Patterns of diversity loss and their potential consequences for marine communities

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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.

   ![Diagram showing resource state and utilization efficiency](image)

   - **Low diversity** = Low productivity, high resource availability.
   - **High diversity** = High productivity, low resource availability. "complementarity"
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)
"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?

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

Myers and Worm 2003
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

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

Global and Regional Extinctions

Consumer 37.6%
Consumer Omnivore 8.3%
Deposit Feeder 0.8%
Herbivore 9.8%
Algae 9.0%
Macroplanktivore 10.5%

San Francisco Bay Invasions

Deposit Feeder 9.4%
Consumer Omnivore 7.1%
Herbivore 2.4%
Predator 2.8%
Parasite 0.9%
Plant 5.7%
Algae 2.4%
Zooplankton 3.8%

Macroplanktivore 39.6%

Gulf of the Farallones Invasions

Deposit Feeder 9.9%
Consumer Omnivore 5.0%
Herbivore 7.5%
Predator 1.9%
Parasite 1.2%
Plant 1.9%
Algae 3.7%

Macroplanktivore 49.7%

Australian Invasions

Deposit Feeder 10%
Consumer Omnivore 10%
Herbivore 5%
Macroplanktivore 44.4%
Zooplankton 0.5%
Algae 13.8%
Predator 0.6%
Parasite 0.6%
Plant 0.6%
Trophic Distribution
Of Species in the
Wadden Sea

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?
Does predator diversity affect the stability of kelp forests?

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.

\[ p = 0.008 \quad r^2 = 0.407 \]

\[ p = 0.0506 \quad r^2 = 0.246 \]

\[ p = 0.0232 \quad r^2 = 0.316 \]
Experimental manipulation

RED ROCK CRAB
DUNGENESS CRAB
SUN STAR

TURBAN SNAILS
PURPLE URCHIN

KELP CRAB
GIANT KELP

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

Complementary effects of predators on different prey species

<table>
<thead>
<tr>
<th></th>
<th>No Predators</th>
<th>C. magister</th>
<th>Pycnopodia</th>
<th>C. productus</th>
<th>Polyculture</th>
<th>No herbivores</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in Kelp Mass (g) Pugettia</td>
<td>c bc</td>
<td>c</td>
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<td>bc</td>
<td>a</td>
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</tr>
<tr>
<td>Change in Kelp Mass (g) S. purpuratus</td>
<td>c c</td>
<td>ab</td>
<td>c</td>
<td>b</td>
<td>a</td>
<td></td>
</tr>
</tbody>
</table>

S. purpuratus

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.

**San Francisco Bay**
- 212 species
- Top Predators
- Secondary Predators
- Herbivores, Detritvores, Filter Feeders
- Algae

**Wadden Sea**
- 38 species
- Mostly sessile filter feeders

**Australia**
- 160 species

Byrnes et al. 2007, PLoS One
Effects of increasing diversity of suspension feeding invertebrates

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

Small plankton

Large Plankton

EVERYTHING!
**Distaplia occidentalis**

**Botrylloides diegensis**

**Ascidia ceratodes**

**Mytilus californianus**

**Didemnum sp. A**

**B. violaceous**

**Ciona intestinalis**

**M. galloprovincialis**
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

Proportion Change of\nIn Vivo Chl

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.

Use microsatellite DNA to identify distinct clones
Create plots that vary in genotypic richness (1-8 / m²)
Human effects on genetic diversity of key species

- Habitat fragmentation
  - decreased Popn size
  - increasing isolation

- Increased influence of Stochastic events
  - natural disaster
  - env. Variability
  - genetic drift

- Greater Inbreeding
  - non-random mating
  - genetic drift

- Inbreeding depression
  - reduced genetic variability
  - accumulation of slightly deleterious mutations

- Loss of genetic variation within populations
- Possible increase in variation among populations

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.
Mechanism? Diverse plots do not become dominated by a single resistant genotype.
"niche-complementarity" among genotypes?

Genotypes with high 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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