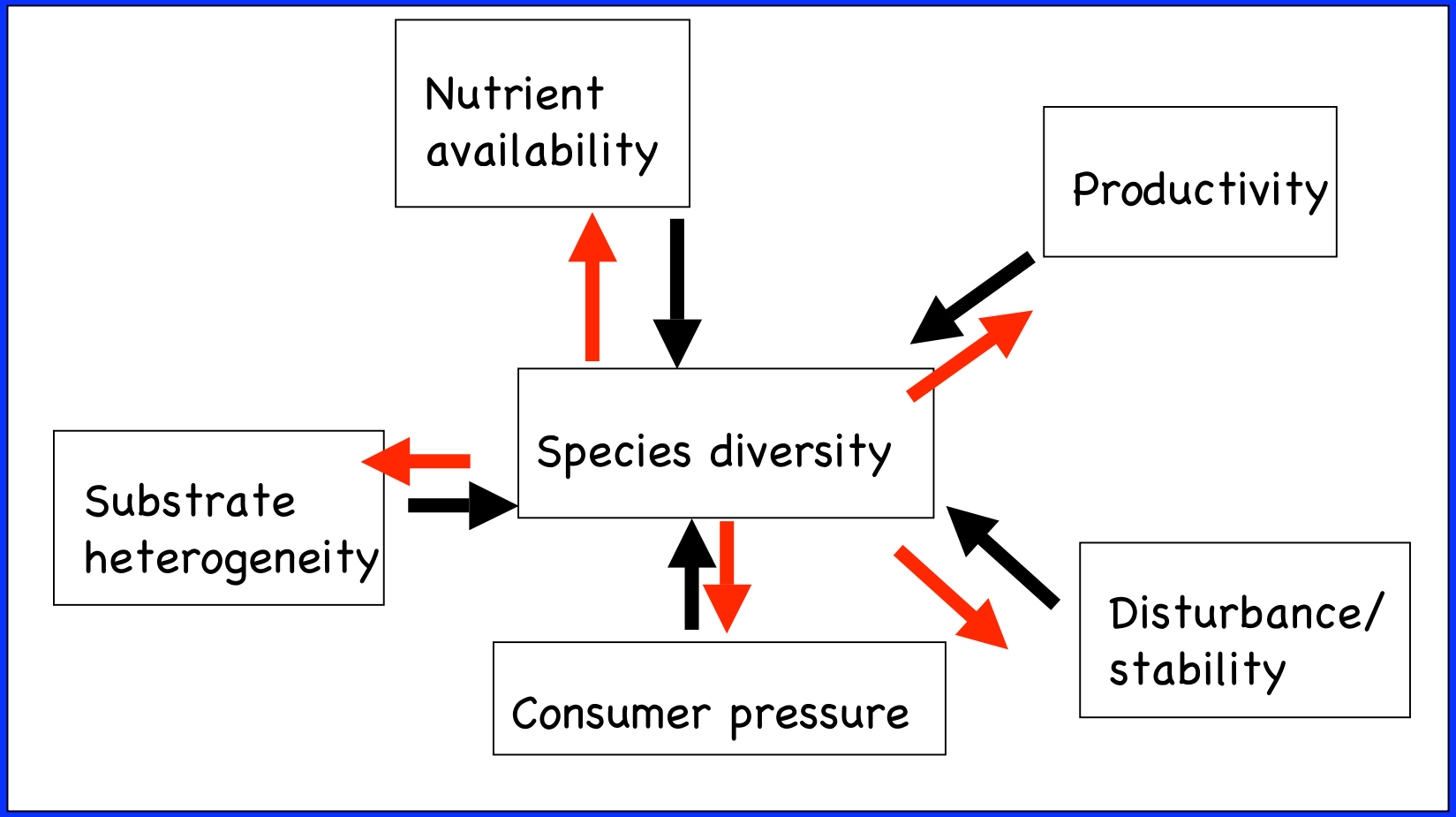
Patterns of diversity loss and their potential consequences for marine communities

Jay Stachowicz,
University of California Davis

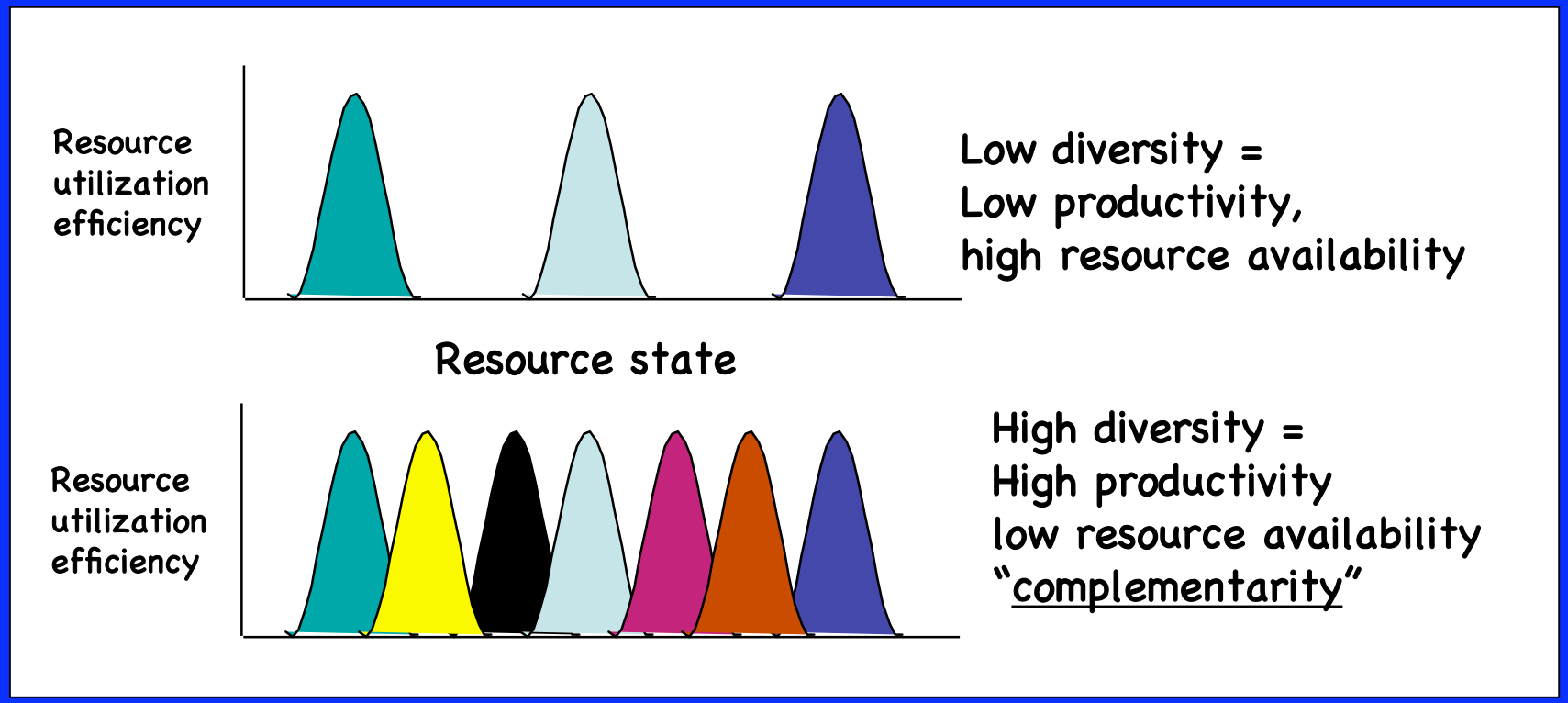
Biologists have long studied the causes of patterns of species diversity in nature...



But have only more recently studied reciprocal links whereby species diversity alters ecosystem processes...

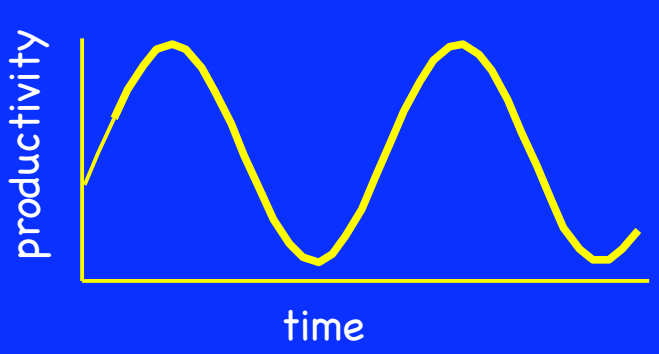
Reasons why we might expect diversity to AFFECT ecosystem processes are related to those that promote diversity

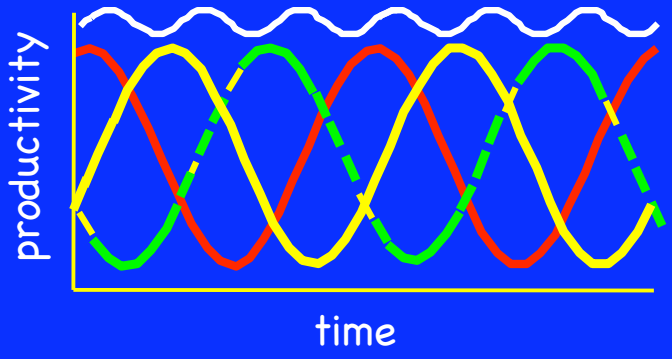
1. Niche complementarity - species differ in resource use such that more resources are converted to production in diverse communities



Mechanisms by which diversity affects ecosystem performance

2. Differential response to temporal fluctuations - species vary in response to the environment, so diverse communities maintain biomass and production in the face of environmental variation



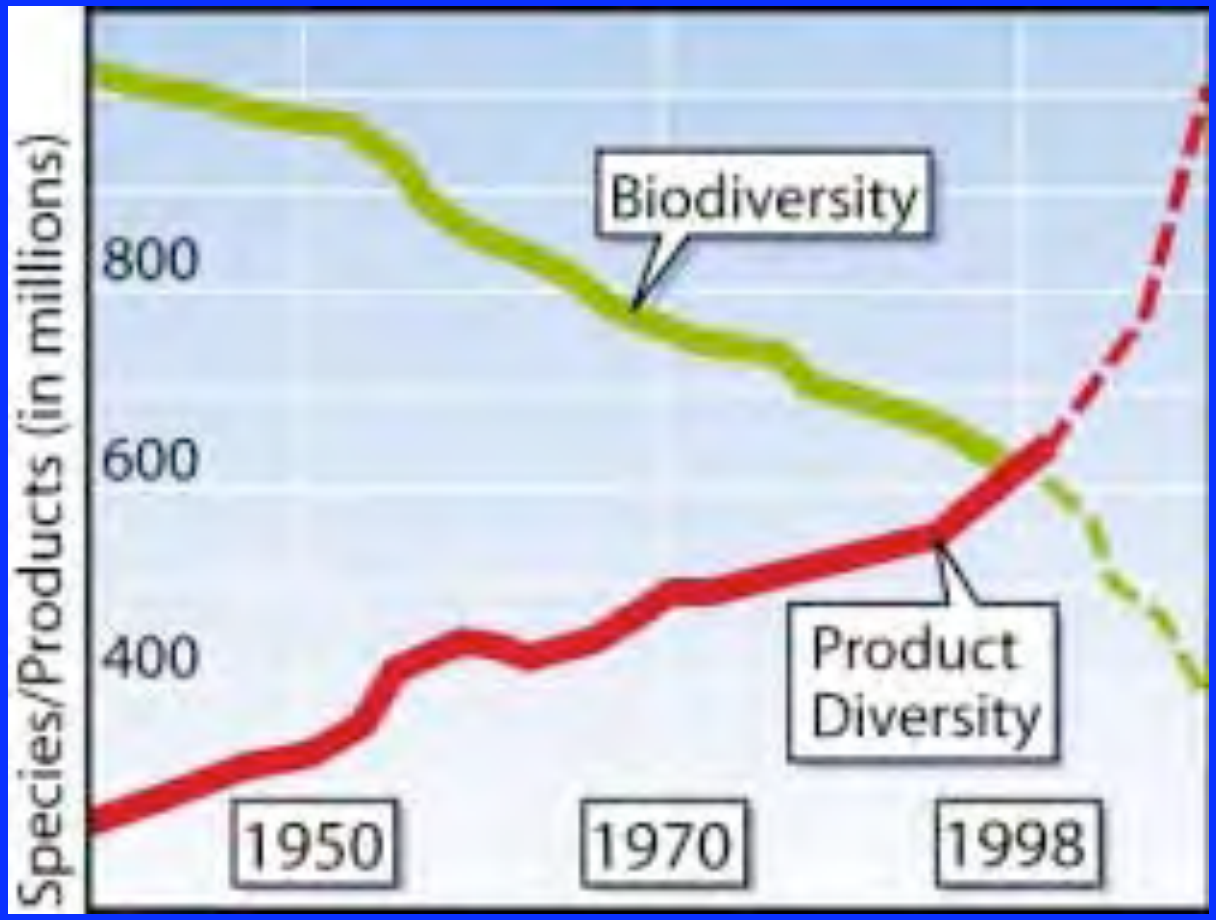


3. Biological insurance - redundancy buffers against species loss (the ecological spare tire)

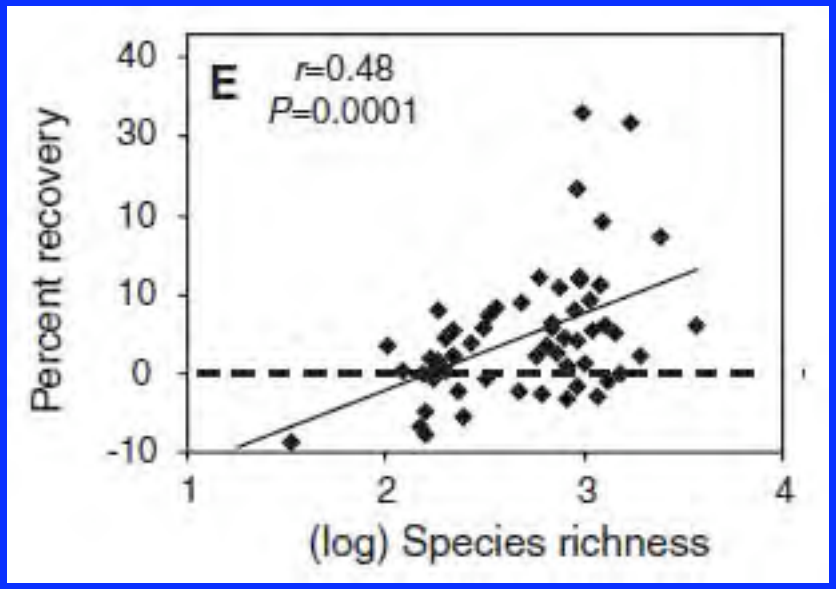
Connecting biodiversity to ecosystem services?

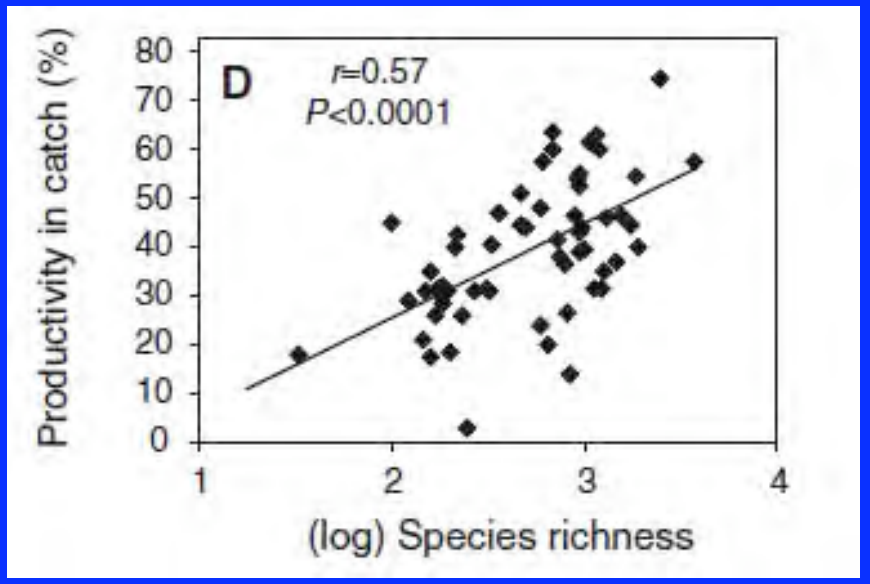
“When a species vanishes, the world loses not only that species, but the wide range of highly specialized physical and biochemical functions that species served. These ecological losses necessitate the creation of new, synthetic products capable of serving the same functions," Quammen said. "So, for example, when we lose a strain of microbe that filters the water we drink, we compensate by developing the amazing Brita water filter, with its patented filtration technology."

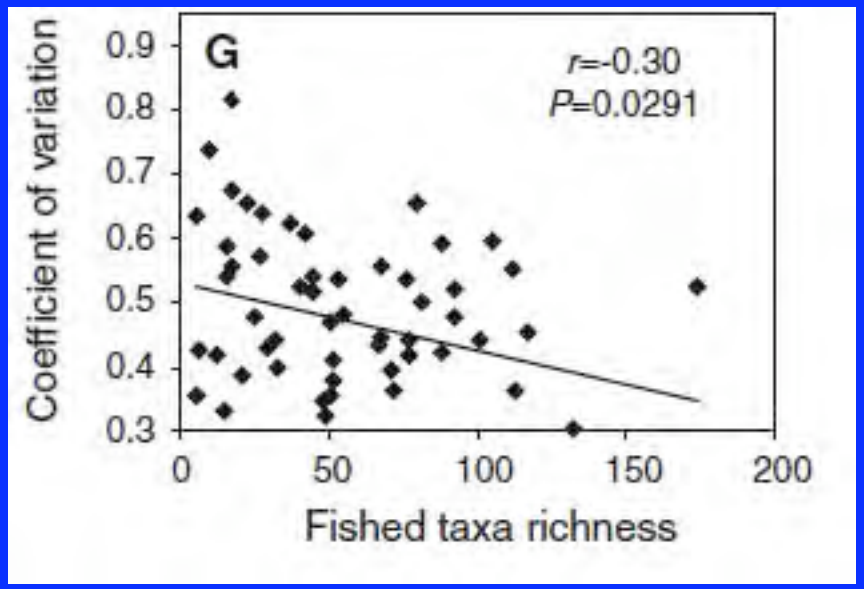
Attributed to David Quammen
The Onion,
November 1998



Species diversity is associated with greater productivity, less variability, and greater resilience







But biological mechanisms underpinning these patterns are not clear

Worm et al. 2006, Science

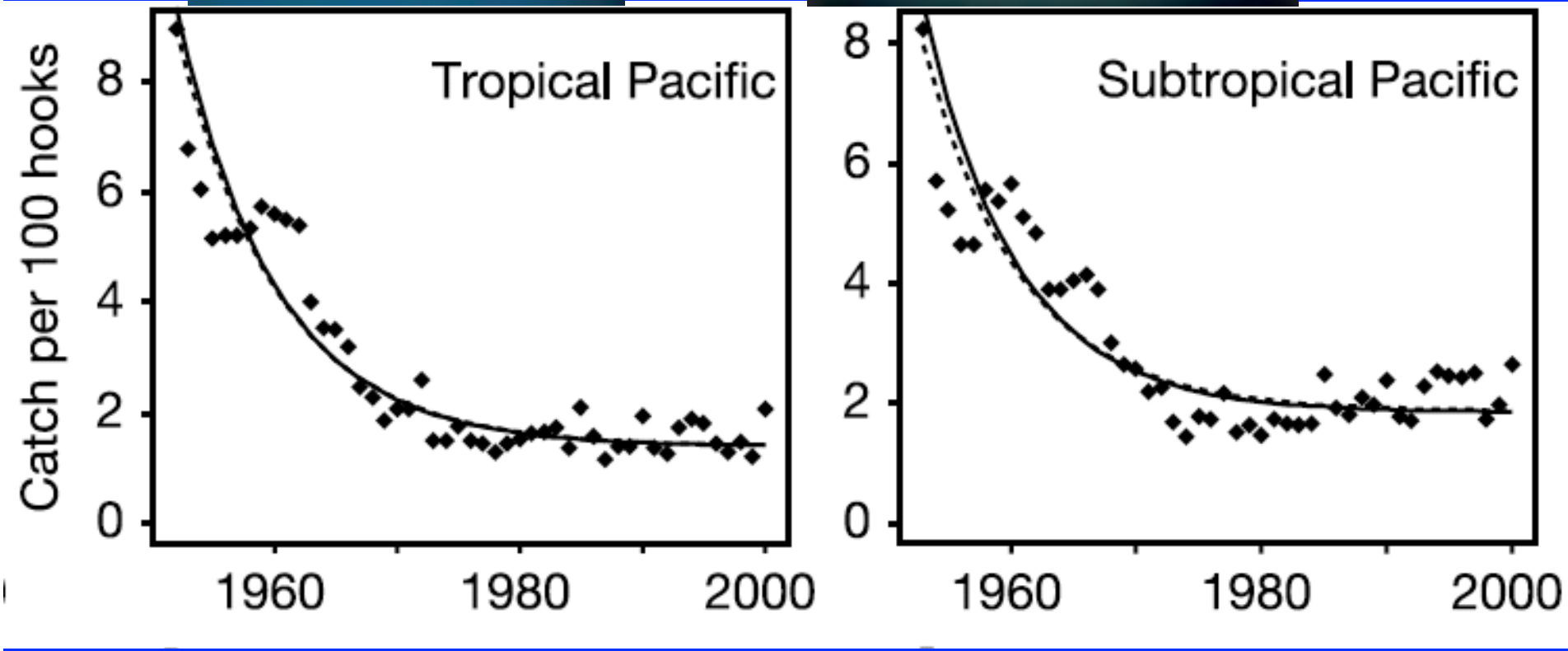
Using experimentally tractable coastal marine systems as models for understanding mechanisms by which changing diversity affects ecosystem functioning

1. Patterns of human-caused change in diversity across trophic levels

2. Consequences of diversity change for coastal marine ecosystems

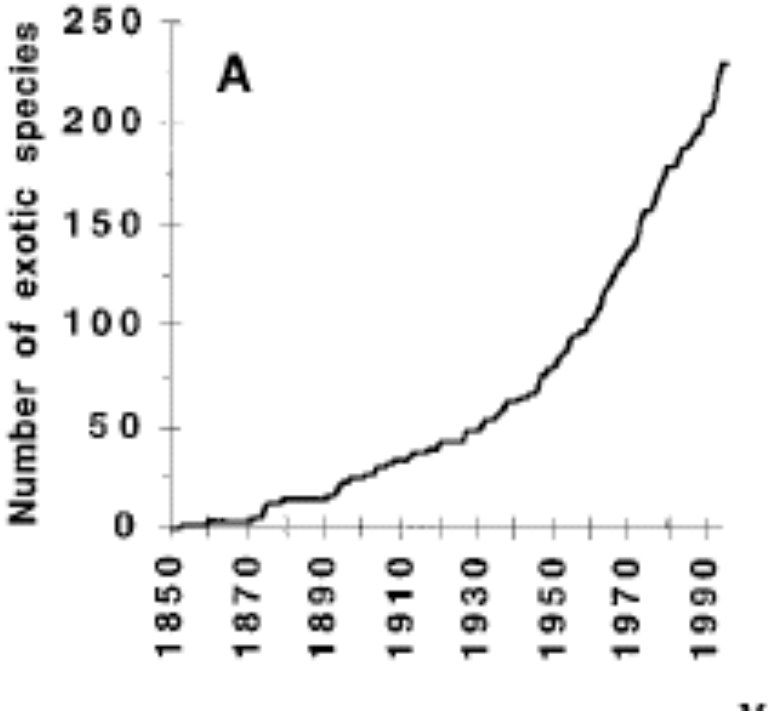
How are humans changing diversity?

Myers and Worm 2003



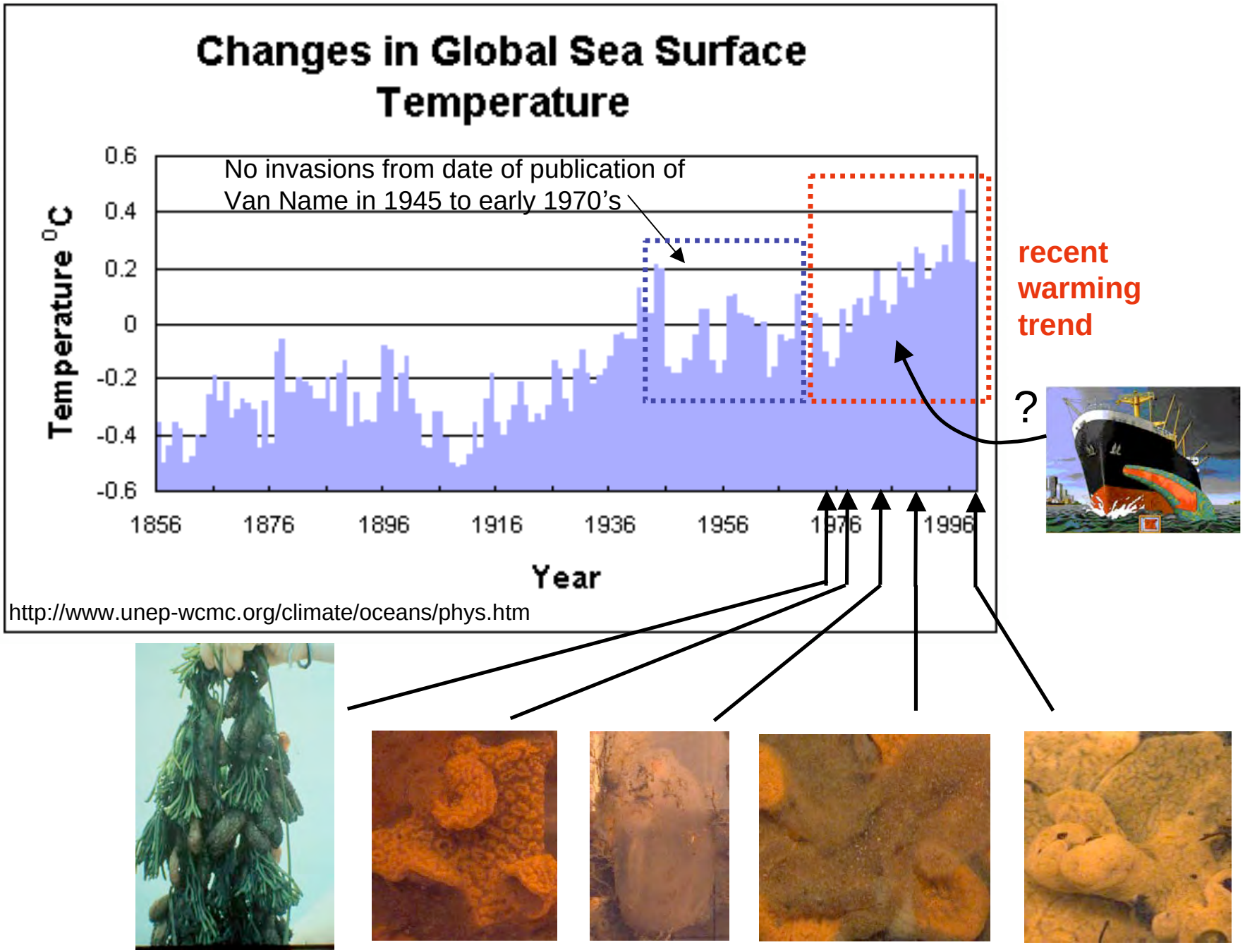
Ecological extinction - occurs when a species has become so rare that has no effect on an ecosystem

Human activities can increase diversity directly…



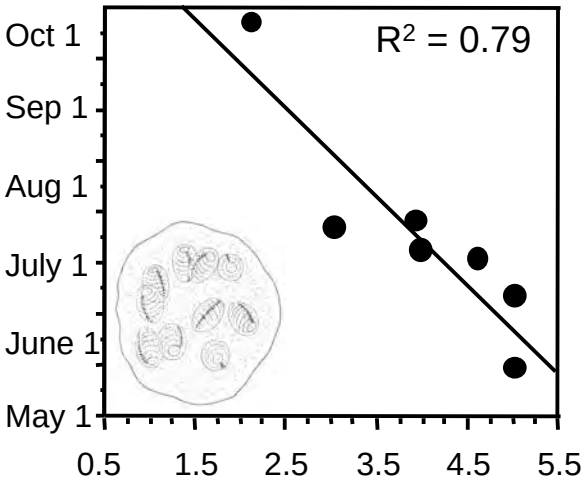
Cohen and Carlton 1998, Science

The timing of new invader establishment is coincident with recent acceleration of warming

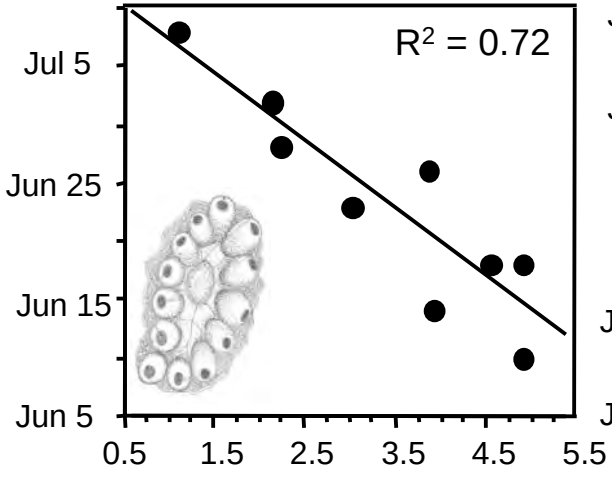


RECENT INVADERS

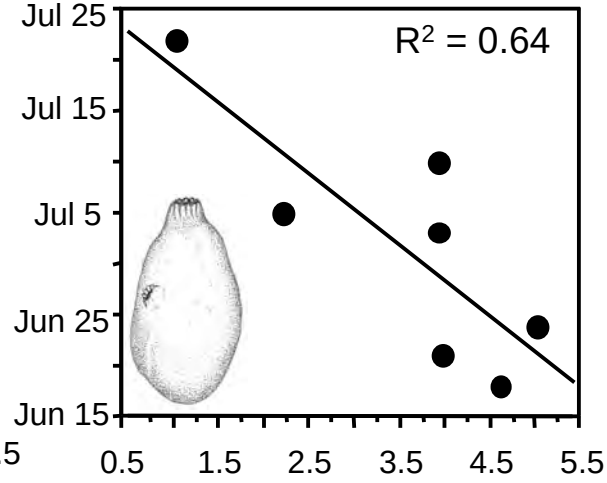
Diplosoma



Botrylloides

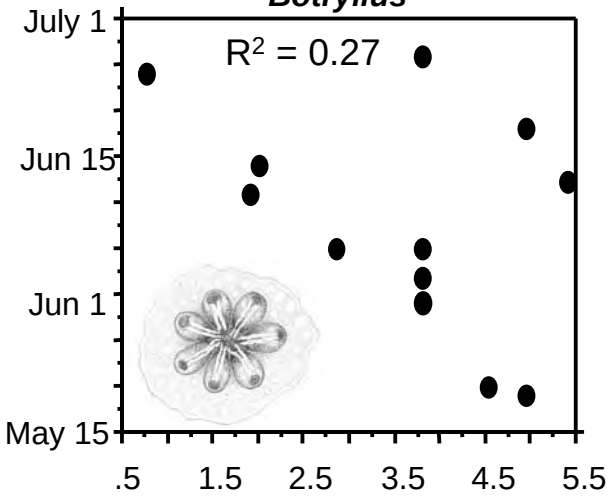


Ascidiella

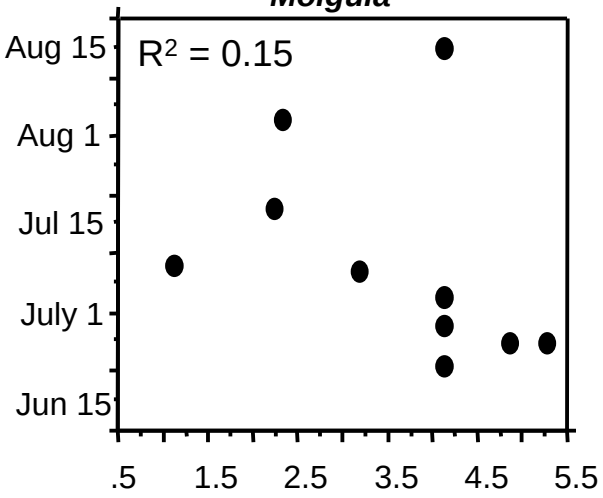


RESIDENTS

Botryllus



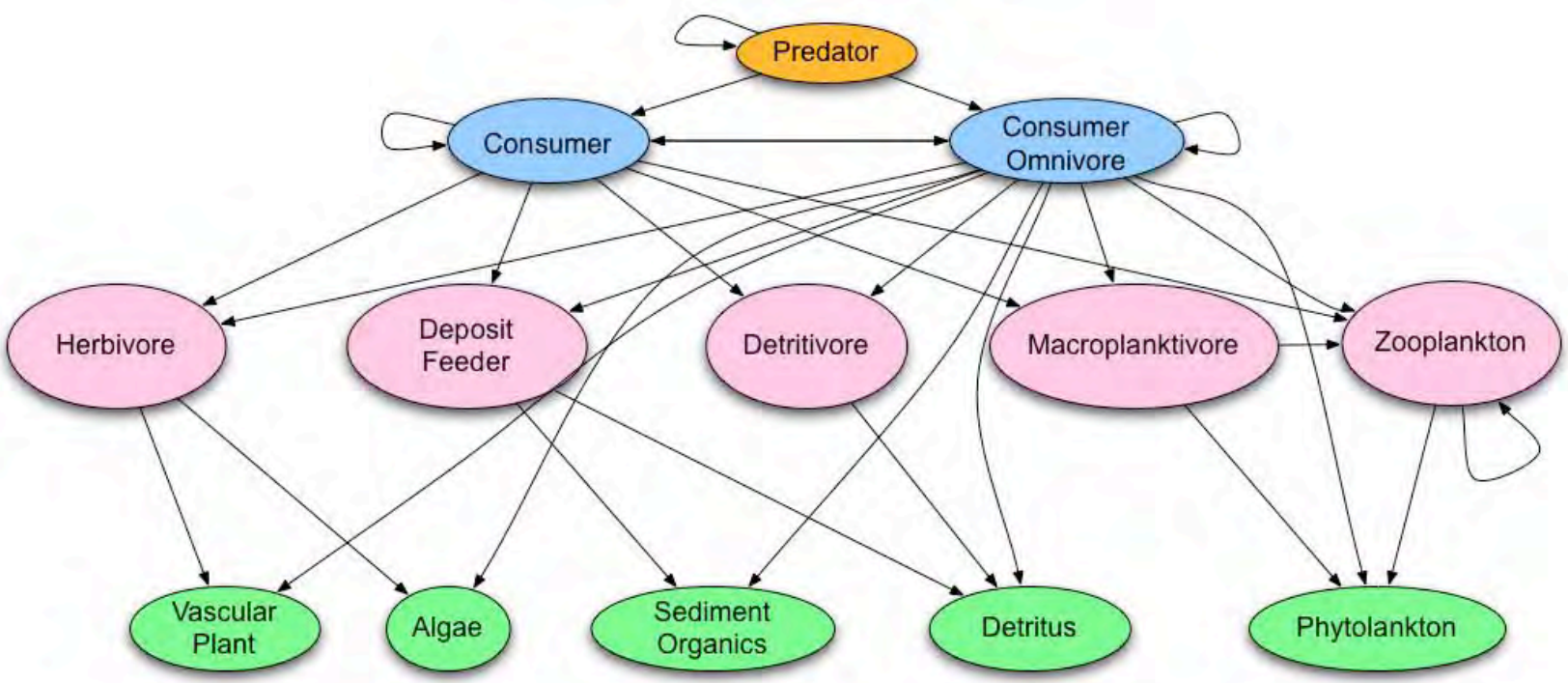
Molgula



Day of onset of recruitment

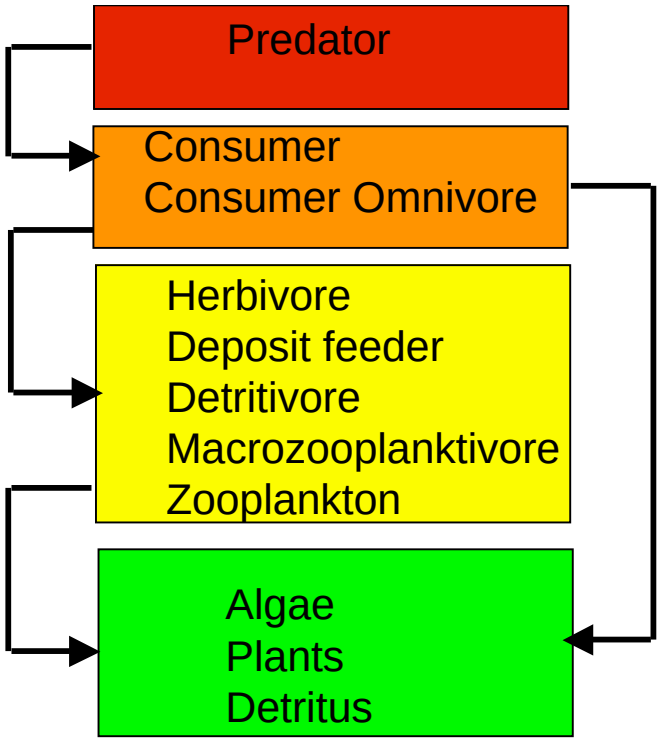
March water temperature (°C)

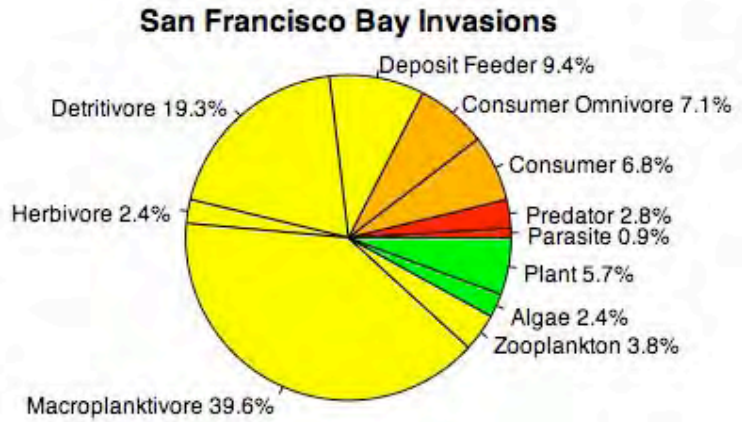
What are the combined effects of invasions and extinctions on marine food webs?

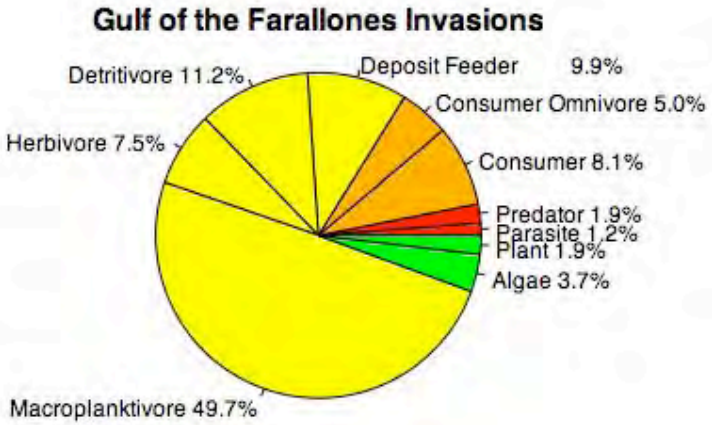


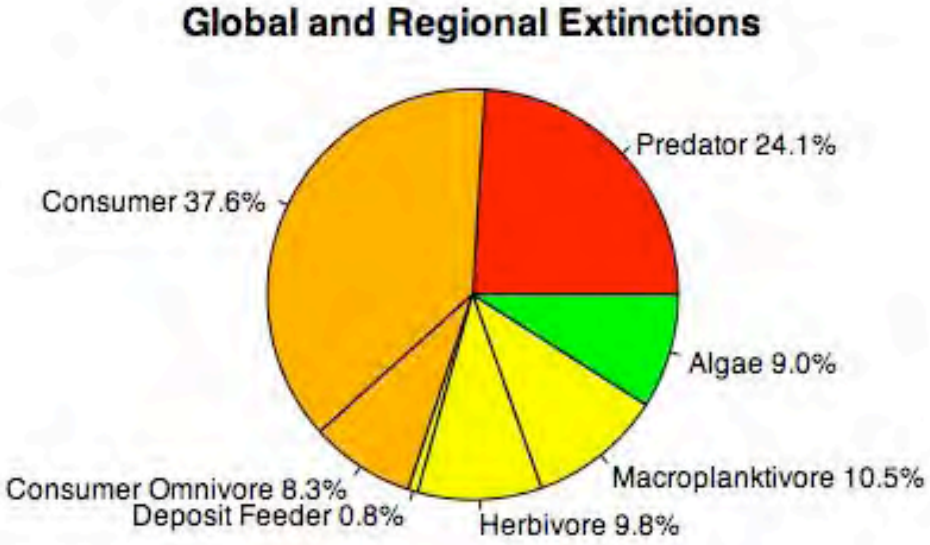
Human activities are altering diversity, increasing the diversity of some groups, and decreasing that of others

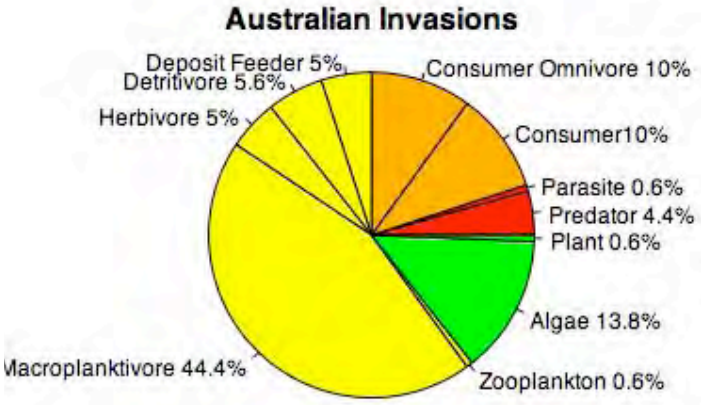
Byrnes, Stachowicz, Reynolds, 2007
PLoS ONE

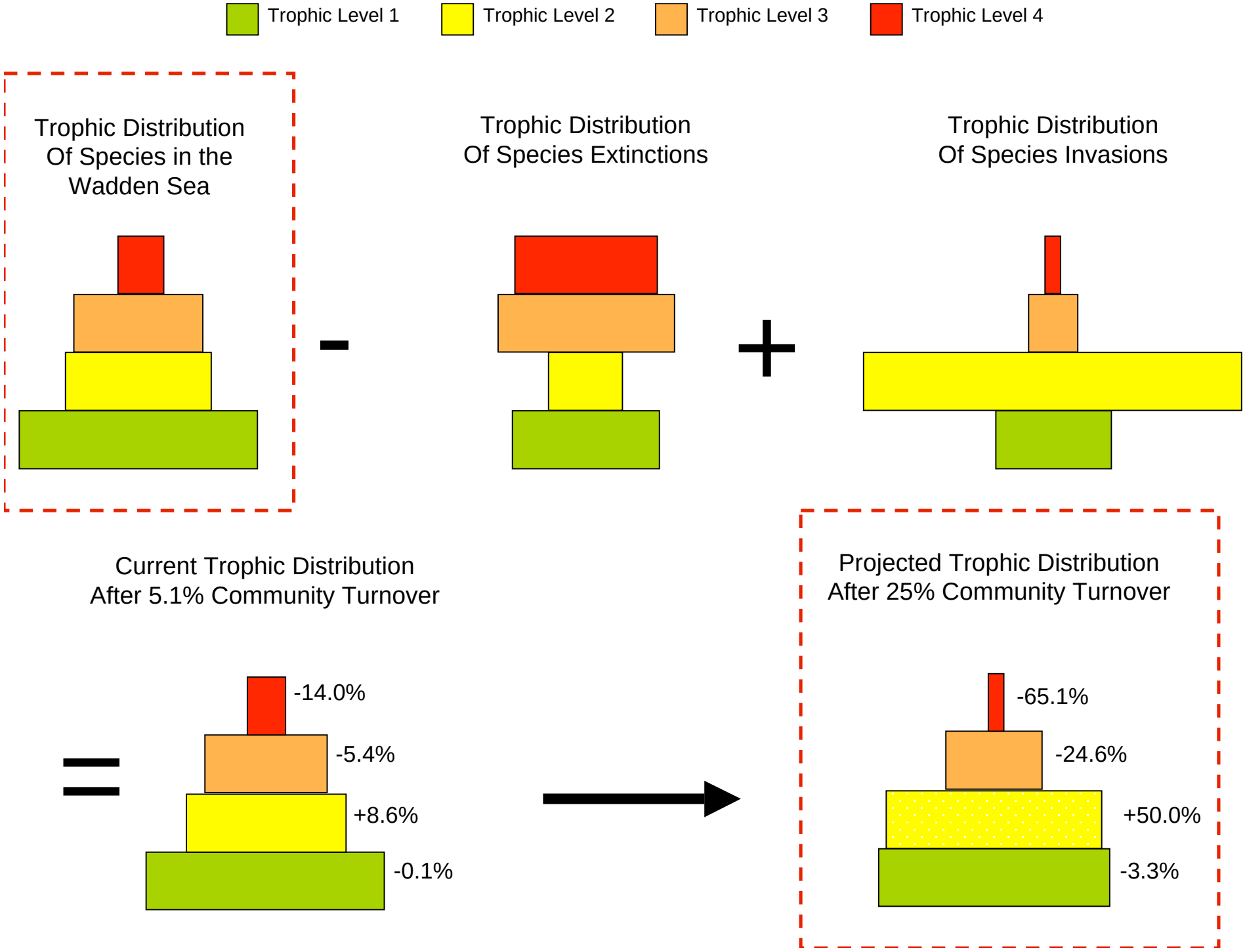

Predator
Consumer
Consumer Omnivore
Herbivore
Deposit feeder
Detritivore
Macrozooplanktivore
Zooplankton
Algae
Plants
Detritus


San Francisco Bay Invasions
Deposit Feeder 9.4%
Consumer Omnivore 7.1%
Consumer 6.8%
Predator 2.8%
Parasite 0.9%
Plant 5.7%
Algae 2.4%
Zooplankton 3.8%
Macroplanktivore 39.6%
Herbivore 2.4%
Detritivore 19.3%


Gulf of the Farallones Invasions
Deposit Feeder 9.9%
Consumer Omnivore 5.0%
Consumer 8.1%
Predator 1.9%
Parasite 1.2%
Plant 1.9%
Algae 3.7%
Macroplanktivore 49.7%
Herbivore 7.5%
Detritivore 11.2%


Global and Regional Extinctions
Predator 24.1%
Algae 9.0%
Macroplanktivore 10.5%
Herbivore 9.8%
Deposit Feeder 0.8%
Consumer Omnivore 8.3%
Consumer 37.6%


Australian Invasions
Consumer Omnivore 10%
Consumer10%
Parasite 0.6%
Predator 4.4%
Plant 0.6%
Algae 13.8%
Zooplankton 0.6%
Macroplanktivore 44.4%
Herbivore 5%
Detritivore 5.6%
Deposit Feeder 5%

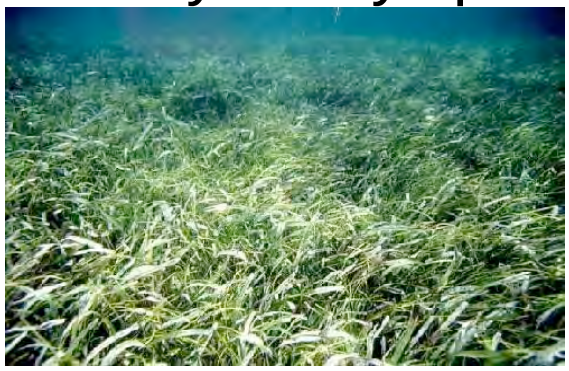

Trophic Level 1
Trophic Level 2
Trophic Level 3
Trophic Level 4
Trophic Distribution Of Species in the Wadden Sea
-
Trophic Distribution Of Species Extinctions
+
Trophic Distribution Of Species Invasions
=
Current Trophic Distribution After 5.1% Community Turnover
-14.0%
-5.4%
+8.6%
-0.1%
Projected Trophic Distribution After 25% Community Turnover
-65.1%
-24.6%
+50.0%
-3.3%

What are the consequences of changing diversity within food webs for ecosystem stability or productivity?

1. Loss of carnivore diversity?

2. Increase in diversity of suspension feeders?

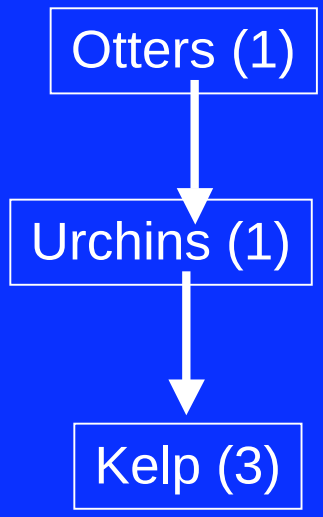
3. Loss of genetic diversity in key species?



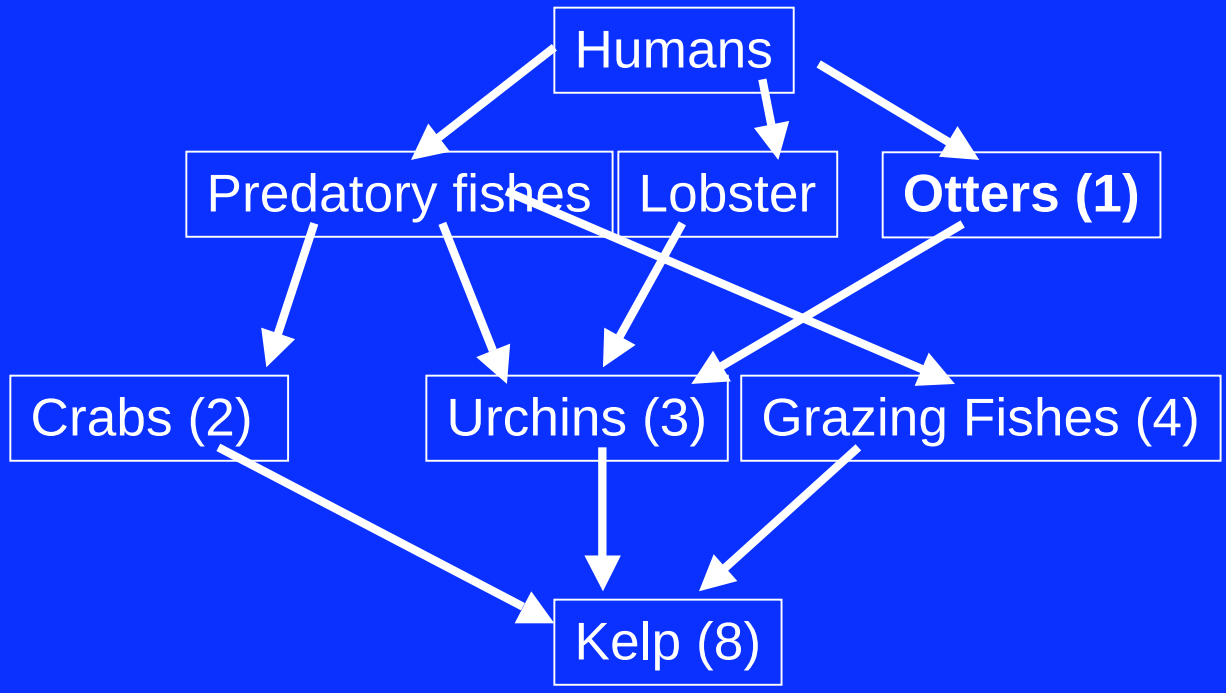
Otters present

Otters absent

Does predator diversity affect the stability of kelp forests?



ALASKA

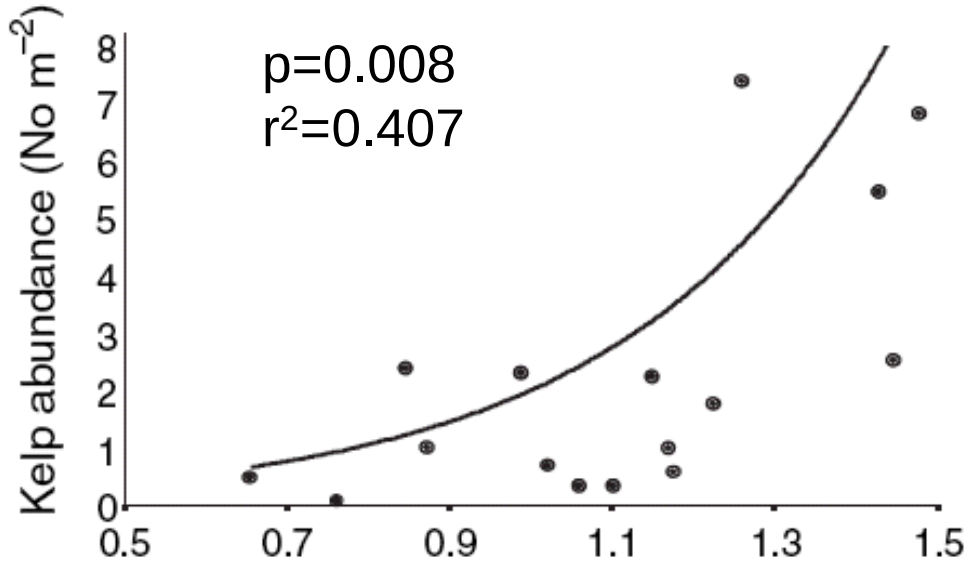


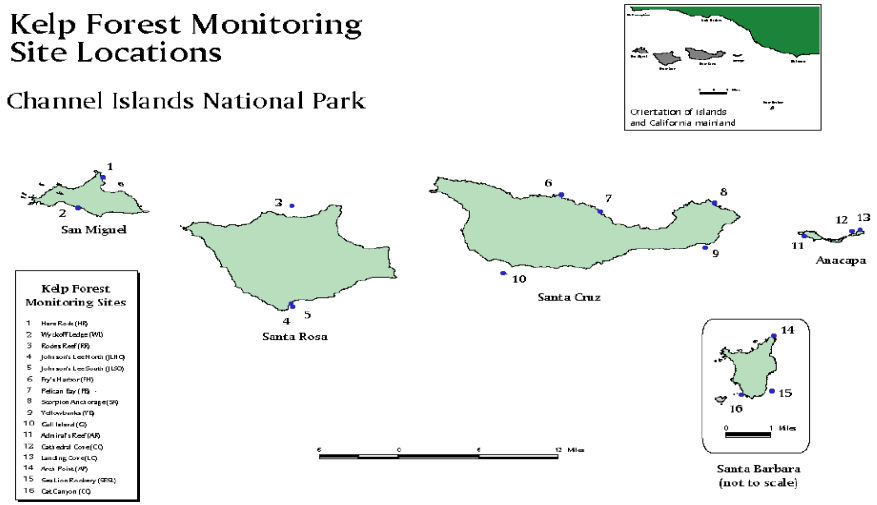
Southern California

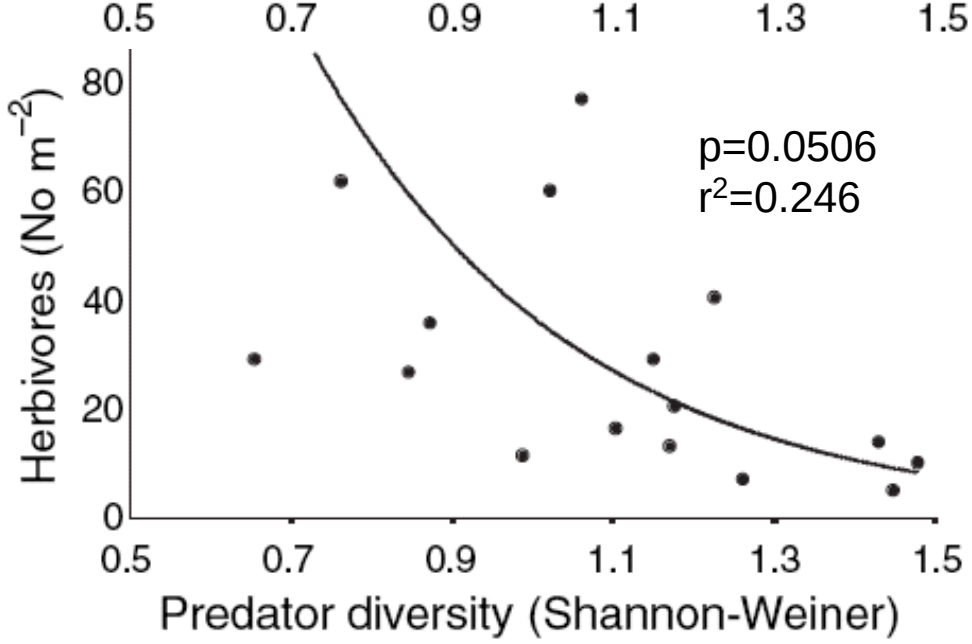
Two possible mechanisms:

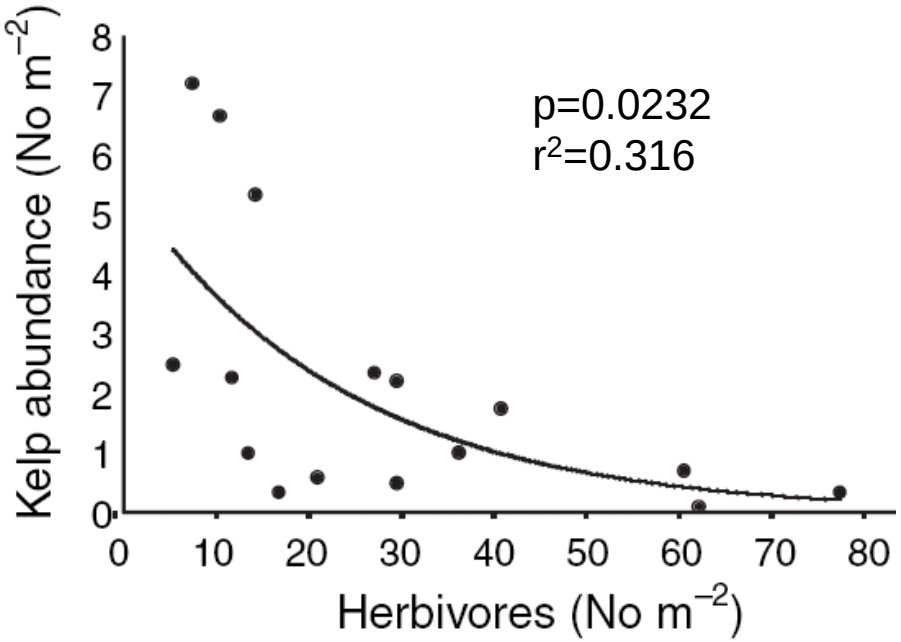
1. **Predators have complementary feeding prefs or strategies**
2. **Multiple predators provide redundancy against extinction**

High predator diversity is associated with lower herbivore abundance and greater abundance of kelp









Data courtesy of National Park Service Channel Islands Kelp Forest Monitoring Project

Experimental manipulation

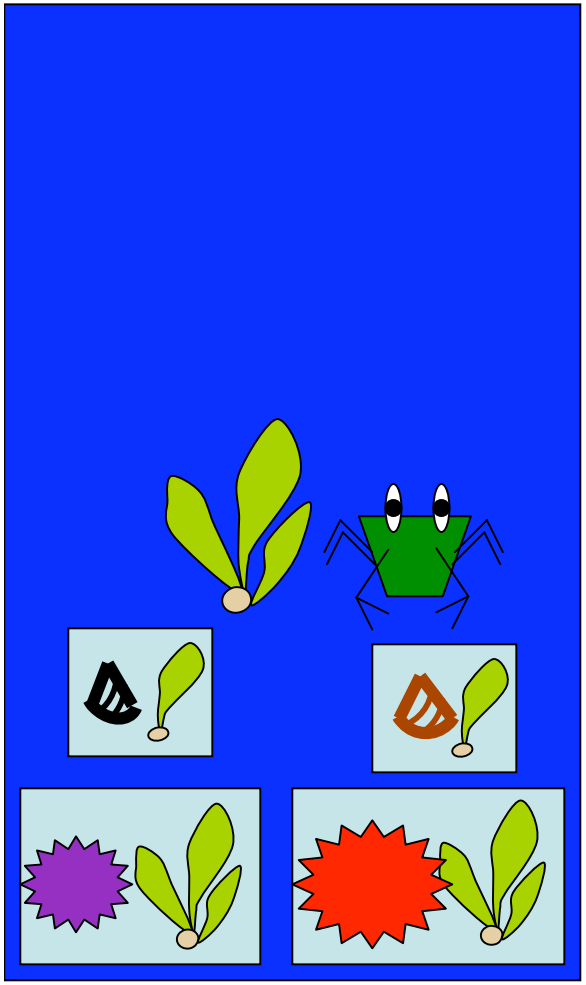
TURBAN SNAILS

PURPLE URCHIN

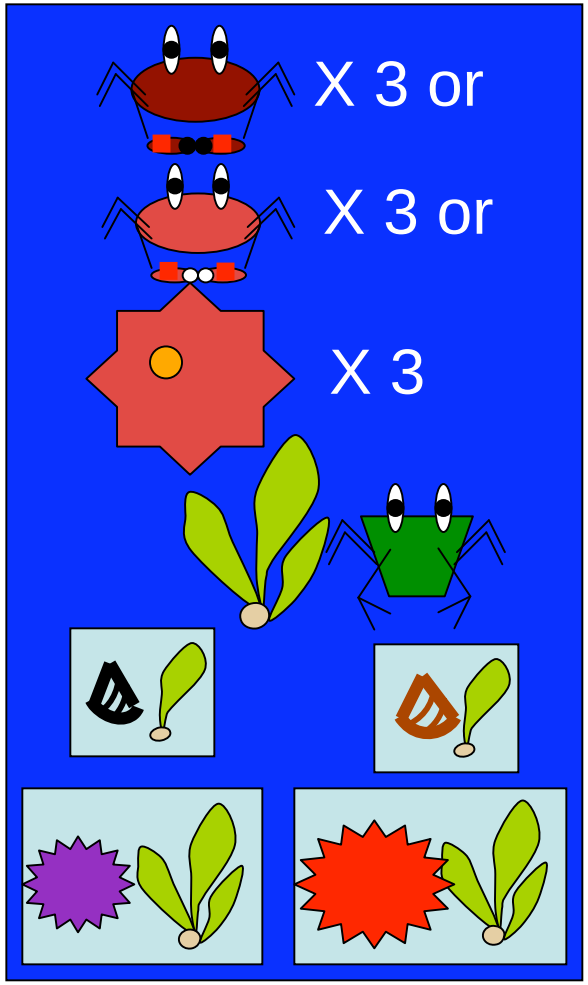
KELP CRAB

RED URCHIN

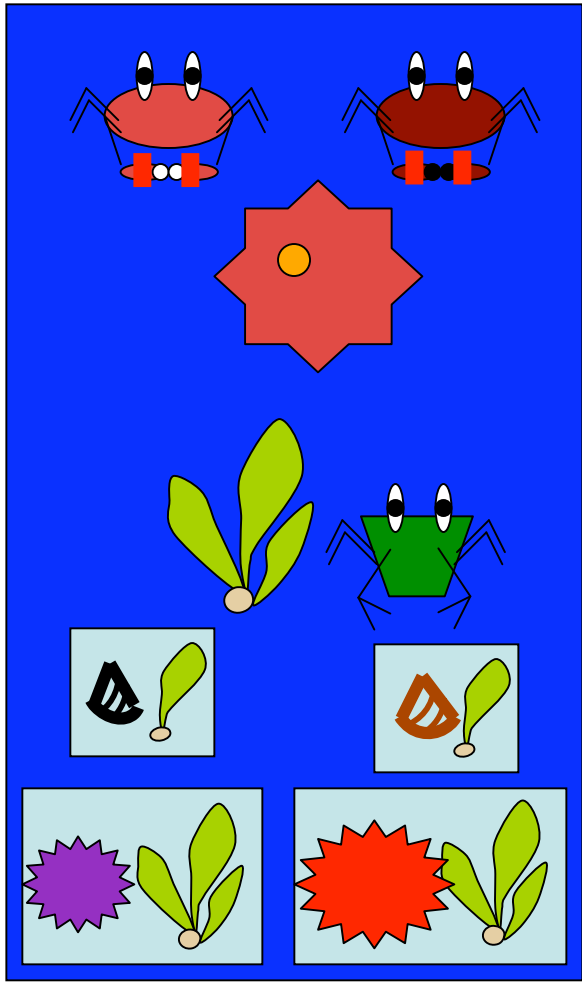
Does Predator Diversity Alter Herbivore Behavior?



n=6

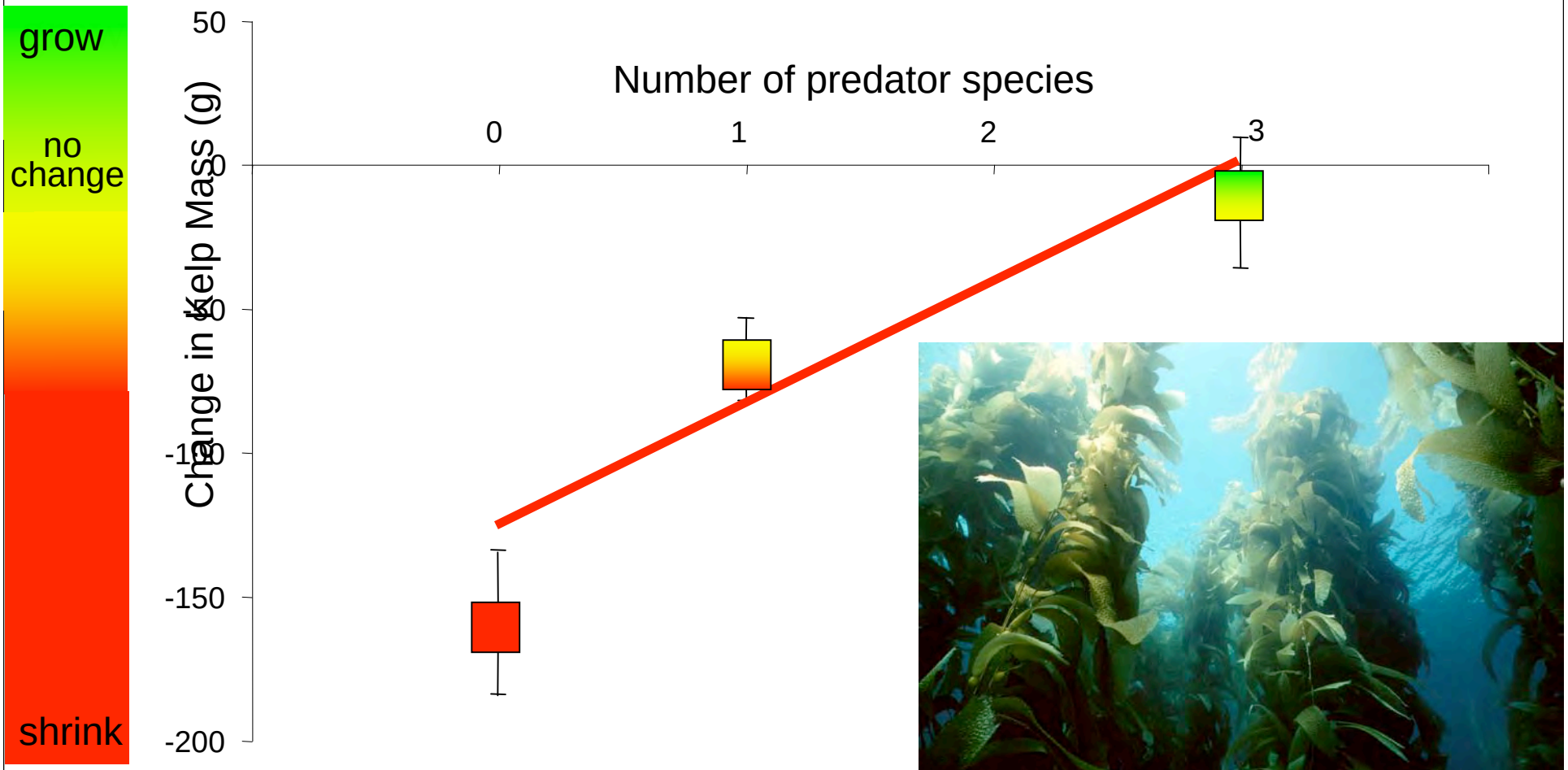


n=6 per species



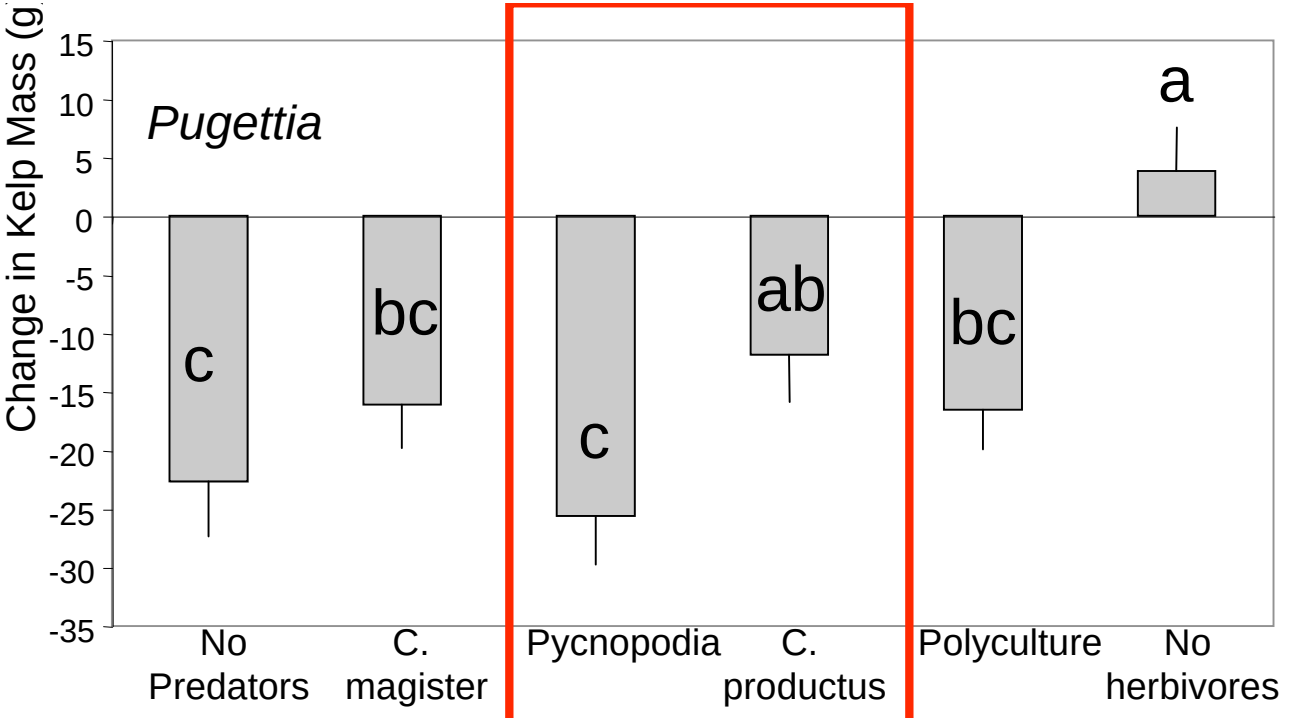
n=8

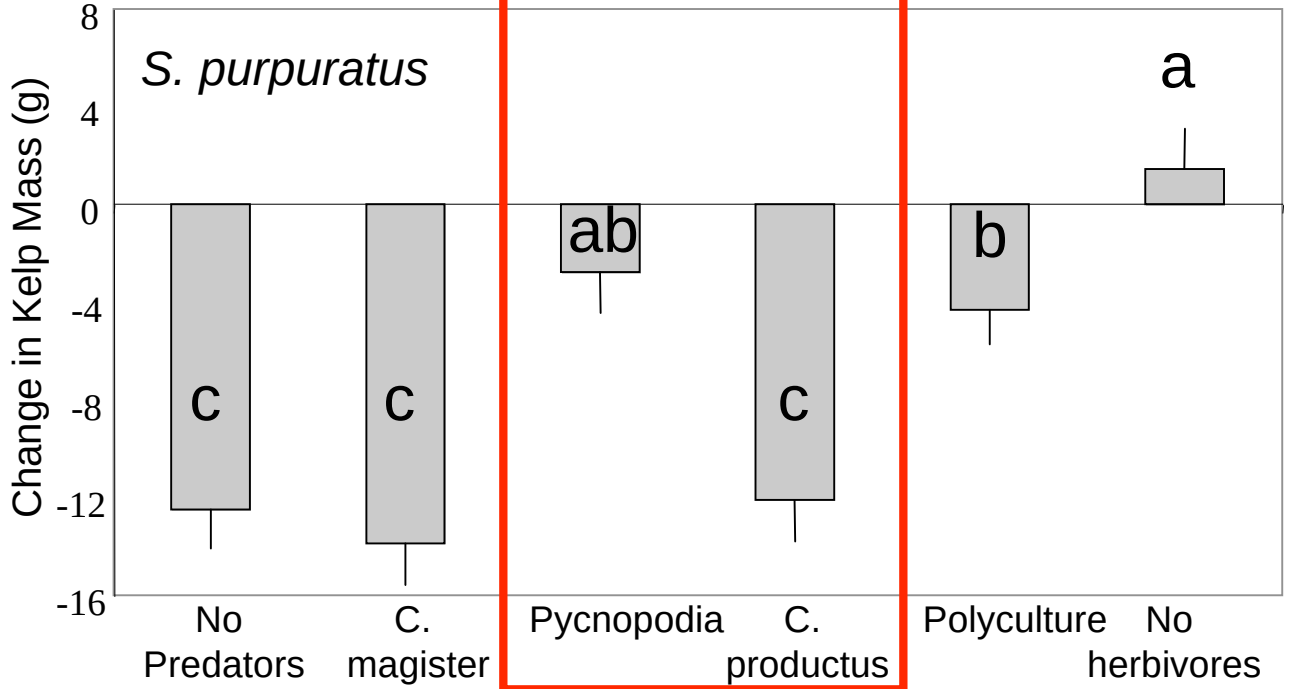
Experimentally isolate the effects of diversity: Increasing predator diversity benefits kelp



Byrnes, Stachowicz, et al. 2006, Ecology Letters

Complementary effects of predators on different prey species



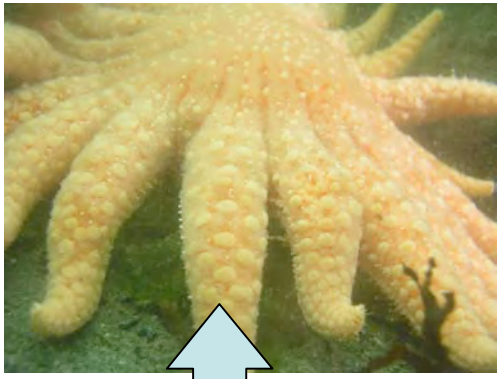


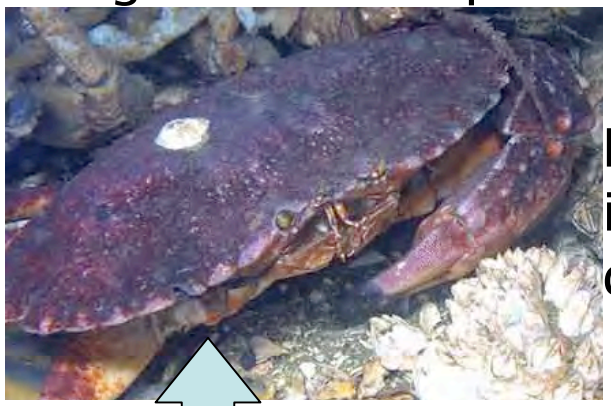
Diversity can buffer kelp forests both through redundancy and complementarity

The guild of invertebrates is redundant to sea otters…

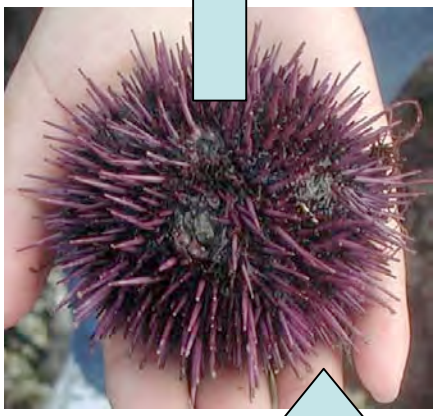
… but both crabs and seastars are needed to compensate for the loss of otters because of their complementary effect on herbivores.

Effects of diversity at a given level depend on diversity at other levels

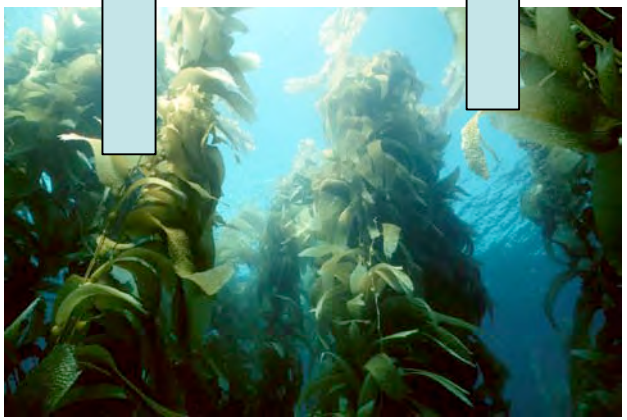




Predator diversity only important when there is a diversity of herbivores

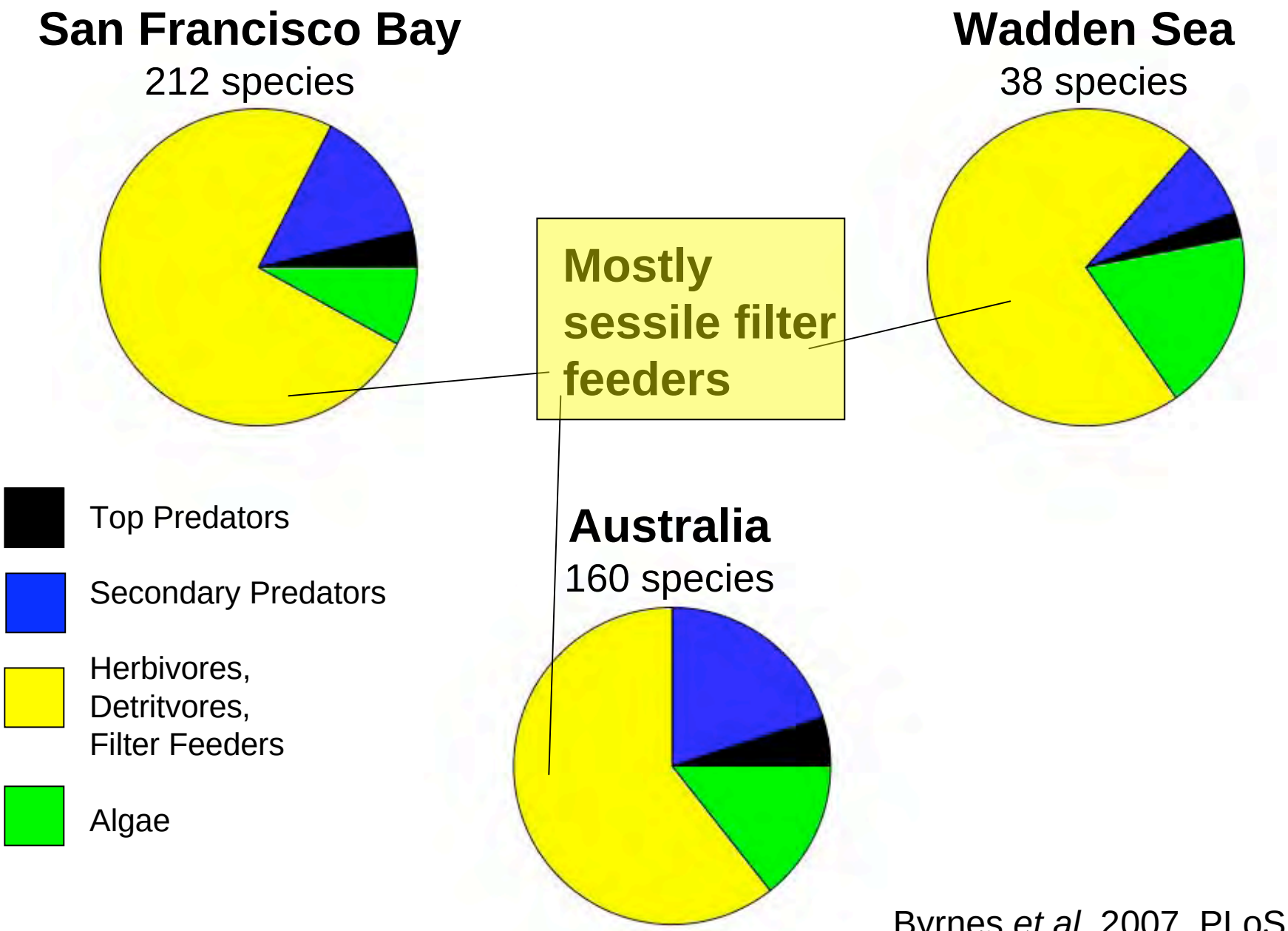


Predatory Crabs would be Unimportant if kelp crabs were absent



Lower trophic level diversity is increasing in some systems due to invasions…

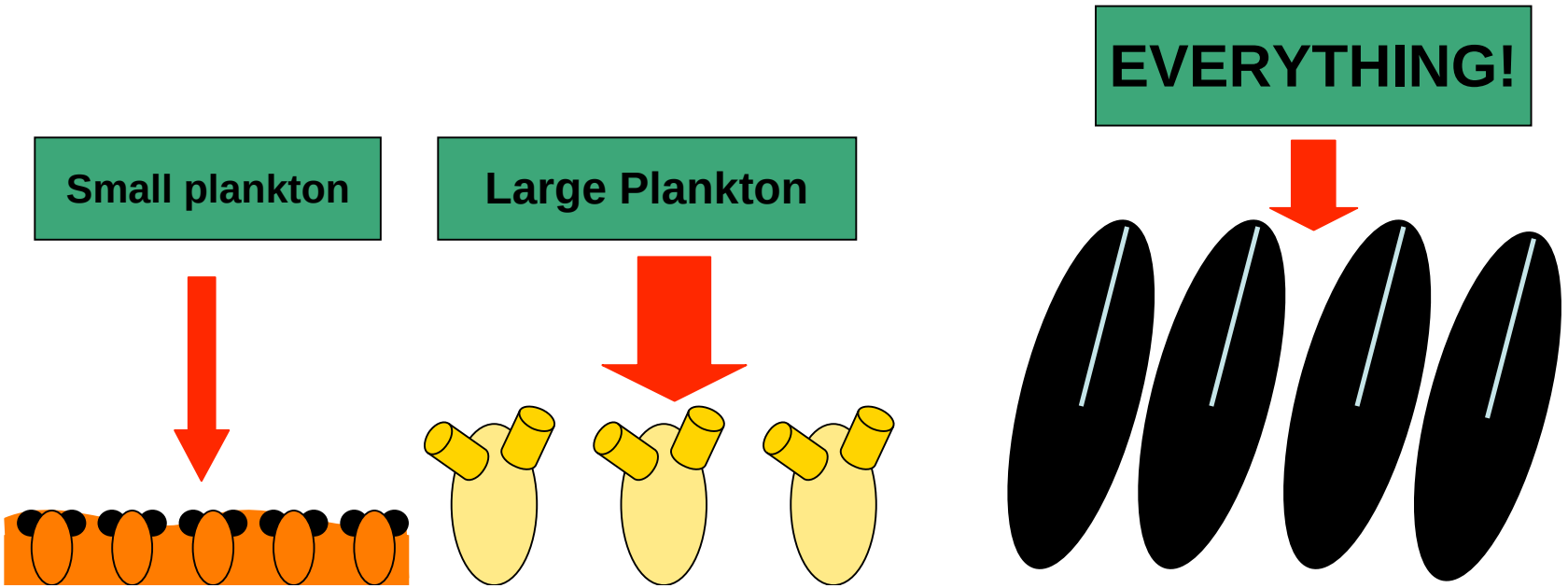
Invasions are dominated by herbivores and suspension feeders



Byrnes *et al.* 2007, PLoS One

Effects of increasing diversity of suspension feeding invertebrates

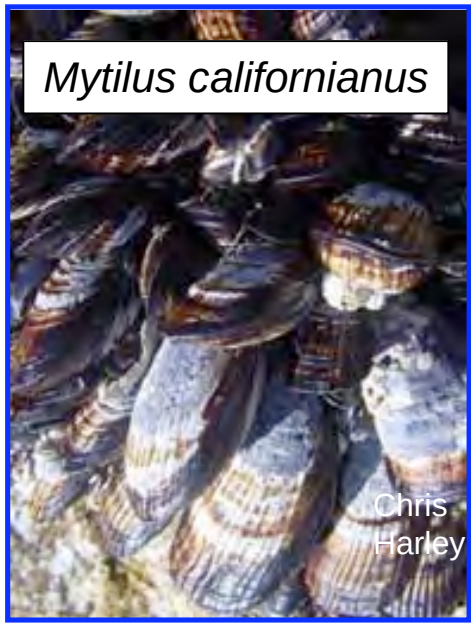
1) More species, greater filtration due to complmentarity?
2) Altered filtration due to shifting abundance of species with a dominant influence
3) Complementary seasonal phenologies?




Distaplia occidentalis


Botrylloides diegensis
SF Exotics Guide

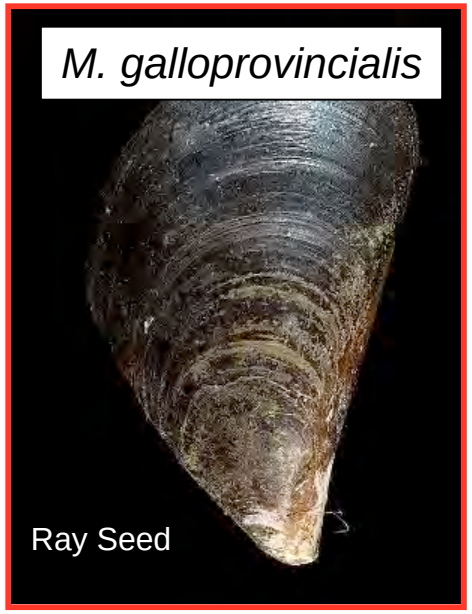

Ascidia ceratodes


Mytilus californianus
Chris Harley

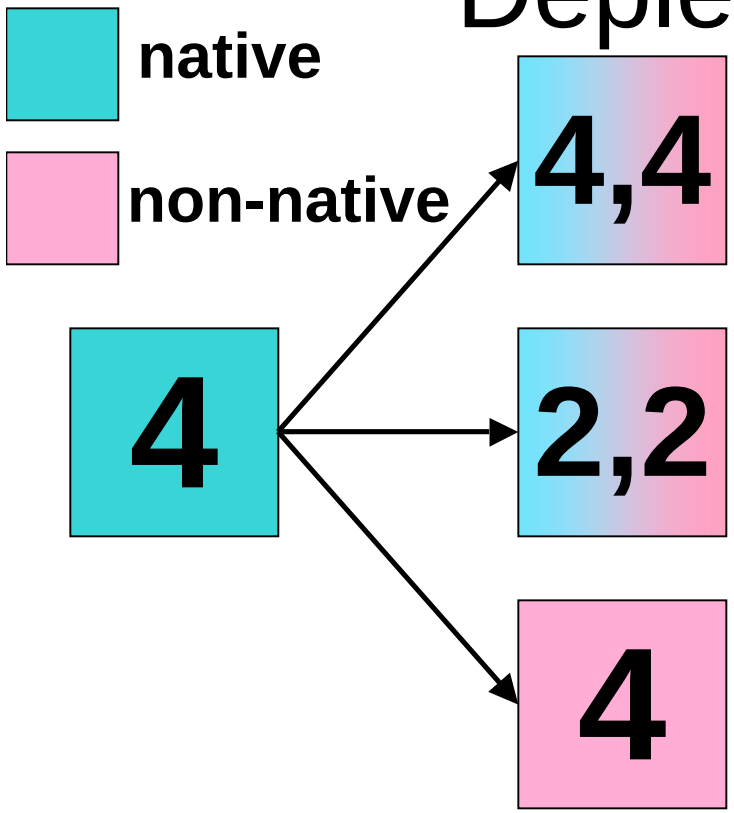

Didemnum sp. A


B. violaceous


Ciona intestinalis
MIT Sea Grant Exotics Guide


M. galloprovincialis
Ray Seed

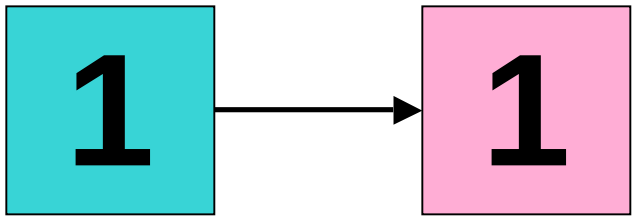
Species Diversity and Chlorophyll Depletion Experiment



How does filtration change when non-native species are added?

Are effects of non-native increases an artifact of increasing richness?

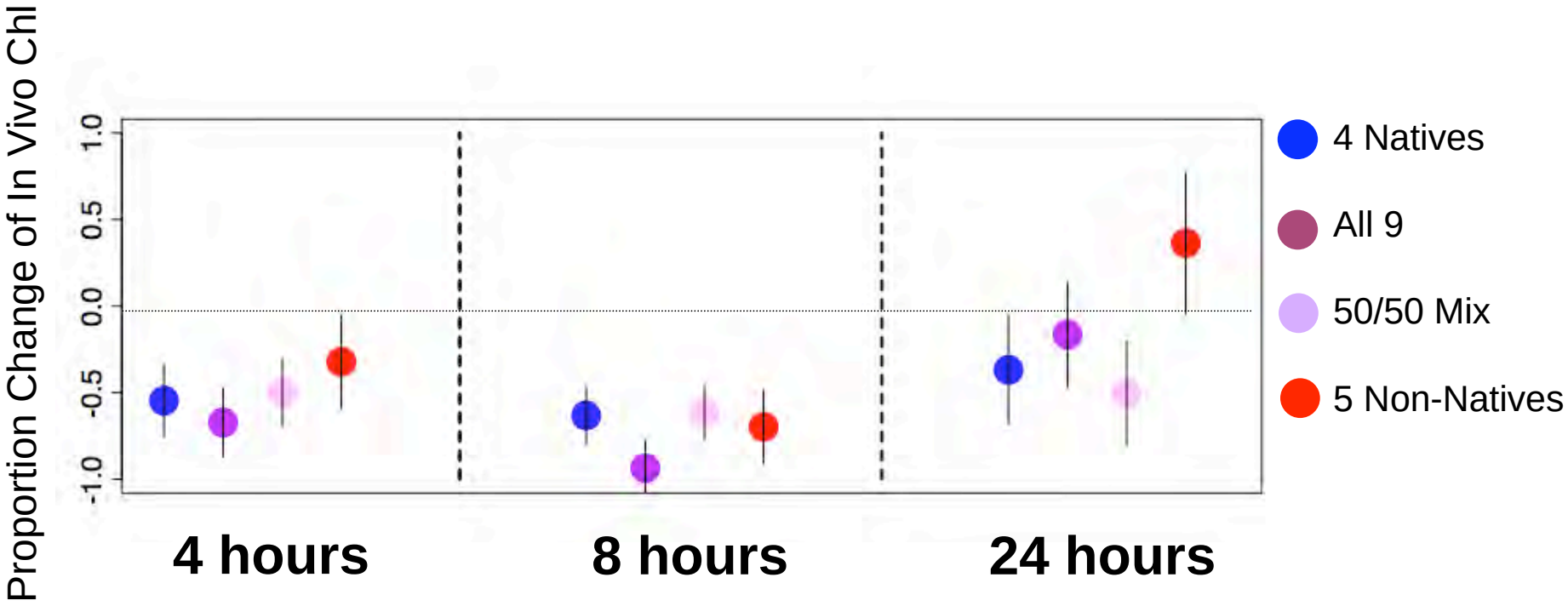
Are native and non-native mixtures different?



Do similar native and non-native species differ?

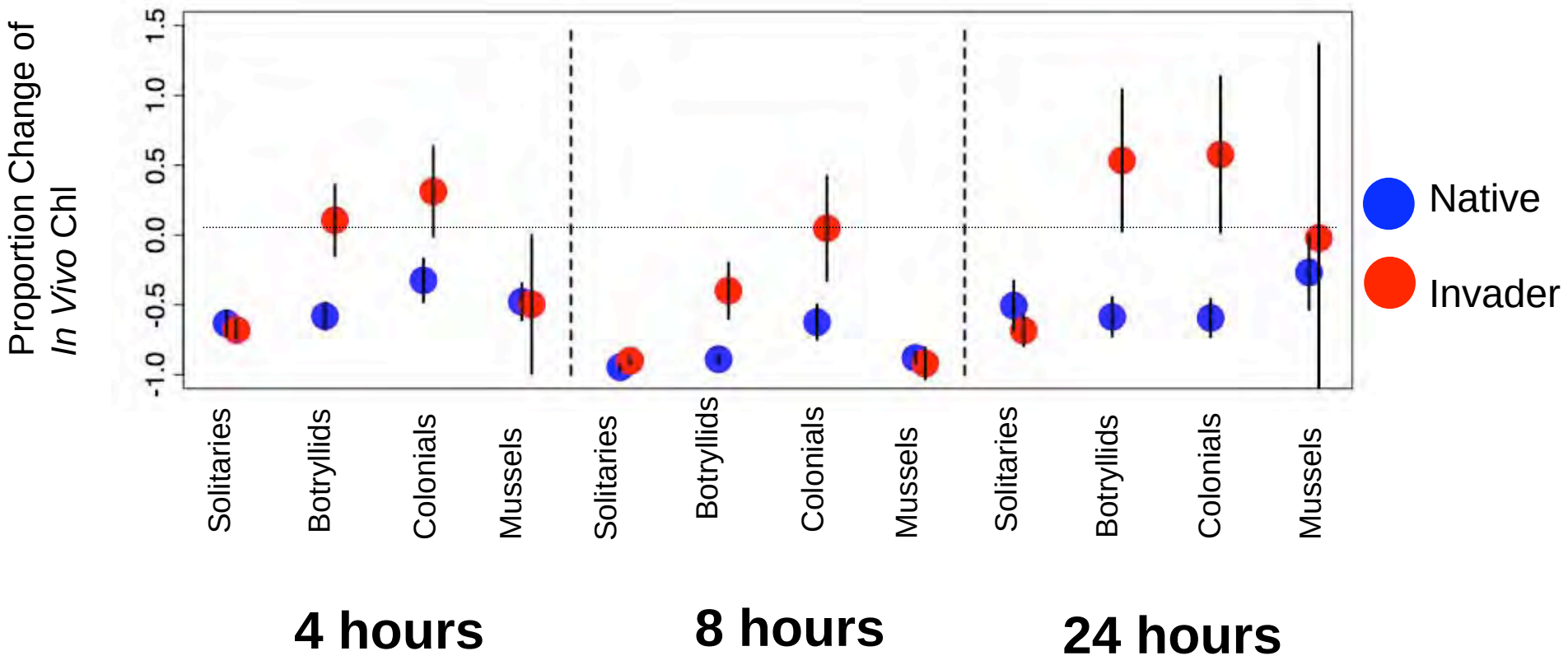
Total Space Covered Held Constant (replacement)

Some evidence that invader communities are less effective



Byrnes and Stachowicz 2009, Ecology Letters

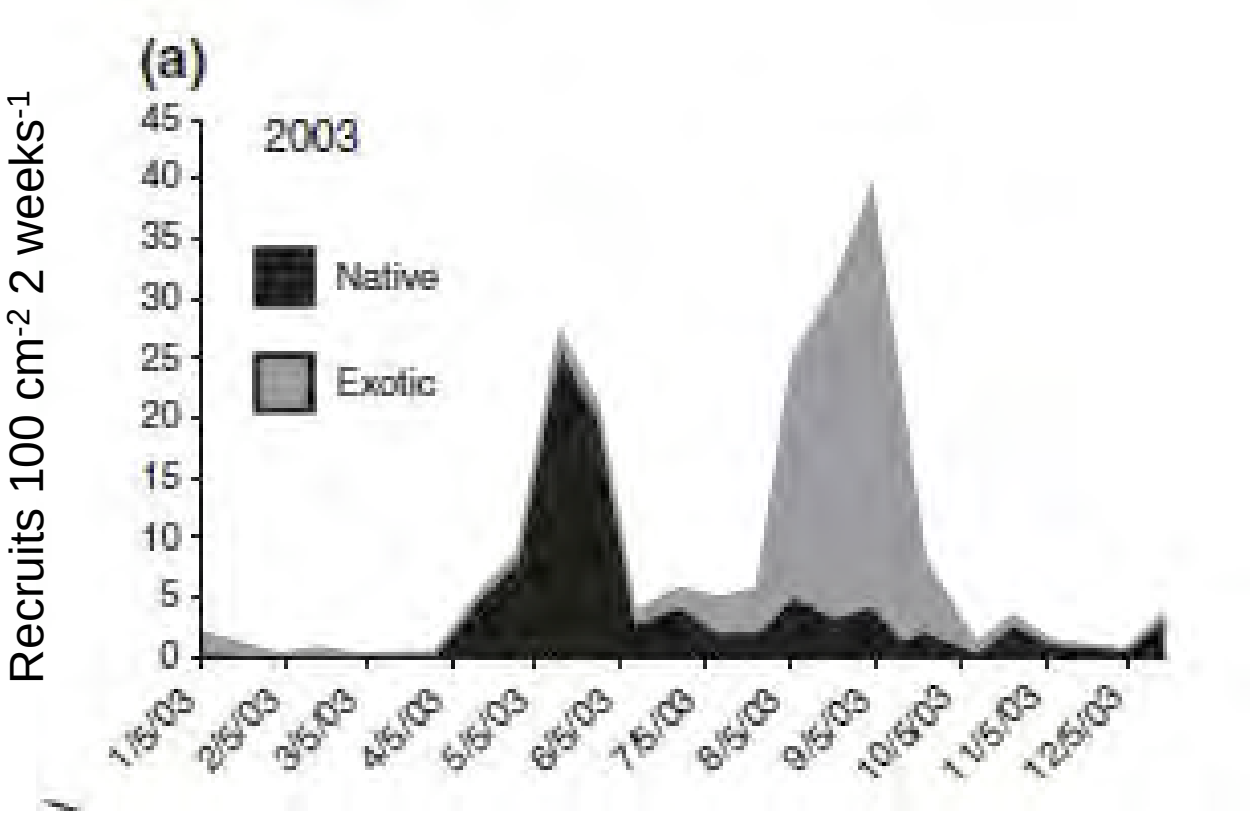
Some Individual Natives Filter more than Invaders



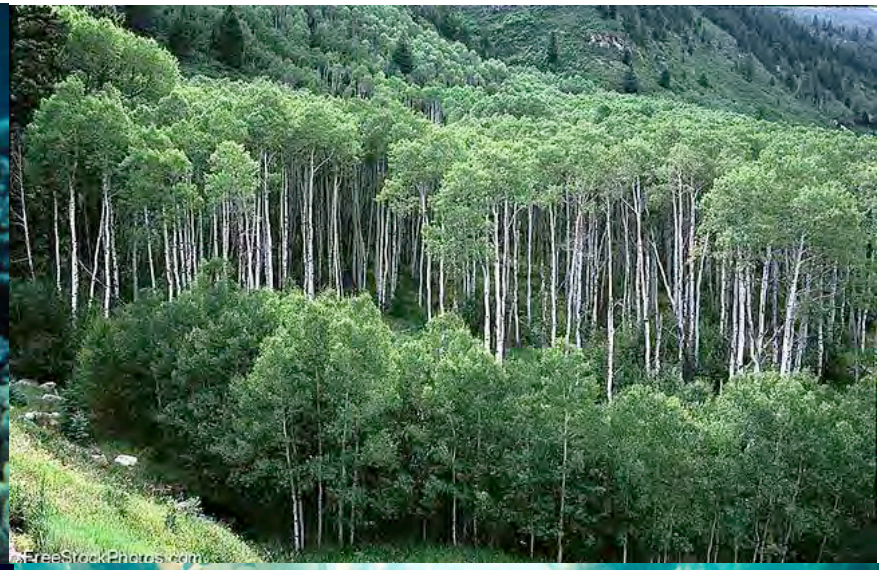
Byrnes and Stachowicz 2009, Ecology Letters

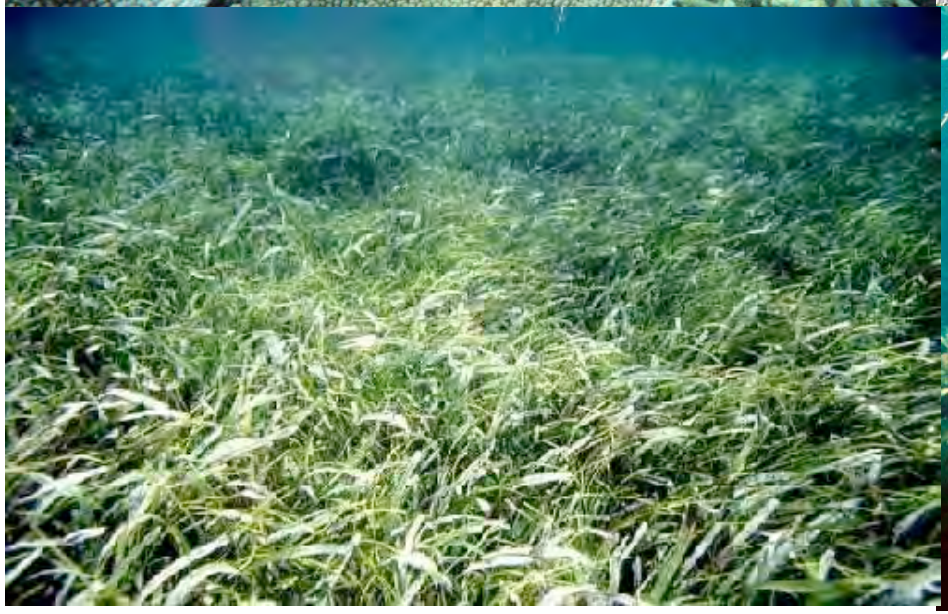
If diversity increases, filtration won't change much in the short term unless certain exotics replace certain natives (no evidence of this).

Complementary seasonal phenologies of natives and invaders could lead to increased consumption integrated over annual timescales.



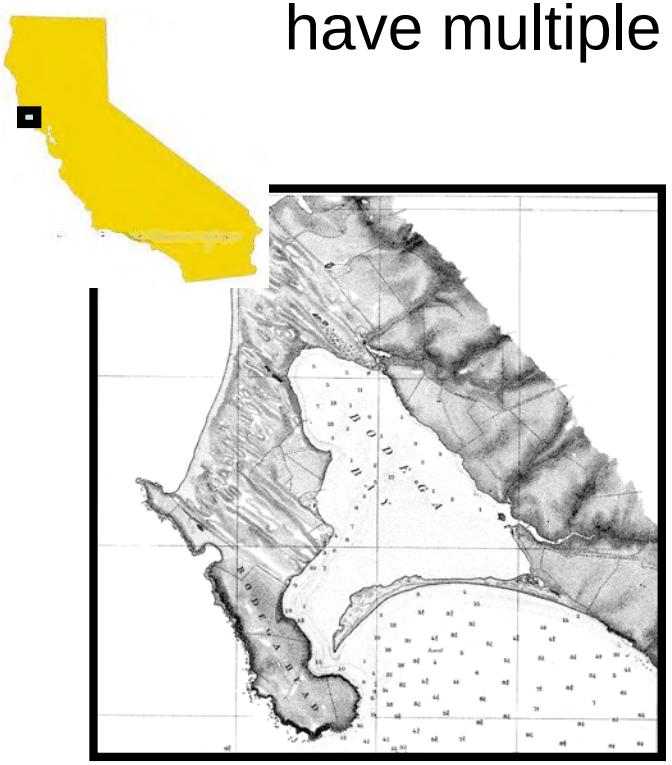
Many communities are dominated by single, “important” species





“Diversity” need not be just at the species level.

Functional diversity can occur at any level of biological organization: species may be redundant or species may have multiple complementary phenotypes

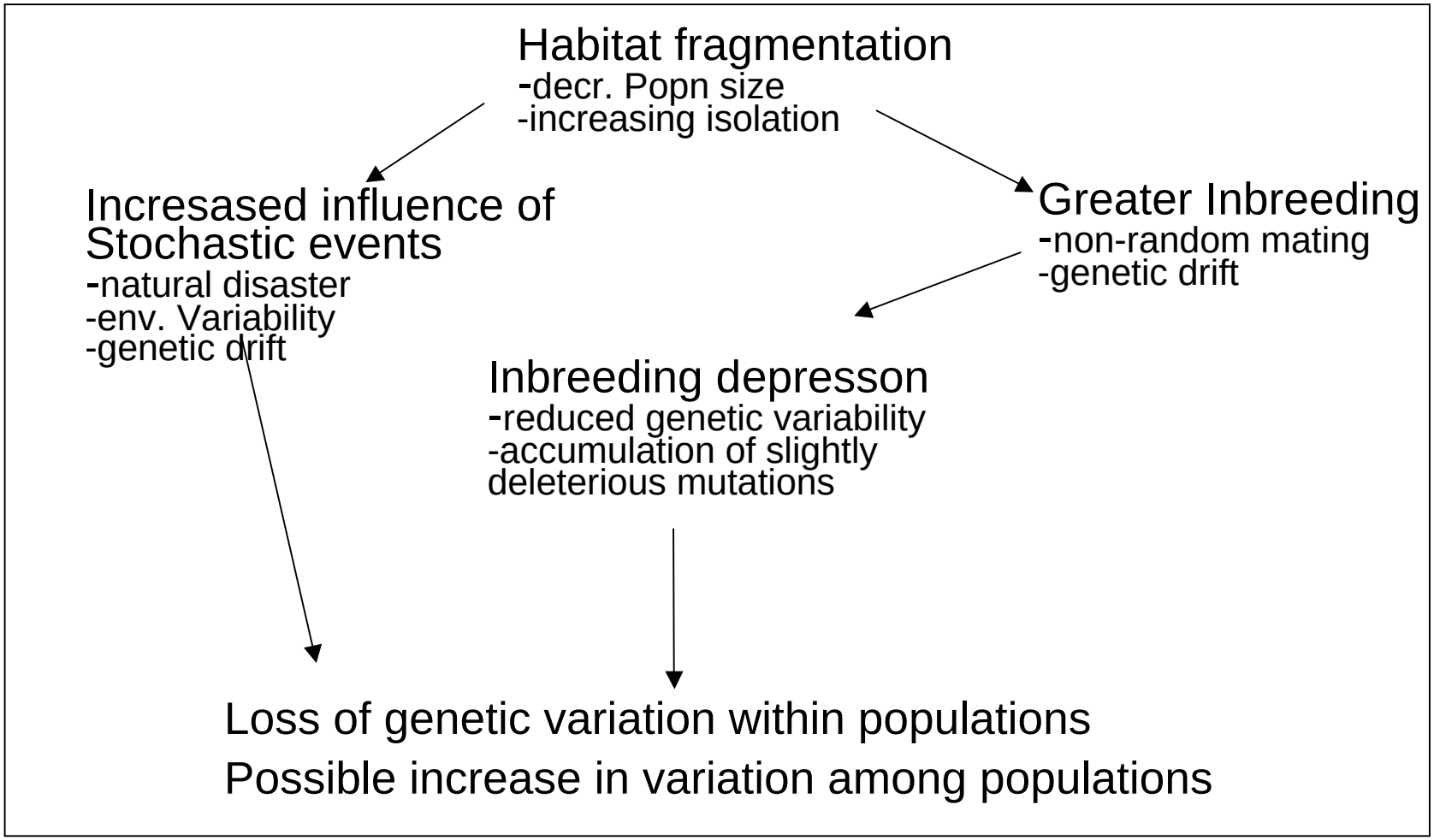


Eelgrass, *Zostera marina*

Use microsatellite DNA to identify distinct clones

Create plots that vary in genotypic richness (1-8 / m^2)

Human effects on genetic diversity of key species



Modified from Lienart, Journal for Nature Conservation 12 (2004) 53–72

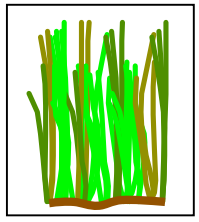
Shoot loss caused by goose grazing

BEFORE

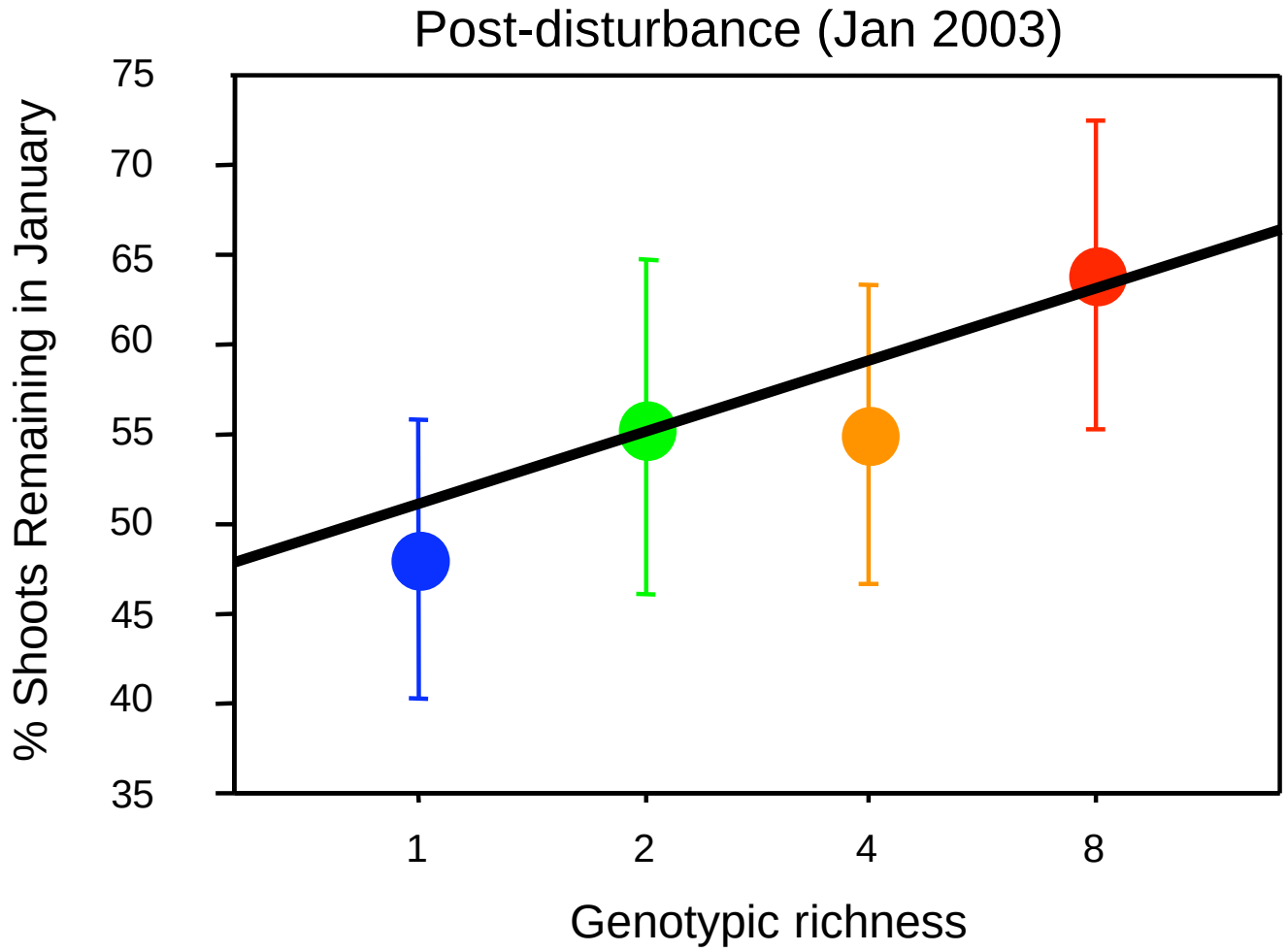
(December 2002)

AFTER

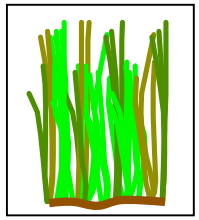
(January 2003)



Genotypic diversity increased shoot survival

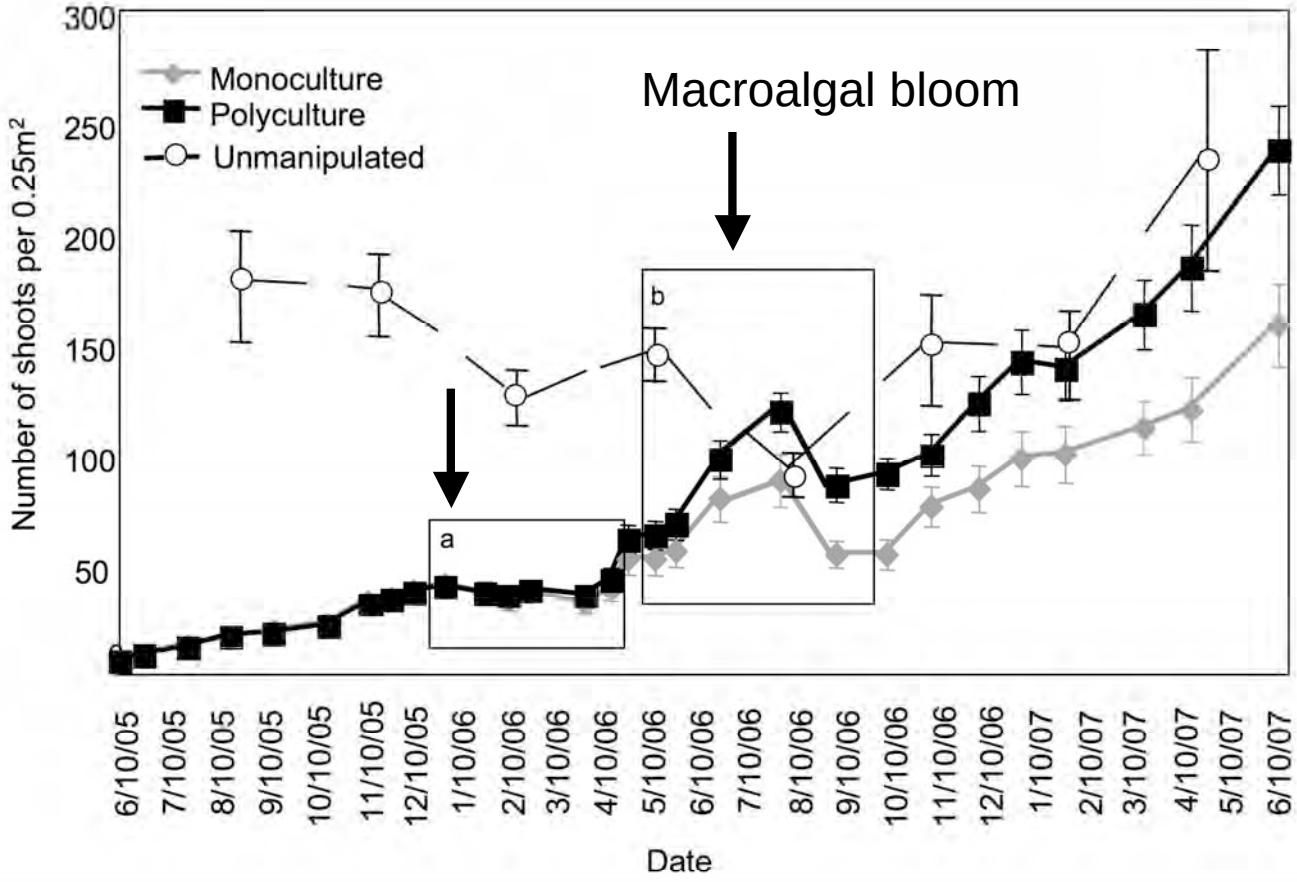


R^2=0.63; Richness P=0.05; Block*Richness P=0.93



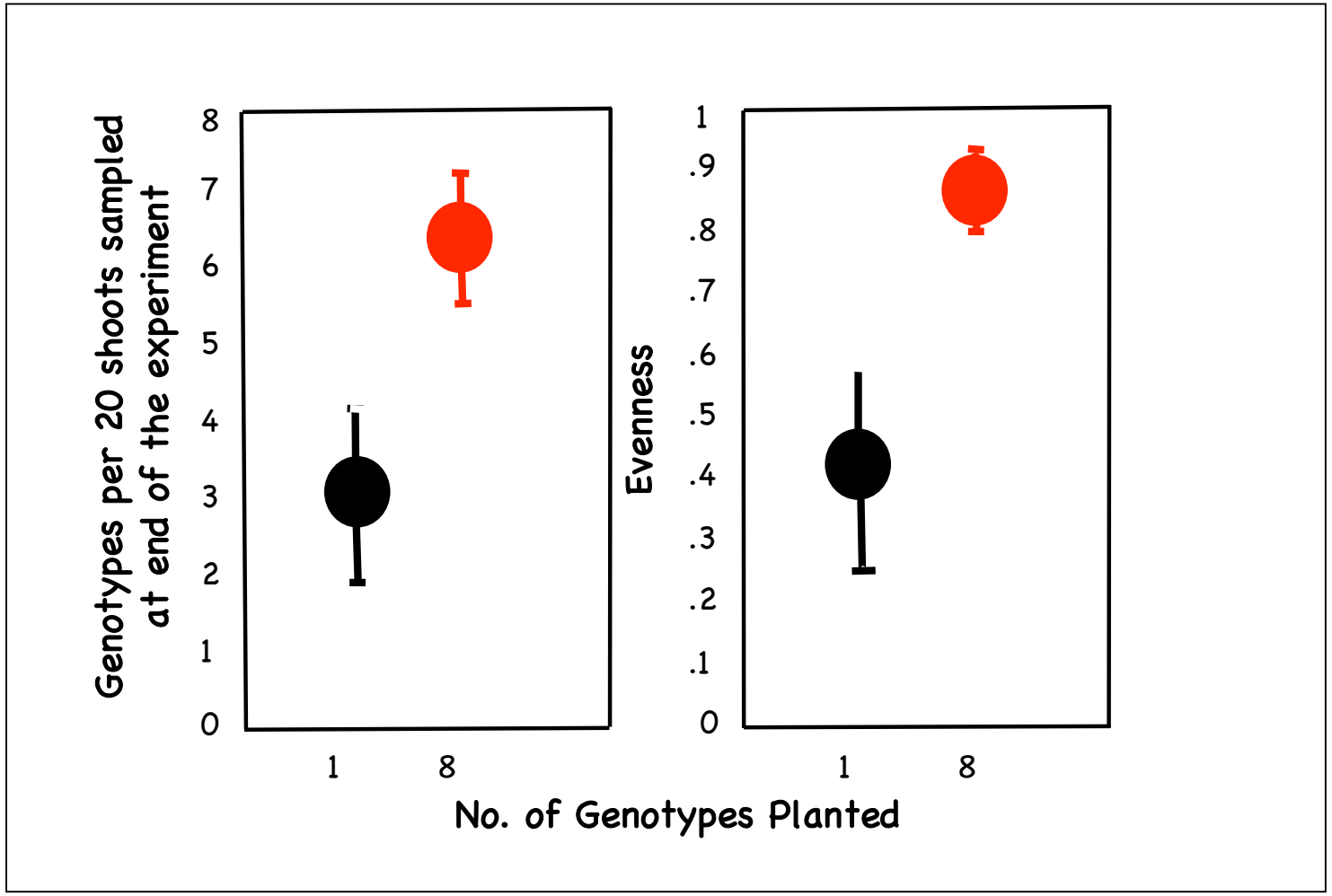
Hughes and Stachowicz 2004, PNAS

Field manipulations show increasing genotypic richness leads to greater biomass and recovery from algal blooms

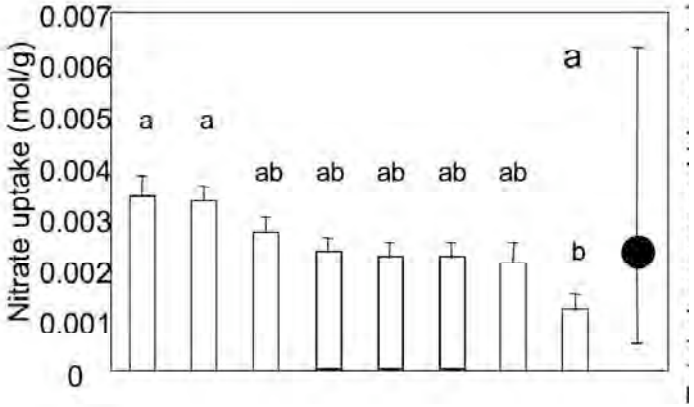


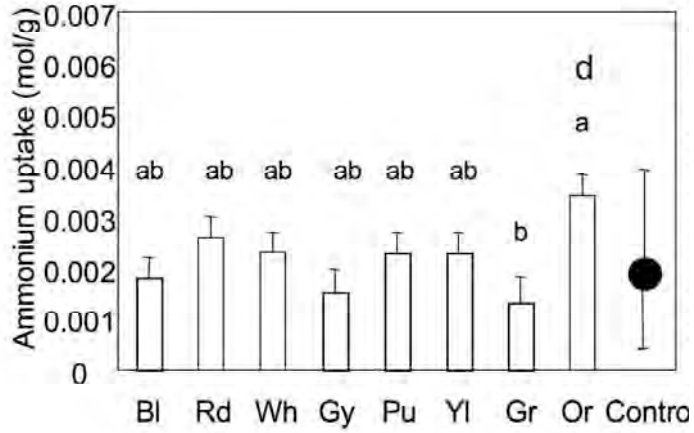
Williams 2001, Ecological Applications
Hughes and Stachowicz 2004, PNAS
Reusch et al. 2005 PNAS

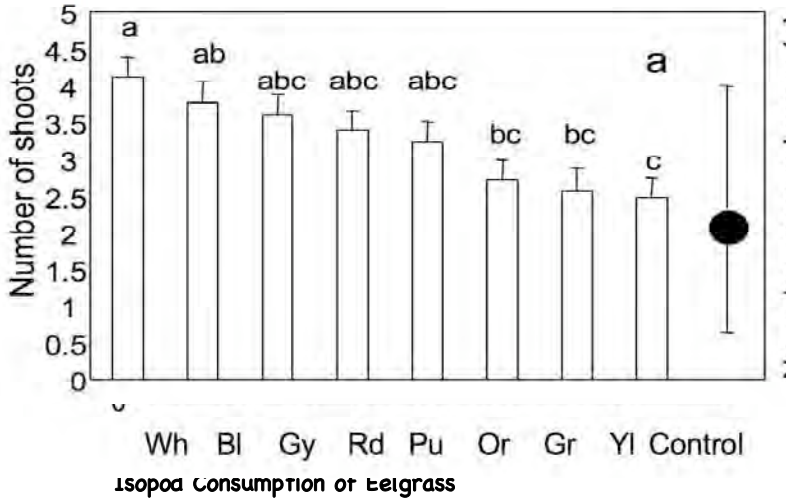
Mechanism? Diverse plots do not become dominated by a single resistant genotype



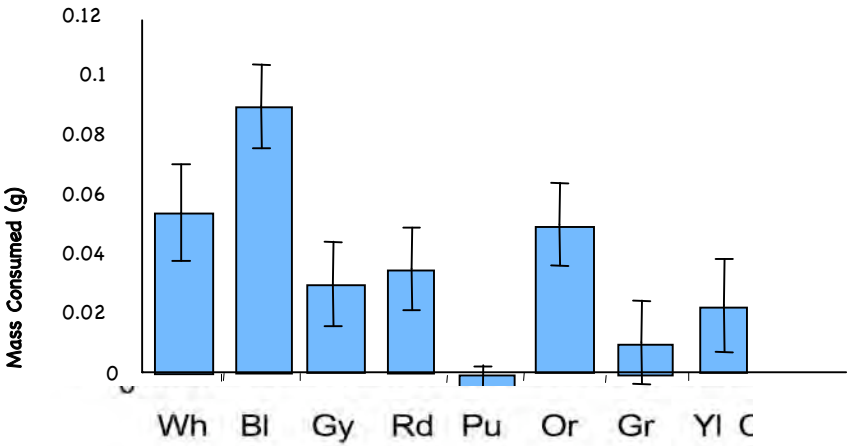
'niche-complementarity' among genotypes ?







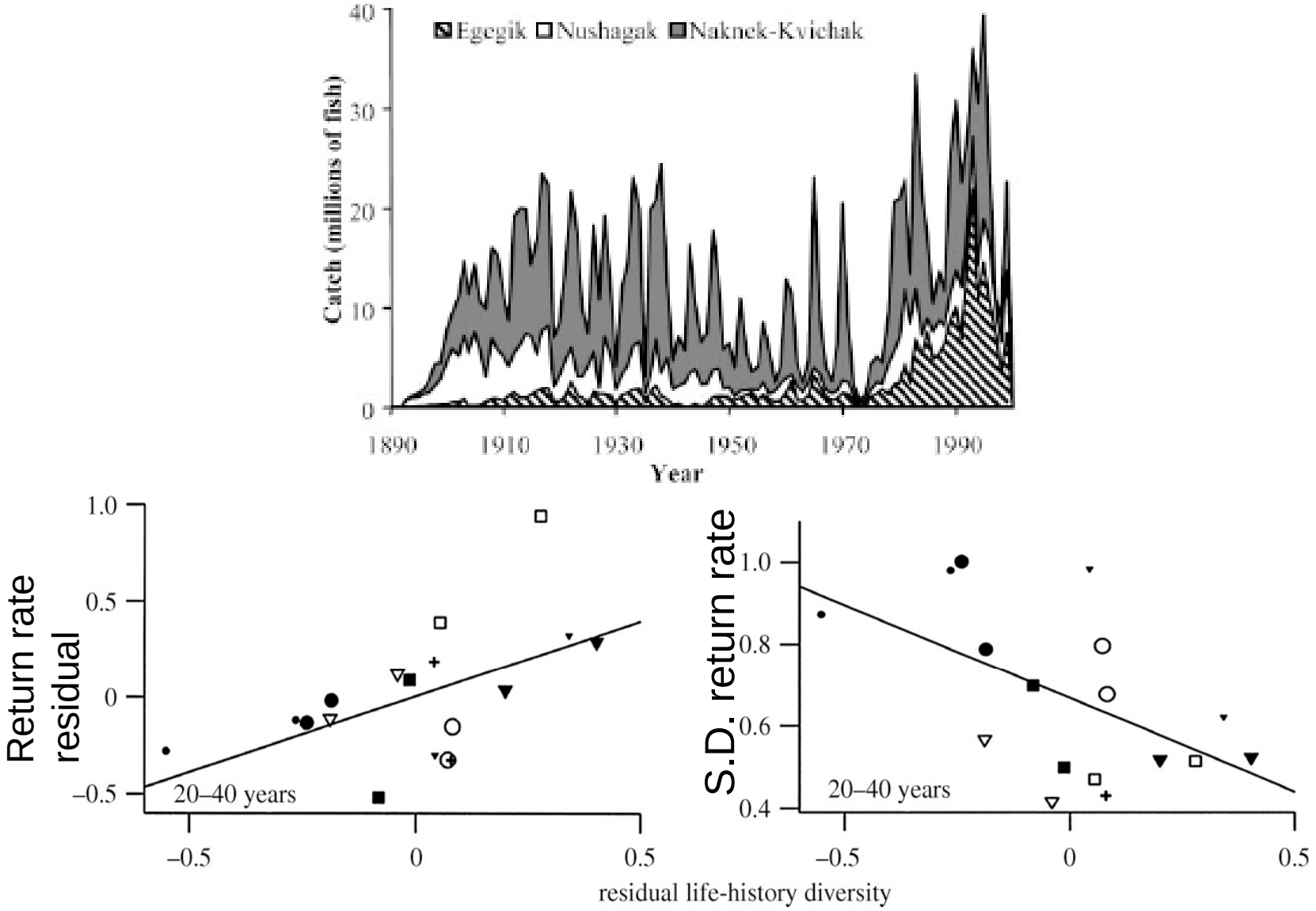
Isopod Consumption of Eelgrass



Genotypes with hi NO_3 uptake have lowest NH_4 uptake

Genotypes that grow fast are preferentially consumed by grazers

Life history diversity increases catch stability in salmon



Hilborn et al 2003 PNAS

Greene et al. 2009 Biology Letters

Summary: multiple stressors affect diversity, and this has consequences for ecosystem functioning

1. Human activities are combining to alter food web diversity
   -decreased richness of predators
   -increased richness of lower order consumers

2. Declining predator diversity can increase the strength of trophic cascades, reducing abundance of habitat-forming species.

3. Invasions by suspension feeders can alter community filtration rates, by ecological replacement or increasing diversity of seasonal phenologies

4. Genetic diversity in key species can enhance community resistance to and resilience from human impacts

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