambda"

Equation provides basis for structured population models

Population Change:



Perspectives:

- **Populations closed vs open to movement**
- **Populations with recruitment & mortality**
- **Structured vs Unstructured populations**

With simple <u>linear</u> models like:

$$N_{t+1} = \lambda \, N_t$$

Populations will not just

stay constant	**but still stay constant forever**
grow	**but will grow toward infinity**
shrink	**but will shrink toward zero**

⇒ Only 3 options

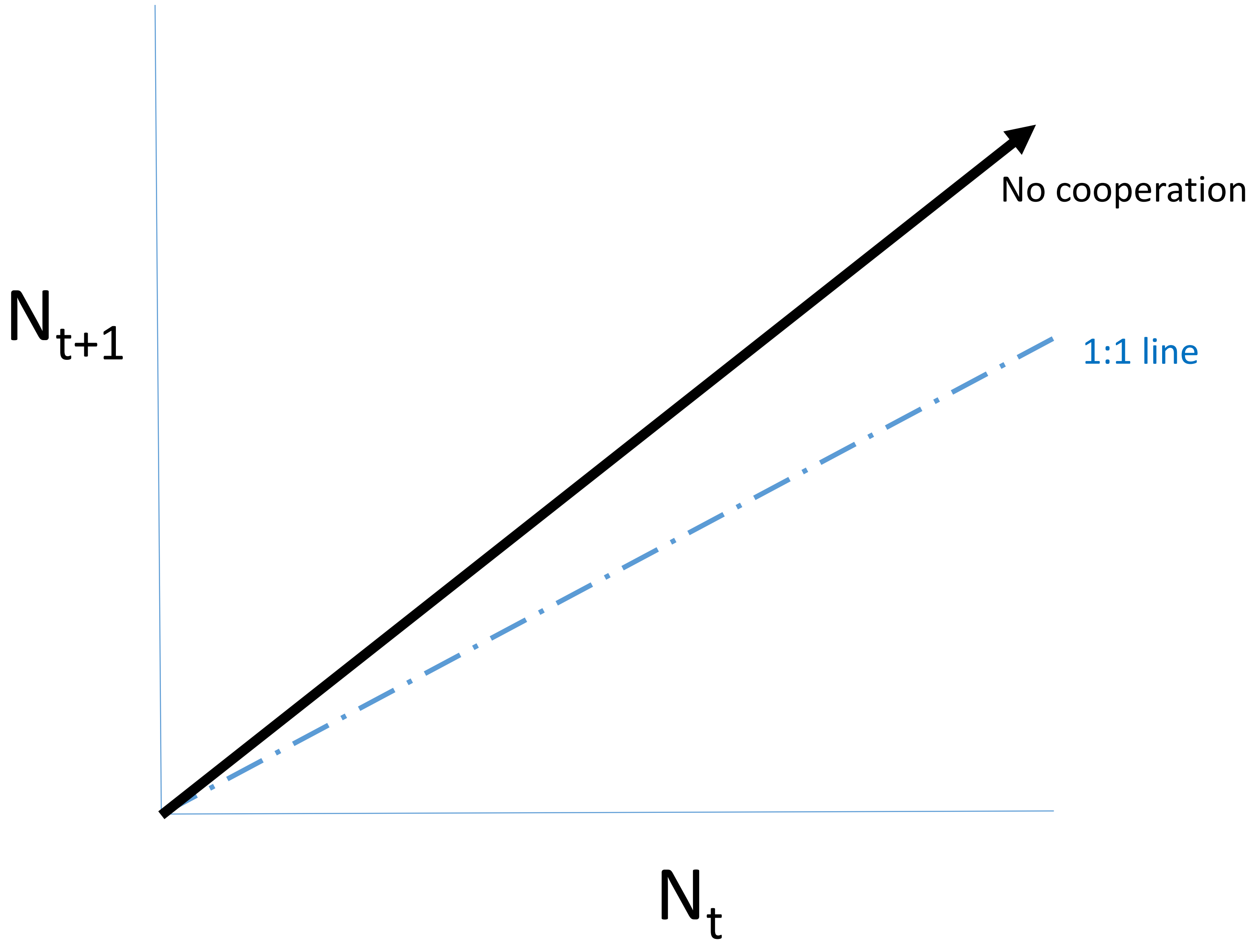
⇒ Usable as short term approximations only

⇒ Other factors will eventually kick in
(e.g., density dependence)

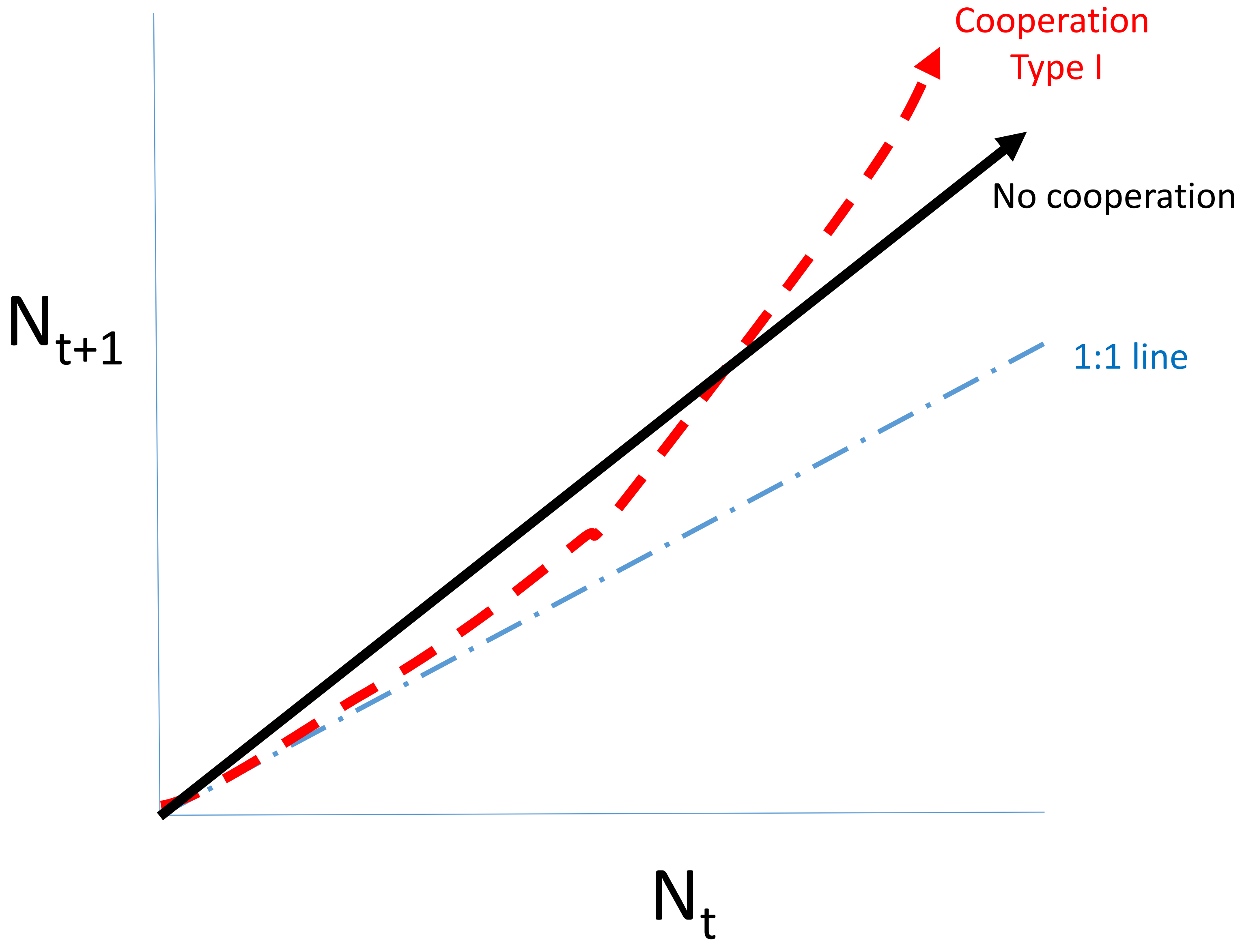
Berryman: On principles, laws, and theory in population ecology. Oikos. 2003

1) Exponential population growth as a null baseline. What causes deviations from that ?

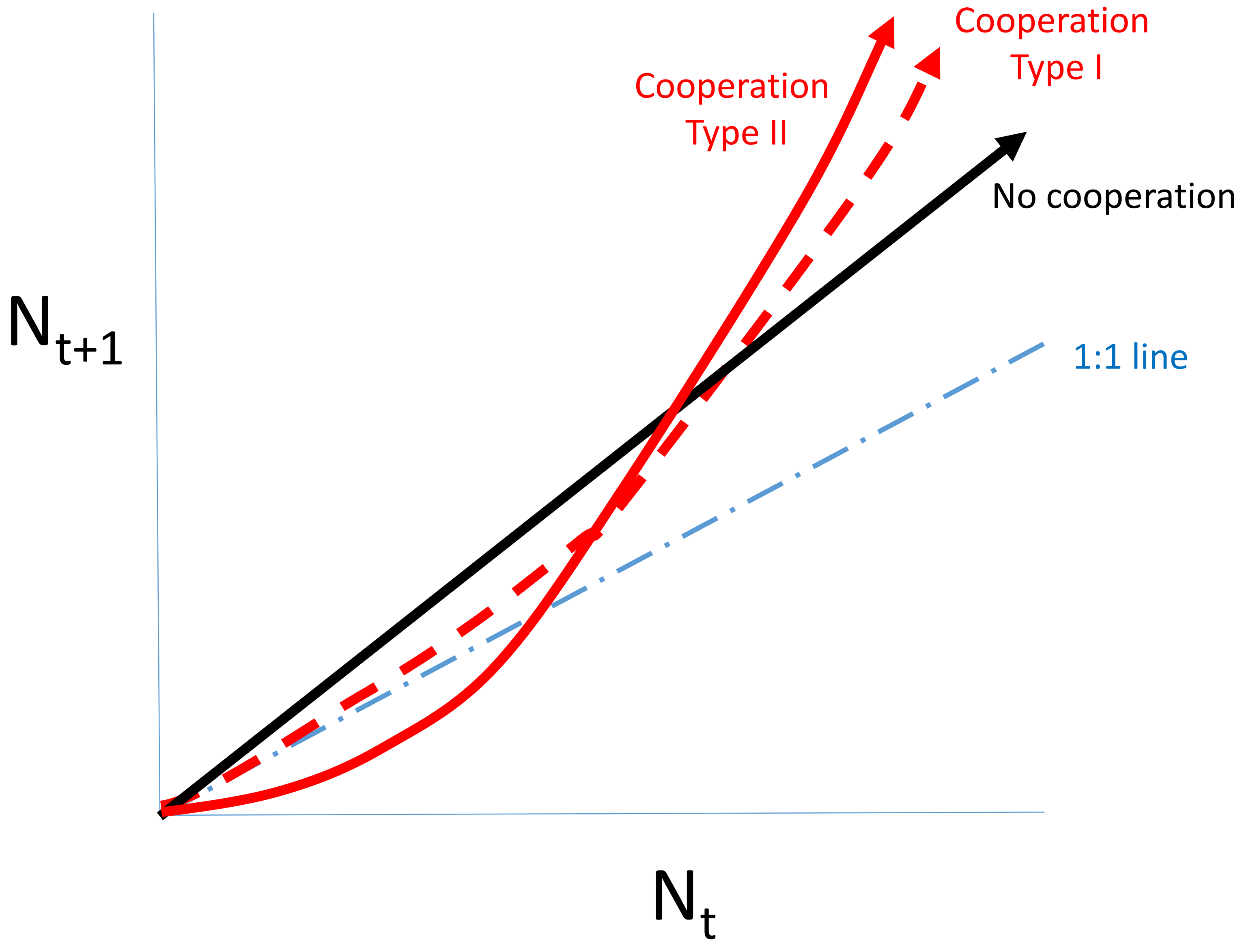
2) Cooperation among individuals: Allee effects and thresholds



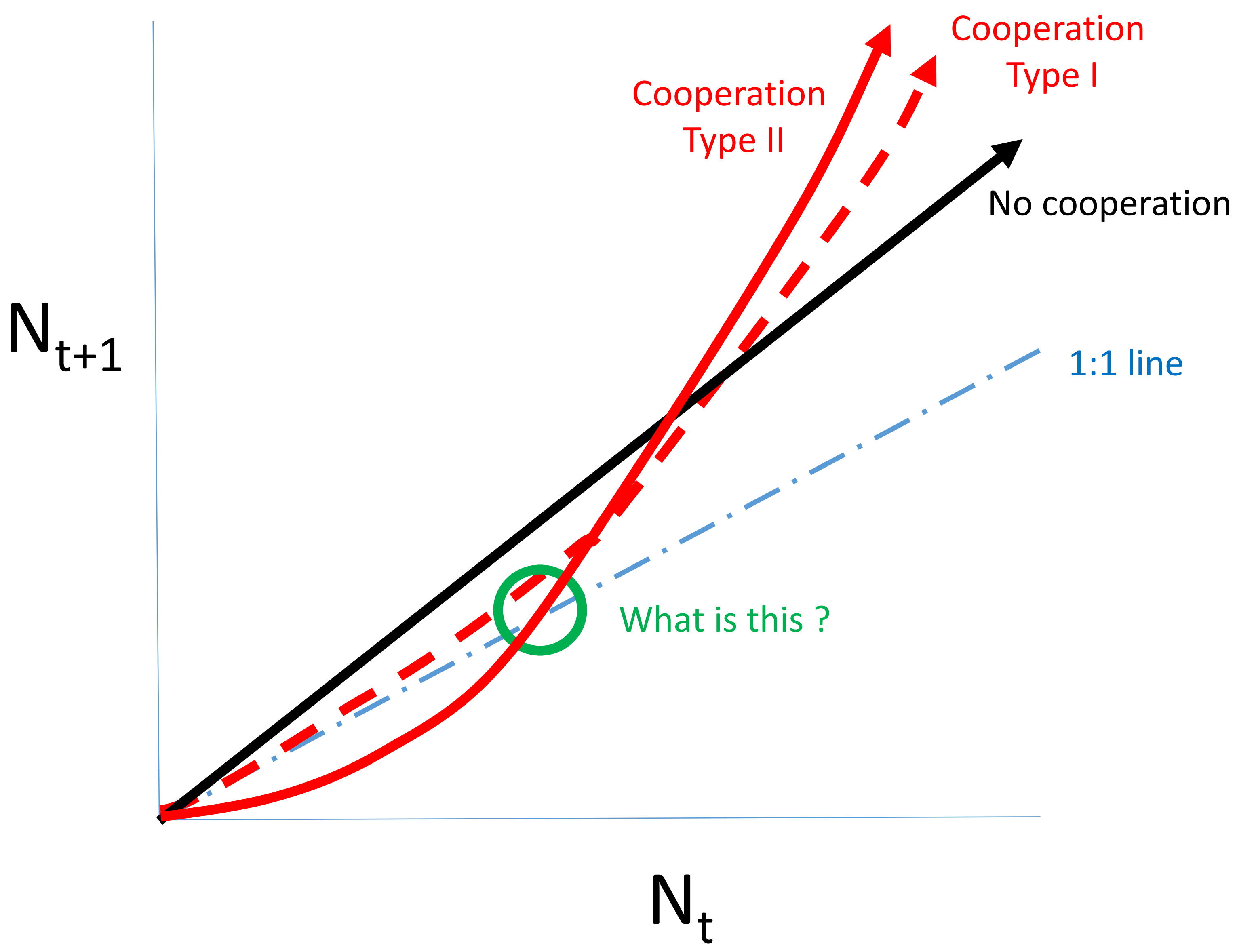
Anazawa. Theoretical Population Biology. 2009



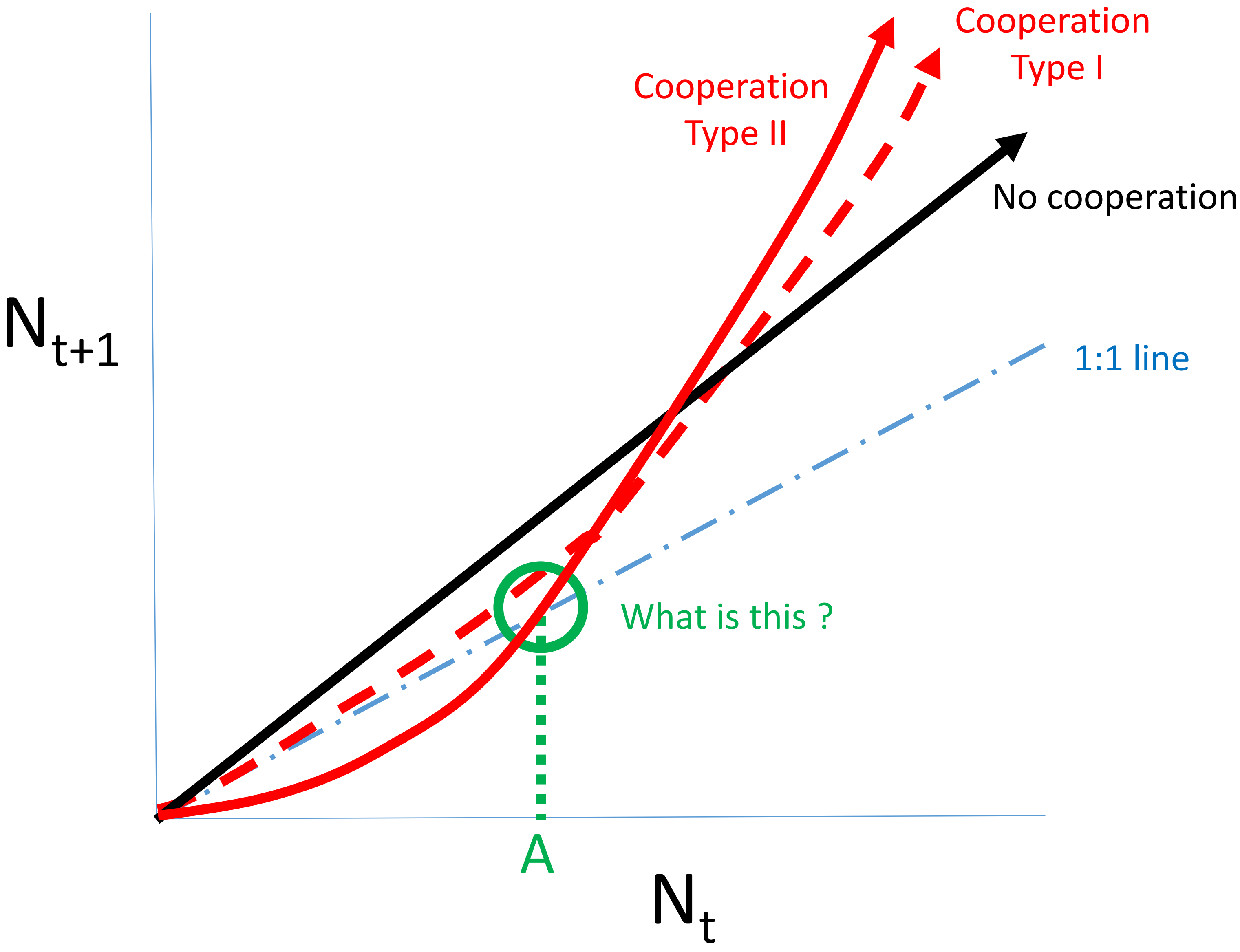
Anazawa. Theoretical Population Biology. 2009



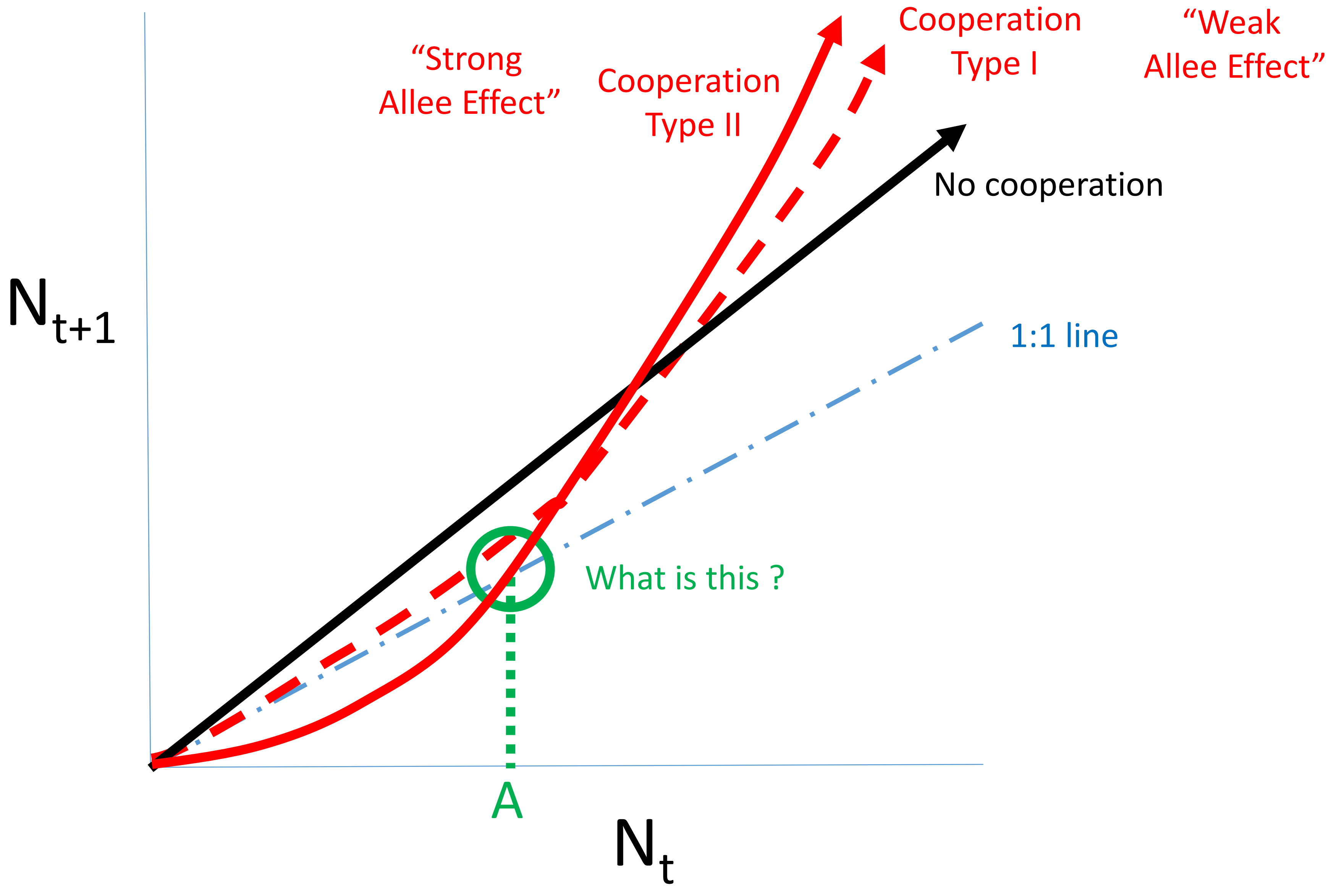
Anazawa. Theoretical Population Biology. 2009



Anazawa. Theoretical Population Biology. 2009



Anazawa. Theoretical Population Biology. 2009



Anazawa. Theoretical Population Biology. 2009

Allee effects

- → **conceptualized as a critical threshold where dynamics change**
- → **“positive density dependence”**
- → **Interactions among individuals of a species are advantageous to further growth of the population**
- → **Applicable to organisms, cells, molecules, even groups of people & cultures**

Allee effects

Ecological mechanisms:

Mutual shading by plants

Mutual defense by groups of animals

Molecules that facilitate the production

of more of their own kind

→ proteins that impact RNA synthesis

Commonality is "autocatalysis"

Berryman: On principles, laws, and theory in population ecology. Oikos. 2003

1) Exponential population growth as a null baseline. What causes deviations from that ?

2) Cooperation among individuals: Allee effects and thresholds

3) Competition among individuals: Too much of a good thing

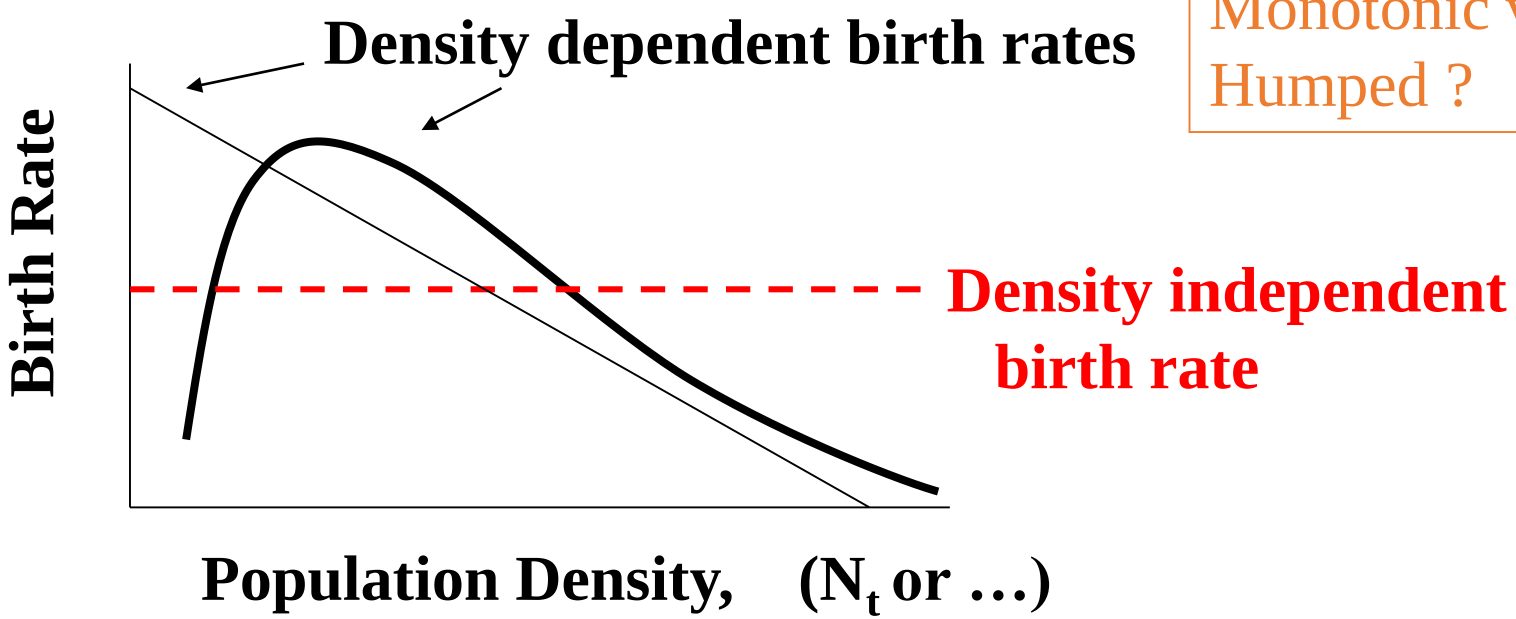
Competition for “Resources” Triggers “Changes” in a Population

Competition for “Resources” Triggers “Changes” in a Population

Resources	Changes
Plants / Animals / Fungi / Microbes	
Within Human Populations	
Between Human Societies	

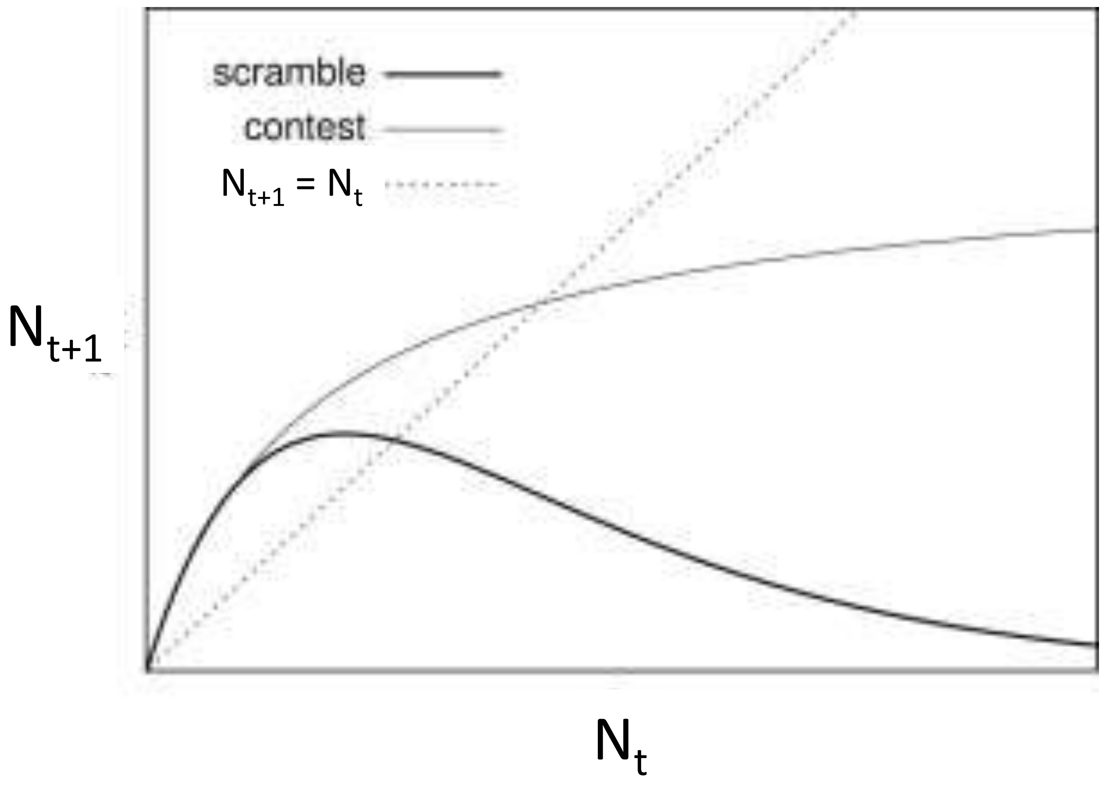
Forms of density dependence:

Some component(s) of population increases or decreases (or ‘changes’) as a function of density



Monotonic vs. Humped ?

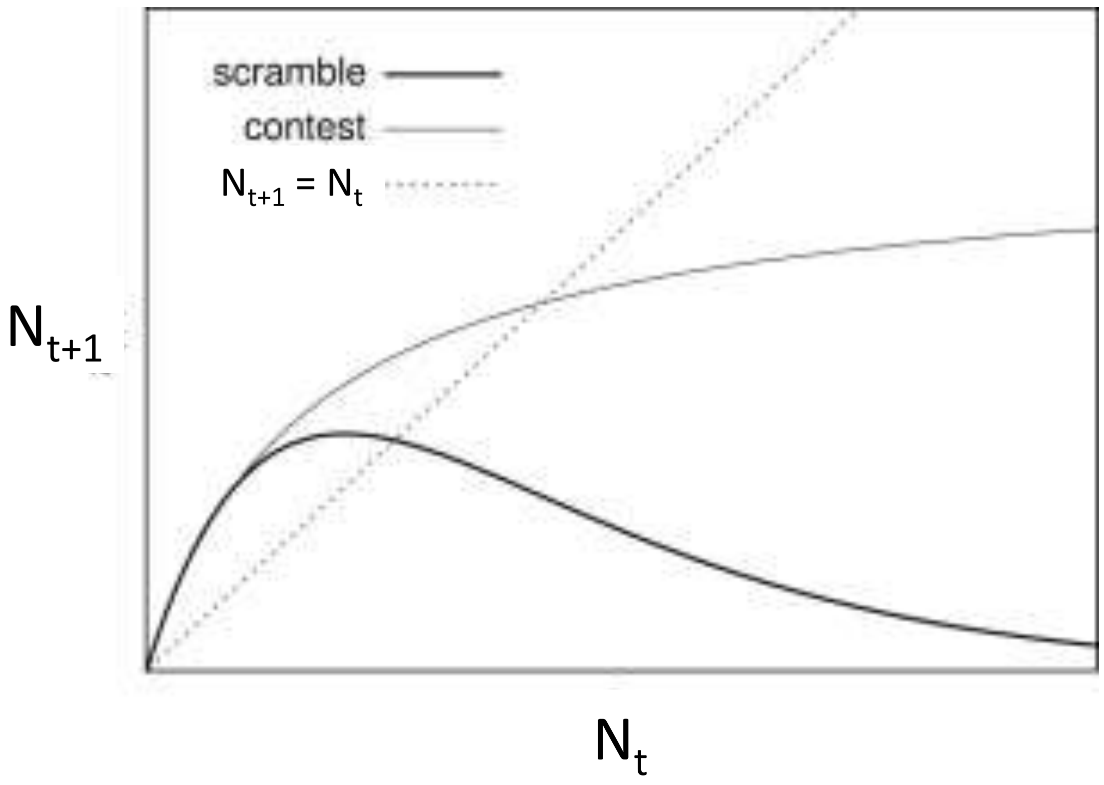
Or death rates, or movement rates …

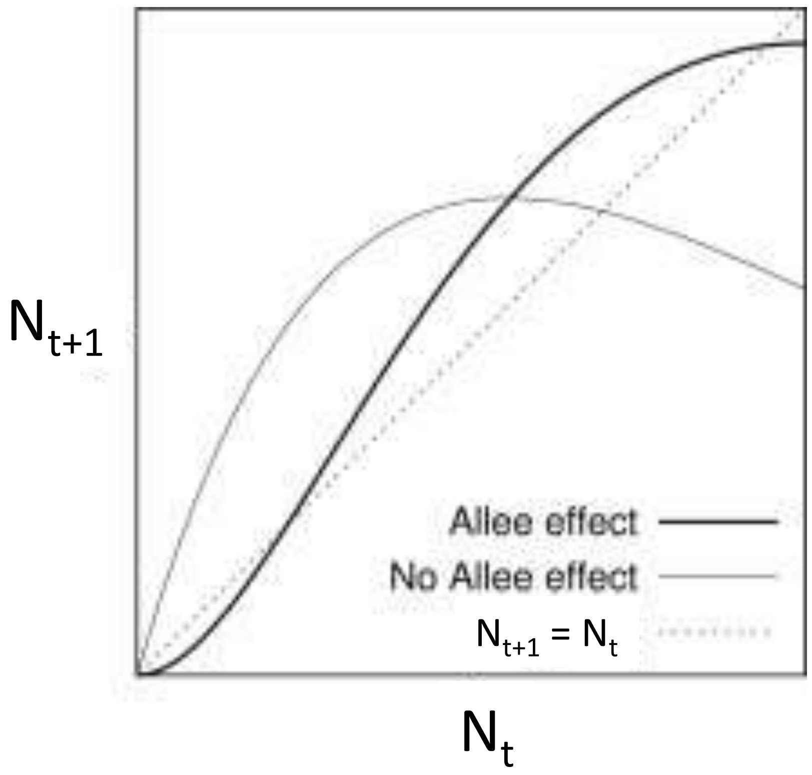


Contest: Individual winners & losers

Scramble: Everybody suffers to some extent

Anazawa. Theoretical Population Biology. 2009





Anazawa. Theoretical Population Biology. 2009

Density Dependence – Mathematical View

Easiest to see in terms of transitions (population ratios):

$$\frac{N_{t+1}}{N_t} = \lambda = e^r$$

Density Independent

No N Appears on right hand side so no dependence on density

$$\frac{N_{t+1}}{N_t} = f(N_t)$$

Density Dependent

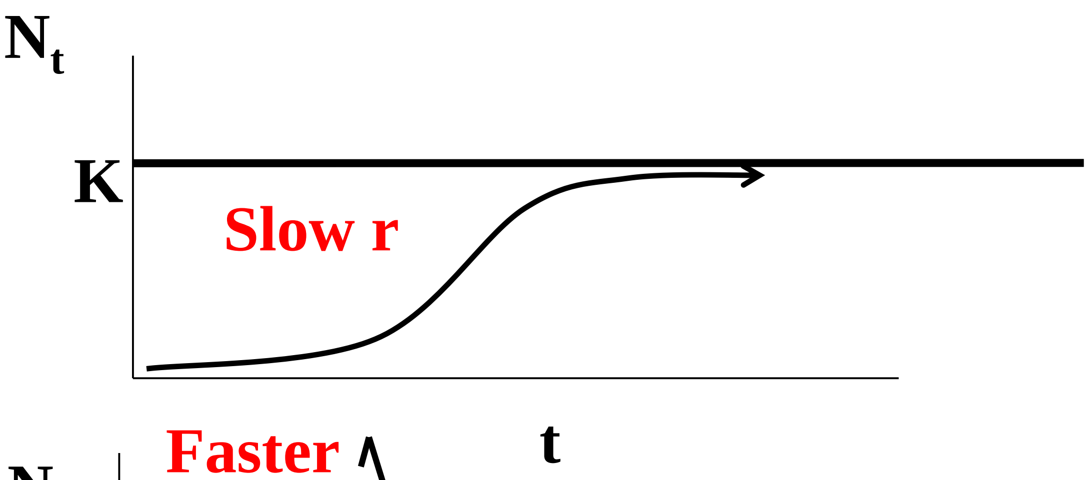
Example: "Ricker model"

$$\frac{N_{t+1}}{N_t} = e^{r\left(1 - N_t/K\right)}$$

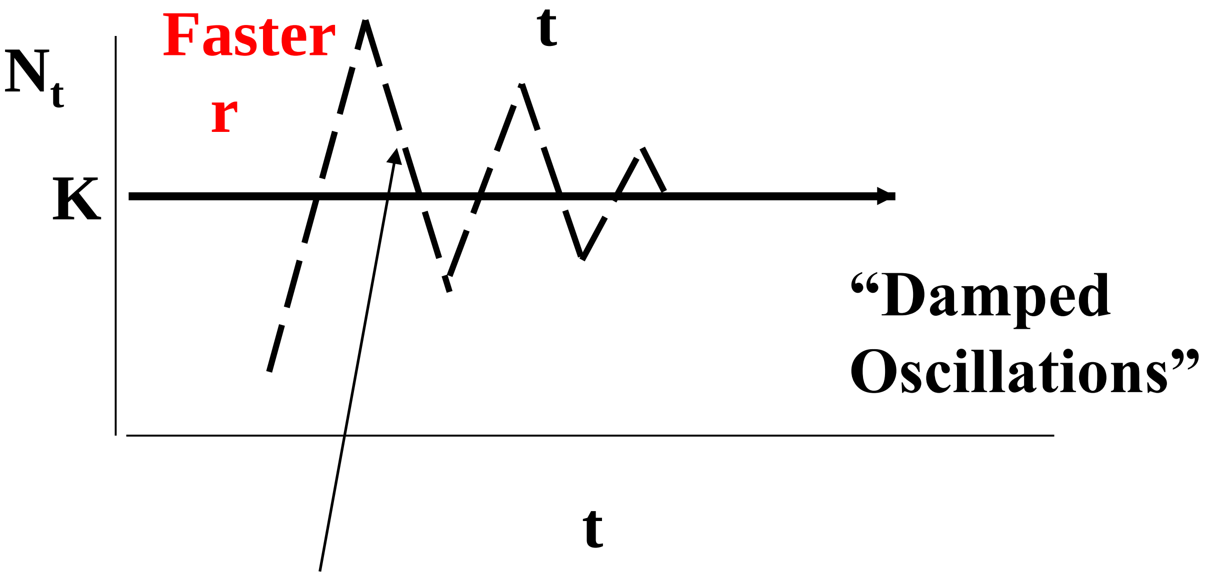
"Carrying Capacity" = Upper bound on positive population growth

How does density dependence work in the Ricker model ? (cont'd)

$$\frac{N_{t+1}}{N_t} = e^{r\left(1-{N_t}/{K}\right)}$$



Behavior of Ricker equation as a function of r



"Overcompensation" → N_t above K is forced down not to K but <u>below</u> K

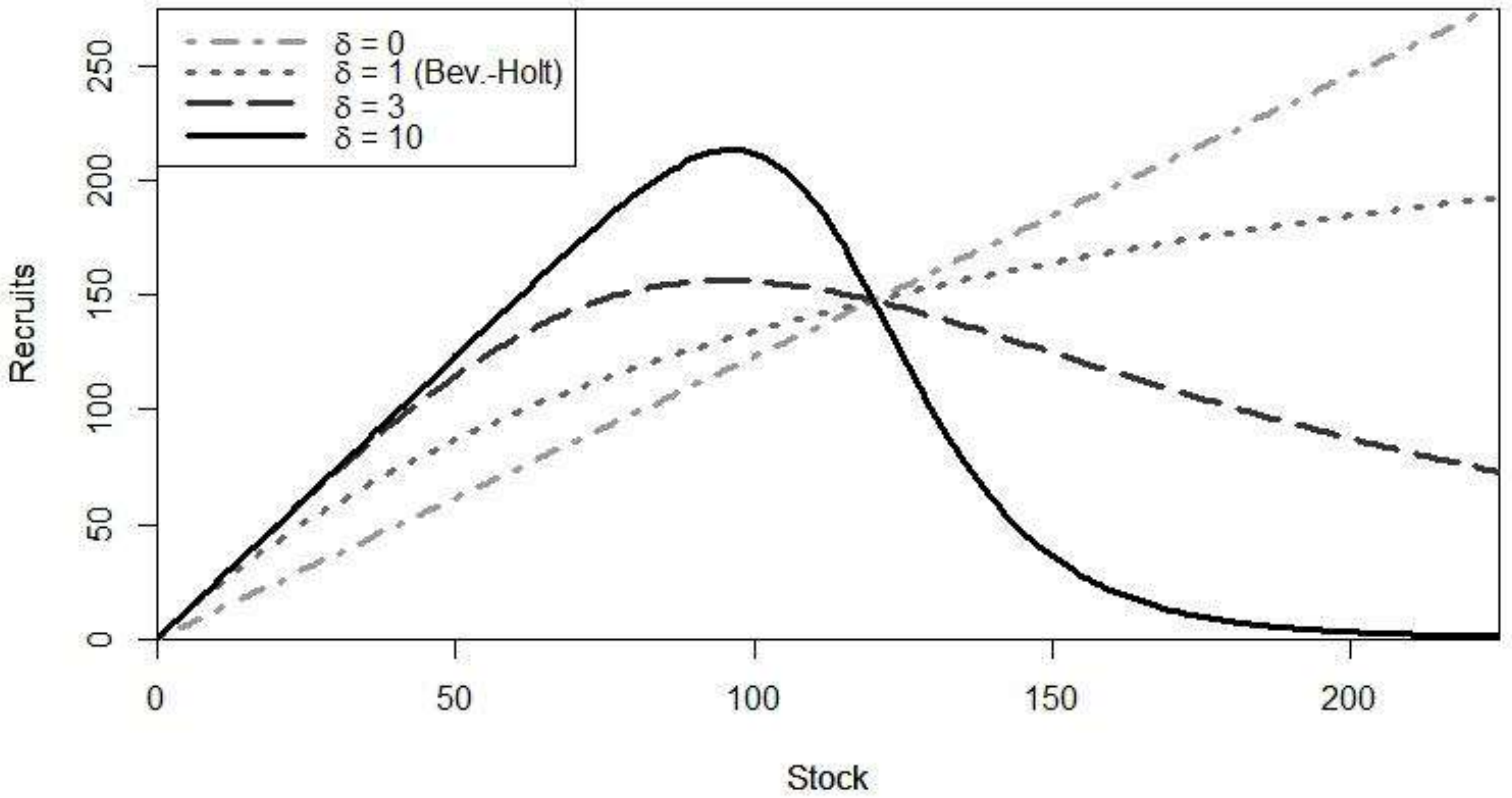
Mechanisms ??

Strength of Density Dependence Can Itself be a Tunable Parameter

Shepherd Model

δ quantifies density - dependence

$$R_{t+1} = \alpha S_t / (1 + (\beta S_t)^{\delta})$$



But it is NOTORIOUSLY difficult to estimate the strength of density dependence …

WHY ?

But it is NOTORIOUSLY difficult to estimate the strength of density dependence …

Problems:

1) Need for long term datasets
2) Must observe behavior under high (and low) density conditions
3) Complicated by environmental stochasticity (year to year variability)
4) Ignores ecosystem context

One partial solution: Fit models hierarchically

Model for a 'Set' of Species

↑

Models for Individual Species

↑

Multiple Populations

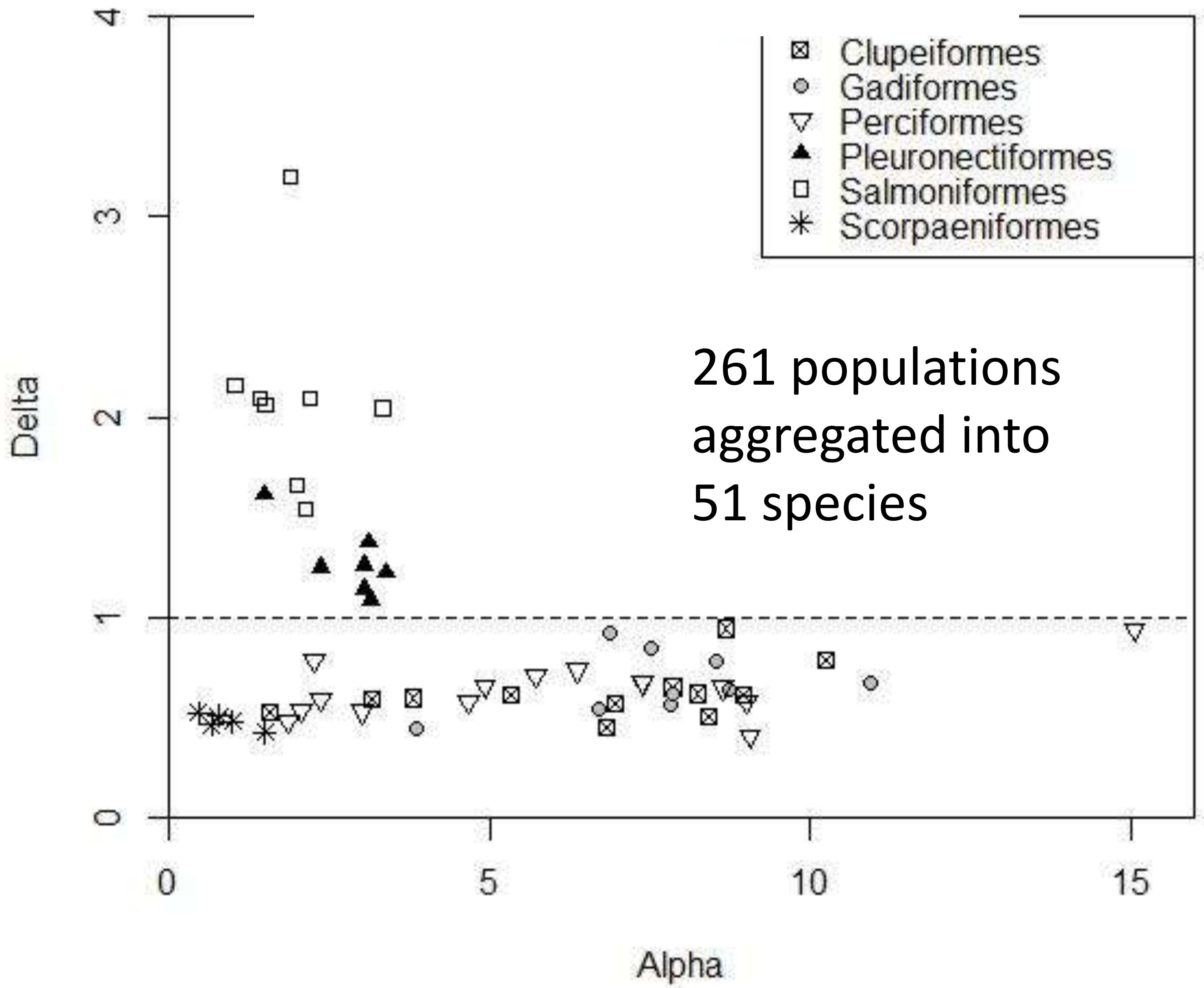
(Each with little data)

Aggregating Datasets
Yields Increasingly Strong
Inference
But at Cost of
'Coarseness'

Foss-Grant et al. Ecology.
In revision

$$R_{t+1} = \alpha S_t / (1 + (\beta S_t)^{\delta})$$

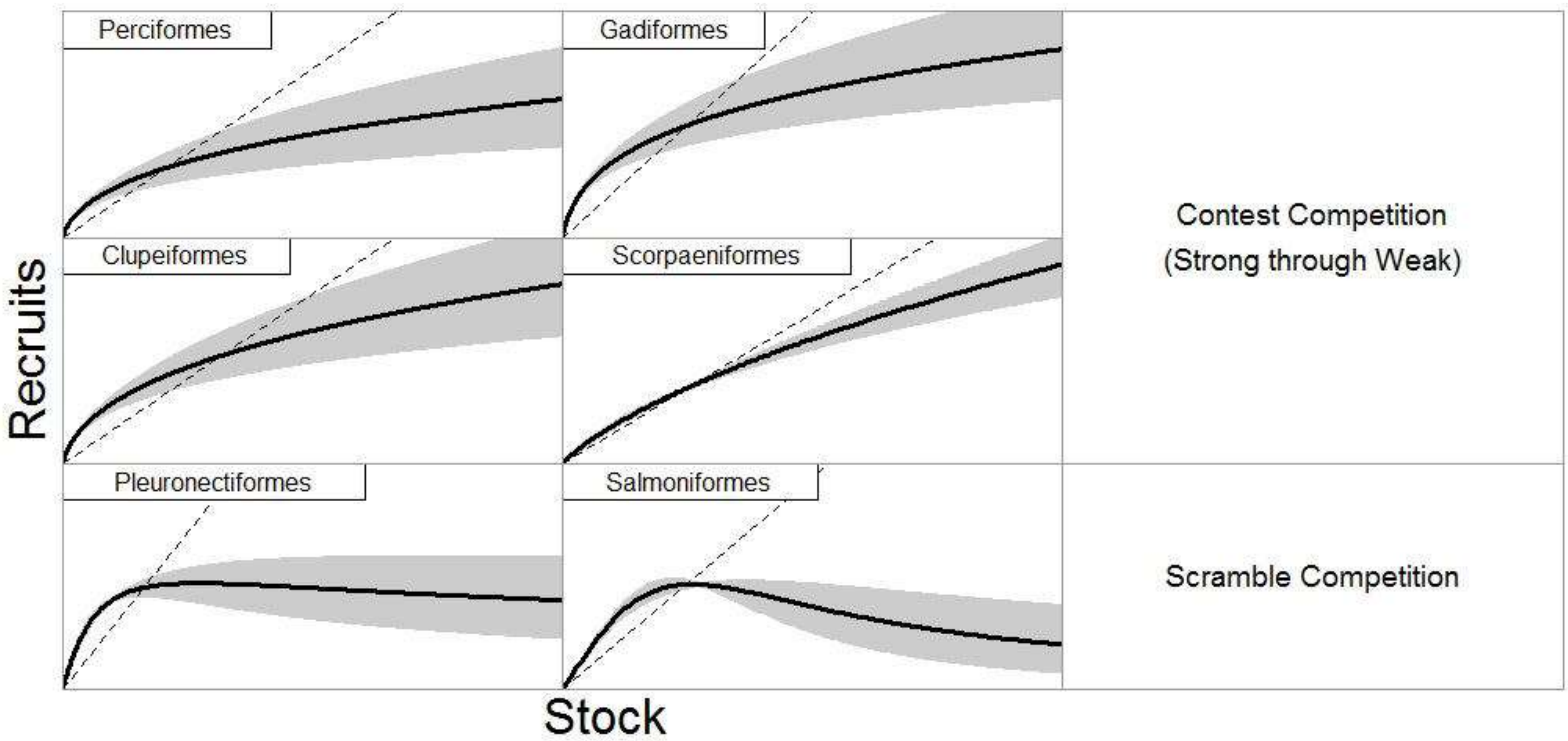
Strength of Density Dependence



261 populations aggregated into 51 species

Growth Rate at Low Population Densities

Foss-Grant et al. Ecology. In revision



Foss-Grant et al. Ecology.
In revision

Berryman: On principles, laws, and theory in population ecology. Oikos. 2003

1) Exponential population growth as a null baseline. What causes deviations from that ?

2) Cooperation among individuals: Allee effects and thresholds

3) Competition among individuals: Too much of a good thing

4) Interactions with other species

5) Limiting factors change in time and space