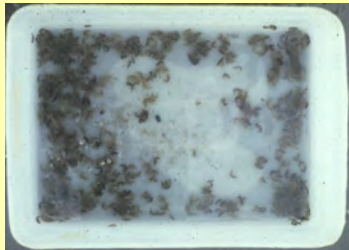




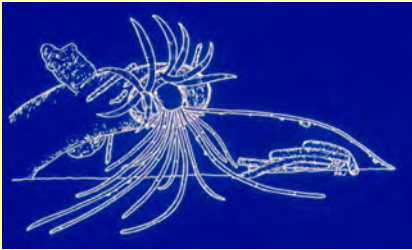
<p style="text-align: center;">High Deep-Sea Diversity, Effects of Pollution on Benthic Community Structure: West Falmouth Oilspill & Boston Harbor Pearson & Rosenberg vs. Hubbell's neutral model</p> <p style="text-align: center;">Class 13: Th Oct 14, 2009</p> <p style="text-align: right;">EEOS630</p>	<p>Slide 1 Goals of today's class</p> <p>NOTES:</p>
<p style="text-align: center;">Required reading, community structure</p> <p>Chapter 5: Global Patterns of Benthic Community Structure Especially Deep-Sea Diversity</p> <p>Etter, R.J. and L. S. Mullineaux. 2001. Deep-sea communities. Pp. 367-393 in M. D. Bertness, S. D. Gaines, and M. Hay ,Eds., Marine Community Ecology. Sinauer Associates, Sunderland, Massachusetts. 550 pp</p> <p>Gallagher, E. D. & K. E. Keay. 1998. Organism-sediment-contaminant interactions in Boston Harbor. Pp. 89-132 in K. D. Stolzenbach and E. E. Adams, eds., Contaminated Sediments in Boston Harbor. MIT Sea Grant College Program, Cambridge MA. 170 p. [There is a slightly expanded version of this document available as a pdf at http://www.es.umb.edu/edg/ECOS630/GallagherKeay98.pdf]</p> <p>Jumars, P. A. and E. D. Gallagher. 1982. Deep-sea community structure: three plays on the benthic proscenium. Pages 217-255 <i>in</i> W. G. Ernst and J. G. Morin, eds., The environment of the deep sea; Rubey Volume II. Prentice-Hall, Englewood Cliffs, N.J.</p> <p style="text-align: right;">EEOS630</p>	<p>Slide 2 Required reading, community structure</p> <p>NOTES:</p>
<p style="text-align: center;">Benthic Pollution Biology</p> <p>Chapter 6</p> <p>Gallagher, E. D. & K. E. Keay. 1998. Organism-sediment-contaminant interactions in Boston Harbor. Pp. 89-132 in K. D. Stolzenbach and E. E. Adams, eds., Contaminated Sediments in Boston Harbor. MIT Sea Grant College Program, Cambridge MA. 170 p. [There is a slightly expanded version of this document available as a pdf at http://www.es.umb.edu/edg/ECOS630/GallagherKeay98.pdf]</p> <p>Grassle, J. F. and J. P. Grassle. 1974. Opportunistic life histories and genetic systems in marine benthic polychaetes. J. Marine Research 32: 253-284.</p> <p>Grassle, J. F. and W. K. Smith. 1976. A similarity measure sensitive to rare species and its use in investigation of marine benthic communities. Oecologia 25: 13-22. also used for Project 1</p> <p>Rosenberg, R. 2001. Marine benthic faunal successional stages and related</p>	<p>Slide 3 Benthic Pollution Biology</p> <p>NOTES:</p>

<div data-bbox="292 168 730 327" data-label="Section-Header"> <h2>Competition in the soft-bottom benthos & the Lotka-Volterra model & Gause's principle</h2> </div> <div data-bbox="652 512 771 541" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="815 134 1427 254" data-label="Section-Header"> <h3>Slide 4 Competition in the soft-bottom benthos & the Lotka-Volterra model & Gause's principle</h3> </div> <div data-bbox="815 331 938 365" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="313 728 703 766" data-label="Section-Header"> <h2>Testing Succession Models</h2> </div> <div data-bbox="285 774 722 804" data-label="Text"> <p>Connell & Slatyer (1977), Gallagher <i>et al.</i> (1983)</p> </div> <div data-bbox="238 823 529 1020" data-label="List-Group"> <ul style="list-style-type: none"> • Enhancement experiment: Enhance the abundance of an early succession species <ul style="list-style-type: none"> • Facilitation if later succession species increased relative to control • Inhibition if later succession species decreased relative to control • Tolerance if no difference (the null model) • Removal experiment: Reduce the abundance of an early succession species <ul style="list-style-type: none"> • Facilitation if later succession species reduced • Inhibition if later succession species increased </div> <div data-bbox="542 823 714 1081" data-label="Figure"> </div>	<div data-bbox="815 695 1427 741" data-label="Section-Header"> <h3>Slide 5 Testing Succession Models</h3> </div> <div data-bbox="815 819 938 852" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="272 1218 755 1255" data-label="Section-Header"> <h2>A controlled removal experiment</h2> </div> <div data-bbox="280 1264 742 1293" data-label="Text"> <p>Eogammarus to play to role of Neill's (1975) <i>Alosa</i></p> </div> <div data-bbox="241 1295 597 1520" data-label="Image"> </div> <div data-bbox="237 1518 589 1591" data-label="Caption"> <p><i>Eogammarus confervicolus</i>, an epifaunal omnivorous gammarid amphipod</p> </div> <div data-bbox="600 1293 750 1579" data-label="Text"> <p>Neill (1975) studied competition among lake zooplankton by using a fish, <i>Alosa</i>, to selectively eliminate the dominant zooplankton</p> </div>	<div data-bbox="815 1184 1427 1230" data-label="Section-Header"> <h3>Slide 6 A controlled removal experiment</h3> </div> <div data-bbox="815 1308 938 1341" data-label="Text"> <p>NOTES:</p> </div>

<p><i>Eogammarus</i> is an omnivore</p> <p>900 <i>Eogammarus</i> in a 1-liter plastic container</p>  <p>EEOS630</p>	<p>Slide 7 <i>Eogammarus</i> is an omnivore</p> <p>NOTES:</p>
<p>Natural sediment enclosed in cut-away 5-gal buckets for 3 days; <i>Eogammarus</i> added to 2 buckets</p>  <p>EEOS630</p>	<p>Slide 8 Natural sediment enclosed in cut-away 5-gal buckets for 3 days; <i>Eogammarus</i> added to 2 buckets</p> <p>NOTES:</p>
<p>Buckets enclosed with 1-mm mesh to retain <i>Eogammarus</i></p> <p><i>Eogammarus</i>, the predator, removed after 3 days</p>  <p>EEOS630</p>	<p>Slide 9 Buckets enclosed with 1-mm mesh to retain <i>Eogammarus</i></p> <p>NOTES:</p>

***Hobsonia florida*, an ampharetid polychaete worm, the major prey**

Tentaculate surface deposit feeder



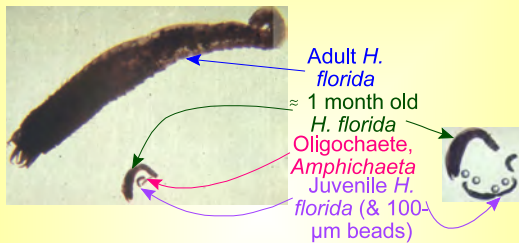
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Slide 10 *Hobsonia florida*, an ampharetid polychaete worm, the major prey

NOTES:

In May, most of the *H. florida* were very small

≈ 90% pass through a 250-μm mesh sieve

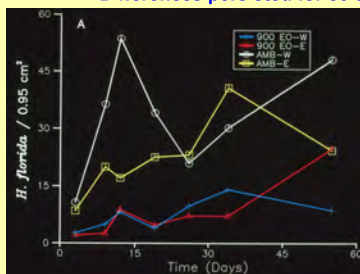


Slide 11 In May, most of the *H. Florida* were very small

NOTES:

Eogammarus* reduced day 3 abundances of *H. florida

Differences persisted for 55 days



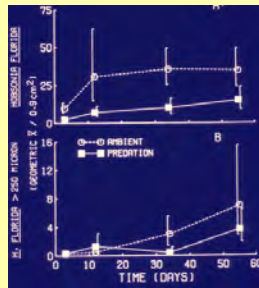
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Slide 12 *Eogammarus* reduced day 3 abundances of *H. Florida*

NOTES:

Only juvenile *H. florida* affected

Juveniles, < 250- μ m width, reduced by *Eogammarus*



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Slide 13 Only juvenile *H. Florida* affected

NOTES:

Asexually reproducing naidid oligochaete: *Amphichaeta leidigii*

Oligochaetes similar in size to *H. florida* juveniles



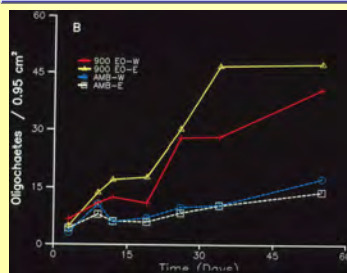
Brian Hentschel would later show that *Amphichaeta leidigii* and *H. florida* juveniles compete small benthic diatoms for food

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Slide 14 Asexually reproducing naidid oligochaete: *Amphichaeta leidigii*

NOTES:

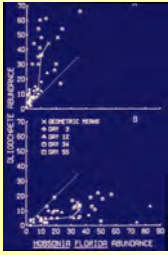
Oligochaetes exhibited 'logistic' growth in predator treatments with low *H. florida* abundances



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Slide 15 Oligochaetes exhibited 'logistic' growth in predator treatments with low *H. Florida* abundances

NOTES:

<p>Two distinct population growth trajectories</p> <p>In predator treatment, oligochaetes > <i>H. florida</i> In natural community, <i>H. florida</i> > Oligochaetes</p>  <p>EEOS630</p>	<p>Slide 16 Two distinct population growth trajectories</p> <p>NOTES:</p>
<p>What is competition?</p> <ul style="list-style-type: none"> • Competition: 'the shared utilization of a resource that is demonstrably in short supply.' • "competition is occurring if the increase in the growth rate of one population leads to the decline in the growth rate of another." <ul style="list-style-type: none"> ▸ "intraspecific competition occurs if increasing density of one population leads to a decrease in the per capita growth rate or density" • Density-dependent limits on abundance or growth is the key element 	<p>Slide 17 What is competition?</p> <p>NOTES:</p>
<p>Types of competition</p> <p>Exploitative ('scramble') vs. Interference</p> <p>In exploitative, or scramble competition, the effects of competition are caused by the consumption of the shared resource.</p> <p>In interference competition, one individual or group of individuals prevents another individual or group of individuals from gaining access to the resource.</p> <p>EEOS630</p>	<p>Slide 18 Types of competition</p> <p>NOTES:</p>

Competition vs. Predation vs. Density-independent control

- Competition for resources is the key factor limiting population growth:
 - Lack's & Darwin's finches
 - A. J. Lotka's logistic growth
 - Volterra-Lotka competition models (1926, 1928) & Gause's (1930) competitive exclusion principle
 - Connell's barnacles crushing each other in the Scottish intertidal
- Predation is the key limiting factor
- Andrewartha & Birch (1954): Neither factor controls populations. It is climate & the environment

Slide 19 Competition vs. Predation vs. Density-independent control

NOTES:

Lotka-Volterra competition

An extension of the logistic equation: invoked to explain high-deep sea diversity in both equilibrium and non-equilibrium explanations

$$\begin{aligned}\frac{dN_1}{dt} &= r_1 N_1 \left(1 - \frac{N_1 + \alpha_{12} N_2}{K_1} \right) \\ \frac{dN_2}{dt} &= r_2 N_2 \left(1 - \frac{N_2 + \alpha_{21} N_1}{K_2} \right)\end{aligned}$$

where, α = Interspecific competition coefficient.
 K = Carrying capacity.
 r = maximum per capita growth rate.

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Slide 20 Lotka-Volterra competition

NOTES:

Model Estimates

Interspecific competition coefficients ≈ 1
 See Gallagher *et al.* (1990) for fitting methods

Taxon	Doubling Time	Carrying Capacity	Competition Coefficient (α_{ij})
<i>Oligochaetes</i>	5.8 Days	57	1.005
<i>Nobsonia florida</i>	2.8 Days	45	0.857

Note that the interspecific competition coefficients make these two taxa competitively equivalent species

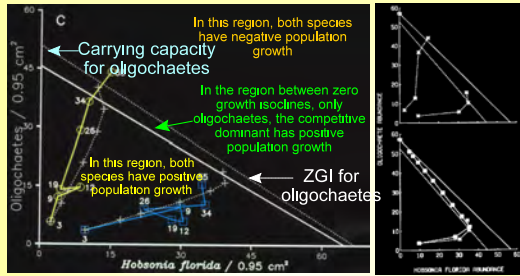
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Slide 21 Model Estimates

NOTES:

Trajectories fit by Lotka-Volterra model

Hutchinson's race to the zero-growth isoclines

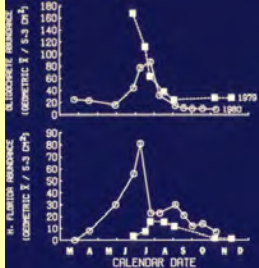


Slide 22 Trajectories fit by Lotka-Volterra model

NOTES:

Ambient community: 1979 v. 1980

Oligochaetes & *H. florida* appear to be competitively equivalent species



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Slide 23 Ambient community: 1979 v. 1980

NOTES:

Corophium salmonis, a large interface feeder, recruits to the sandflat each July AS ADULTS

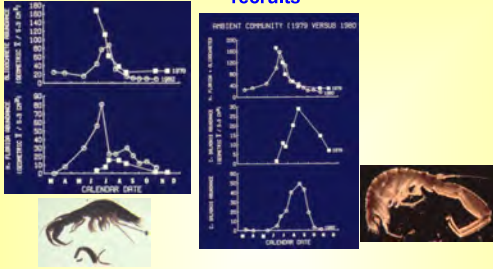


Slide 24 Corophium salmonis, a large interface feeder, recruits to the sandflat each July AS ADULTS

NOTES:

Ambient community: 1979 v. 1980

Oligochaetes & *H. florida* appear to be competitively equivalent species & both crash as *C. salmonis* recruits

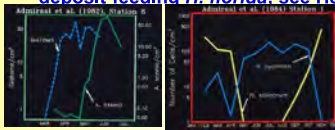


Slide 25 Ambient community: 1979 v. 1980

NOTES:

What is the limiting resource for oligochaetes & juvenile *H. florida*? Small benthic diatoms

The juvenile stage is a competitive bottleneck for the deposit-feeding *H. florida*; see Hentschel & Jumars



Admiraal et al. (1984): *Amphichaeta sannio* [regarded as identical to *A. leidigii* by Baker] blooms follow the diatom blooms on Dutch mudflats; *N. pygmaea*, a diatom resistant to digestion, takes over the diatom community

Slide 26 What is the limiting resource for oligochaetes & juvenile *H. Florida*? Small benthic diatoms

NOTES:

Case Study 5: High deep-sea diversity

See Jumars & Gallagher (1982) & Etter & Mullineaux

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Slide 27 Case Study 5: High deep-sea diversity

NOTES:

Milestones in deep-sea diversity

Documenting High Deep-Sea diversity

- 1846 Forbes dredged shells from the abyss, indicating that there is life in the deep sea.
- 1873-1876 Challenger expedition
 - Dredged animals from 5500 m to 1880
 - Thomas: The deep sea fauna is stable and ancient, containing the ancestral forms of many shallow water taxa.
- 1967 Hessler and Sanders
 - First quantitative demonstration of high deep-sea diversity.
 - Gayhead MA to Bermuda transect.

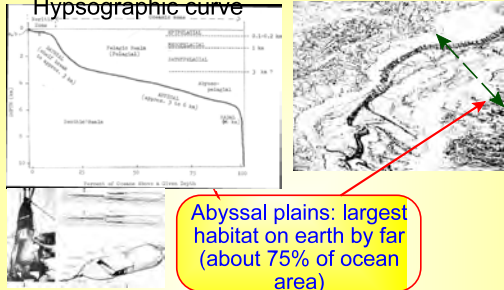
Slide 28 Milestones in deep-sea diversity

NOTES:

High deep-sea diversity

Gayhead to Bermuda transect: Sanders & Hessler 1967

Hypsographic curve



Abyssal plains: largest habitat on earth by far (about 75% of ocean area)

Slide 29 High deep-sea diversity

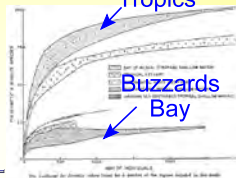
NOTES:

Sanders-Hurlbert rarefaction

Sanders (1968) & Hurlbert (1971)

- Each sample is plotted as a rarefaction curve, with the end being the observed number of species and individuals
- The expected number of species at a smaller, or 'rarefied' sample size is noted $E(S_n)$, with n being the rarefied sample size
- Hurlbert corrected Sanders' algorithm using the hypergeometric distribution

Soft-bottom benthic diversity

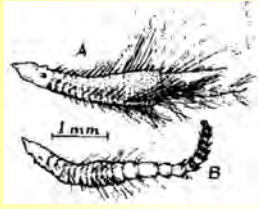


Slide 30 Sanders-Hurlbert rarefaction

NOTES:

Deposit-feeding polychaetes may be the most species-rich group on earth (10^7 - 10^8 species; Grassle & Maciolek, 1992)

Chaetozone, a surface deposit feeder typical of the deep sea.



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Slide 31 Deposit-feeding polychaetes may be the most species-rich group on earth (107-108 species; Grassle & Maciolek, 1992)

NOTES:

Jumars & Fauchald strategies

50:50 surface and subsurface feeders in deep sea
Discretely motile Surface Feeding

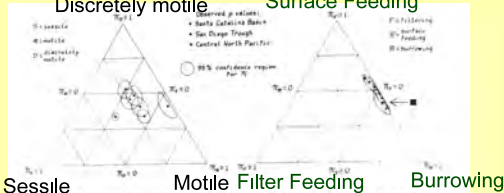


Fig. 6. Triangular chart presentation of feeding strategy variation by location for the deep-sea samples. Only the values $\epsilon = 0$ (sides of triangle) and $\epsilon = 1$ (vertices of triangle) are labeled, but isopleths correspond to those of Figure 4 (left).
Data from Abyssal Pacific: Apparent selection to pulsed food input with food caching

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Slide 32 Jumars & Fauchald strategies

NOTES:

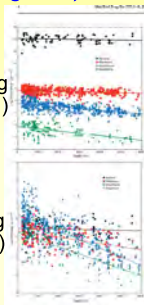
Global distribution of biomass

Rex et al. (2006, Marine Ecol. Prog. Ser.)



Log (abund)

Log (biomass)

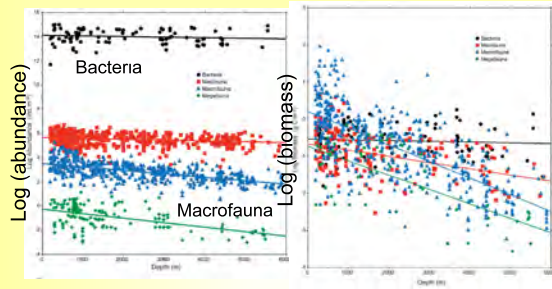


Slide 33 Global distribution of biomass

NOTES:

Abundance & Biomass

Rex et al. (2006, MEPS)

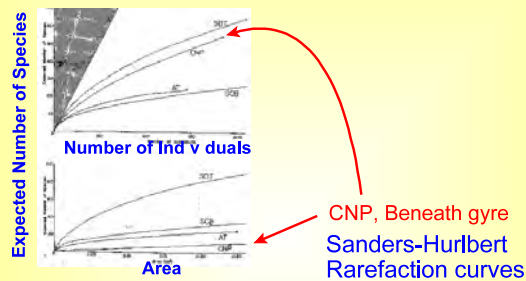


Slide 34 Abundance & Biomass

NOTES:

High Deep-Sea α diversity

Hurlbert's $E(S_n)$ highest in San Diego Trough & Central North Pacific, under gyre.



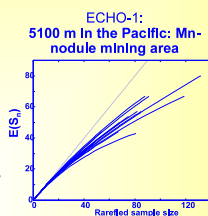
Slide 35 High Deep-Sea α diversity

NOTES:

High deep-sea diversity

Grassle & Maciolek (1992)

- Analysis of the rate at which new species being added along a transect in the North Atlantic deep sea: 1 species every 0.5 m²
- 10⁵ species globally estimated based on beta diversity in the North Atlantic
- Since, abundances lower in the abyssal Pacific, lowered estimate to 10⁴ species
 - But note that beta diversity appears to be much higher in the Pacific than in the Atlantic Ocean
- Far higher species richness than any other biome on earth



Slide 36 High deep-sea diversity

NOTES:

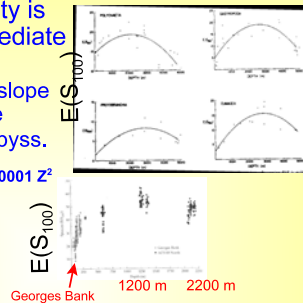
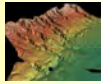
Slope & rise diversity> abyss

Rex (1973); Etter & Mullinaux (2001)

- Deep-sea diversity is highest at intermediate depths

- ▶ Maximum at lower slope and continental rise
- ▶ declining into the abyss.

- $E(S_{100}) = 14.6 + 0.004 Z - 0.000001 Z^2$
- ▶ $r = 0.68$



Slide 37 Slope & rise diversity> abyss

NOTES:

Sanders' Stability-time hypothesis

Proposed in 1968 American Naturalist

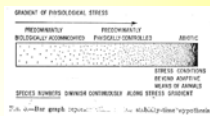
- The deep sea is 10's of millions of years old in the N. Atlantic and older still in the Pacific.

- Deep sea is the most stable environment on earth

- Animals evolve adaptations to the finest dimensions of the niche, allowing coexistence

- "We might expect stenotopy, complex behavior of rather specific and stereotyped kinds, and the possibility of specialization to specific foods, hiding places, hunting methods, and environmental periodicities—in short to the details of the most significant parts of the environment."

- Note that Whittatch (1980) analyzes the relation between resource specialization on food in intertidal benthic communities

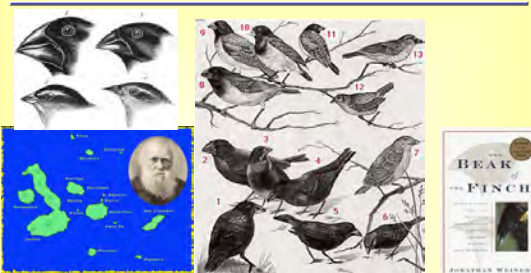


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Slide 38 Sanders' Stability-time hypothesis

NOTES:

Sanders (1968): adaptive radiation to the finest dimensions of the niche, like Darwin's finches



Slide 39 Sanders (1968): adaptive radiation to the finest dimensions of the niche, like Darwin's finches

NOTES:

Sanders (1968): adaptive radiation to the finest dimensions of the niche, like Darwin's finches



Slide 40 The cropper hypothesis

NOTES:

Spatial heterogeneity

Grassle & Sanders (1973), Jumars (1975 a & b, 1976)

- Written as a rebuttal to Dayton & Hessler's (1972) cropper hypothesis based on predation and disturbance
- Grassle & Sanders (1973): little evidence for 'cropping' in the deep-sea
- **Habitat specialization, aided by deep-sea spatial heterogeneity** may be the key to maintaining high deep-sea diversity
- Jumars (1975a & b, 1976, Jumars & Eckman 1980): Deep sea may be the most spatially heterogeneous environment on earth.

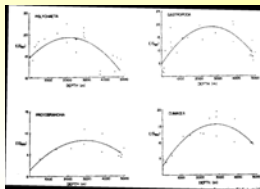
Slide 41 Spatial heterogeneity

NOTES:

Explanations based on competition

Interaction of predation and competition: Increasing predation in the deep sea may keep competitors below their carrying capacity, allowing coexistence.

- 1976 Rex Both predation and competition control the gradient in species richness producing an intermediate peak
- 1976 Menge and Sutherland: Predation and competition interact to produce high deep-sea diversity
- 1979 Huston's dynamic equilibrium model

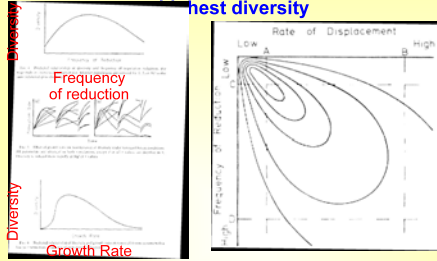


Slide 42 Explanations based on competition

NOTES:

Huston's 1979 dynamic (non- equilibrium) model

Based on Lotka-Volterra competition equations;
Intermediate disturbance & growth rates lead to
nest diversity



Slide 43 Huston's 1979 dynamic

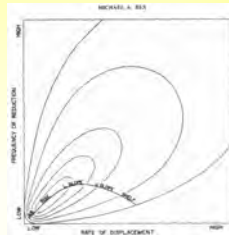
(non- equilibrium) model

NOTES:

Application of Huston's model

Rex (1983): Contours of species diversity

- Shelf: high rate of displacement due to higher food input and growth rate, lower frequency of reduction
- Lower slope & rise, slightly higher frequency of reduction (higher predation & disturbance) and lower rate of displacement due to competition (slower population growth)
- Abyss: lower rate of displacement & low growth



Slide 44 Application of Huston's model

NOTES:

Deep-sea as a spatial-temporal mosaic

Grassle, Jumars, and Snelgrove

- 1975, 1976 Jumars: high spatial heterogeneity (patchiness at all scales documented. **The deep-sea may be the most spatially heterogeneous habitat on earth.**)
- 1977, 1978 Grassle's spatio-temporal mosaic theory of deep-sea diversity and community structure
 - "Although disturbance is infrequent, when it does occur, a few species slowly colonize. These species composition in the disturbed area remains different from the surrounding environment for years...infrequent small disturbances...are the sources of environmental heterogeneity.

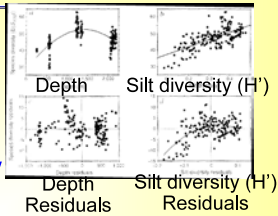
Slide 45 Deep-sea as a spatial-temporal mosaic

NOTES:

Silt-diversity hypothesis

Etter & Grassle (1992), explanation based on Whitlatch's (1980) Barnstable Harbor analysis of particle diversity

- H' (silt) correlated with $E(S_n)$
- Species diversity at 2100 m depth, measured by $E(S_{100})$ is positively correlated with the diversity in sizes of silt particles, measured with Shannon's H' .
 - Increased food diversity may allow coexistence of more species
 - Or, more species produce higher diversity of silt particles



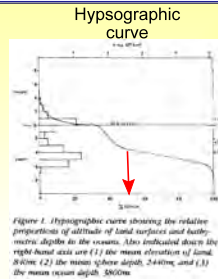
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Slide 46 Silt-diversity hypothesis

NOTES:

Biogeographic explanations: The rich species pool hypothesis

- 1978 Osman and Whitlatch's Island Biogeographic Hypothesis.
 - Deep-sea diversity is high because the deep sea is the largest habitat 'island' on earth.
 - All else being equal, larger islands support larger numbers of species.
 - This hypothesis is rejected by Rex's finding that the highest diversity is found on continental slopes and rises, which have much less area than the abyssal plains.
- Species pool in the deep sea:
 - results from long-term, evolutionary time scale rates of speciation and extinction.
 - Species richness on the local scale high because of a large species pool.

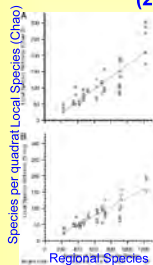


Slide 47 Biogeographic explanations: The rich species pool hypothesis

NOTES:

Importance of the regional species pool in determining α diversity

Ricklefs (1987), Osman and Dean (1987), Hubbell (2001), Witman et al. (2004)



"Local diversity bears a demonstrable dependency upon regional diversity. ...regional and historical processes, as well as unique events and circumstances, profoundly influence local community structure."
Ricklefs (1987)

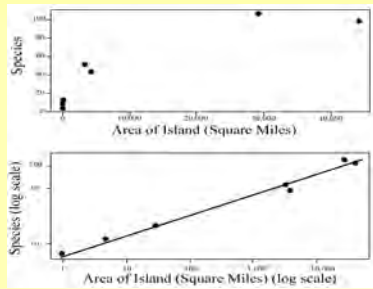
EEOS630

Slide 48 Importance of the regional species pool in determining α diversity

NOTES:

Island biogeography

MacArthur & Wilson (1967): Island-area effect



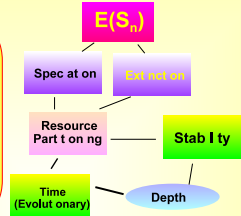
Slide 49 Island biogeography

NOTES:

Graphical models of deep-sea diversity: Conditional independence models

Sanders' (1968) Stability-time hypothesis

Graphical models of the major hypotheses. One variable's statistical association with another can be accounted for by intermediate 'causal' variables. Depth is conditionally independent of diversity if one considers the intervening causal links.



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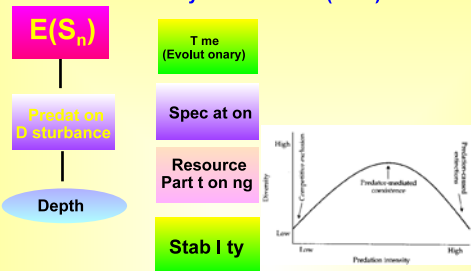
Slide 50 Graphical models of deep-sea diversity:

Conditional independence models

NOTES:

Cropper hypothesis

Dayton & Hessler (1972)



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Slide 51 Cropper hypothesis

NOTES:

<div data-bbox="240 163 760 541"> <h3>Spatial heterogeneity</h3> <p>Grassle & Sanders (1973), Jumars (1975)</p> <p>“Habitat specialization, aided by deep-sea spatial heterogeneity may be the key to maintaining high deep-sea diversity.”</p> <p>EEOS630</p> </div>	<div data-bbox="824 132 1247 174"> <h4>Slide 52 Spatial heterogeneity</h4> </div> <div data-bbox="824 258 938 300"> <p>NOTES:</p> </div>
<div data-bbox="240 657 760 1035"> <h3>Dynamic Equilibrium/Spatial Temporal mosaic hypothesis</h3> <p>Huston (1979) & Rex (1983)</p> <p>Grassle & Sanders' temporal mosaic model is a form of Huston's dynamic equilibrium model</p> <p>EEOS630</p> </div>	<div data-bbox="824 627 1369 701"> <h4>Slide 53 Dynamic Equilibrium/Spatial Temporal mosaic hypothesis</h4> </div> <div data-bbox="824 785 938 827"> <p>NOTES:</p> </div>
<div data-bbox="240 1182 760 1560"> <h3>Rex et al. (2005) Source-Sink Hypothesis</h3> <p>Mass effect with major implications for conservation</p> <p>Few endemic abyssal species</p> <p>Abyssal populations (of neogastropods) maintained by larval recruitment from the bathyal (Continental rise depths)</p> <p>EEOS630</p> </div>	<div data-bbox="824 1155 1369 1228"> <h4>Slide 54 Rex et al. (2005) Source-Sink Hypothesis</h4> </div> <div data-bbox="824 1312 938 1354"> <p>NOTES:</p> </div>

<div data-bbox="207 132 784 560"> <h3>Source-Sink Theory</h3> <p>First proposed by Rex et al. (2005, Am. Nat)</p> <p>The diagram illustrates the Source-Sink Theory. At the top, a pink box labeled 'Species pool' is connected by a horizontal line to a pink box labeled $E(S_n)$. Below the 'Species pool' box, two arrows point downwards: one labeled 'Recruitment' and another labeled 'Extinction (Allee effect)'. These arrows point to a blue oval at the bottom labeled 'Depth & Distance to Margin'. To the right of the diagram, red text states: 'Abyssal α diversity is controlled by recruitment from the bathyal regions (200 m - 4000 m)'. The text 'EEOS630' is in the bottom right corner.</p> </div>	<div data-bbox="821 132 1414 560"> <h3>Slide 55 Source-Sink Theory</h3> <p>NOTES:</p> </div>
<div data-bbox="207 630 784 1056"> <h3>Major theories today</h3> <ul style="list-style-type: none"> • Spatial-temporal mosaic model: abundant evidence for the deep sea (but also shallow water) • Huston's dynamic equilibrium model <ul style="list-style-type: none"> ▸ Applies to shallow water as well as deep sea ▸ Can be reconciled with Hubbell's neutral model • Biogeographic explanation, due originally to Sanders <ul style="list-style-type: none"> ▸ Deep-sea α diversity a result of high regional diversity ▸ Regional diversity a result of long-term extinction & and speciation rates <ul style="list-style-type: none"> ▪ Speciation rates much higher in shallow water than the abyss ▪ Extinction rates may be much lower in the abyss </div>	<div data-bbox="821 630 1414 1056"> <h3>Slide 56 Major theories today</h3> <p>NOTES:</p> </div>
<div data-bbox="207 1123 784 1551"> <h3>Benthic Pollution Biology</h3> <p>EEOS630</p> </div>	<div data-bbox="821 1123 1414 1551"> <h3>Slide 57 Benthic Pollution Biology</h3> <p>NOTES:</p> </div>

<div data-bbox="233 163 769 562"> <h3>Types of benthic surveys</h3> <p>Green (1979, p. 68)</p> <ul style="list-style-type: none"> • Baseline study: determine the present state of the system (EPA's EMAP) • Impact study: The effects of an impact are assessed (Oil spill) • Monitoring study <ul style="list-style-type: none"> ▸ Detect change from the present state ▸ BACI, Before-After comparative impact design ▸ Baseline data must be available in an impact study to provide a standard against which to detect a change. ▸ MWRA monitoring <p>EEOS630</p> </div>	<div data-bbox="812 121 1427 176"> <h3>Slide 58 Types of benthic surveys</h3> </div> <div data-bbox="812 239 1427 604"> <p>NOTES:</p> </div>
<div data-bbox="233 657 769 1056"> <h3>Why monitor the benthos?</h3> <p>A standard part of monitoring world-wide</p> <ul style="list-style-type: none"> • Infaunal populations relatively sedentary & don't migrate • Generation times <ul style="list-style-type: none"> ▸ Short enough to respond numerically ▸ Populations adapted to short-term changes in the environment ▸ Biodiversity sensitive to changes in pollutant load • Human health links (flounder) <p>EEOS630</p> </div>	<div data-bbox="812 615 1427 669"> <h3>Slide 59 Why monitor the benthos?</h3> </div> <div data-bbox="812 732 1427 1098"> <p>NOTES:</p> </div>
<div data-bbox="233 1150 769 1549"> <h3>A definition of monitoring</h3> <p>Gallagher's definition</p> <p>Monitoring is a sampling program designed to detect ecologically significant changes in the value of 'response' variables and to account for observed changes in these variables in terms of 'explanatory' or 'predictor' variables.</p> <ul style="list-style-type: none"> • There should be a theory or model to account for any changes observed • There is a difference between ecological significance & statistical significance • All communities are changing. One should be able to demonstrate whether the changes are due to changes in the physical or chemical environment </div>	<div data-bbox="812 1108 1427 1163"> <h3>Slide 60 A definition of monitoring</h3> </div> <div data-bbox="812 1226 1427 1577"> <p>NOTES:</p> </div>

<div data-bbox="380 168 641 207" data-label="Section-Header"> <h3>Monitoring plans</h3> </div> <div data-bbox="339 214 691 241" data-label="Section-Header"> <h4>Monitoring designs should describe:</h4> </div> <div data-bbox="240 243 742 516" data-label="List-Group"> <ul style="list-style-type: none"> • The null hypotheses to be tested, usually 'no change in time' or 'no change relative to control areas' • The statistical model and test statistics to be employed. • Alternate hypotheses necessary for the calculation of statistical power. <ul style="list-style-type: none"> ▸ Ecologically meaningful effects ▸ Another way of specifying the alternate hypothesis is to answer the question, "What level of change should the monitoring program be designed to detect?" </div>	<div data-bbox="816 134 1196 174" data-label="Section-Header"> <h3>Slide 61 Monitoring plans</h3> </div> <div data-bbox="816 258 940 291" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="297 655 738 695" data-label="Section-Header"> <h3>Examples of pollution effects</h3> </div> <div data-bbox="267 699 766 749" data-label="Section-Header"> <h4>Analyzed with PCA-H, diversity analyses & sediment profiling</h4> </div> <div data-bbox="237 745 743 945" data-label="List-Group"> <ul style="list-style-type: none"> • Case Study 1: 1969 West Falmouth oilspill: an impact survey • Case Study 2: Boston Harbor & MA Bay <ul style="list-style-type: none"> ▸ 1982 Section 301 (h) waiver application: Boston Harbor at its worst ▸ Ongoing MWRA Harbor monitoring with profile imaging: Boston Harbor's recovery • Case Study 3: EMAP-E Virginian Province </div>	<div data-bbox="816 623 1356 661" data-label="Section-Header"> <h3>Slide 62 Examples of pollution effects</h3> </div> <div data-bbox="816 743 940 777" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="292 1140 725 1207" data-label="Section-Header"> <h3>Case Study 1: West Falmouth Oilspill</h3> </div> <div data-bbox="272 1213 748 1262" data-label="Text"> <p>12/10/02 Boston Globe; Effects of West Falmouth 33 years later</p> </div> <div data-bbox="251 1264 435 1501" data-label="Image"> </div> <div data-bbox="654 1486 771 1516" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="816 1108 1367 1184" data-label="Section-Header"> <h3>Slide 63 Case Study 1: West Falmouth Oilspill</h3> </div> <div data-bbox="816 1268 940 1302" data-label="Text"> <p>NOTES:</p> </div>

Don't be misled by seemingly sophisticated multivariate analyses

Gillfillan et al. (1995) Exxon Valdez oilspill CCA

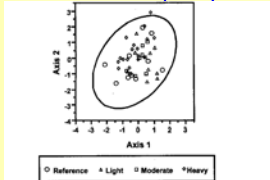


FIGURE 8—Ordination diagram for mid-shelf intertidal polychaete/gravel samples from the 1990 SRS program. The 95% probability ellipse is estimated from the subset of samples from undisturbed reference sites, assuming a bivariate normal distribution of sample scores.

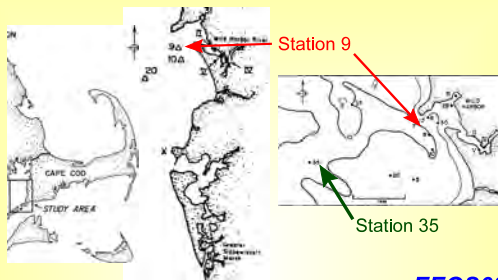
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Slide 64 Don't be misled by seemingly sophisticated multivariate analyses

NOTES:

West Falmouth Oilspill

September 16, 1969



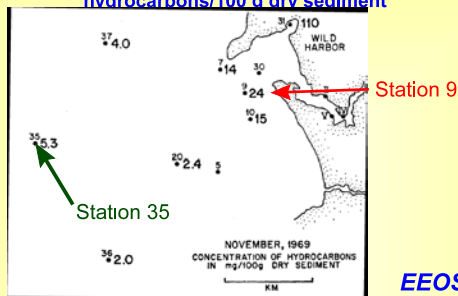
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Slide 65 West Falmouth Oilspill

NOTES:

Hydrocarbons at W. Falmouth

Farrington's data in Sanders (1980); mg hydrocarbons/100 g dry sediment



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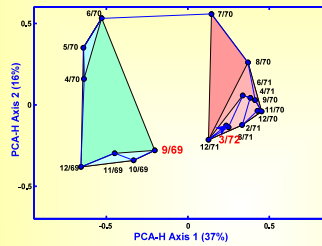
Slide 66 Hydrocarbons at W. Falmouth

NOTES:

<div data-bbox="360 168 656 205" data-label="Section-Header"> <h3>Amphipod mortality</h3> </div> <div data-bbox="282 214 740 241" data-label="Text"> <p>Amphipods (<i>Ampelisca</i>) killed at 9, abundant at 35</p> </div> <div data-bbox="237 245 698 508" data-label="Figure"> <p>The figure consists of two side-by-side line graphs. The left graph is for Station 9 and the right is for Station 35. Both graphs have two y-axes: the left axis represents 'DENSITY AMPHIPODS / 1/25 m²' (0 to 500) and the right axis represents '% AMPHIPODS ALIVE' (0 to 100). The x-axis represents time from 1969 to 1972, with months labeled (S, O, N, D, J, F, M, A, M, J, J, A, S, O, N, D). In both graphs, a solid line represents density and a dashed line represents percent alive. At Station 9, density is high (peaking around 400) and percent alive is low (around 10-20%). At Station 35, density is low (peaking around 100) and percent alive is high (around 80-90%).</p> </div> <div data-bbox="656 514 769 541" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="824 134 1240 172" data-label="Section-Header"> <h3>Slide 67 Amphipod mortality</h3> </div> <div data-bbox="824 256 938 289" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="272 655 776 693" data-label="Section-Header"> <h3>Opportunistic vs equilibrium spp.</h3> </div> <div data-bbox="386 701 623 728" data-label="Text"> <p>Grassle & Grassle (1974)</p> </div> <div data-bbox="240 735 760 991" data-label="List-Group"> <ul style="list-style-type: none"> • We propose defining degree of opportunism both in terms of ability to respond to unpredictable events and the mortality rates sustained by the species. <ul style="list-style-type: none"> ▶ High abundance, high reproductive rate and high mortality rate are all part of the life history of the opportunist. • Two major life history patterns in marine benthic opportunists <ul style="list-style-type: none"> ▶ planktonic larvae or ▶ rapidly exploit local resource through direct development or a brief planktonic existence. </div> <div data-bbox="656 1001 769 1029" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="824 625 1360 697" data-label="Section-Header"> <h3>Slide 68 Opportunistic vs equilibrium spp.</h3> </div> <div data-bbox="824 781 938 814" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="344 1180 678 1218" data-label="Section-Header"> <h3>West Falmouth Oilspill</h3> </div> <div data-bbox="360 1226 646 1253" data-label="Text"> <p>St. 9: <i>Capitella</i> → <i>Mediomastus</i></p> </div> <div data-bbox="233 1251 766 1503" data-label="Image"> <p>The image shows a photograph of a Capitella worm on the left and a diagram of a Mediomastus worm on the right. Both are polychaete worms.</p> </div> <div data-bbox="259 1453 711 1545" data-label="Text"> <p>Both are capitellids, members of the polychaete family Capitellidae. <i>Mediomastus ambiseta</i> is the most abundant macrofaunal species in the EMAP Virginian province (Nantucket to Virginia)</p> </div>	<div data-bbox="824 1146 1279 1184" data-label="Section-Header"> <h3>Slide 69 West Falmouth Oilspill</h3> </div> <div data-bbox="824 1268 938 1302" data-label="Text"> <p>NOTES:</p> </div>

Station 9: heavily oiled

PCA-H display CNESS distances, $m=18$, Cluster membership as hulls: A unidirectional succession, see Grassle & Smith (1976)



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Slide 70 Station 9: heavily oiled

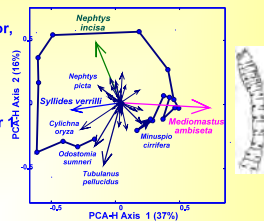
NOTES:

West Falmouth Oilspill

Station 9: a heavily oiled nearshore station

•Patterns

- Initial amphipod mortality
- Early *Capitella* dominance
- Syllides verrilli*, perhaps a predator, & 2 gastropods (*Cylichna oryza* & *Odostomia summeri*) increased in relative
- Another capitellid, *Mediomastus ambiseta*, the natural dominant in Buzzards Bay increased after year
- Diversity
 - Species richness remained high
 - Evenness strongly affected
 - Drastic departures from log-series expectation
- Very rapid succession

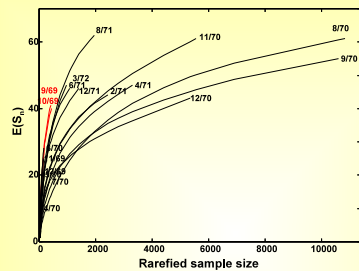


Slide 71 West Falmouth Oilspill

NOTES:

Rarefaction, Station 9

Highest alpha diversity immediately after the spill!!

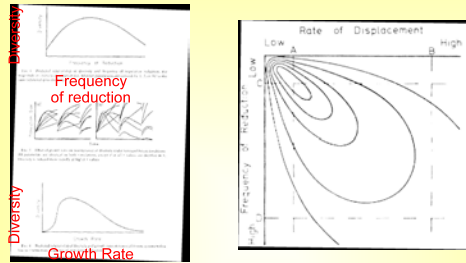


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Slide 72 Rarefaction, Station 9

NOTES:

Huston's 1979 dynamic (non- equilibrium) model



Slide 76 Huston's 1979 dynamic

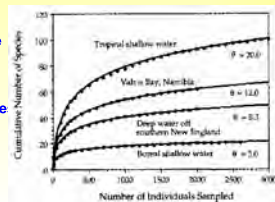
(non- equilibrium) model

NOTES:

Hubbell's (2001) neutral model

Fisher's $\alpha \approx \theta$ = Fundamental Biodiversity Number

- On the local scale, species are drawn from the metacommunity, with a rate set by the migration rate, an m of 0.9 indicates that 90% of the individuals on the local scale are drawn from the regional pool & 10% from local reproduction
- Ecological drift alters species abundance distribution from log-series like to log-normal (S-shaped dominance curves)
 - Ecological drift with relatively low migration rates leads to the local loss of singleton species
 - A high frequency of singletons can only be modeled with high migration, m
- Close fit to the log series indicates high immigration

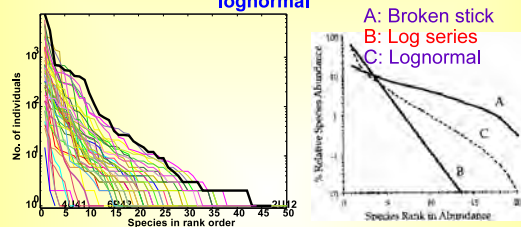


Slide 77 Hubbell's (2001) neutral model

NOTES:

Dominance curves for Boston Harbor

Hubbell (2001) neutral model predicts S-shaped curves
Hughes (1984, 1986): Benthic dominance curves are usually **concave up**, not log series & certainly not lognormal



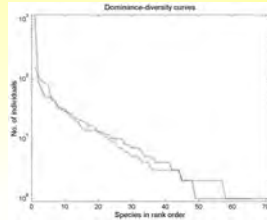
Slide 78 Dominance curves for Boston Harbor

NOTES:

Benthic dominance diversity curves from MA Bay

Spector (2005, UMB M.Sc. Thesis)

- Fisher et al. (1943): insect communities distributed as log series
- Preston: most communities distributed as lognormal
- Caswell's neutral model: log series
- Benthos
 - John Gray: lognormal
 - May, Hughes, Lamshead: log series or modified log series
 - Hubbell (2001): Zero-sum multinomial



Slide 79 Benthic dominance diversity curves from MA Bay

NOTES:

Neutral model programs

Based on Hubbell (2001)

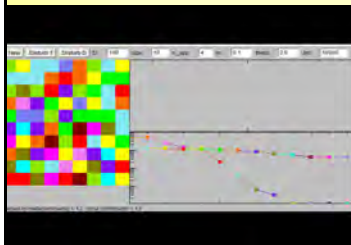
- Hubbell (2001) described algorithms but did not provide programs
 - Oksanen provides R programs to simulate Hubbell's neutral model. See his website for an exposition of the model
 - <http://cc.oulu.fi/~jarioksa/index.html>
- McGill (2003) criticized the neutral model and provided Matlab software to fit the model
 - McGill, B. J. 2003. A test of the unified neutral theory of biodiversity. *Nature* 422: 881-885.
 - <http://www.brianmcgill.org/zsmcode.html>
- Volkov et al. (2003) propose analytical solution
 - Volkov, I. J. R. Banavar, S. P. Hubbell, and A. Maritan. 2003. Neutral theory and relative species abundance in ecology. *Nature* 424: 1035-1037.
 - Volkov et al. Provide c routines to generate distribution
 - McGill programs Volkov et al. Analytical solution in Matlab & provides copies on website (see above)
- Chisholm & Burgman (2004) *Ecology* 85: 3172 argued that disturbance recovery needed to be a parameter in the model
- Hubbell & Borda-de-Agua (2004) *Ecology* 85: 3175. defended theory & provided 2 C routines for Hubbell (2001) model

Slide 80 Neutral model programs

NOTES:

Simulation of Hubbell's Neutral model

Simulation from U. Washington Ecology website

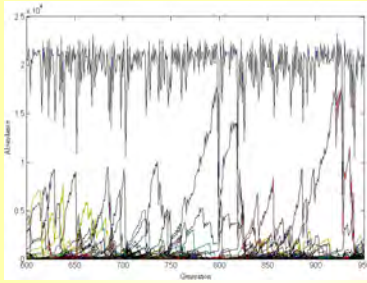


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Slide 81 Simulation of Hubbell's Neutral model

NOTES:

Spector's neutralized Hughes model

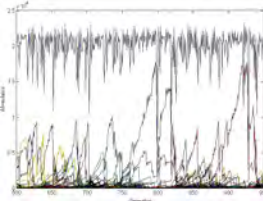


Slide 82 Spector's neutralized Hughes model

NOTES:

Spector's neutralized Hughes model

- Lotka-Volterra like dynamics
 - Gregarious larval settlement from an external pool of larvae
 - Random catastrophes key to producing concave up dominance curves
- Like Huston's dynamic model for deep-sea diversity, disturbance plays a key role in maintaining the relative abundance of species
- Spector: ... "the concave-up pattern resulted from random catastrophe disrupting the deterministic forces of the model, which would, in the absence of catastrophe, produce a flat dominance-diversity curve."



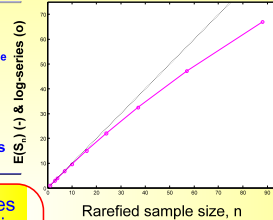
Slide 83 Spector's neutralized Hughes model

NOTES:

Non-dimensional diversity

Comparison of Sanders rarefaction to log series
Echo-1 deep-sea data from Wilson & Hessler

- Non-dimensional diversity curves
 - Generate a rarefaction curve
 - Generate the log-series rarefaction
 - Divide the observed diversity at each n by the log-series expectation
 - Non-dimensionalize & scale by dividing numbers by the species total and expected species by observed total species
- Straight line indicates log-series fit
- A deeply dipping curve indicates less evenness than log series



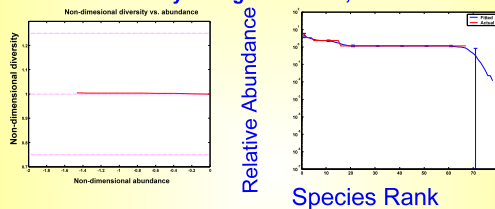
As noted by May (1975), Hughes (1984) & Hubbell (2001), Benthic communities follow a modified log series distribution

Slide 84 Non-dimensional diversity

NOTES:

Wilson & Hessler's deep-sea data, close fit to log series & neutral model

McGill 2003 algorithm: $[J=88, S=65]; \theta=148, m=0.99$
 The long tail of singletons, 52 in this sample, can only be met by immigration=0.99; $\alpha=128\pm16$

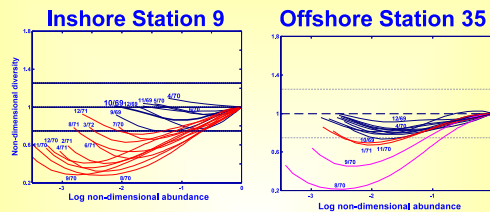


Slide 85 Wilson & Hessler's deep-sea data, close fit to log series & neutral model

NOTES:

Non-dimensional diversity

Samples <0.75 or >1.25 may indicate severe disturbance



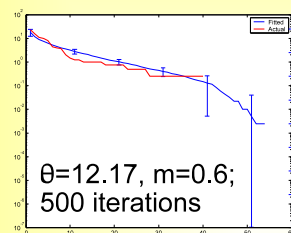
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Slide 86 Non-dimensional diversity

NOTES:

Oct. 1969 Station 9

Fit with McGill's (2003, Nature) Matlab program of Hubbell's neutral model
 13 of 40 species are singletons
 Fisher's $\alpha=11.0 \pm 1.7$



$\theta=12.17, m=0.6;$
 500 iterations

Volkov et al.'s (2003, Nature) analytical model allows theta and m to be fit without random simulations, but there is still a lot of computer time involved

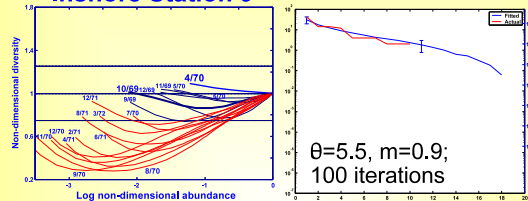
Slide 87 Oct. 1969 Station 9

NOTES:

West Falmouth April 1970

Fisher's $\alpha = 3.8 \pm 1.2$; 10 species, 50 individuals

Inshore Station 9



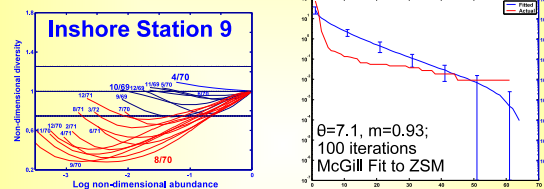
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Slide 88 West Falmouth April 1970

NOTES:

August 1970, Station 9, Heavily Impacted; Oil affected 1970 recruitment

10826 individuals, 61 species, 17 singletons; Fisher's $\alpha = 8.5 \pm 1.1$; $\theta = 7.1$, immigration rate is 93%, but the fit is very poor; **extreme dominance by *Mediomastus ambiseta***



Slide 89 August 1970, Station 9, Heavily Impacted; Oil affected 1970 recruitment

NOTES:

Station 9, Theta & m for Station 9

Joan Tracey Seguin: theta is nearly always equal to Fisher's alpha for benthic communities and m is usually > 0.9

RESEARCH & DEVELOPMENT EXPENSES AND FINANCIAL STATEMENT INFORMATION				
FINANCIAL STATEMENT INFORMATION				
DATE	THETA	M	DATE	THETA
4/70	3.8	0.9	10/70	8.5
10/69	3.8	0.9	11/69	3.8
11/69	3.8	0.9	12/71	3.8
12/71	3.8	0.9	1/72	3.8
1/72	3.8	0.9	2/72	3.8
2/72	3.8	0.9	3/72	3.8
3/72	3.8	0.9	4/72	3.8
4/72	3.8	0.9	5/72	3.8
5/72	3.8	0.9	6/72	3.8
6/72	3.8	0.9	7/72	3.8
7/72	3.8	0.9	8/72	3.8
8/72	3.8	0.9	9/72	3.8
9/72	3.8	0.9	10/72	3.8
10/72	3.8	0.9	11/72	3.8
11/72	3.8	0.9	12/72	3.8
12/72	3.8	0.9	1/73	3.8
1/73	3.8	0.9	2/73	3.8
2/73	3.8	0.9	3/73	3.8
3/73	3.8	0.9	4/73	3.8
4/73	3.8	0.9	5/73	3.8
5/73	3.8	0.9	6/73	3.8
6/73	3.8	0.9	7/73	3.8
7/73	3.8	0.9	8/73	3.8
8/73	3.8	0.9	9/73	3.8
9/73	3.8	0.9	10/73	3.8
10/73	3.8	0.9	11/73	3.8
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2/74	3.8	0.9	3/74	3.8
3/74	3.8	0.9	4/74	3.8
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5/74	3.8	0.9	6/74	3.8
6/74	3.8	0.9	7/74	3.8
7/74	3.8	0.9	8/74	3.8
8/74	3.8	0.9	9/74	3.8
9/74	3.8	0.9	10/74	3.8
10/74	3.8	0.9	11/74	3.8
11/74	3.8	0.9	12/74	3.8
12/74	3.8	0.9	1/75	3.8
1/75	3.8	0.9	2/75	3.8
2/75	3.8	0.9	3/75	3.8
3/75	3.8	0.9	4/75	3.8
4/75	3.8	0.9	5/75	3.8
5/75	3.8	0.9	6/75	3.8
6/75	3.8	0.9	7/75	3.8
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2/76	3.8	0.9	3/76	3.8
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6/76	3.8	0.9	7/76	3.8
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12/76	3.8	0.9	1/77	3.8
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2/77	3.8	0.9	3/77	3.8
3/77	3.8	0.9	4/77	3.8
4/77	3.8	0.9	5/77	3.8
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6/77	3.8	0.9	7/77	3.8
7/77	3.8	0.9	8/77	3.8
8/77	3.8	0.9	9/77	3.8
9/77	3.8	0.9	10/77	3.8
10/77	3.8	0.9	11/77	3.8
11/77	3.8	0.9	12/77	3.8
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8/78	3.8	0.9	9/78	3.8
9/78	3.8	0.9	10/78	3.8
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11/78	3.8	0.9	12/78	3.8
12/78	3.8	0.9	1/79	3.8
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3/79	3.8	0.9	4/79	3.8
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8/80	3.8	0.9	9/80	3.8
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11/80	3.8	0.9	12/80	3.8
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5/81	3.8	0.9	6/81	3.8
6/81	3.8	0.9	7/81	3.8
7/81	3.8	0.9	8/81	3.8
8/81	3.8	0.9	9/81	3.8
9/81	3.8	0.9	10/81	3.8
10/81	3.8	0.9	11/81	3.8
11/81	3.8	0.9	12/81	3.8
12/81	3.8	0.9	1/82	3.8
1/82	3.8	0.9	2/82	3.8

Station 35 fit to the neutral model

Fisher's alpha \approx Hubbell's theta

TABLE 1 FUNDING OF THE NATIONAL INSTITUTE OF ENVIRONMENTAL HEALTH SAFETY				
Year of Funding	Funding Source	Funding (\$1000)	Year of Funding	Funding (\$1000)
1980	NIH	1.00	1985	1.00
1981	NIH	0.40	1986	0.40
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1989	NIH	0.40	1994	0.40
1990	NIH	0.40	1995	0.40
1991	NIH	0.40	1996	0.40
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1995	NIH	0.40	2000	0.40
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1997	NIH	0.40	2002	0.40
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2001	NIH	0.40	2006	0.40
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2003	NIH	0.40	2008	0.40
2004	NIH	0.40	2009	0.40
2005	NIH	0.40	2010	0.40
2006	NIH	0.40	2011	0.40
2007	NIH	0.40	2012	0.40
2008	NIH	0.40	2013	0.40
2009	NIH	0.40	2014	0.40
2010	NIH	0.40	2015	0.40
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2017	NIH	0.40	2022	0.40
2018	NIH	0.40	2023	0.40
2019	NIH	0.40	2024	0.40
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EEOS630

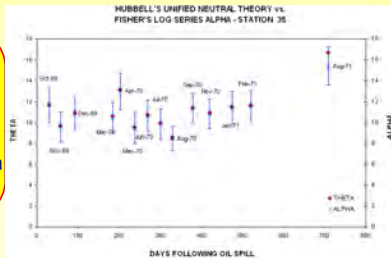
Slide 91 Station 35 fit to the neutral model

NOTES:

Hubbell natural theory: Fisher's alpha vs. Hubbell's theta, Stn 35

Joan Tracey Seguin 2006 UMB M.Sc.

Relatively unpolluted
Station 35
Fisher's alpha
(x) and
Hubbell's theta
(●)



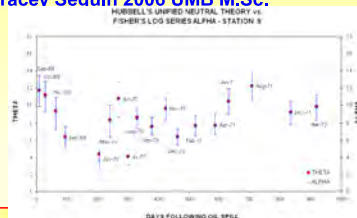
Slide 92 Hubbell natural theory: Fisher's alpha vs. Hubbell's theta, Stn 35

NOTES:

Hubbell natural theory: Fisher's alpha vs. Hubbell's theta

Joan Tracev Sequin 2006 UMB M.Sc.

Heavily impacted
Station 9
Fisher's alpha
(x) and
Hubbell's theta
(●)



Note that largest effects on species richness were 7-10 months after spill

EEOS630

Slide 93 Hubbell natural theory: Fisher's alpha vs. Hubbell's theta

NOTES:

<div data-bbox="279 168 755 205" data-label="Section-Header"> <h3>Conclusions on West Falmouth</h3> </div> <div data-bbox="279 214 750 241" data-label="Text"> <p>The September 1969 spill had long-lasting effects</p> </div> <div data-bbox="233 239 758 535" data-label="List-Group"> <ul style="list-style-type: none"> Species richness remained relatively high throughout the Sanders & Grassle's monitoring <ul style="list-style-type: none"> Similar pattern found in Amoco Cadiz oilspill "Species diversity, richness and evenness if anything increased after the spill, and remained at a higher level than the pre-spill conditions until the end of the sampling period." Dauvin (1984) after the Amoco Cadiz spill Major effects nearly 1 year after the oil spill: Extreme dominance by <i>Mediomastus ambiseta</i> & <i>Nephtys incisa</i>, normal numerical dominance of the Buzzards Bay benthos (dominants in Sanders' Station R surveys) Major effects on species evenness </div>	<div data-bbox="815 134 1386 170" data-label="Section-Header"> <h3>Slide 94 Conclusions on West Falmouth</h3> </div> <div data-bbox="815 258 940 291" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="269 682 758 802" data-label="Section-Header"> <h3>Case Study 2: the recovery of Boston Harbor benthic communities in the 1990s</h3> </div> <div data-bbox="253 812 774 863" data-label="Text"> <p>Pearson & Rosenberg vs. Hubbell's (2001) unified neutral model</p> </div> <div data-bbox="652 1001 771 1029" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="815 621 1411 732" data-label="Section-Header"> <h3>Slide 95 Case Study 2: the recovery of Boston Harbor benthic communities in the 1990s</h3> </div> <div data-bbox="815 819 940 852" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="360 1218 646 1255" data-label="Section-Header"> <h3>Geology of MA Bay</h3> </div> <div data-bbox="232 1289 758 1568" data-label="Figure"> </div> <div data-bbox="652 1564 771 1591" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="815 1184 1229 1222" data-label="Section-Header"> <h3>Slide 96 Geology of MA Bay</h3> </div> <div data-bbox="815 1306 940 1341" data-label="Text"> <p>NOTES:</p> </div>

<div data-bbox="360 165 647 205" data-label="Section-Header"> <h3>Geology of MA Bay</h3> </div> <div data-bbox="232 237 769 541" data-label="Figure"> </div> <div data-bbox="656 514 769 541" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="816 132 937 168" data-label="Section-Header"> <h3>Slide 97</h3> </div> <div data-bbox="816 254 940 291" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="282 653 751 693" data-label="Section-Header"> <h3>William Wood's Boston Harbor</h3> </div> <div data-bbox="357 697 656 728" data-label="Text"> <p>New England's Prospect (1634)</p> </div> <div data-bbox="222 751 462 953" data-label="List-Group"> <ul style="list-style-type: none"> ▪ Mudflats ▪ Soft-shelled clams as big as a loaf of English whitebread ▪ Oysters as half as big around as a keg ▪ Shore birds so numerous that in flight they darken the sky </div> <div data-bbox="487 747 779 970" data-label="Image"> </div> <div data-bbox="656 1001 769 1029" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="816 619 1401 657" data-label="Section-Header"> <h3>Slide 98 William Wood's Boston Harbor</h3> </div> <div data-bbox="816 741 940 779" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="319 1138 706 1211" data-label="Section-Header"> <h3>17-18th Century pollution problems</h3> </div> <div data-bbox="300 1213 709 1245" data-label="Text"> <p>Mill Creek, Site of offal discharge 1656</p> </div> <div data-bbox="225 1241 751 1505" data-label="Image"> </div> <div data-bbox="656 1488 769 1516" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="816 1108 1317 1184" data-label="Section-Header"> <h3>Slide 99 17-18th Century pollution problems</h3> </div> <div data-bbox="816 1266 940 1304" data-label="Text"> <p>NOTES:</p> </div>

Calf Pasture Pumping station

Boston's first sewage plant: opened January



Slide 100 Calf Pasture Pumping station

NOTES:

Boston Harbor 1630 to present

From "Mapping Boston"



EEOS630

Slide 101 Boston Harbor 1630 to present

NOTES:

Harbor of Shame: Raw sewage, closed Mya beds, closed beaches & flounder liver cancer

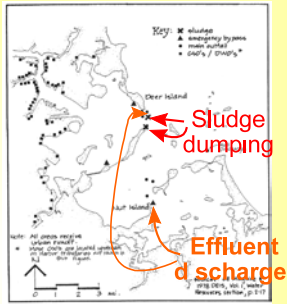


Slide 102 Harbor of Shame: Raw sewage, closed Mya beds, closed beaches & flounder liver cancer

NOTES:

Boston Harbor in the 1980s

- 250-500 mgd sewage effluent, only primary treated, discharged at Deer & Nut Islands
- 20 tons sludge daily in Presidents Roads
 - A high percentage of the sludge (30%) remained in the harbor
- >90% *Capitella* in Inner Harbor & Deer Island Sediments
- Few *Ampelisca*
- 17% of Winter flounder with active liver cancer

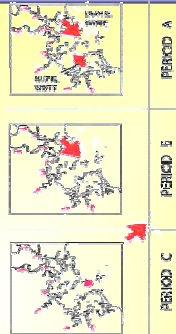


Slide 103 Boston Harbor in the 1980s

NOTES:

Key dates in the harbor cleanup

- **Period A**
 - 1991 Sludge dumping ended
 - 1991 & 1992 Monitoring of Harbor & Bay began
 - 1996 New primary treatment facility at Deer Island
 - 1997-2001 Upgrade to secondary treatment at Deer Island
- **1998 Period B. Inter-island transfer tunnel to Deer Island**
- **September 2000 Period C. Offshore 15 km outfall**



Slide 104 Key dates in the harbor cleanup

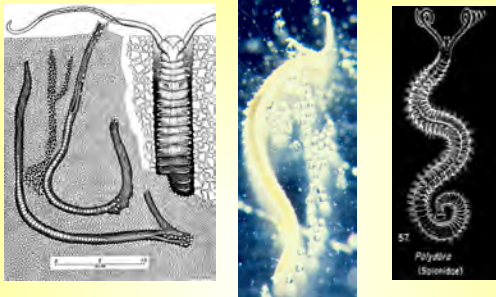
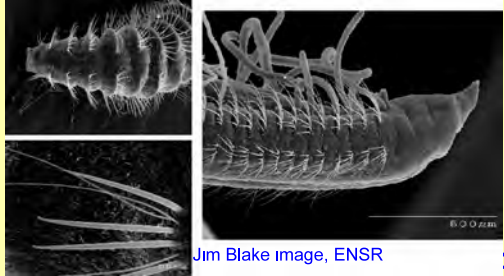

NOTES:

The Actors in this Ecological Play

EEOS630

Slide 105 The Actors in this Ecological Play

NOTES:

<p>The most common animals in Boston Harbor & MA Bay sediments: Spionid polychaetes</p> <p>Millions per m² on Boston mudflats</p> 	<p>Slide 106 The most common animals in Boston Harbor & MA Bay sediments: Spionid polychaetes</p> <p>NOTES:</p>
<p>Chaetozone, new species, a common polychaete in Boston Harbor</p> <p>Feeds on mud at the sediment-water interface</p>  <p>Jim Blake image, ENSR</p>	<p>Slide 107 Chaetozone, new species, a common polychaete in Boston Harbor</p> <p>NOTES:</p>
<p>Capitella sp. Ia, flounder food</p> <p>Can reach 9 cm, dominant in Boston's Inner Harbor & Nut Island</p> 	<p>Slide 108 Capitella sp. Ia, flounder food</p> <p>NOTES:</p>

Slide 109

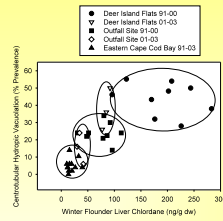


Capitella sp. la



Deer Island 1988

M. Moore Photo



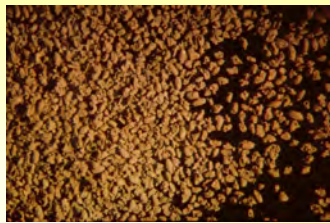
Moore, M., Lefkowitz, L., Hall, M., Hillman, R., Mitchell, D., and Burnett, J. 2004. Reduction in organic contaminant exposure and resultant hepatic hydropic vacuolation in winter flounder (*Pseudopleuronectes americanus*) following improved effluent quality and relocation of the Boston sewage outfall into Massachusetts Bay, USA: 1987-2003. *Marine Pollution Bulletin*. In Press

NOTES:

Capitella fecal pellets

30-70% of the mass of some harbor sediments

High percentage of pelletized sediments in Inner Harbor & Peddocks Island deposition areas (Nut Island Sludge)

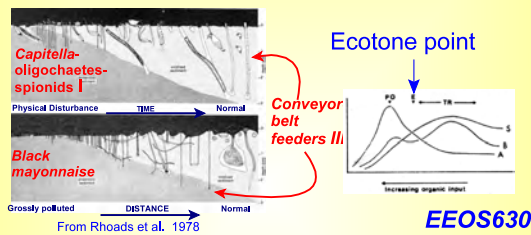


Slide 110 Capitella fecal pellets

NOTES:

Pearson & Rosenberg's model used in the 1983 EPA waiver rejection

MA Bay already at a Pearson & Rosenberg (1978) ecotone point; additional organic enrichment will lead to an opportunist-dominated community

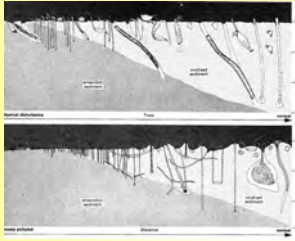


Slide 111 Pearson & Rosenberg's model used in the 1983 EPA waiver rejection

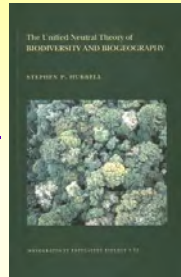
NOTES:

Pearson & Rosenberg vs. Hubbell

Directional succession vs. The Neutral Theory



Vs.



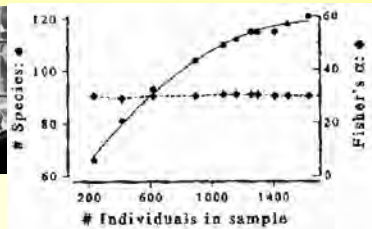
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Slide 112 Pearson & Rosenberg vs. Hubbell

NOTES:

Fisher's log-series α diversity index

Fisher *et al.* 1943



EEOS630

Slide 113 Fisher's log-series α diversity index

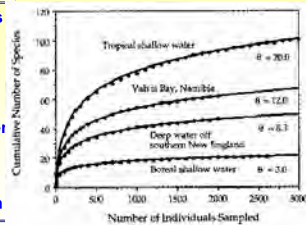
NOTES:

Hubbell's (2001) neutral model

Fisher's $\alpha \approx \theta = 2 J_M v$, Fundamental biodiversity Number

J_M is the metapopulation size, v is the speciation rate

- On the local scale, species are drawn from the metacommunity, with a rate set by the migration rate
- Ecological drift and biological interactions alter species abundance distributions
- Close fit to the log series indicates high immigration



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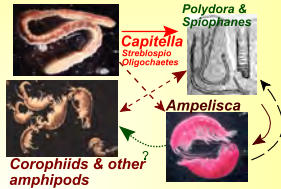
Slide 114 Hubbell's (2001) neutral model

NOTES:

Why use Hubbell's neutral model for Boston Harbor?

Certainly, species & individuals are not identical!

- It provides a null expectation for species richness, based on Fisher's α diversity index
- It incorporates the regional metacommunity biodiversity in the analysis
- It has the potential to explain the effects of ecological drift on species composition & succession



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Slide 115 Why use Hubbell's neutral model for Boston Harbor?

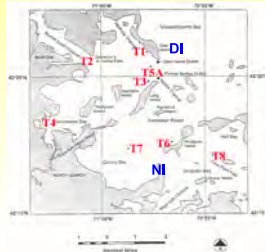
NOTES:

MWRA Sampling Stations

8 Stations, May & Aug

3 replicate 0.043-m² Ted Young grabs; 300- μ m sieves

- T1: Deer Island
- T2: Governor's Island Flats
- T3: Long Island
- T4: Savin Hill Cove
- T5A: Presidents Road
- T6: Peddocks Island
- T7: Quincy Bay
- T8: Hingham/Hull Bay
- NI: Nut Island
- DI: Deer Island



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Slide 116 MWRA Sampling Stations

NOTES:

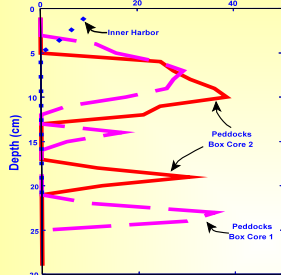

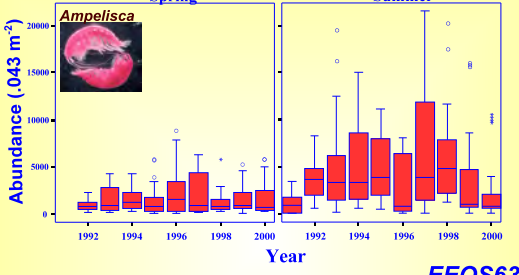

Inner Harbor: Still degraded



EEOS630

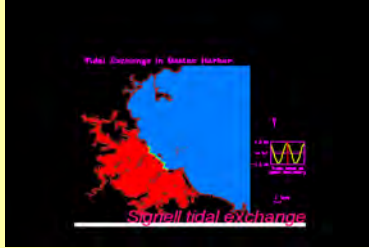
Slide 117 Inner Harbor: Still degraded

NOTES:

<p>Peddock's Island, 1989</p> <p><i>Capitella</i> prior to 1989; After 1989: No <i>Capitella</i></p> <p>Fecal pellets (% Dry Weight)</p>   <p>EEOS630</p>	<p>Slide 118 Peddock's Island, 1989</p> <p>NOTES:</p>
<p>Infaunal Abundance in the 90s</p> <p>Summer increase largely due to <i>Ampelisca abdita</i></p> <p>Spring Summer</p>  <p>EEOS630</p>	<p>Slide 119 Infaunal Abundance in the 90s</p> <p>NOTES:</p>
<p>Boston Harbor <i>Ampelisca</i></p> <p><i>Ampelisca</i> mats rare in 1982, Sludge dumping stopped Dec. 1991, amphipods abundant by 1991, peak in 1997, nearly gone by 2001, but back in 2002 & 2003: gone in 2006, 2007</p>  <p>EEOS630</p>	<p>Slide 120 Boston Harbor <i>Ampelisca</i></p> <p>NOTES:</p>

<div data-bbox="285 165 745 212" data-label="Section-Header"> <h2>Sediment Profile Imaging</h2> </div> <div data-bbox="254 222 774 273" data-label="Text"> <p>Rhoads' Type II <i>Ampelisca</i> assemblage, Hull Bay (1997)</p> </div> <div data-bbox="285 266 711 539" data-label="Image"> </div> <div data-bbox="474 493 771 537" data-label="Text"> <p>Image from R. Diaz & ENSR EEOS630</p> </div>	<div data-bbox="816 130 1325 170" data-label="Section-Header"> <h3>Slide 121 Sediment Profile Imaging</h3> </div> <div data-bbox="816 254 941 287" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="360 655 656 699" data-label="Section-Header"> <h2><i>Ampelisca</i> mats</h2> </div> <div data-bbox="315 703 704 735" data-label="Text"> <p>Near Peddocks Island in Quincy Bay</p> </div> <div data-bbox="264 735 704 1039" data-label="Image"> </div> <div data-bbox="264 1008 368 1035" data-label="Text"> <p>Shull graphic</p> </div>	<div data-bbox="816 621 1192 659" data-label="Section-Header"> <h3>Slide 122 <i>Ampelisca</i> mats</h3> </div> <div data-bbox="816 741 941 774" data-label="Text"> <p>NOTES:</p> </div>
<div data-bbox="276 1138 756 1197" data-label="Section-Header"> <h2>Peddocks Island, affected by Nut Island sewage</h2> </div> <div data-bbox="350 1199 673 1222" data-label="Text"> <p>From <i>Capitella</i> to amphipods in late 1980s</p> </div> <div data-bbox="248 1232 743 1514" data-label="Image"> </div>	<div data-bbox="816 1108 1365 1184" data-label="Section-Header"> <h3>Slide 123 Peddocks Island, affected by Nut Island sewage</h3> </div> <div data-bbox="816 1266 941 1302" data-label="Text"> <p>NOTES:</p> </div>

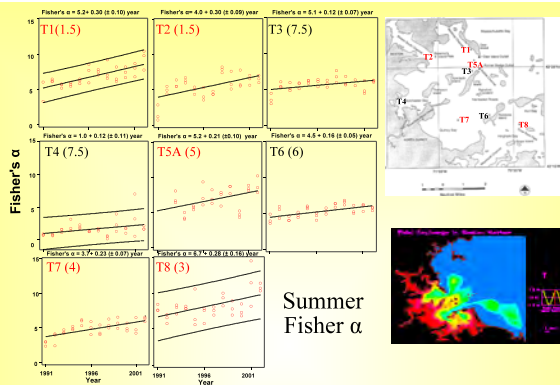
Boston Harbor tidal currents



EEOS630

Slide 124 Boston Harbor tidal currents

NOTES:



Slide 125

NOTES:

Metacommunity terms

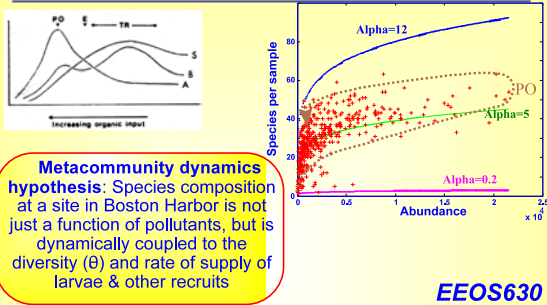
Holyoak et al. 2005. Metacommunities.

- **Community** The individuals of all species that potentially interact within a single patch or local area of habitat
- **Metacommunity** A set of local communities that are linked by dispersal of multiple potentially interacting species
- **Mass effect** A mechanism for spatial dynamics in which there is a net flow of individuals created by differences in population size or density

Slide 126 Metacommunity terms

NOTES:

Reconciling Pearson and Rosenberg (1976, 1978) & Hubbell

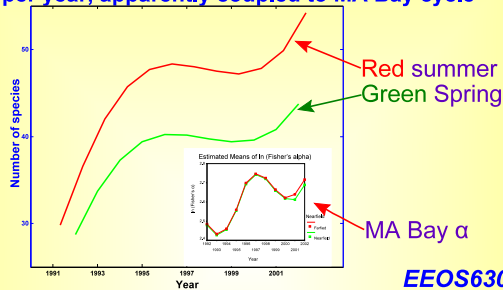


Slide 127 Reconciling Pearson and Rosenberg (1976, 1978) & Hubbell

NOTES:

Boston Harbor Species richness

31% annual increase in median species richness per year, apparently coupled to MA Bay cycle

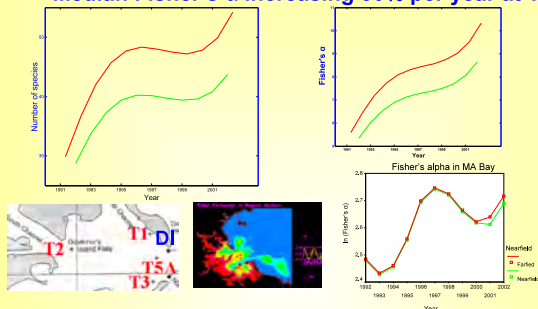


Slide 128 Boston Harbor Species richness

NOTES:

Deer Island species richness

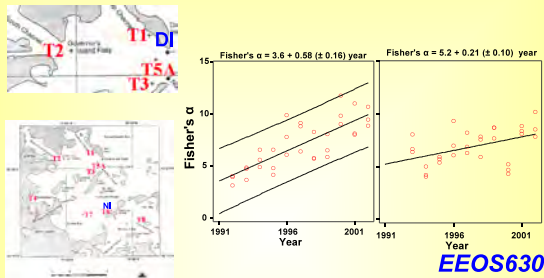
Median Fisher's α increasing 30% per year at T1



Slide 129 Deer Island species richness

NOTES:

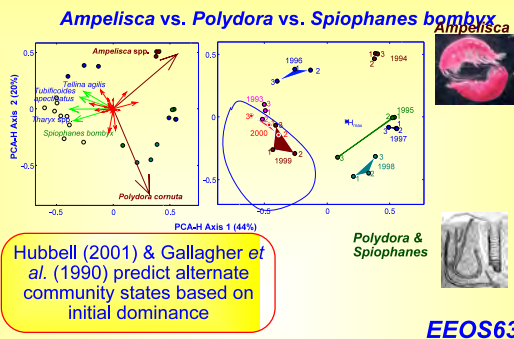
T5A: President's Roads sludge dumping site



Slide 130 T5A: President's Roads sludge dumping site

NOTES:

T5A Summer: Numerical dominant crap shoot

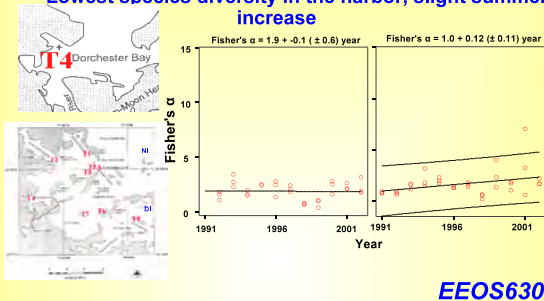


Slide 131 T5A Summer: Numerical dominant crap shoot

NOTES:

T4: Savin Hill Cove

Lowest species diversity in the harbor, slight summer increase



Slide 132 T4: Savin Hill Cove

NOTES:

<div data-bbox="264 168 758 205" data-label="Section-Header"> <h3>Pearson & Rosenberg vs. Hubbell</h3> </div> <div data-bbox="233 216 763 541" data-label="List-Group"> <p>Hubbell & Bell's neutral models: not successional</p> <table border="0"> <tr> <td> Pearson & Rosenberg, Rhoads et al. (1978) <ul style="list-style-type: none"> • Unidirectional Succession • Opportunistic species replaced by equilibrium species • No metacommunity dynamics • Relatively silent on species diversity, except for SAB curves </td> <td> Hubbell's Neutral model <ul style="list-style-type: none"> • Ecological drift; stochastic equilibrium • All individuals & all species equivalent • Emphasis on metacommunity dynamics • A theory for species abundance curves </td> </tr> </table> </div>	Pearson & Rosenberg, Rhoads et al. (1978) <ul style="list-style-type: none"> • Unidirectional Succession • Opportunistic species replaced by equilibrium species • No metacommunity dynamics • Relatively silent on species diversity, except for SAB curves 	Hubbell's Neutral model <ul style="list-style-type: none"> • Ecological drift; stochastic equilibrium • All individuals & all species equivalent • Emphasis on metacommunity dynamics • A theory for species abundance curves 	<div data-bbox="816 132 1318 205" data-label="Section-Header"> <h3>Slide 133 Pearson & Rosenberg vs. Hubbell</h3> </div> <div data-bbox="816 294 940 327" data-label="Text"> <p>NOTES:</p> </div>
Pearson & Rosenberg, Rhoads et al. (1978) <ul style="list-style-type: none"> • Unidirectional Succession • Opportunistic species replaced by equilibrium species • No metacommunity dynamics • Relatively silent on species diversity, except for SAB curves 	Hubbell's Neutral model <ul style="list-style-type: none"> • Ecological drift; stochastic equilibrium • All individuals & all species equivalent • Emphasis on metacommunity dynamics • A theory for species abundance curves 		
<div data-bbox="409 693 605 728" data-label="Section-Header"> <h3>Conclusions</h3> </div> <div data-bbox="230 760 743 1033" data-label="List-Group"> <ul style="list-style-type: none"> • The biodiversity of Boston Harbor's benthic infauna has undergone a tremendous change since the mid 1980s • The early succession fit the Pearson-Rosenberg/Rhoads model with <i>Capitella</i> being replaced by spionids & amphipod crustaceans • Hubbell's neutral model appears to apply now <ul style="list-style-type: none"> ▸ A theory for assessing biodiversity ▸ Boston Harbor is coupled to MA Bay metacommunities ▸ Ecological drift produces interannual shifts in dominants: spionids one year, ampeliscids on other years </div> <div data-bbox="654 1039 771 1066" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="816 659 1140 695" data-label="Section-Header"> <h3>Slide 134 Conclusions</h3> </div> <div data-bbox="816 781 940 816" data-label="Text"> <p>NOTES:</p> </div>		
<div data-bbox="259 1205 727 1478" data-label="Section-Header"> <h3>High Deep-Sea Diversity, Effects of Pollution on Benthic Community Structure: West Falmouth Oilspill & Boston Harbor</h3> <h3>Pearson & Rosenberg vs. Hubbell's neutral model</h3> </div> <div data-bbox="354 1495 623 1524" data-label="Text"> <p>Class 13: Th Oct 14, 2009</p> </div> <div data-bbox="654 1526 771 1554" data-label="Text"> <p>EEOS630</p> </div>	<div data-bbox="816 1148 1419 1295" data-label="Section-Header"> <h3>Slide 135 High Deep-Sea Diversity, Effects of Pollution on Benthic Community Structure: West Falmouth Oilspill & Boston Harbor</h3> </div> <div data-bbox="816 1320 1391 1392" data-label="Text"> <p>Pearson & Rosenberg vs. Hubbell's neutral model</p> </div> <div data-bbox="816 1480 940 1514" data-label="Text"> <p>NOTES:</p> </div>		