TOWARDS BRIDGING THEORY AND PRACTICE TO CONSIDER BIODIVERSITY AND RESILIENCE FOR ECOSYSTEM SERVICES

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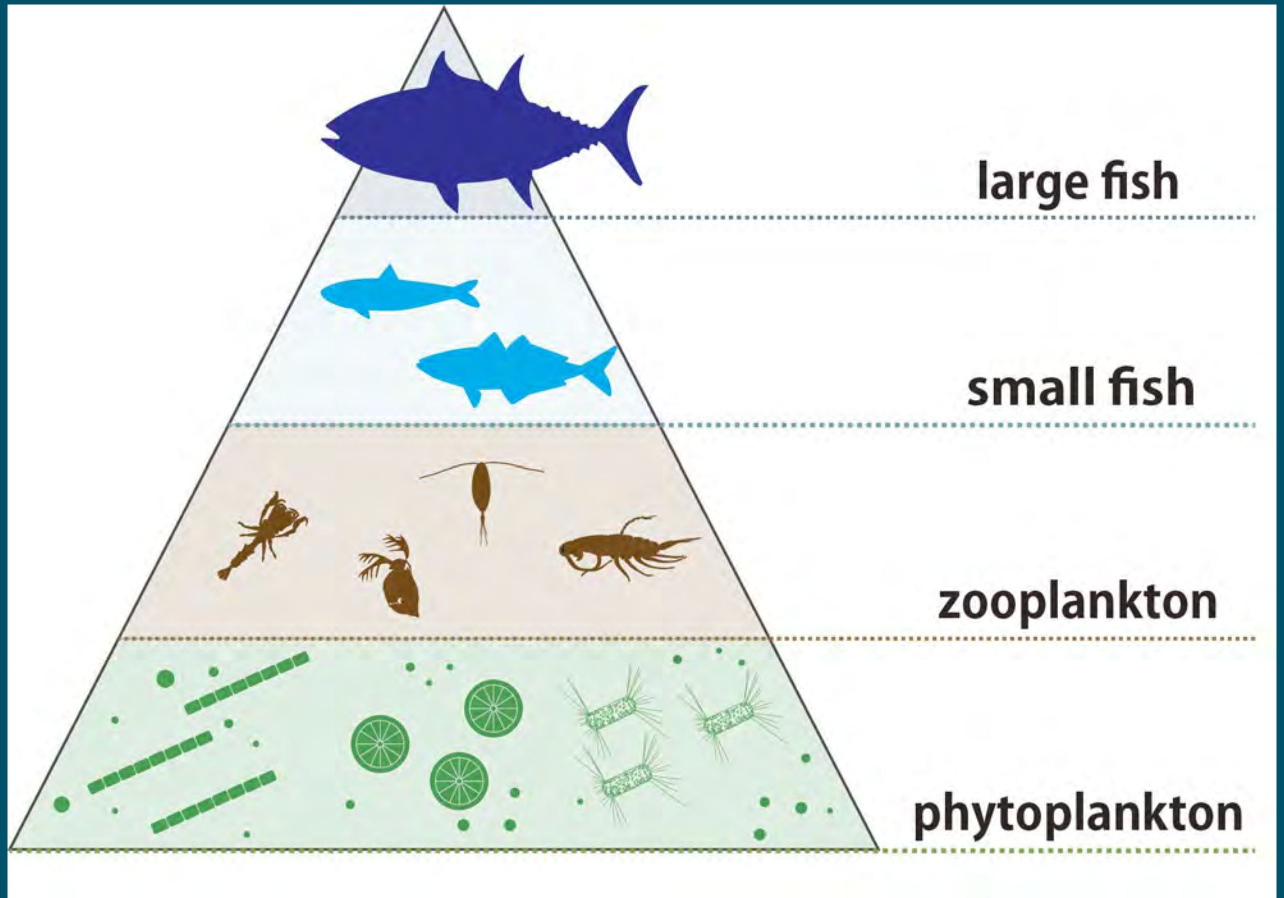
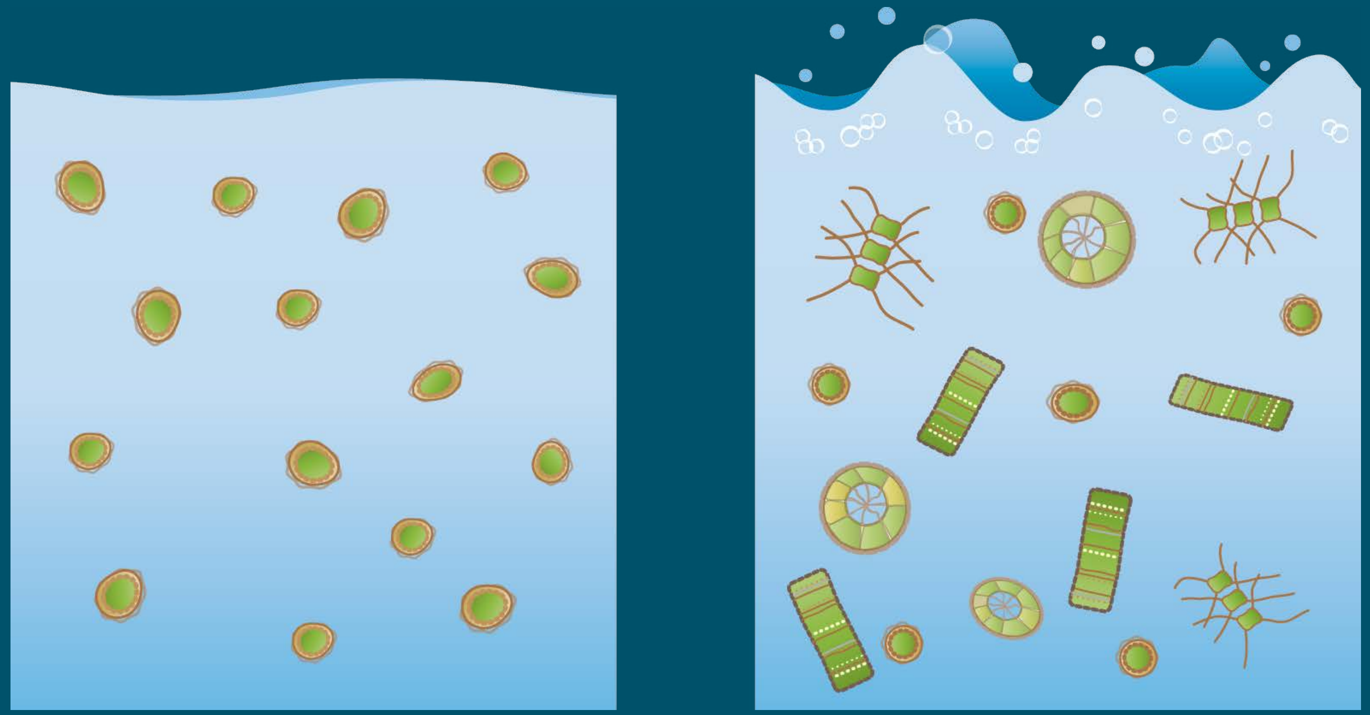
How do Ecosystem Services depend on Biodiversity?

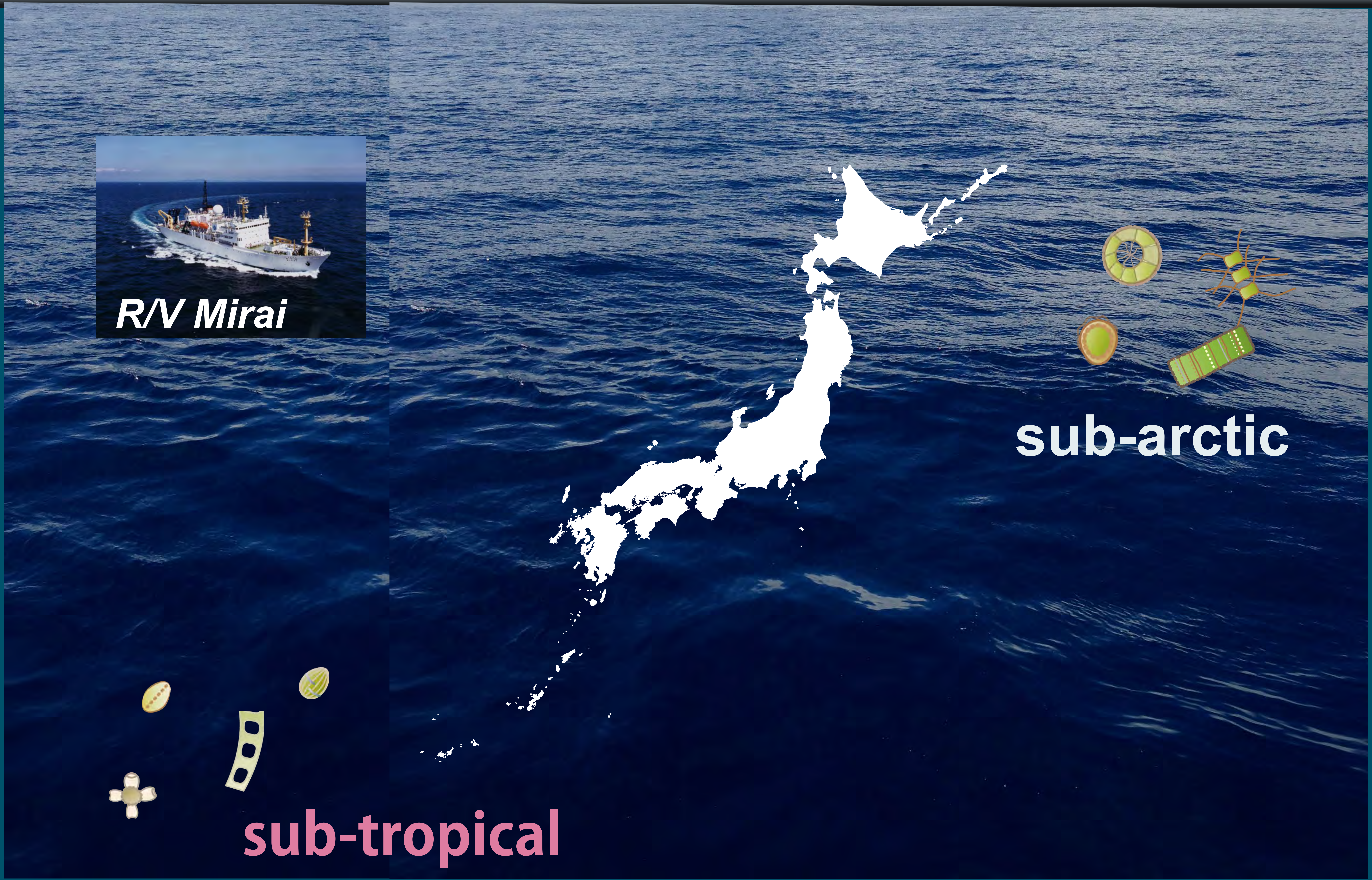


Recent Theoretical Results for Phytoplankton show that the answer depends on the Frequency of Environmental Disturbance.



Smith et al. *Scientific Reports*, 2016

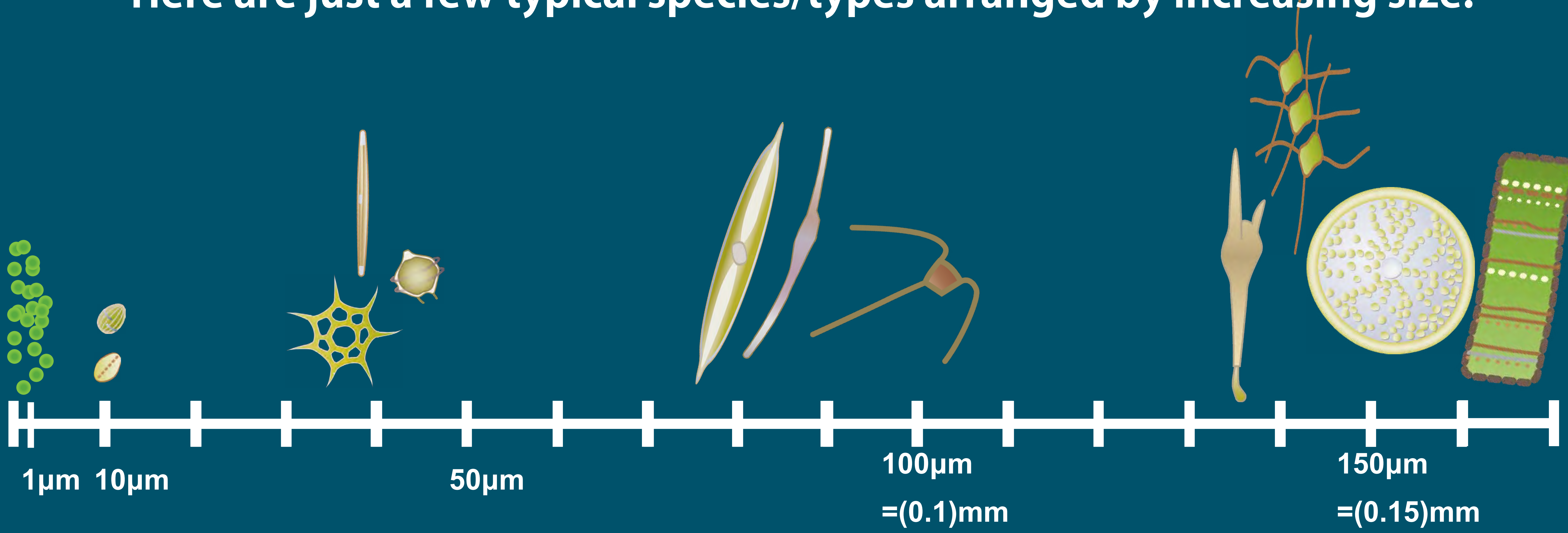
Obsserved Patterns of Plankton Biodiversity



Biodiversity: Size and other Traits of Phytoplankton

Species of different size typically are adapted (have evolved) for different environmental conditions.

Here are just a few typical species/types arranged by increasing size.



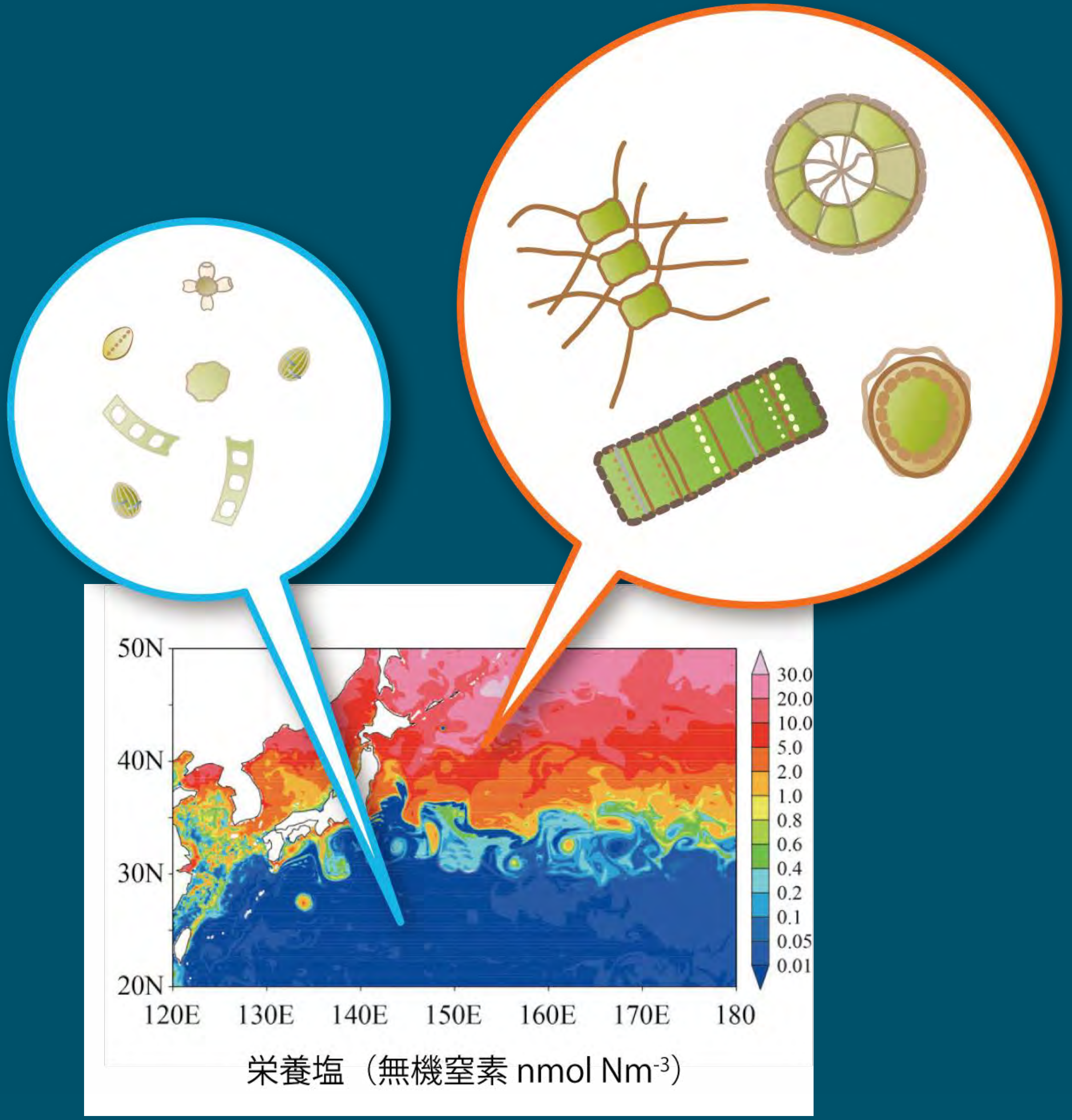
Size-based models of plankton Biodiversity use size as a Master Trait.

Size and many other traits differ.

sub-arctic:

rougher waters, higher nutrients

Larger Plankton



sub-tropical:

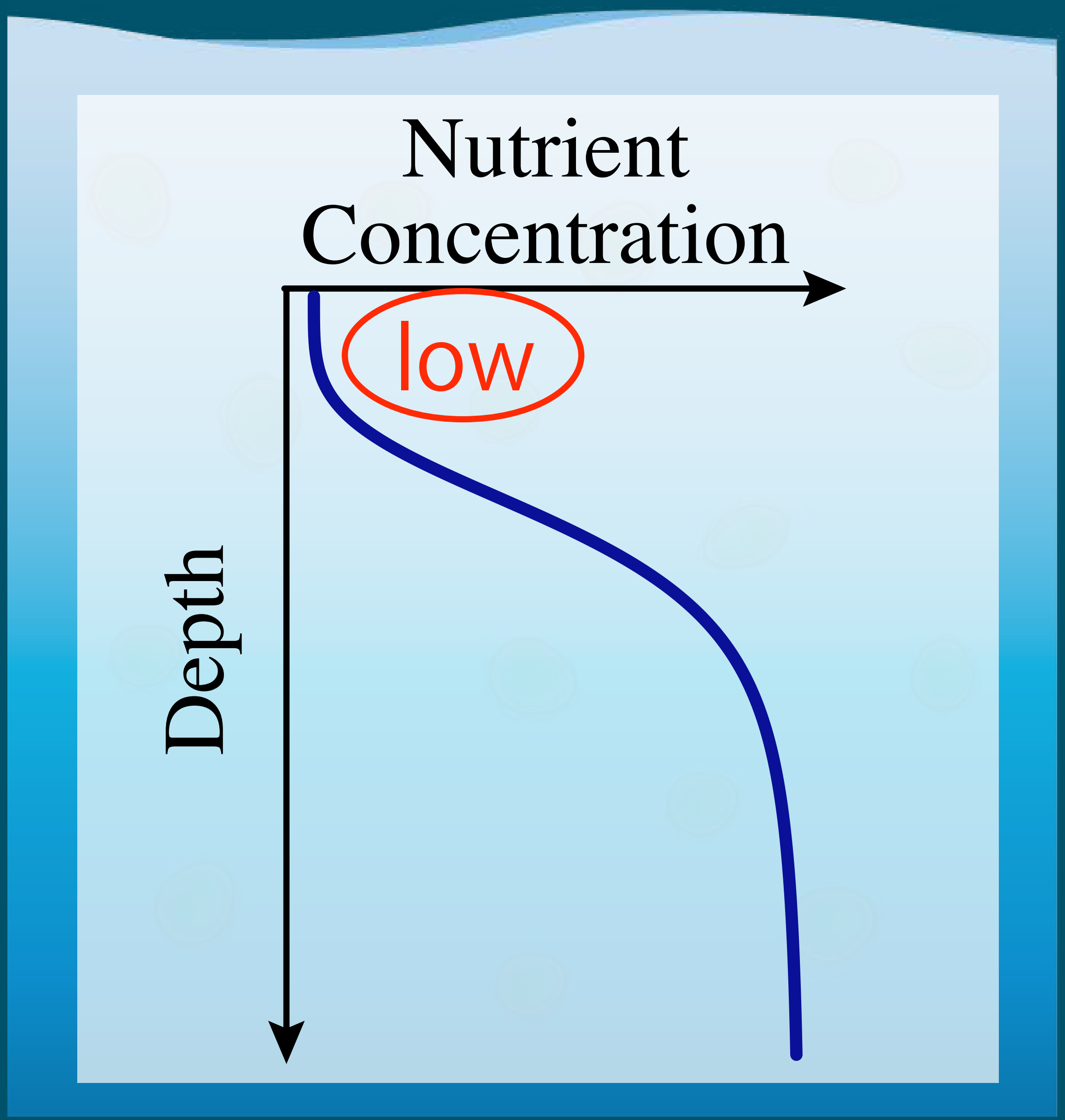
calmer waters, lower nutrients

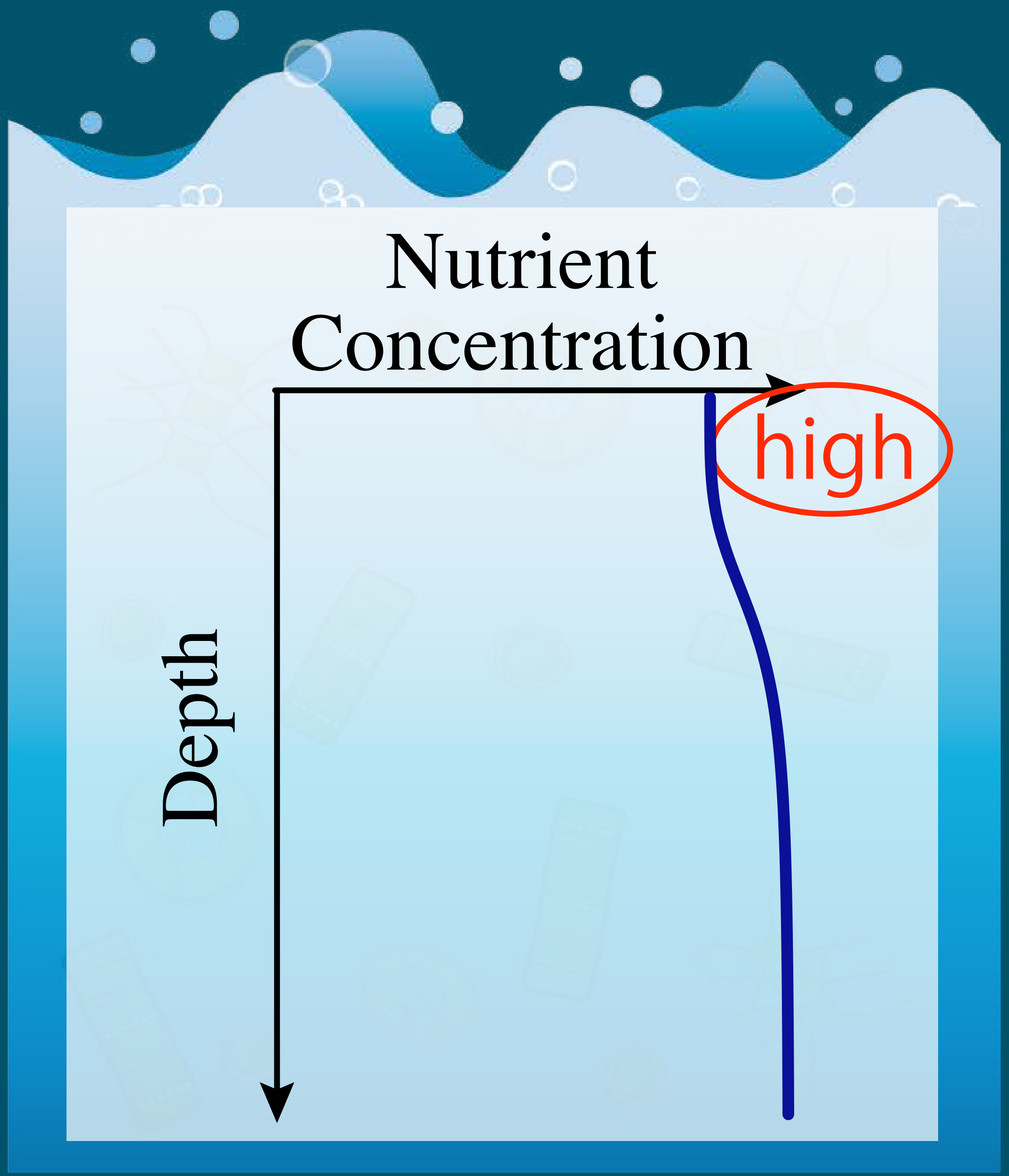
Smaller Plankton

Mixing and Nutrient Supply in the Ocean

In calm regions, nutrients become depleted near-surface.

Disturbances mix the water and supply nutrients from below.



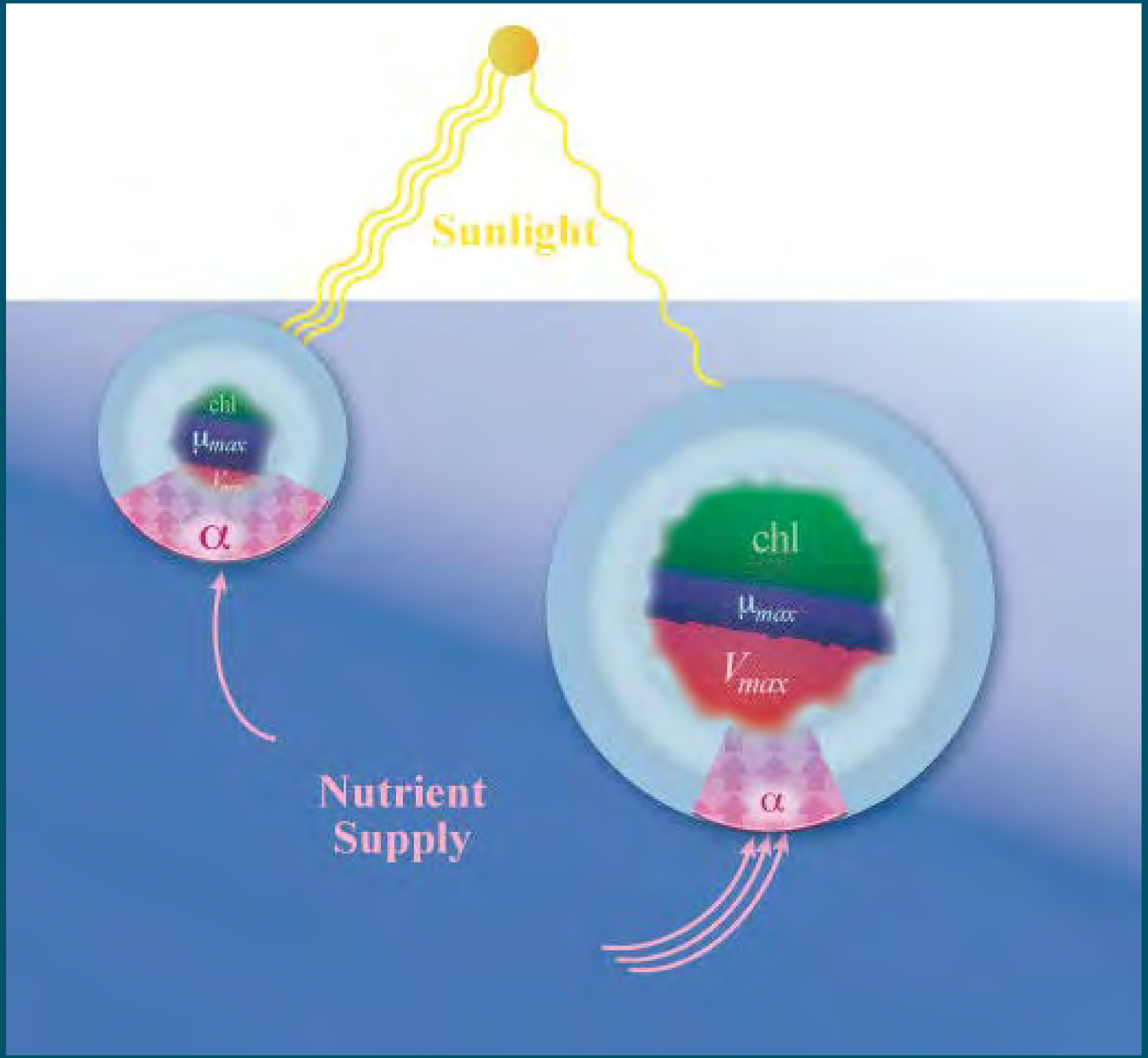


Overall Approach to Modelling Adaptive Response

‘Leaving mis-leading legacies behind in plankton ecosystem modelling’
Smith, Merico, Wirtz and Pahlow (*J. Plankton Res.* 2014)

Combine Traits and Trade-offs

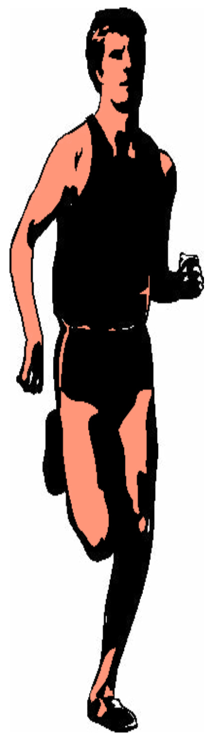
Typical small cell adapted to high-light, low-nutrients



Typical large cell adapted to low-light, high-nutrients

A Physiological Trade-off for humans

Mass & Strength



marathon runner

Sumo wrestler

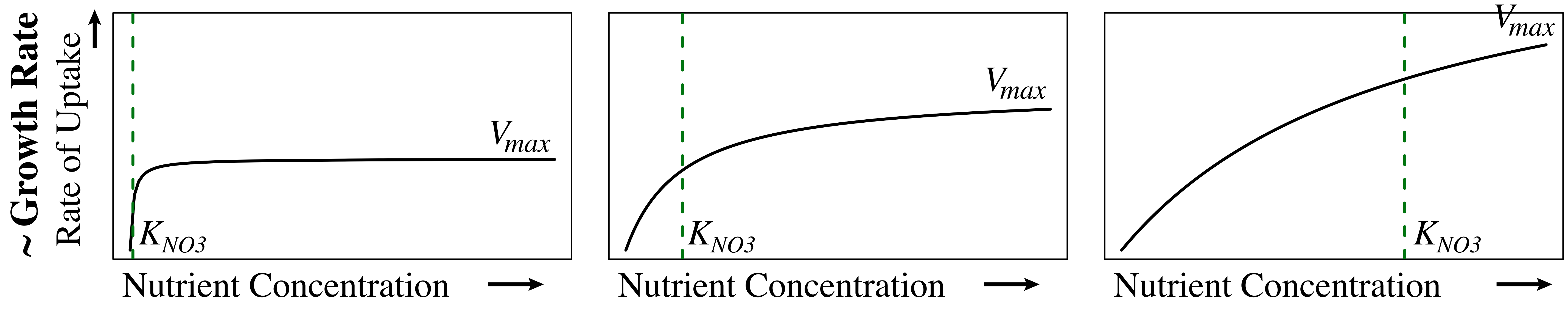
Speed & Endurance

No one is Superman.

Trade-offs abound in physiology, ecology, economics...

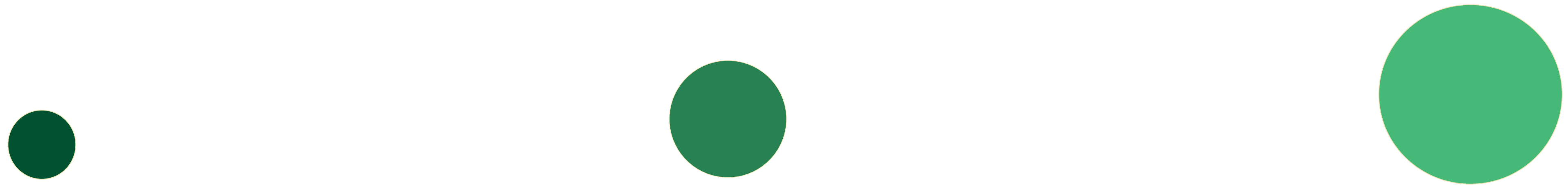
Gleaner-Opportunist Trade-off for Phytoplankton

A Physiological Trade-off



Typical for small cells.

Typical for large cells.



Tend to grow faster, and hence dominate, in nutrient-poor waters. ←

→ **Tend to grow faster, and hence dominate, in nutrient-rich waters.**

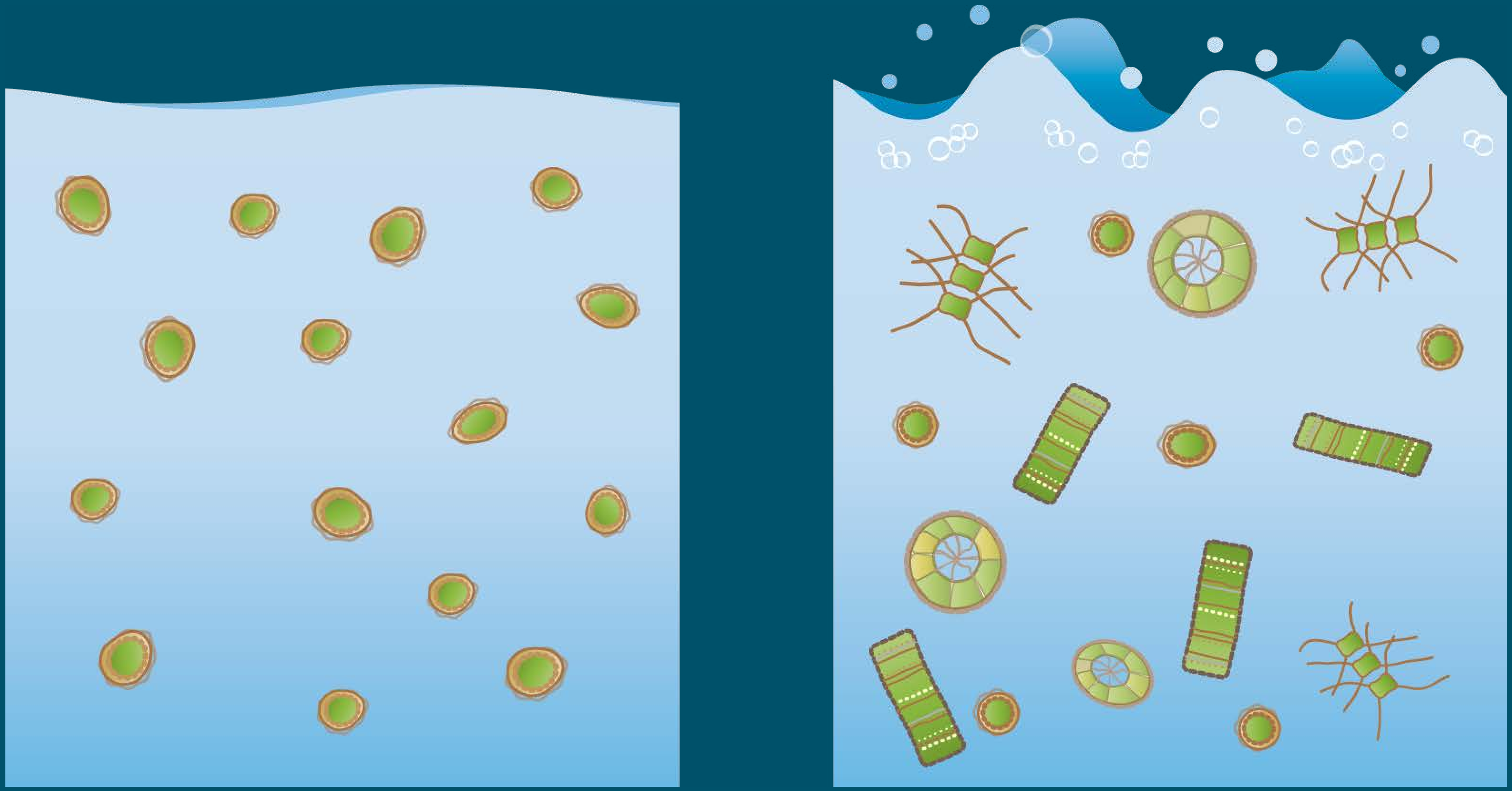
This and similar trade-offs are important determinants of competition, and are central to our understanding of biodiversity.

e.g., Tilman et al. *Ann. Rev. Ecol. Evol. Sys.* 2014

We considered Phytoplankton Communities

Different levels of Biodiversity,

Different frequencies of Disturbance.



In addtion to their important role as the base of aquatic food webs, Phytoplankton are also excellent model organims for understanding ecology.

Biodiversity as Adaptive Capacity: How trait distributions change

The mean of trait *x* , e.g., size, should change in proportion to its effect on fitness, *F*:

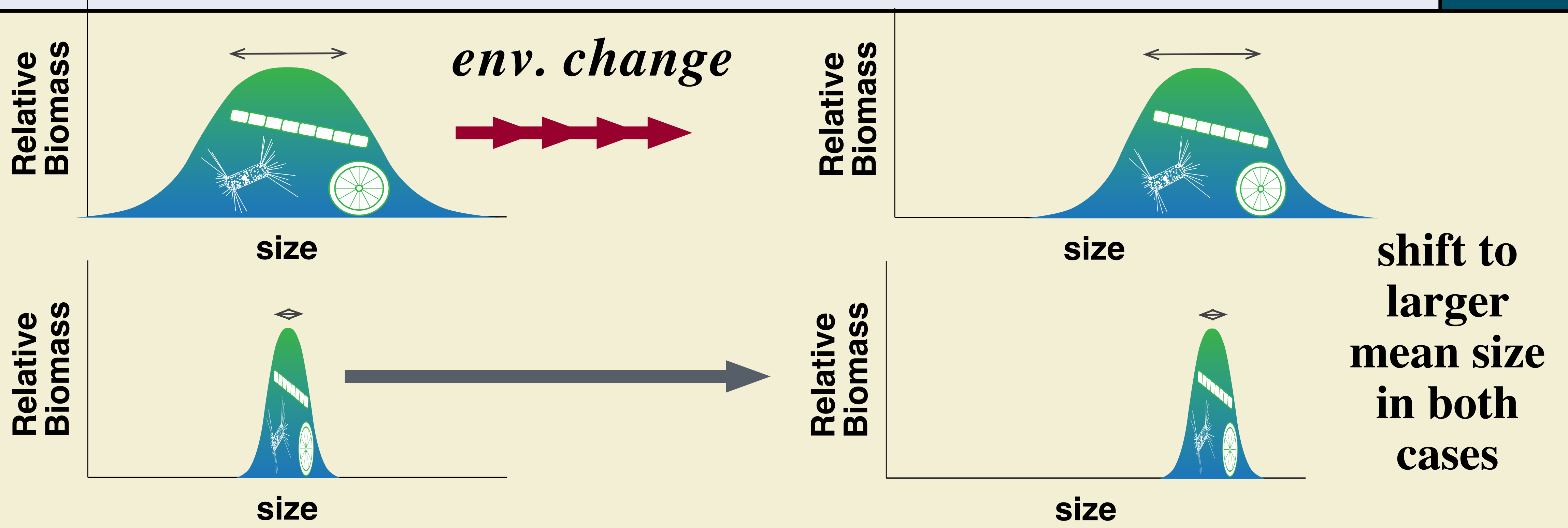
$$\frac{dx}{dt} = \delta_x \frac{\partial F(x,E)}{\partial x}$$

in the direction that increases Fitness.
For plankton, we assume *F* = *Growth rate* (Smith et al. *L&O*, 2011).

δ_x: diversity of trait distribution
E: Environment (nutrients, light, temperature, etc.)

More Diverse Communities adjust *faster*:

Less Diverse Communities adjust more slowly:



'Adaptive Dynamics': evolutionary changes
McGill and Brown (*An. Rev. Ecol. Evol. Syst.* 2007), Litchman et al. (*PNAS* 2009)

'adaptive dynamics': species succession, communities
Wirtz & Eckhardt (*Ecol. Modell.* 1996), Abrams (*J. Evol. Biol.* 2005), Merico et al. (*MEPS* 2009)

Disturbance Frequency varies naturally

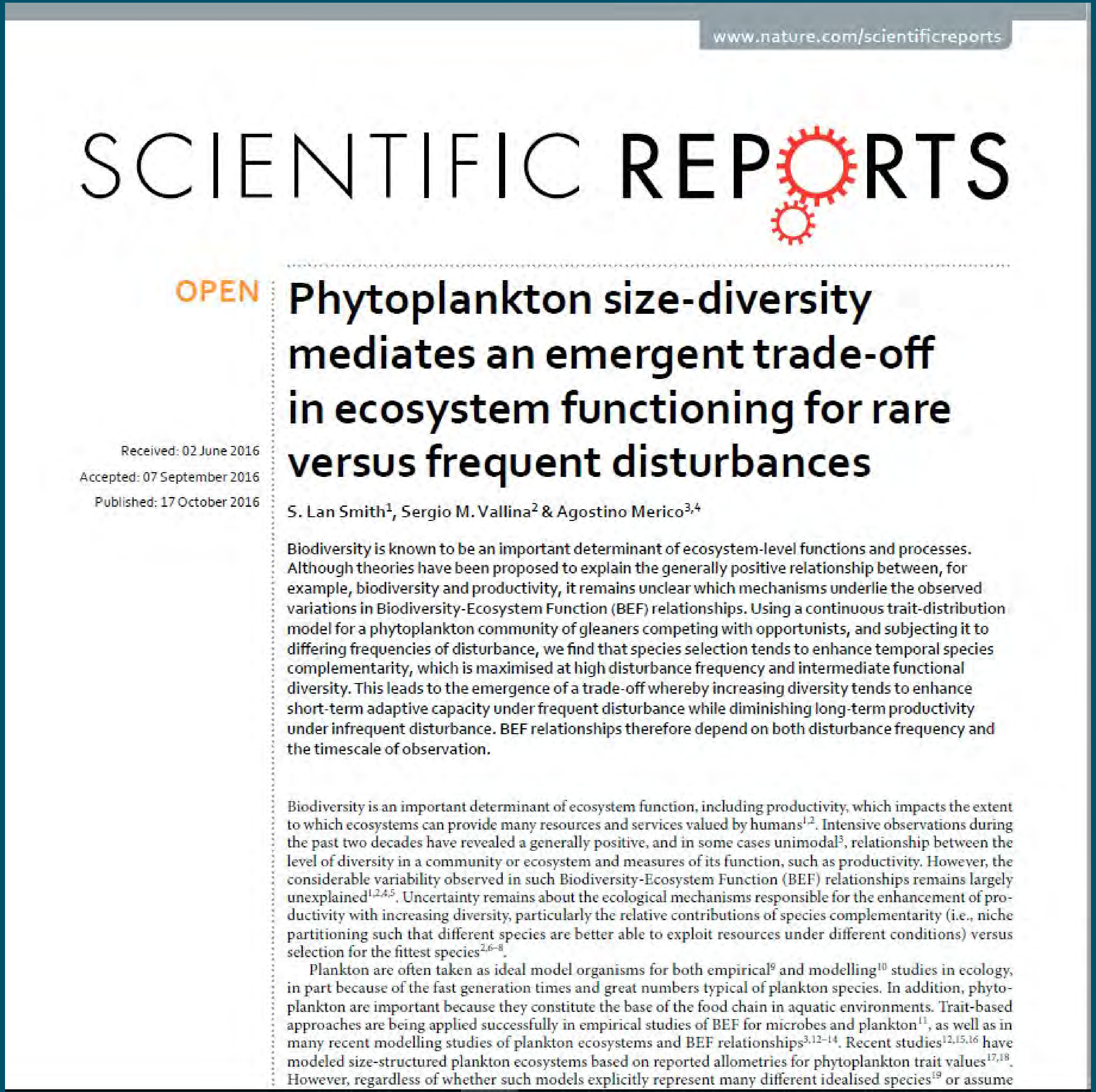
Regionally and over time

Calm sub-tropics

Rough sub-arctic, storms

Biodiversity Ecosystem Function (BEF) Relations change with Disturbance

Recent theoretical results.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Phytoplankton size-diversity mediates an emergent trade-off in ecosystem functioning for rare versus frequent disturbances

S. Lan Smith[1], Sergio M. Vallina[2] & Agostino Merico[3,4]

Biodiversity is known to be an important determinant of ecosystem-level functions and processes. Although theories have been proposed to explain the generally positive relationship between, for example, biodiversity and productivity, it remains unclear which mechanisms underlie the observed variations in Biodiversity-Ecosystem Function (BEF) relationships. Using a continuous trait-distribution model for a phytoplankton community of gleaners competing with opportunists, and subjecting it to differing frequencies of disturbance, we find that species selection tends to enhance temporal species complementarity, which is maximised at high disturbance frequency and intermediate functional diversity. This leads to the emergence of a trade-off whereby increasing diversity tends to enhance short-term adaptive capacity under frequent disturbance while diminishing long-term productivity under infrequent disturbance. BEF relationships therefore depend on both disturbance frequency and the timescale of observation.

Biodiversity is an important determinant of ecosystem function, including productivity, which impacts the extent to which ecosystems can provide many resources and services valued by humans[1,2]. Intensive observations during the past two decades have revealed a generally positive, and in some cases unimodal[3], relationship between the level of diversity in a community or ecosystem and measures of its function, such as productivity. However, the considerable variability observed in such Biodiversity-Ecosystem Function (BEF) relationships remains largely unexplained[1,2,4,5]. Uncertainty remains about the ecological mechanisms responsible for the enhancement of productivity with increasing diversity, particularly the relative contributions of species complementarity (i.e., niche partitioning such that different species are better able to exploit resources under different conditions) versus selection for the fittest species[2,6–8].

Plankton are often taken as ideal model organisms for both empirical[9] and modelling[10] studies in ecology, in part because of the fast generation times and great numbers typical of plankton species. In addition, phytoplankton are important because they constitute the base of the food chain in aquatic environments. Trait-based approaches are being applied successfully in empirical studies of BEF for microbes and plankton[11], as well as in many recent modelling studies of plankton ecosystems and BEF relationships[3,12–14]. Recent studies[12,15,16] have modeled size-structured plankton ecosystems based on reported allometries for phytoplankton trait values[17,18]. However, regardless of whether such models explicitly represent many different idealised species[19] or assume

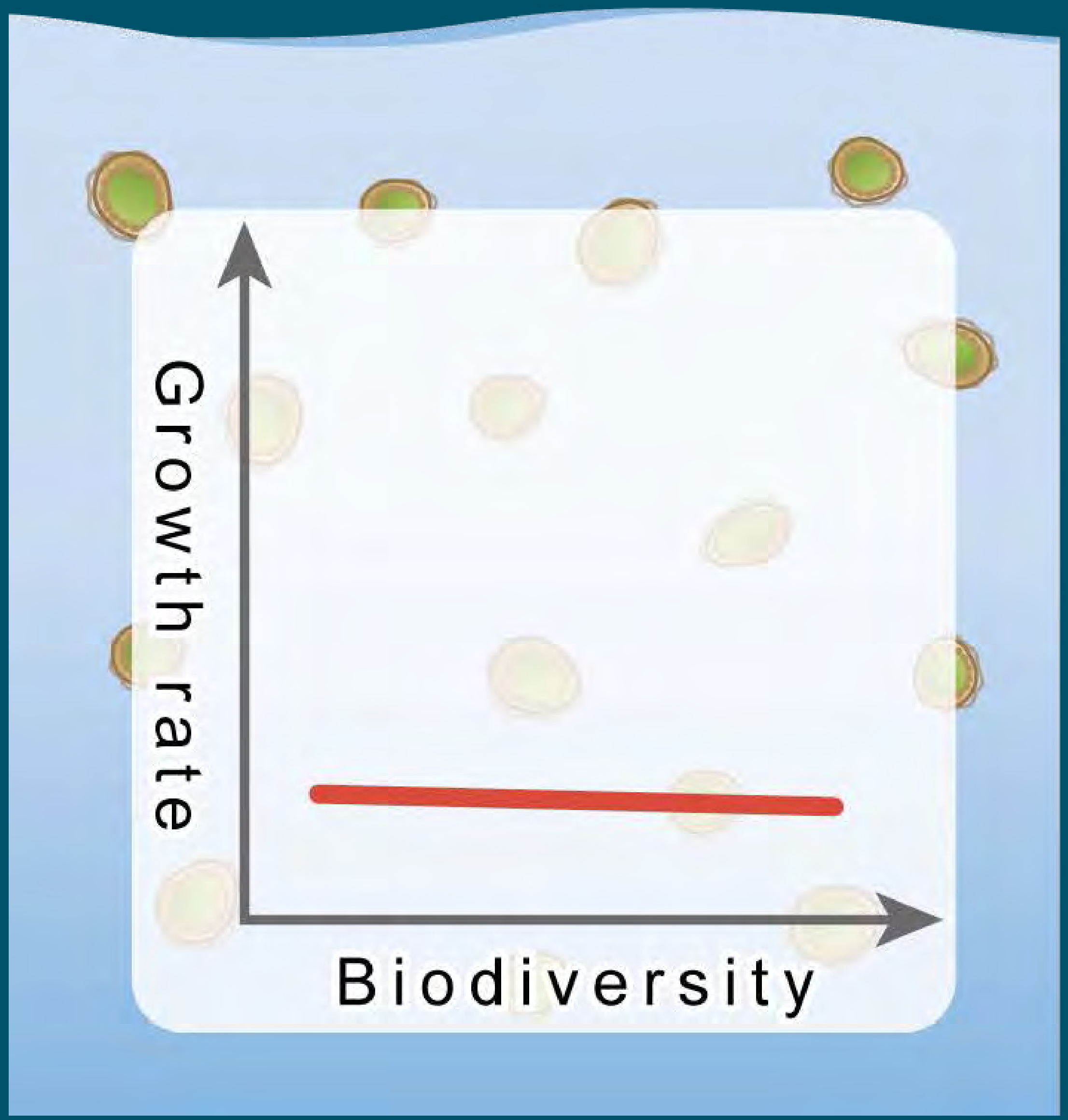
More diverse phytoplankton communities are more productive under frequent or intense disturbance,

but tend to be slightly less productive during long periods of relatively stable conditions.

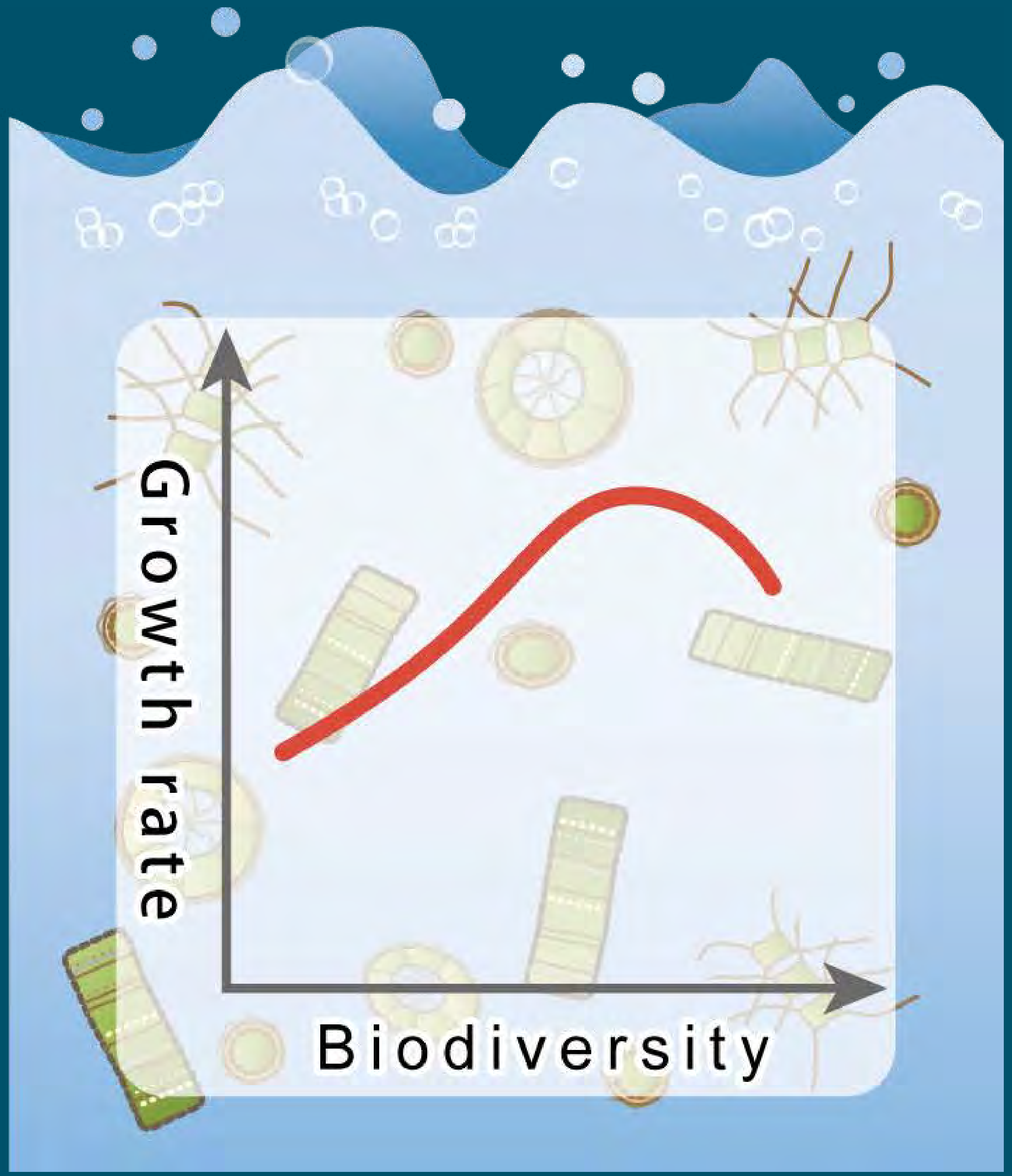
Smith et al., *Scientific Reports* 2016

Theoretical Diversity-Productivity Relationships

Greater Biodiversity does not in all cases enhance productivity.



The optimal level of diversity depends on timescale and disturbance frequency.



This is a community-level trade-off, not the physio-logical (individual-level) trade-off that we assumed.

The benefits of biodi-versity depend on the disturbance regime.

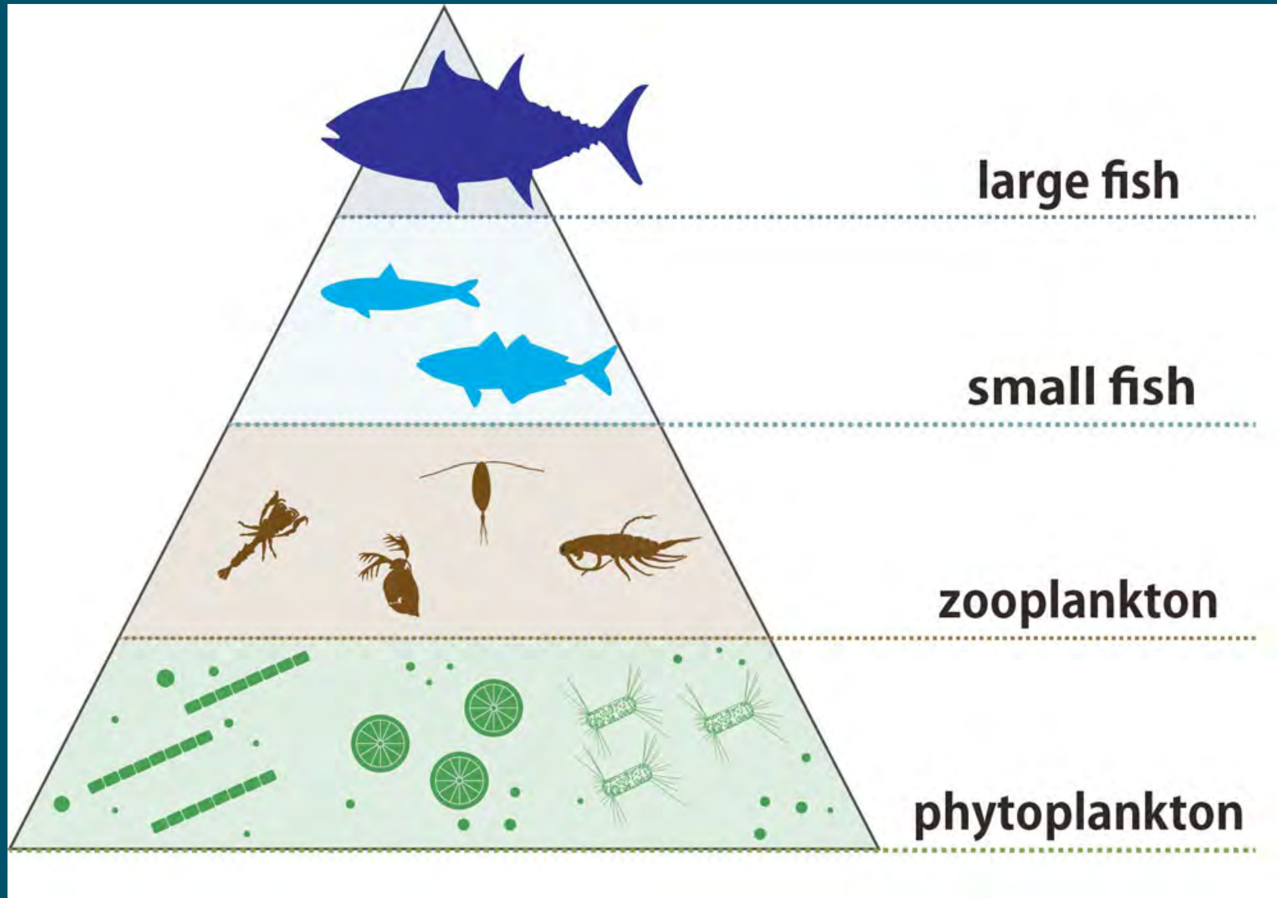
Smith et al., *Scientific Reports* 2016

Implications: Resource allocation & What level of Biodiversity is Healthy?

Given limited resources for management / conservation, our results suggest that it may be more cost effective to concentrate efforts on areas with more frequent or intense disturbance.

At least for Services that are proportional to the productivity of phytoplankton.

In other cases it may be desirable to sustain greater biodiversity in order to decrease plankton productivity.



Santa Fe river, Florida