Stressor-Response Modeling of the Interactive Effects of Climate Change and Land Use Patterns on the Alteration of Coastal Marine Systems by Invasive Species

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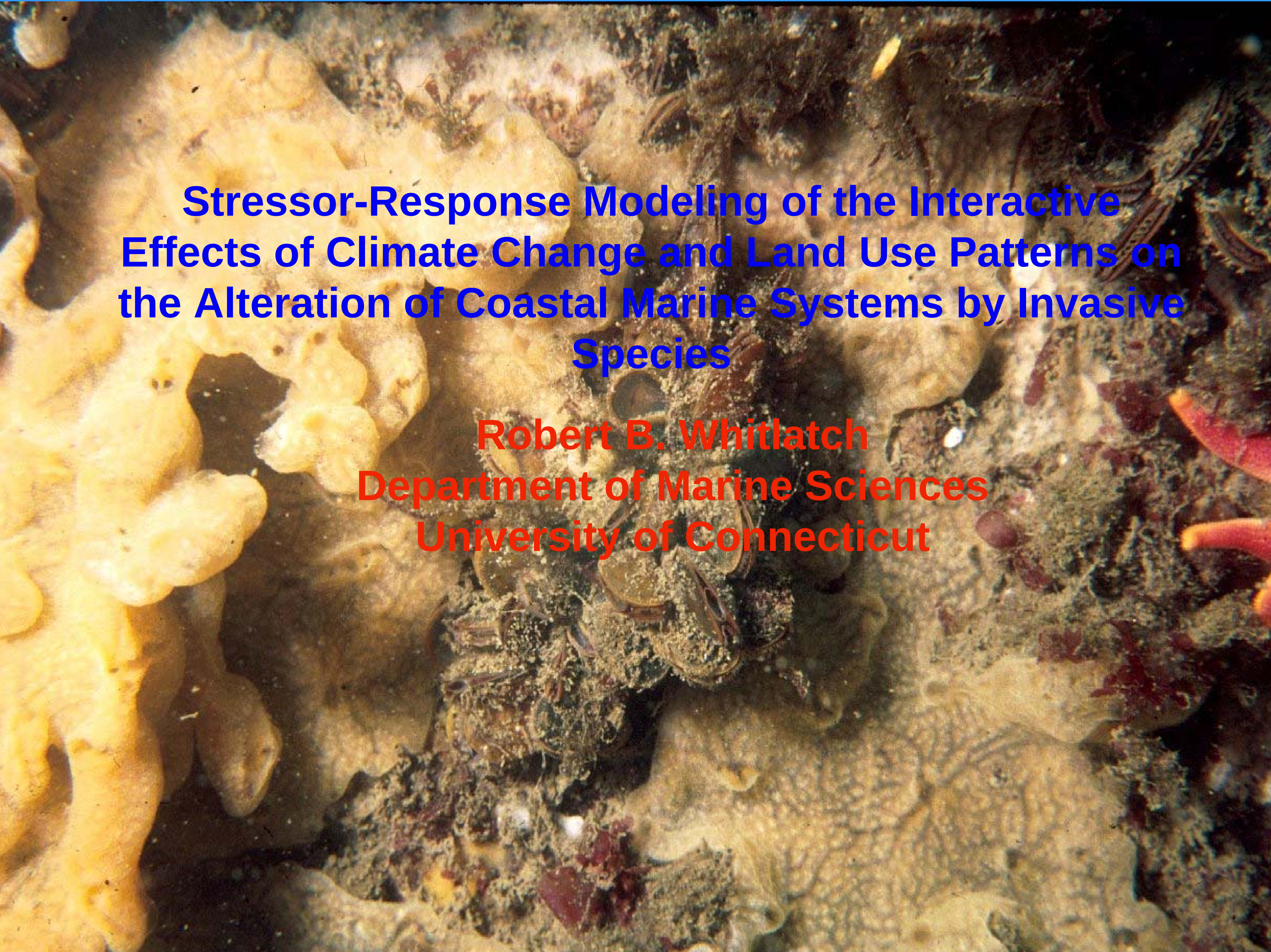
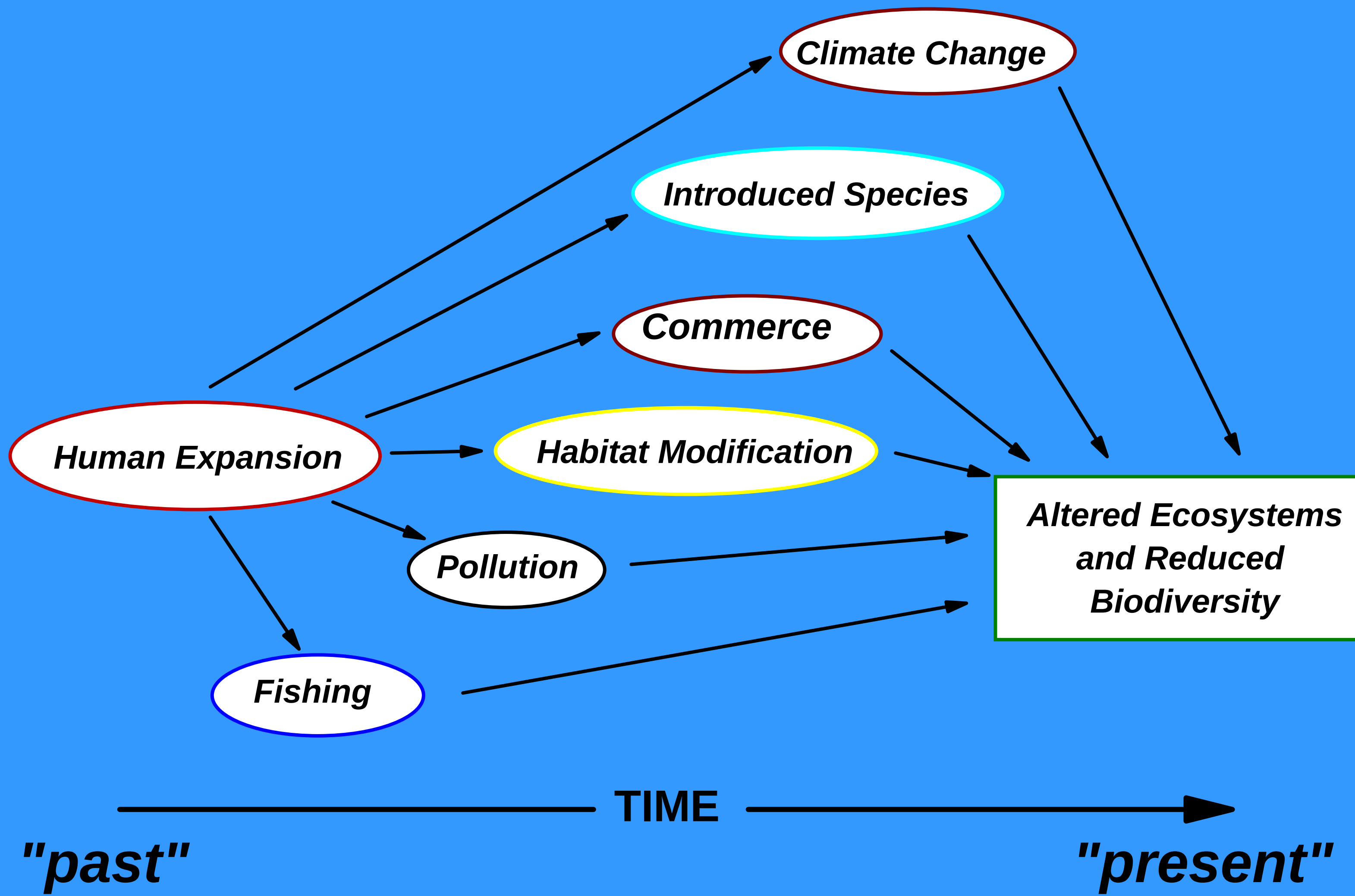


Multiple Threats to Marine Coastal Ecosystems: A chronology of human-related environmental impacts



From: modified from Jackson et al. Science 293: 629

Examining the effects of these stressors by studying recent invasions into southern New England coastal invertebrate fouling assemblages

... an experimentally tractable system:

-small individuals
-easily cultured
-rapid growth
-rapid generation time
-easily manipulated
-space for settlement and growth generally thought to be the limiting resource
- Fouling species comprise a large fraction of the ~300+ non-native species recorded in U.S. coastal waters

Principal Macro-organism Fouling Taxa

Primary space occupants:

- Barnacles
- Hydroids
- Bryozoans
- Entoprocts
- Attached gastropods
- Anemones
- Ascidians
- Sponges
- Attached bivalves
- Serpulid annelids
- Attached macroalgae

Secondary space occupants;

- Arthropods (amphipods, isopods, decapods, pycnogonids)
- "Worms" (annelids, flatworms, nemertines, nematodes, sipunculids)
- Decapods
- Bivalves
- Gastropods
- Pycnogonids
- Arachnids
- Echinoderms
- Attached macroalgae

Human-related vectors of invasive fouling species transport… lots of them…

Once they are here, what abiotic and biotic factors contribute to their success or failure? Which coastal habitats are most vulnerable to invasion? What are the potential interactions of variations in coastal land use patterns, climate change and invasions? Can invaders be used as indicators of stress?

Importance of habitat modification -- fouling species generally are found in greatest abundance in protected bays harbors and estuaries – important recipient and donor sites

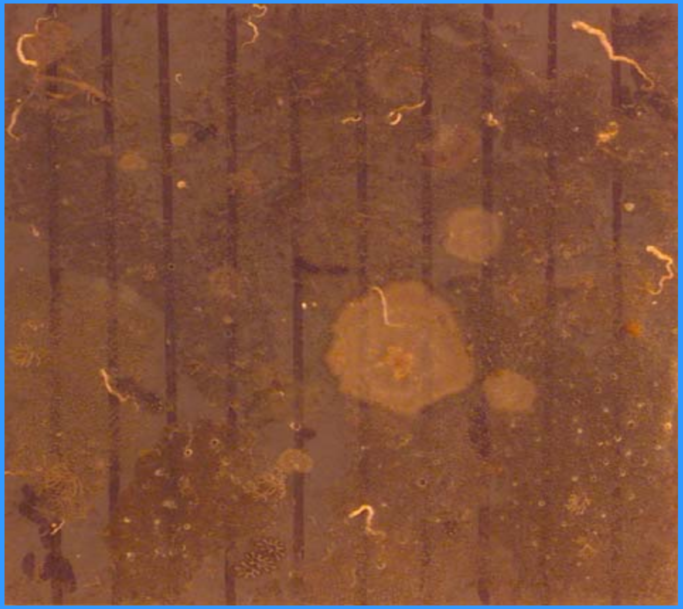
– as more and more structures are built, there are more and more habitats for colonization of the species.

Off-bottom aquaculture facility

Marina and breakwater development

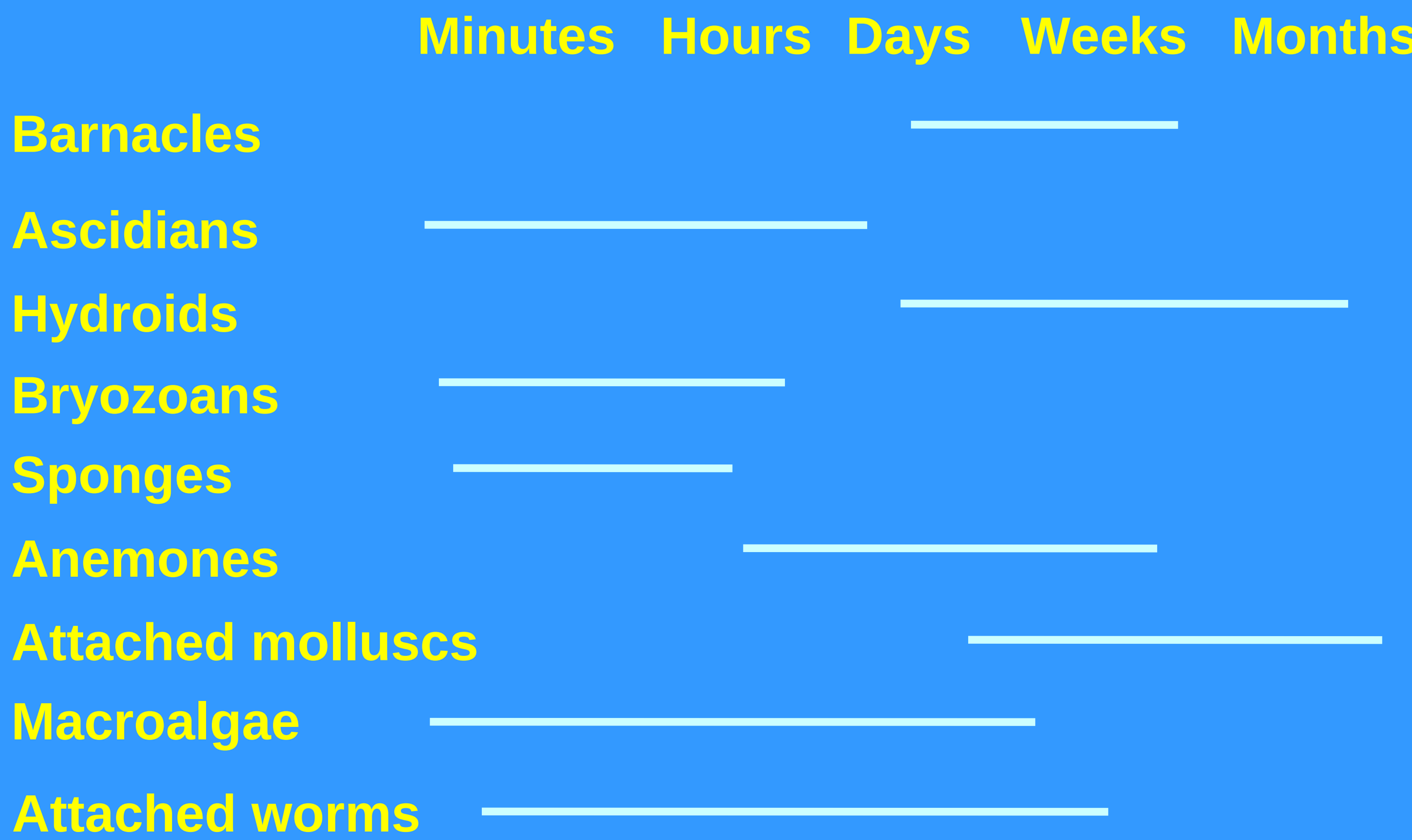
Habitat modification: Many of the human-made structures (e.g., floating docks, off-bottom aquaculture gear) provide fouling organisms with a refuge from benthic predators and reduced effects of sedimentation.

Substrate exposed 2 months in the absence of benthic predators

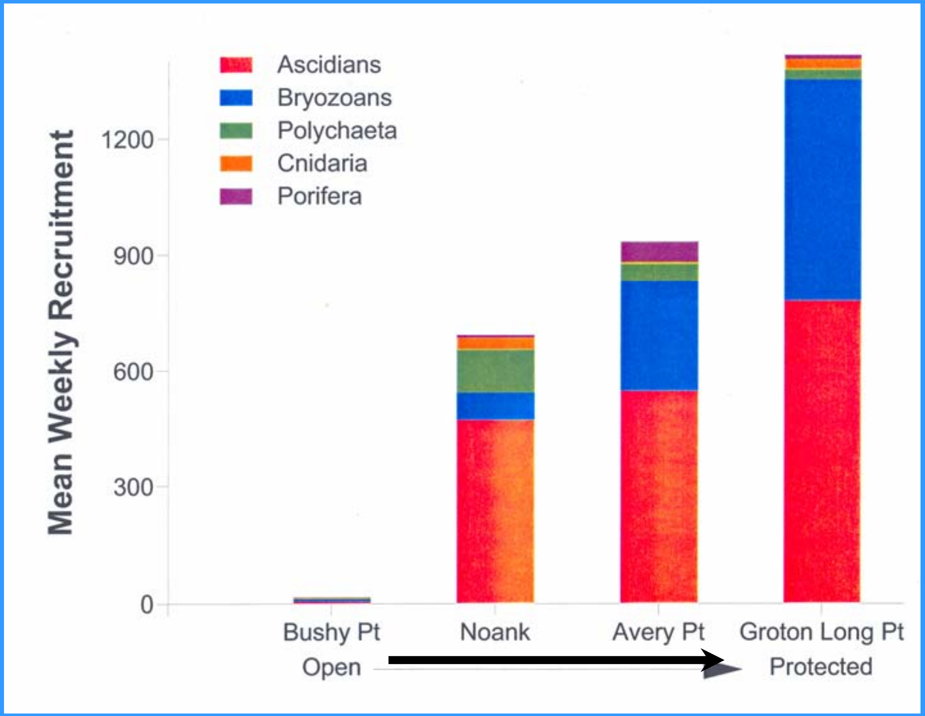


Substrate exposed 2 months in the presence of benthic predators

Fouling Organism Propagule Life Spans



Habitat modification: Coastal marinas/ports purposefully constructed as safe havens from weather conditions and strong currents. As a consequence, hydrodynamic alterations (e.g, breakwaters, piers) tend to retain propagules of fouling species.

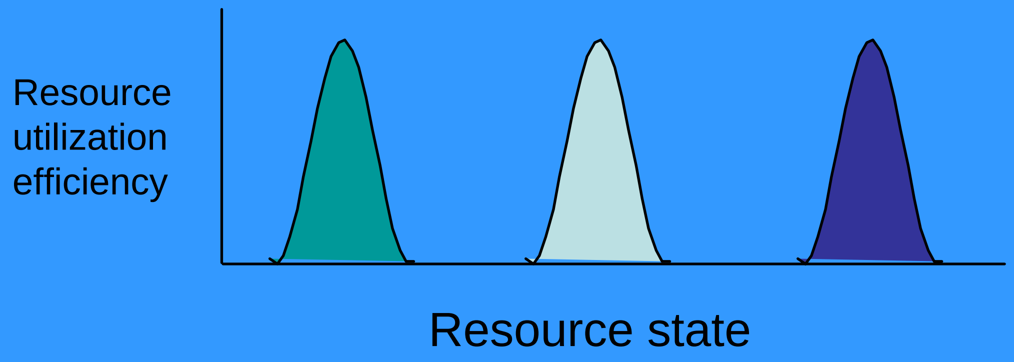


Fouling species recruitment abundances as a function of increasing protection in several coastal Connecticut sites

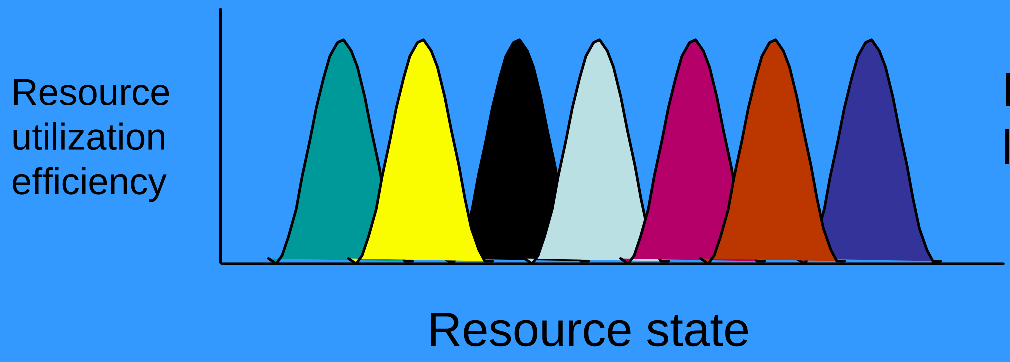
Importance of local biodiversity on invasion success

Charles Elton's (1958) -- *"theory of invasions"*:
Communities with more species should be more resistant to invasion.

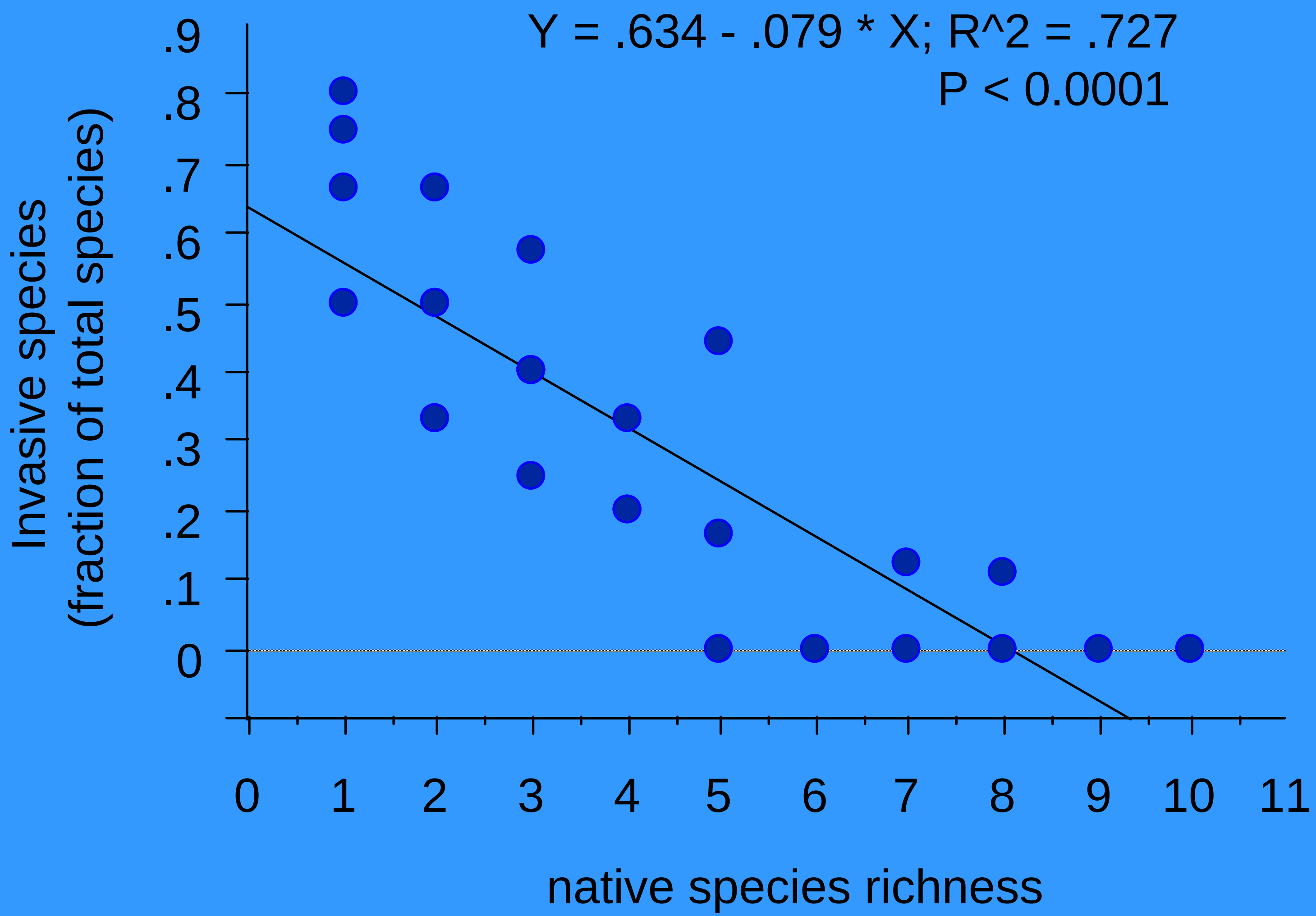
With increasing numbers of species in a community, an increasing proportion of the available resources are utilized, leaving fewer resources for new species (invaders).



Low diversity =
high resource availability

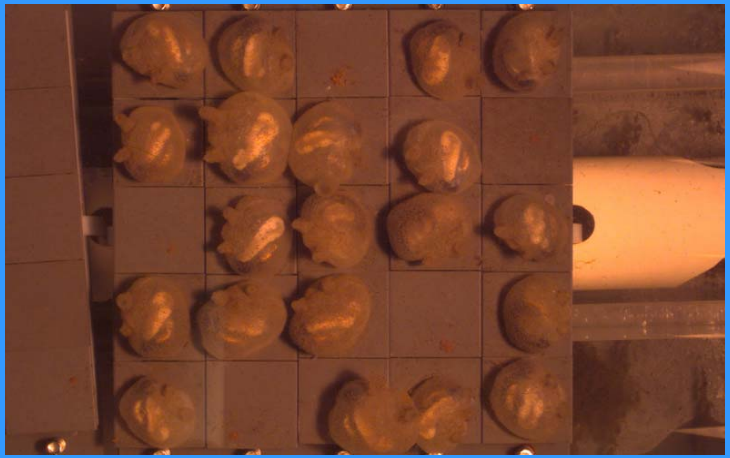


High diversity =
low resource availability

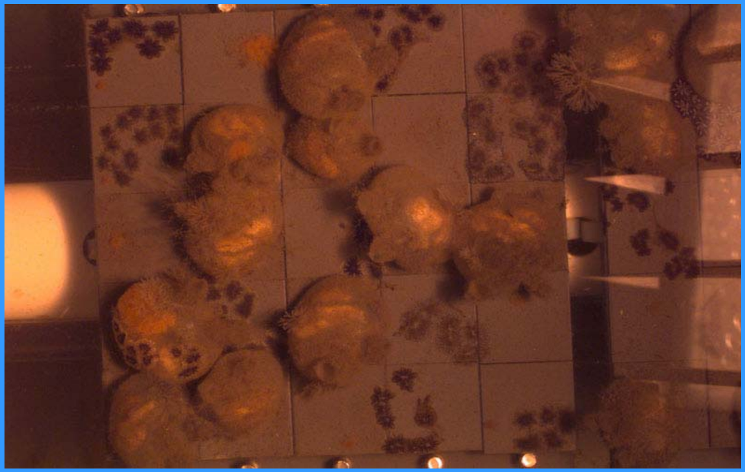


Within a number of southern New England embayments, invasive fouling species are less common in 0.25 x 0.25 m plots that have more resident fouling species.

Test of Invasibility vs Species Richness using Experimentally Assembled Communities

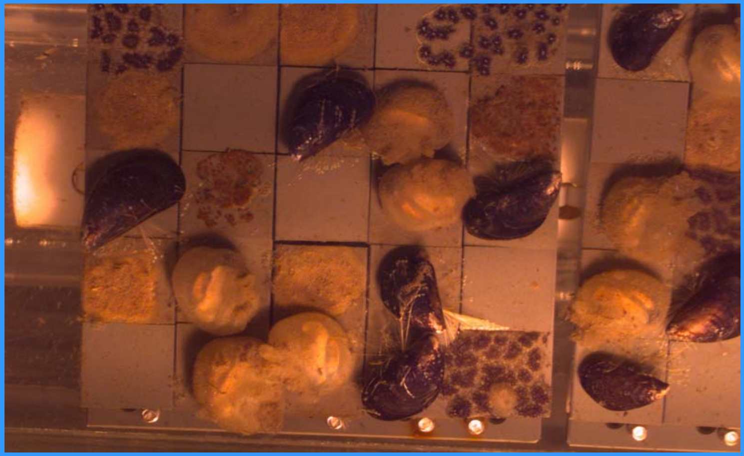


Example of a 1 sp assemblage



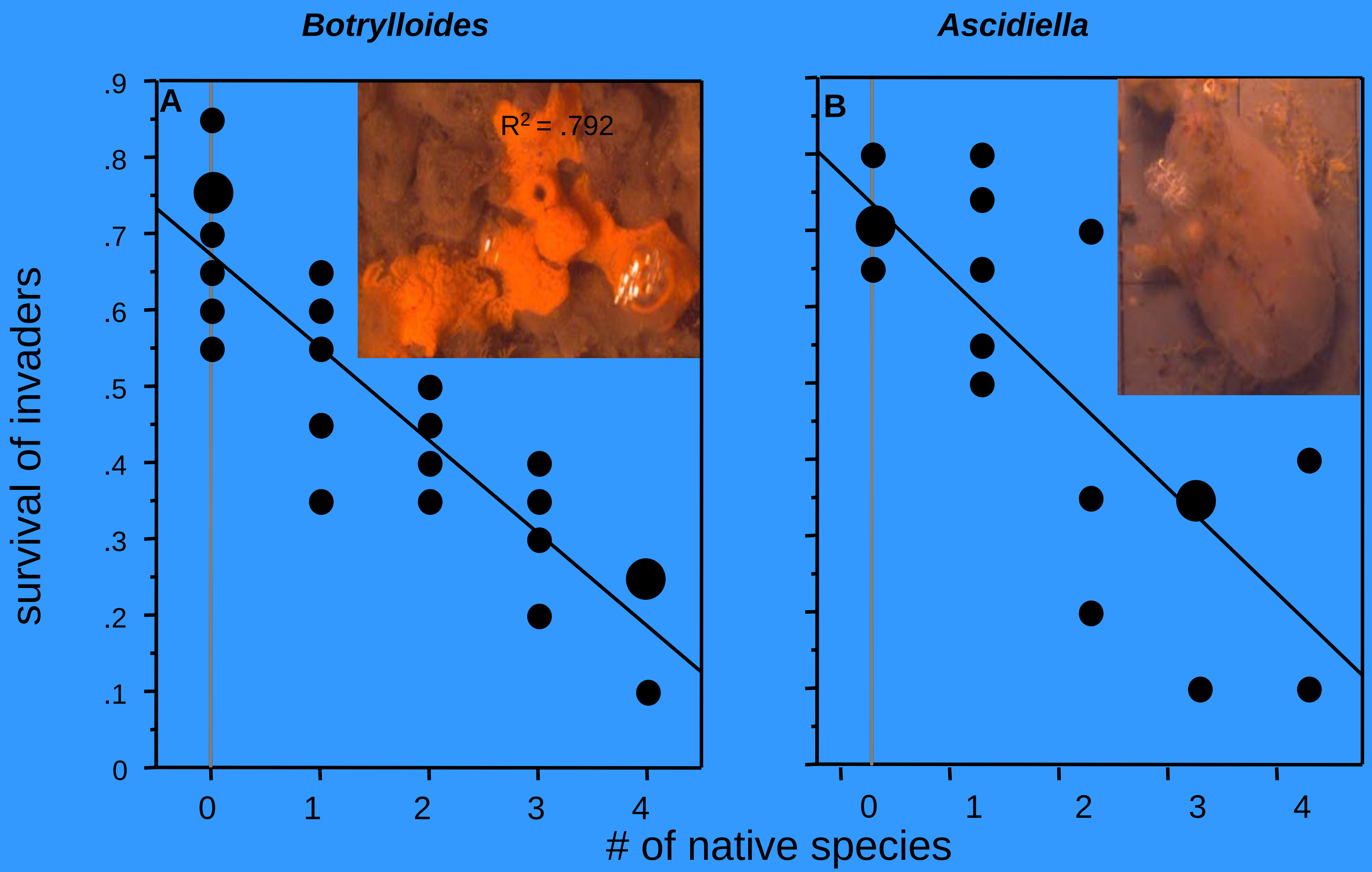
Example of a 2 spp assemblage

Example of a 3 spp assemblage

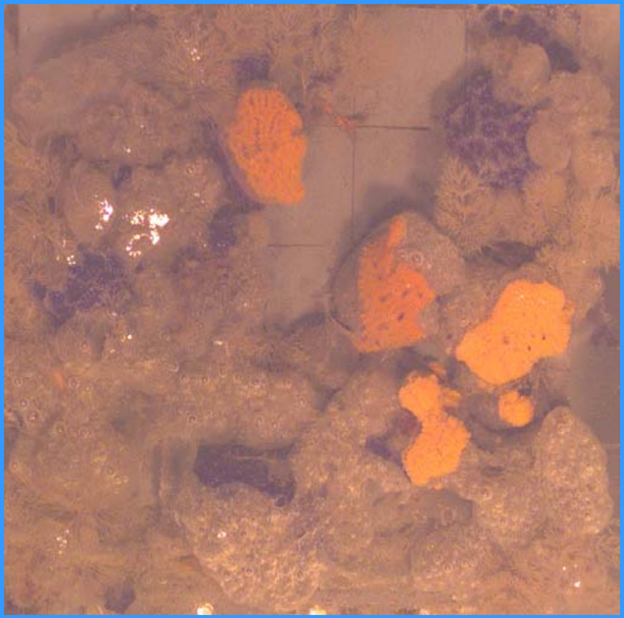


Example of a 4 spp assemblage

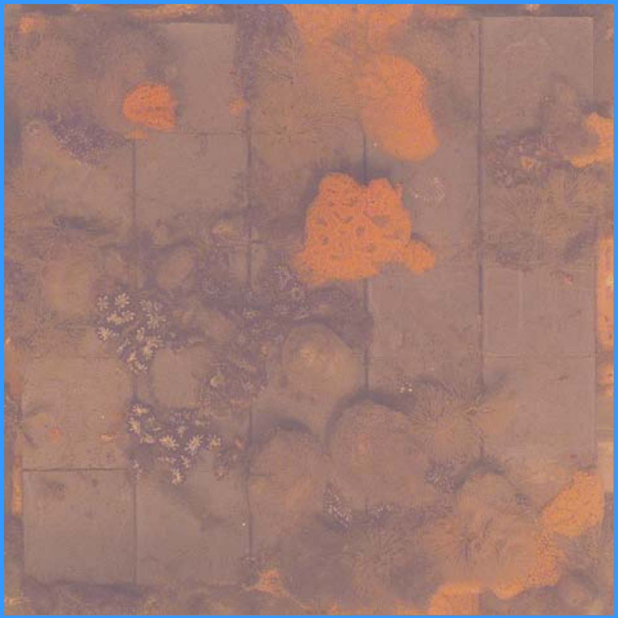
Declining native biodiversity facilitates invasion success



Importance of Disturbance on Invasion Success

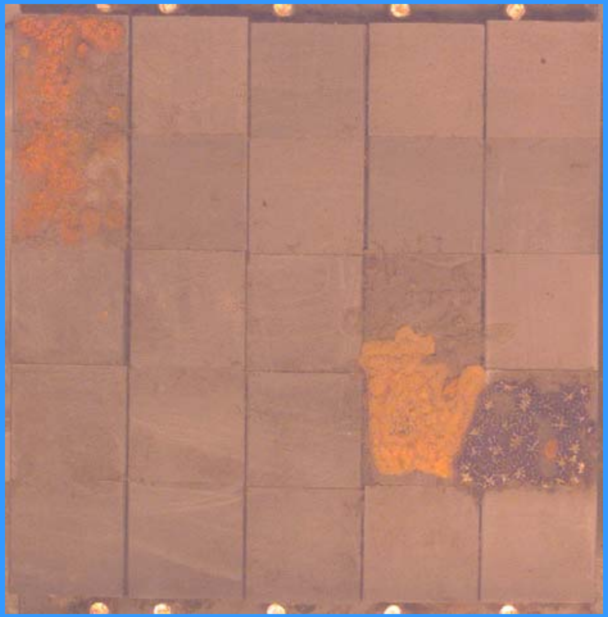


20%



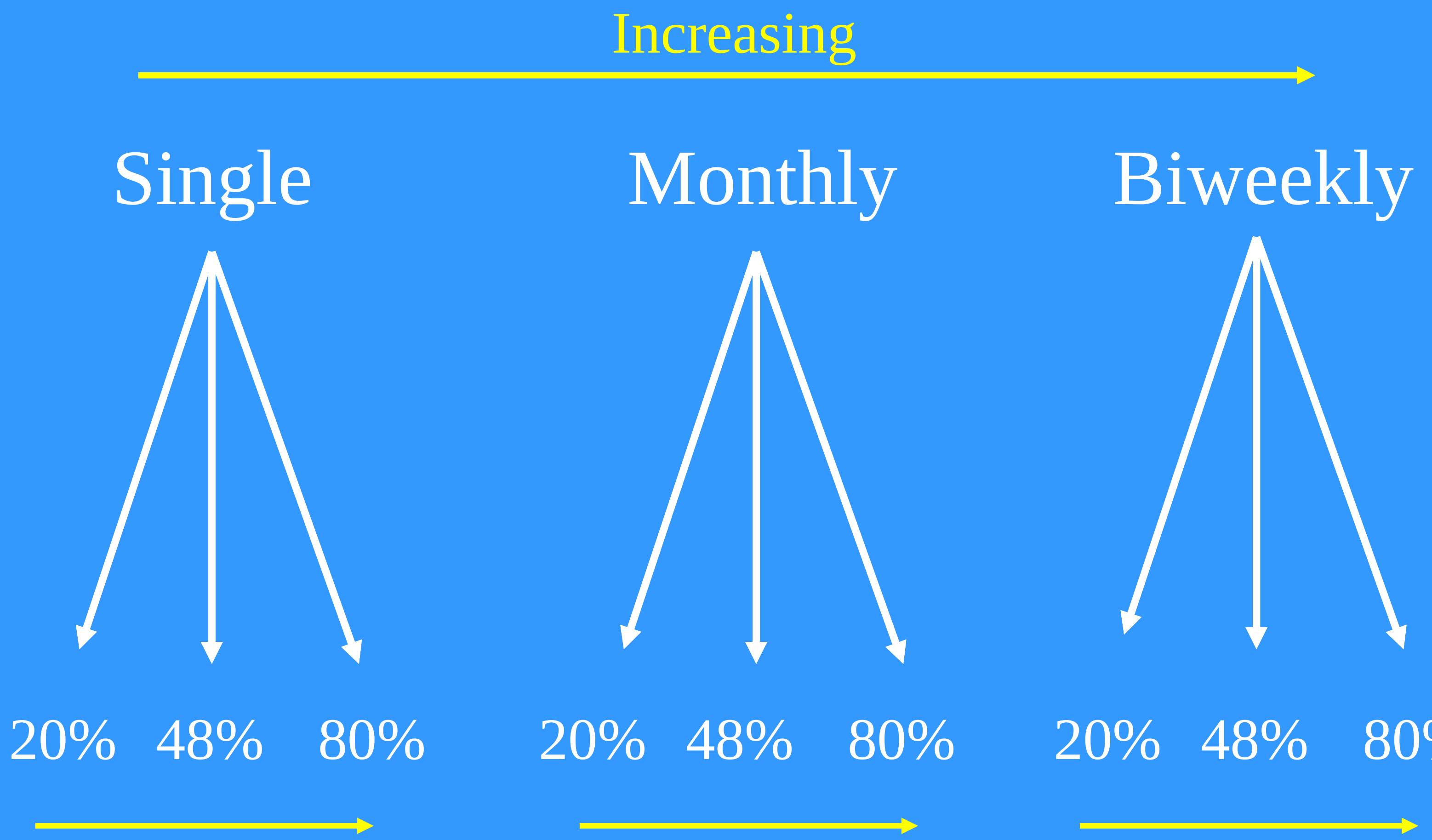
48%

10cm



80%

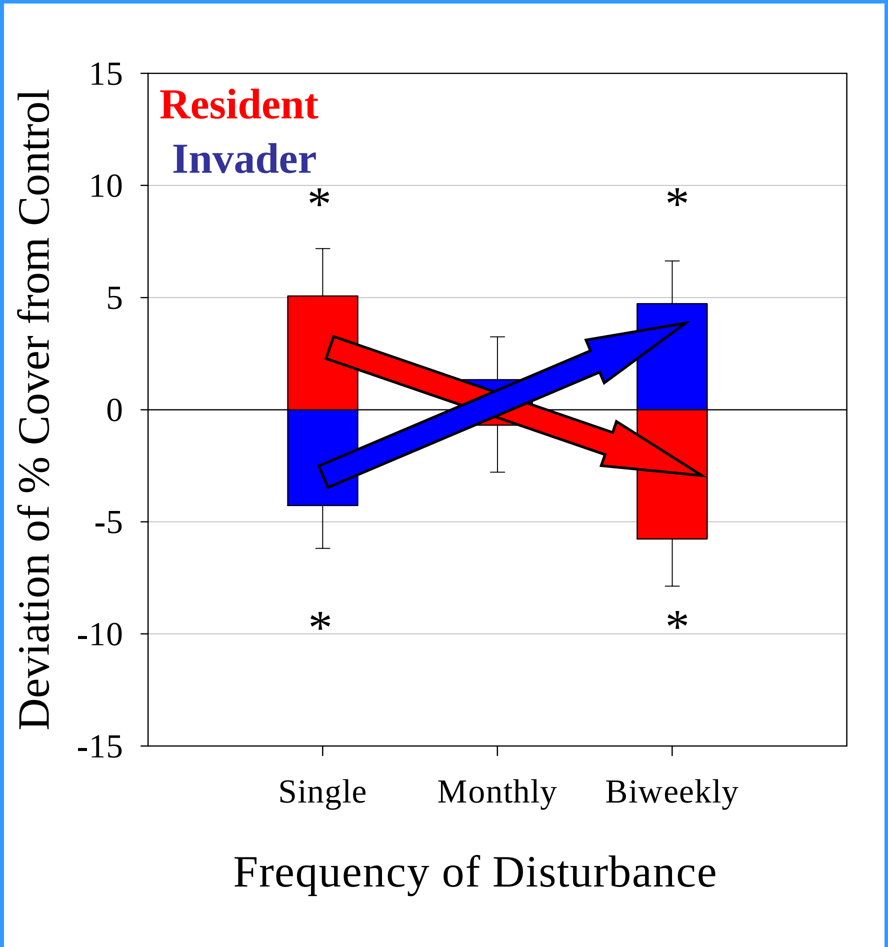
Disturbance Frequency

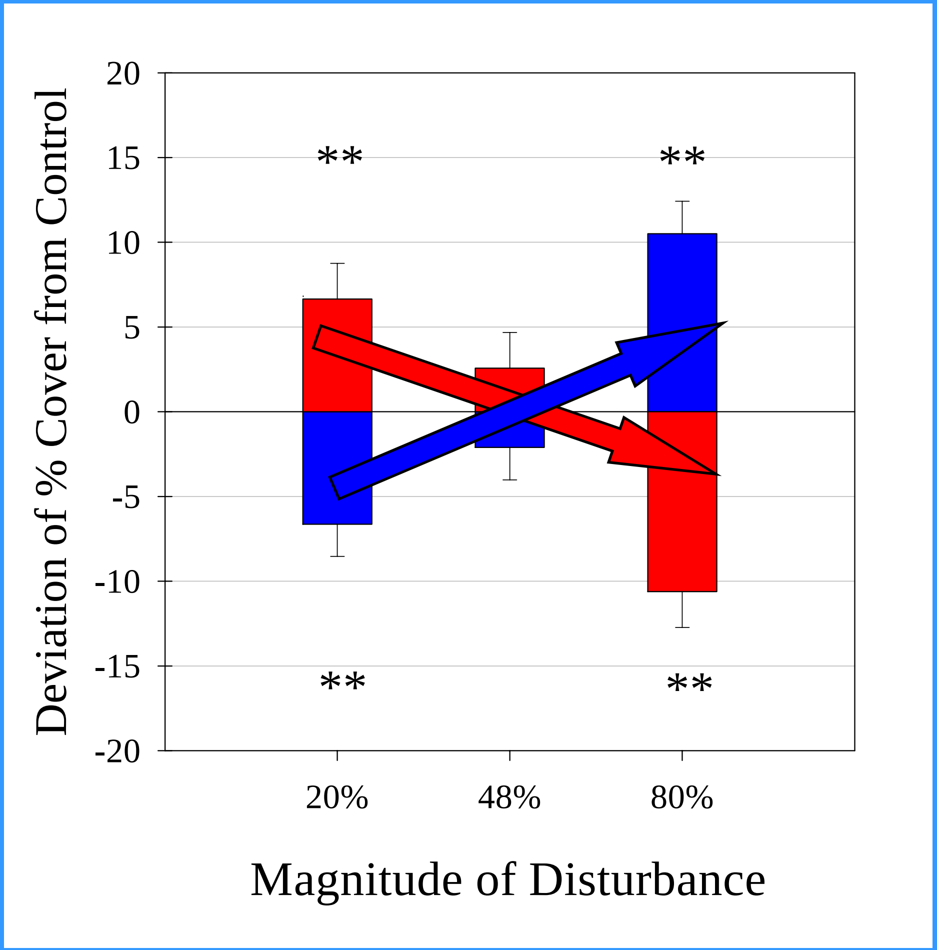


Disturbance Magnitude

Differential Responses to Disturbance

Invaders vs. Residents





From: S. Altman 2002.
UCONN Masters Thesis

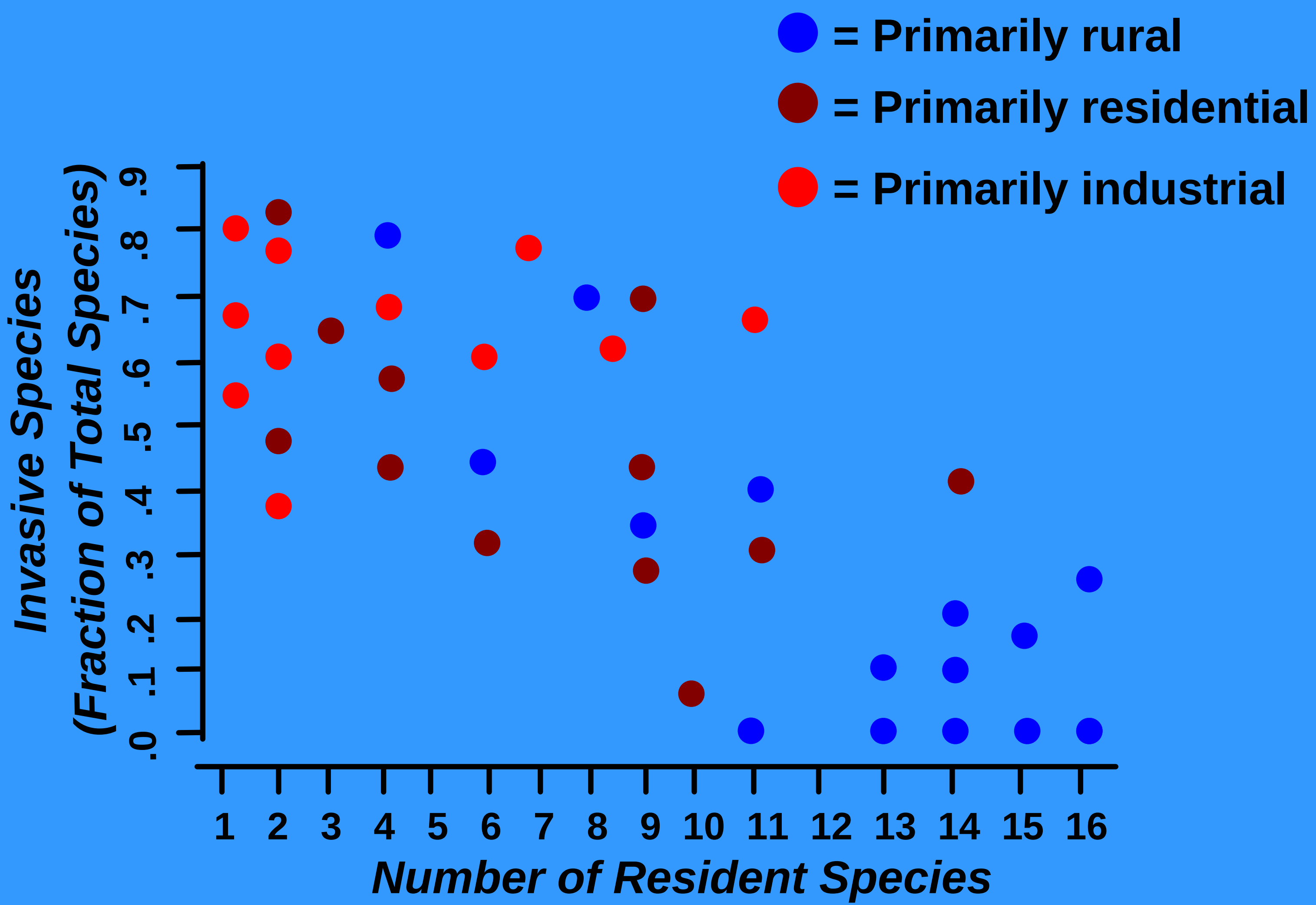
Variations in Land Use Along the Connecticut Coastline

Primarily Industrial

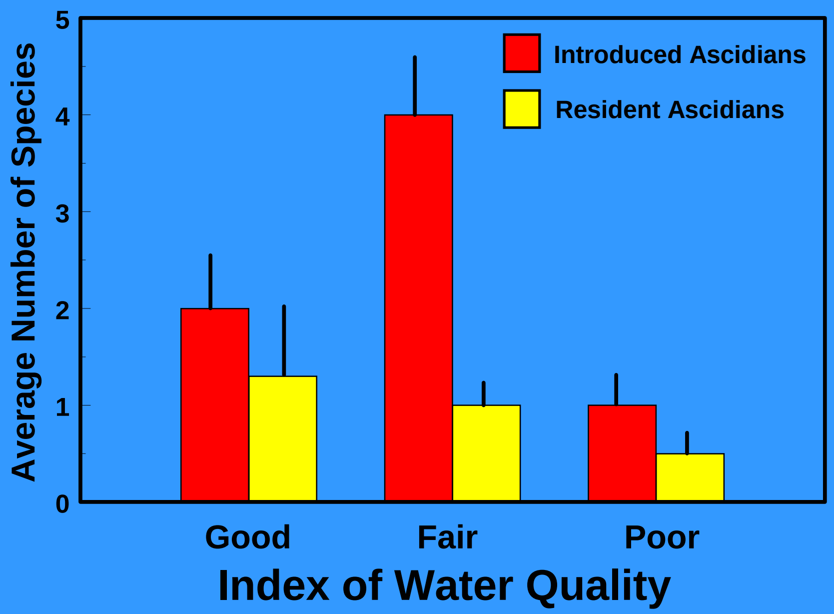
Primarily Residential

Primarily Rural

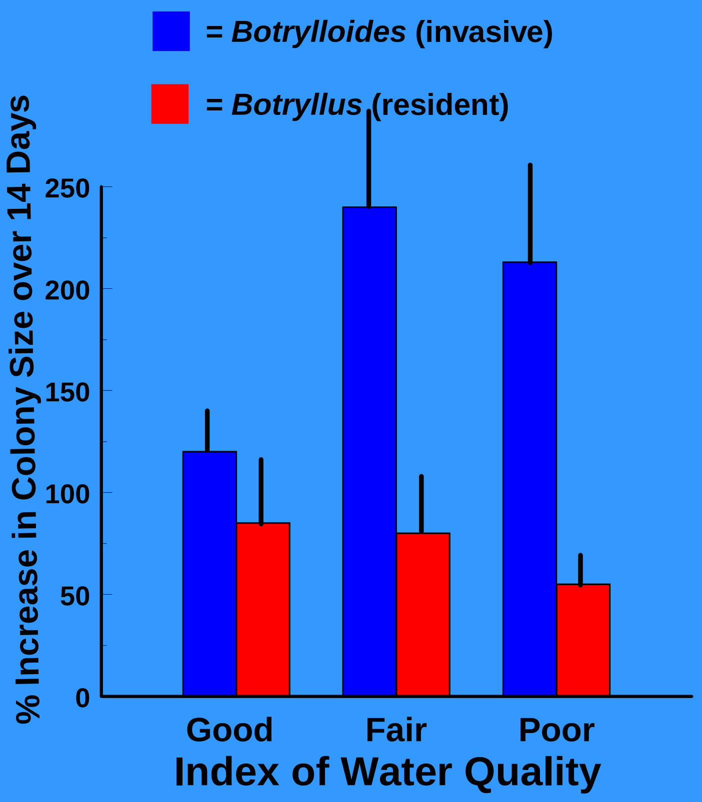
Influence of variations in coastal land use on invasions: Correlation between resident species richness and the fraction of invasive species in areas of different coastal land use in coastal Connecticut



Effects of water quality: species richness and growth rates of resident and non-native ascidians

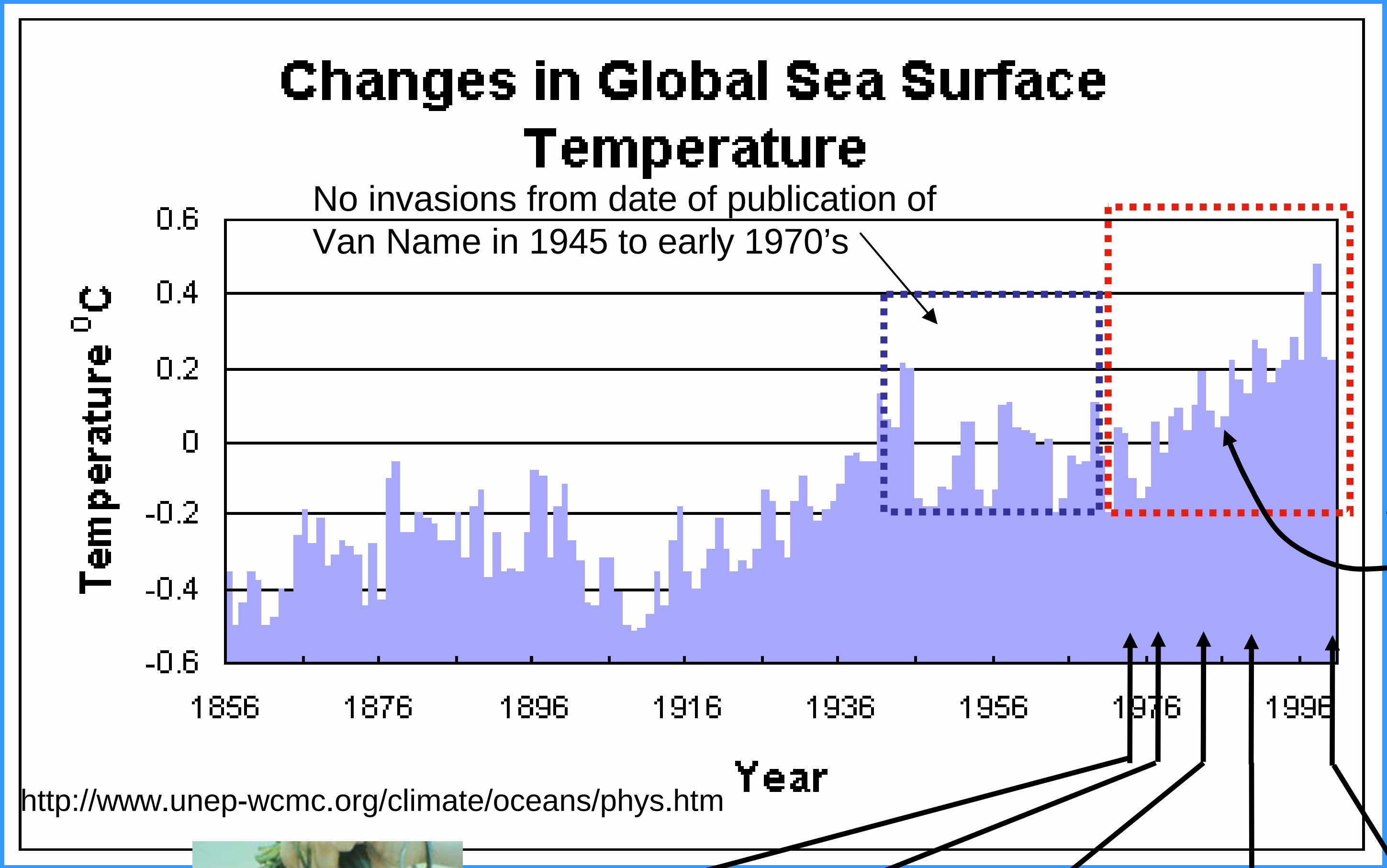


Relationship between differences coastal water quality and species richness of resident and introduced ascidians



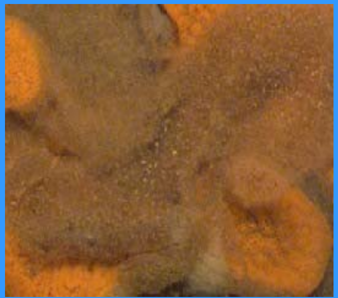
Relationship between coastal water quality and growth rates of a resident and non-native colonial ascidian

The timing of invader establishment into Long Island Sound is coincident with recent acceleration of warming

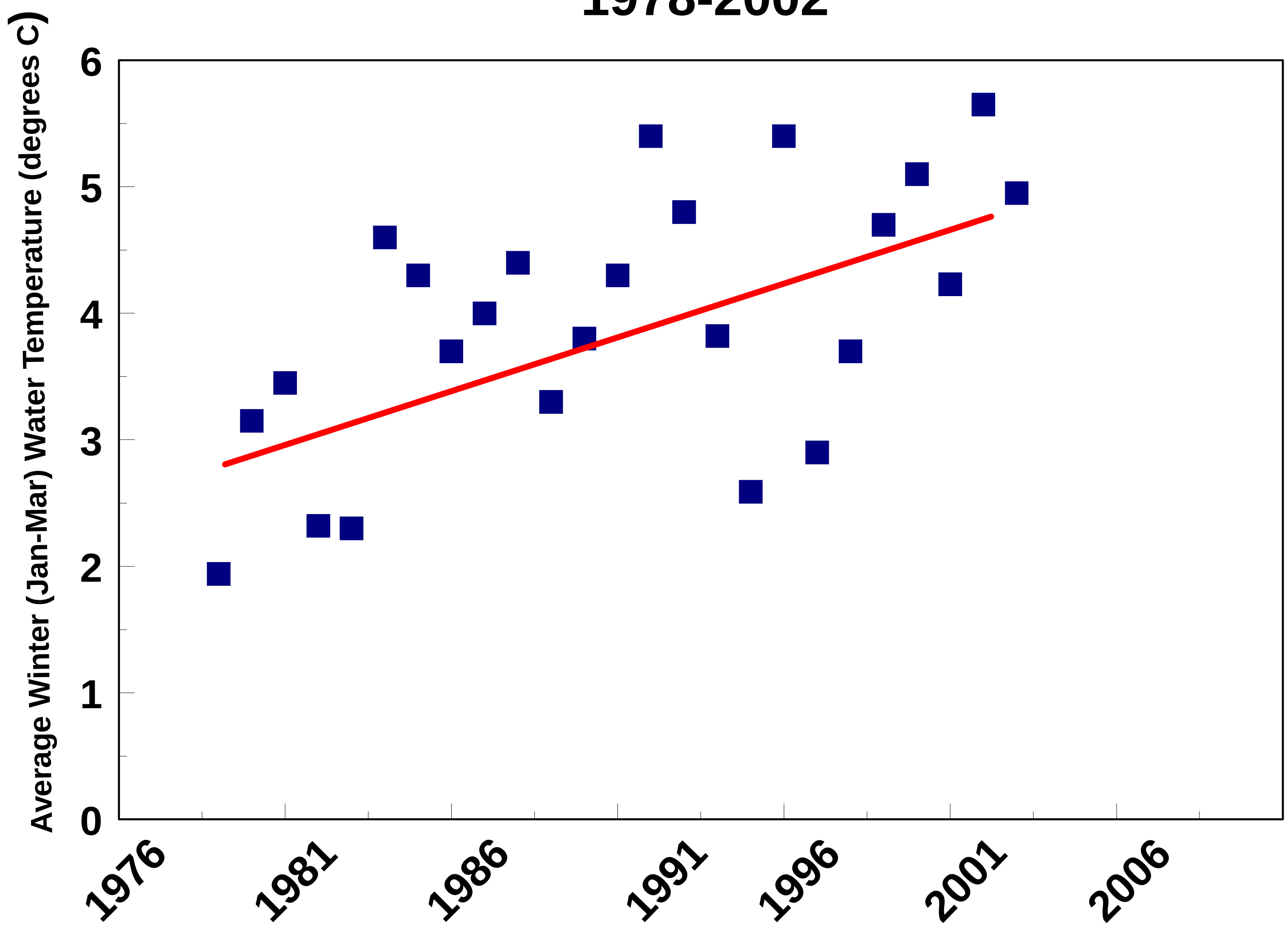


recent warming trend

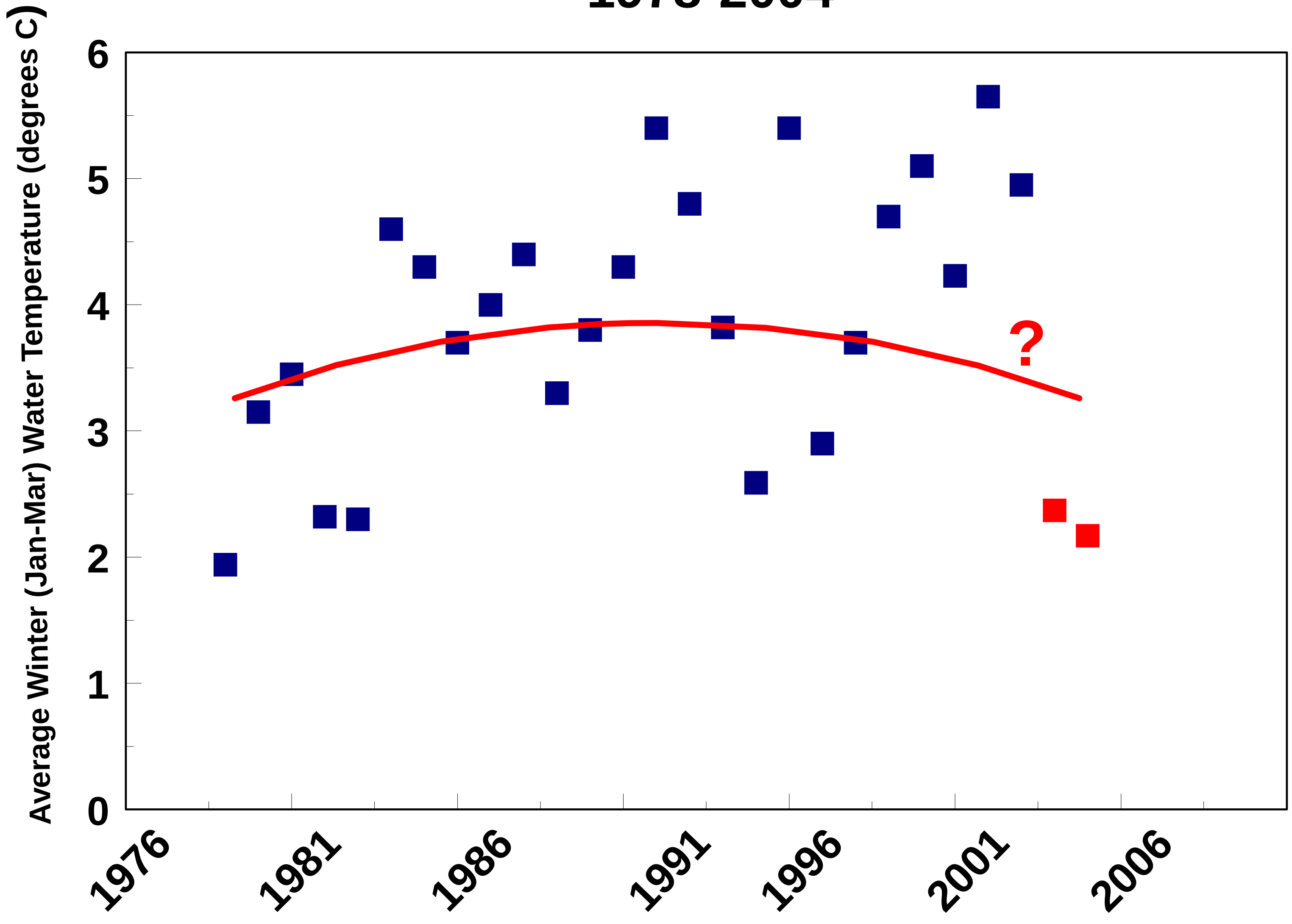
?



Long-Term Patterns of Surface Seawater Temperatures in Eastern Long Island Sound: Average Winter (Jan-Mar) Temps from 1978-2002

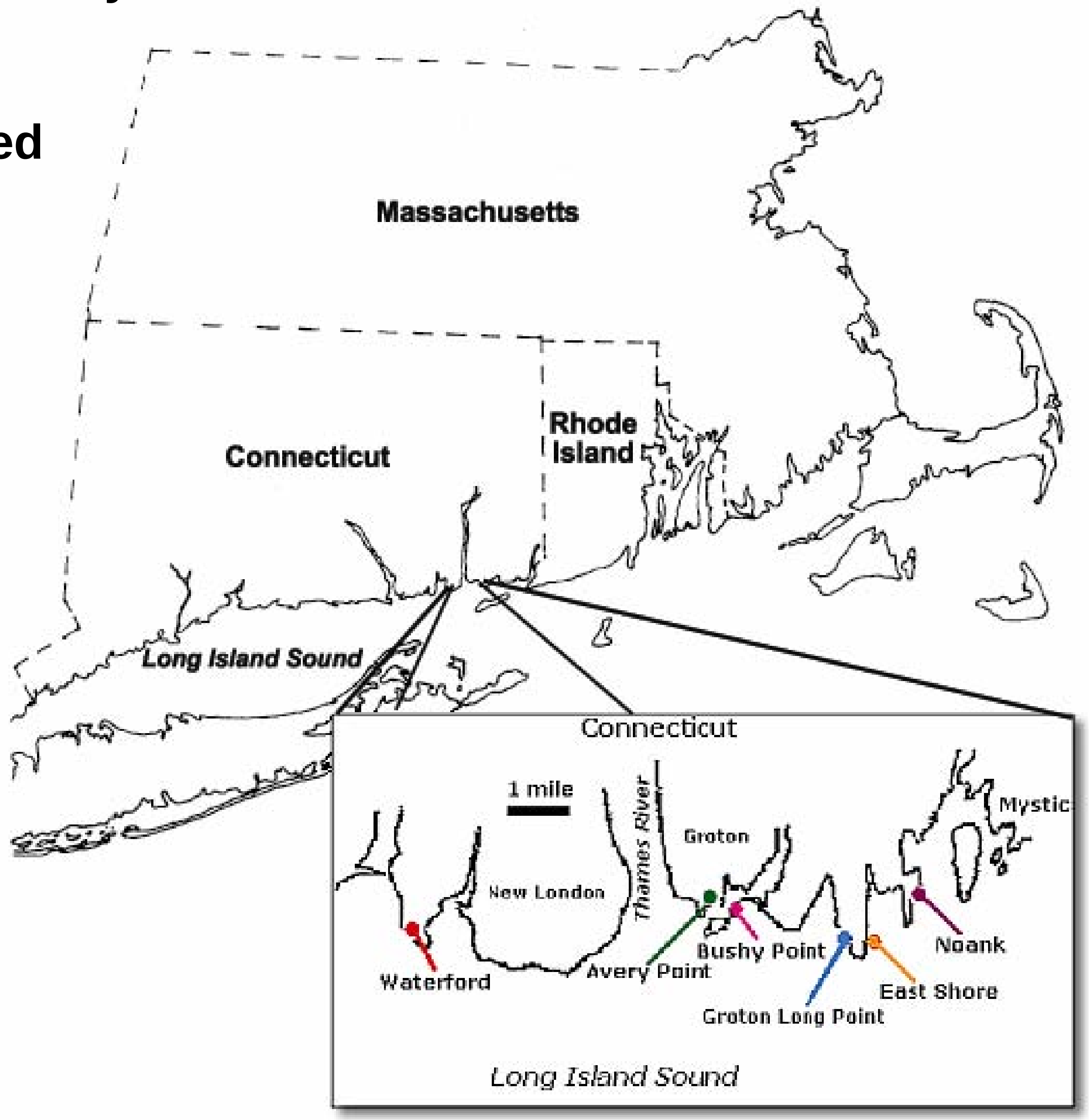


Long-Term Patterns of Surface Seawater Temperatures in Eastern Long Island Sound: Average Winter (Jan-Mar) Temps from 1978-2004

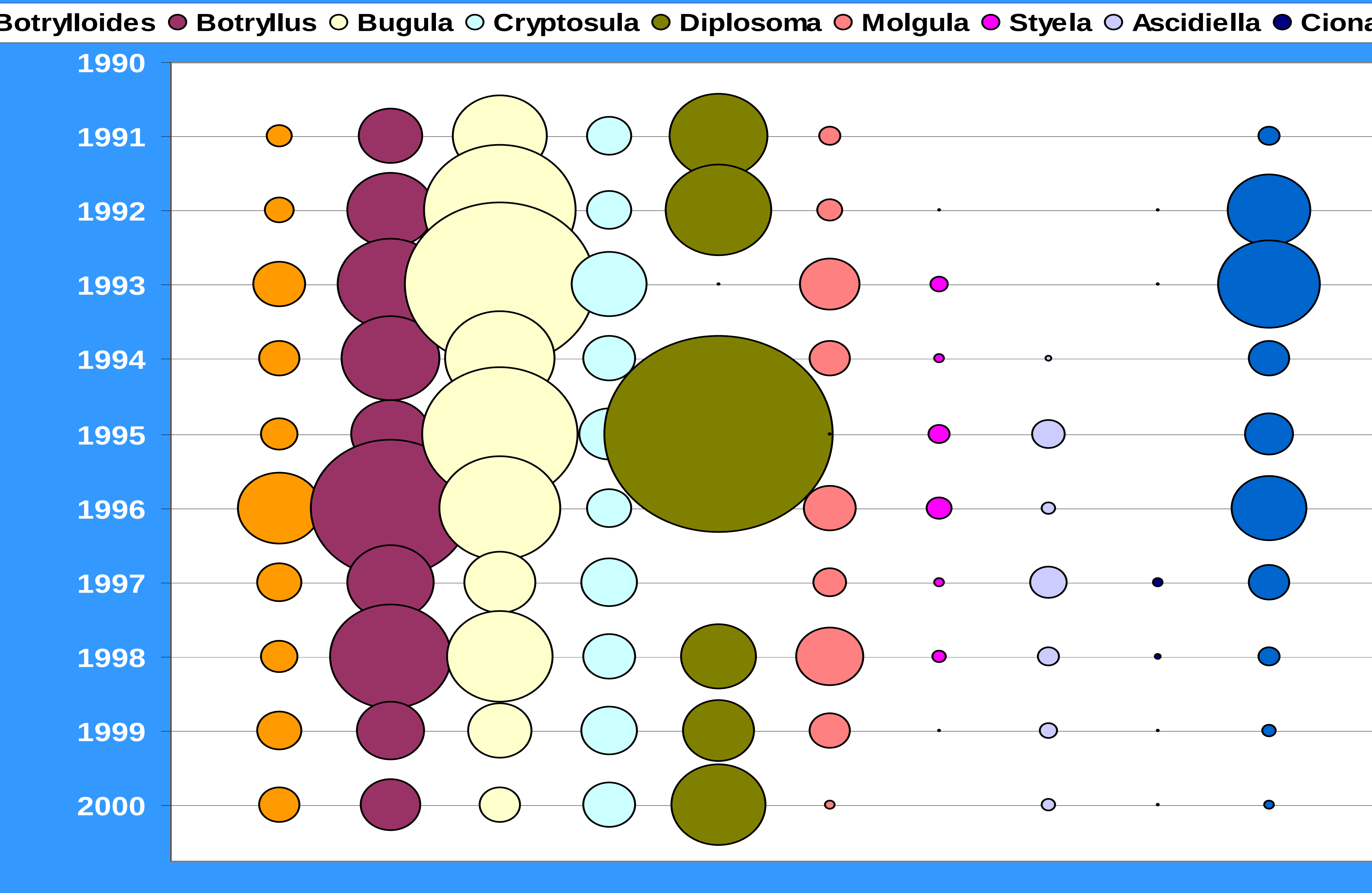


Recruitment of sessile marine invertebrates measured weekly since 1991 at Avery Point

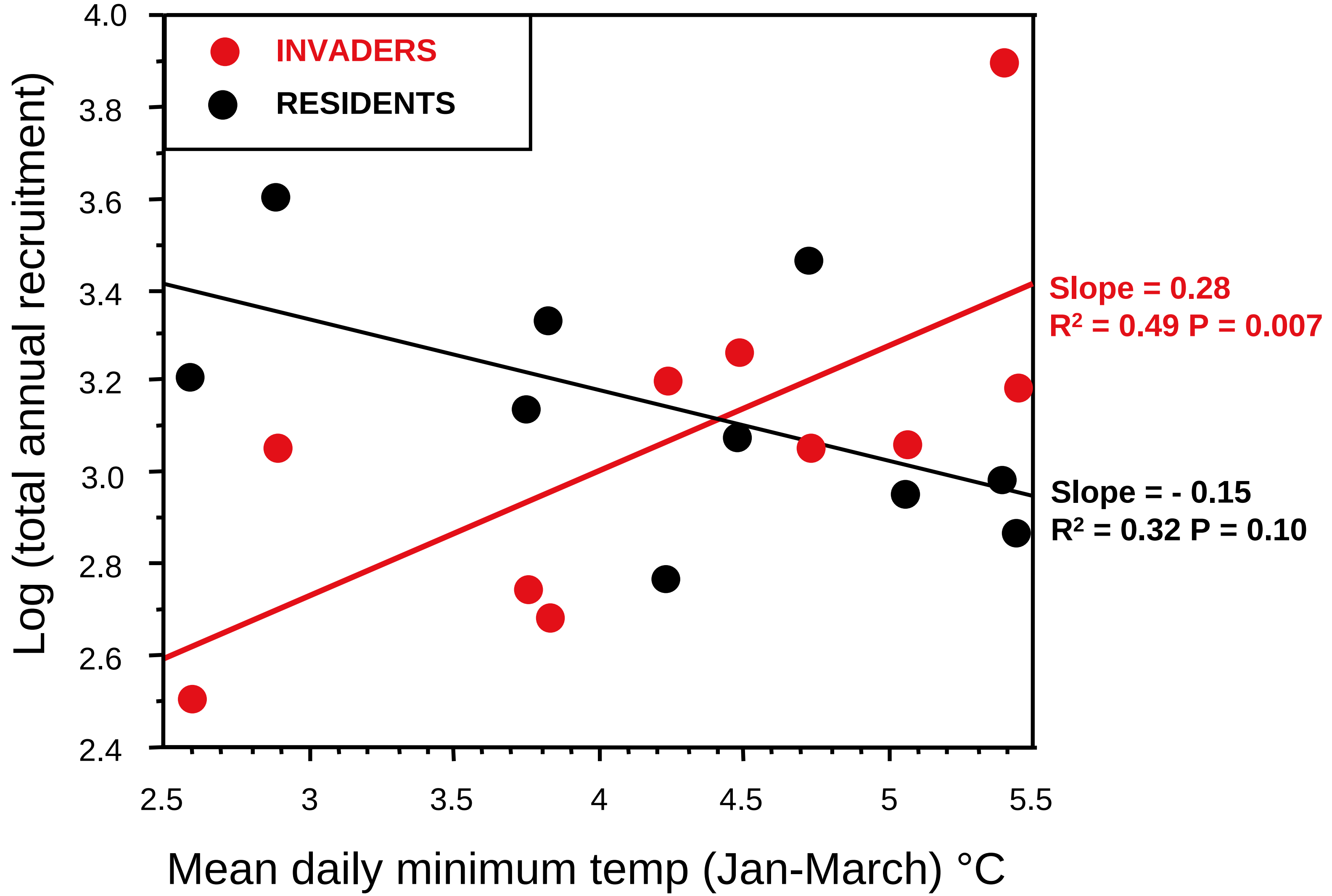
Five additional sites added in 2001



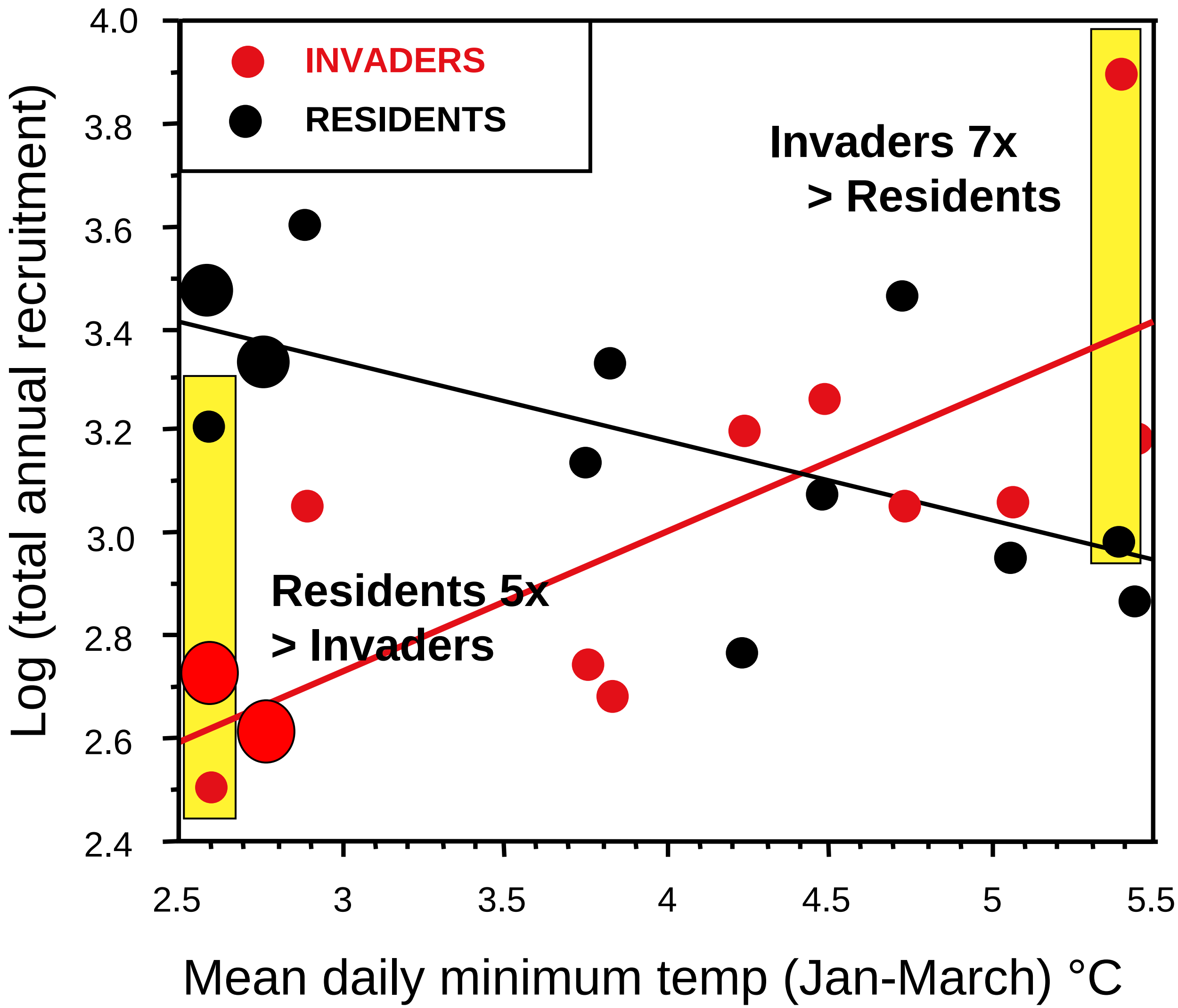
Inter-Annual Differences in Total Recruitment Abundances of the Dominant Fouling Species



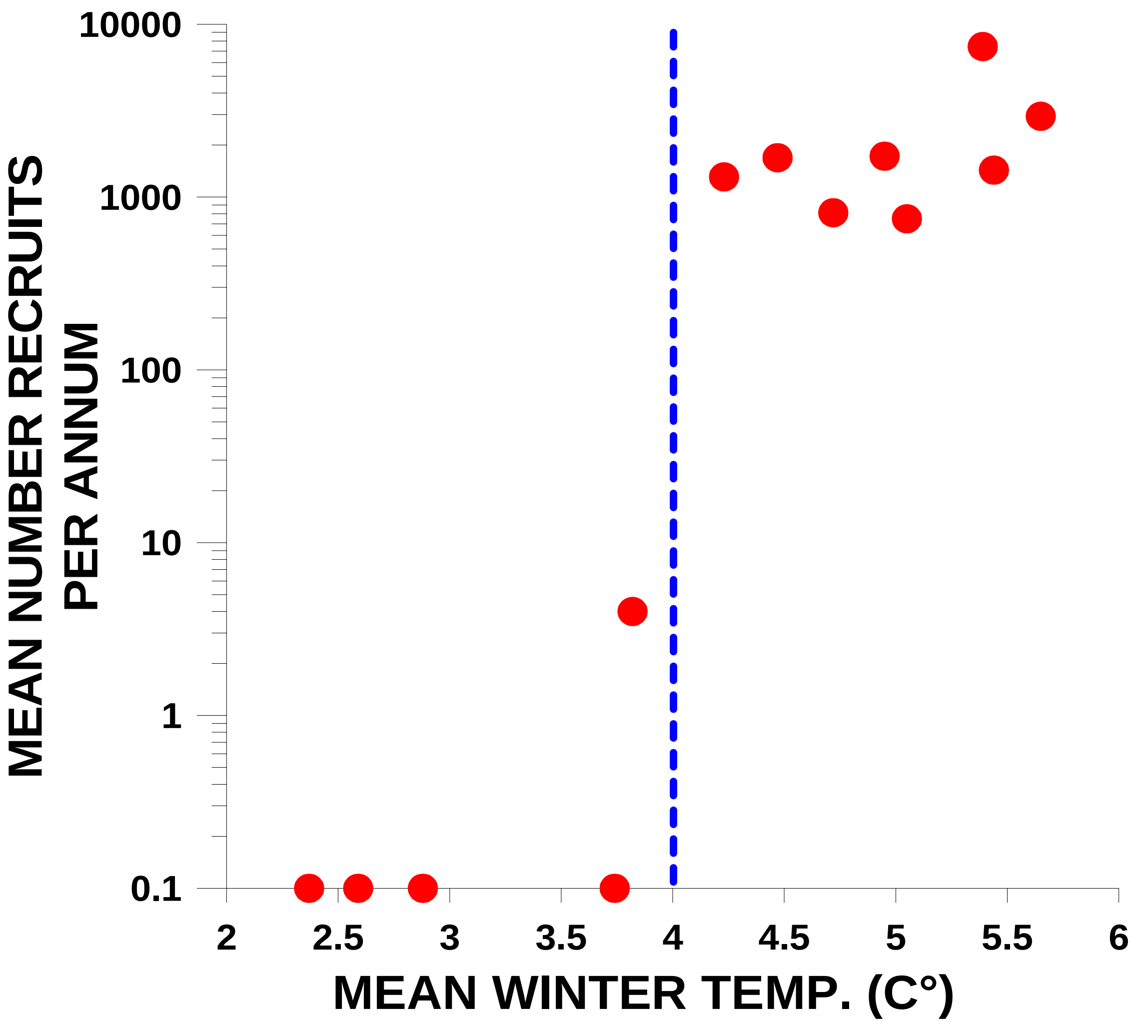
Rising winter temperatures (1991-2002): 1. Increases in the recruitment abundance of recent invaders. 2. Decreases in recruitment abundance of resident species



A few degrees difference in mean winter temp. correlates with a large reversal in the relative dominance of residents and invaders



Threshold effects: small temperature changes can result in large recruitment abundance changes for some species



Colonial non-native ascidian *Diplosoma*

Summary I -

- Modifications of coastal habitats (e.g., breakwaters, marinas, ports) facilitate invader success
  - -- more habitats for species to occupy
  - -- fewer natural predators
  - -- enhanced retention of larvae leading to rapid population growth and expansion

- -Factors reducing local biodiversity can lead to increased habitat vulnerability to invasion
  - -- reduced water quality
  - -- increased habitat disturbance

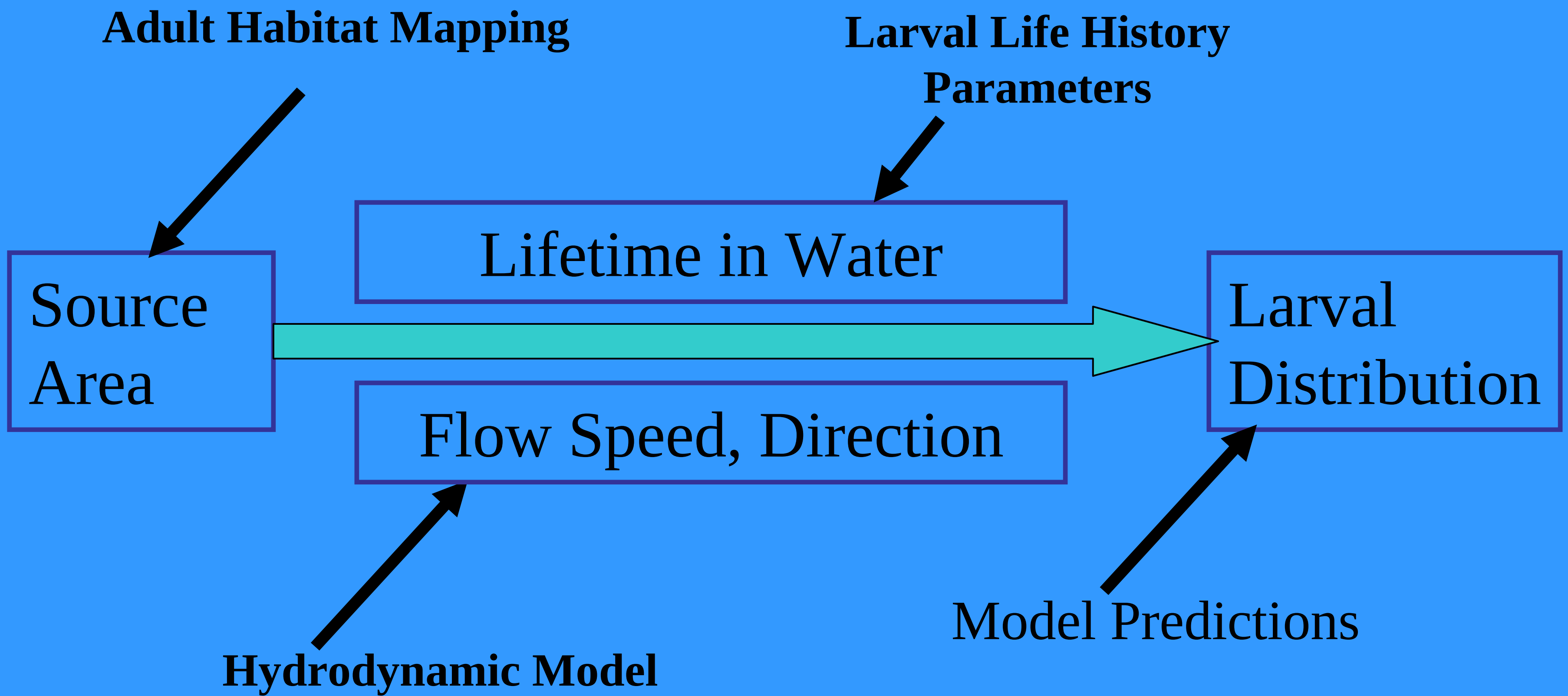
- -Increasing water temperatures facilitate invader success
  - -- enhanced recruitment of invaders
  - -- enhanced growth of invaders
  - -- earlier recruitment timing relative to resident species

The Challenge -- how to bring these all together to assess the combined effects on the susceptibility of habitats to species invasion and subsequent ecosystem changes in a manner that can be used by managers and planners

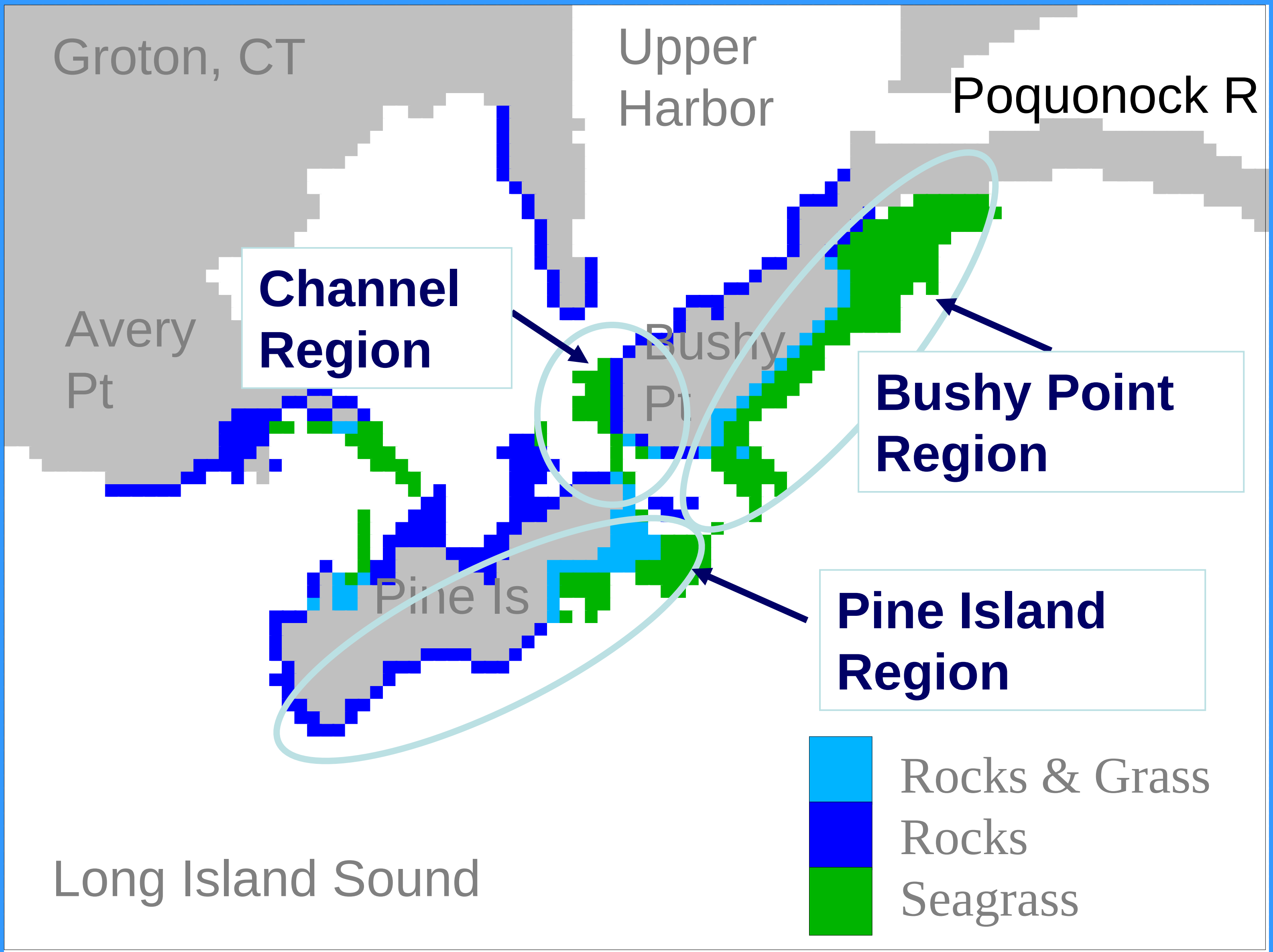
Stressor-Response Model Development: Development Criteria

1. Flexible application to different types of coastal habitats
2. Incorporation of the two-phase life cycles of the species – pelagic larval phase and the adult benthic phase
3. Incorporation of abiotic and biotic stressors and their effects on the biology of coastal ecosystems
    a. Effects of temperature (e.g., growth, competitive ability, timing of reproduction, etc.)
    b. Effects of coastal land use patterns (e.g., pollution, shore-line modifications)
    c. Effects of invasion species (e.g, competition with residents, changes in biodiversity)
4. Interactive modeling approach which can be used to easily examine different types of environmental impact scenarios

Multi-Tiered Modeling Approach

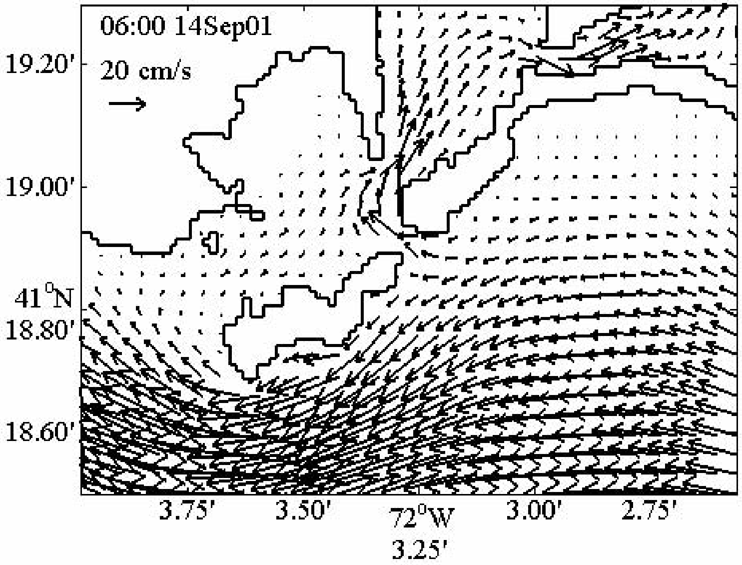


Potential Adult Benthic Habitats



Habitat + Hydrodynamics -> Larval Dispersal Patterns

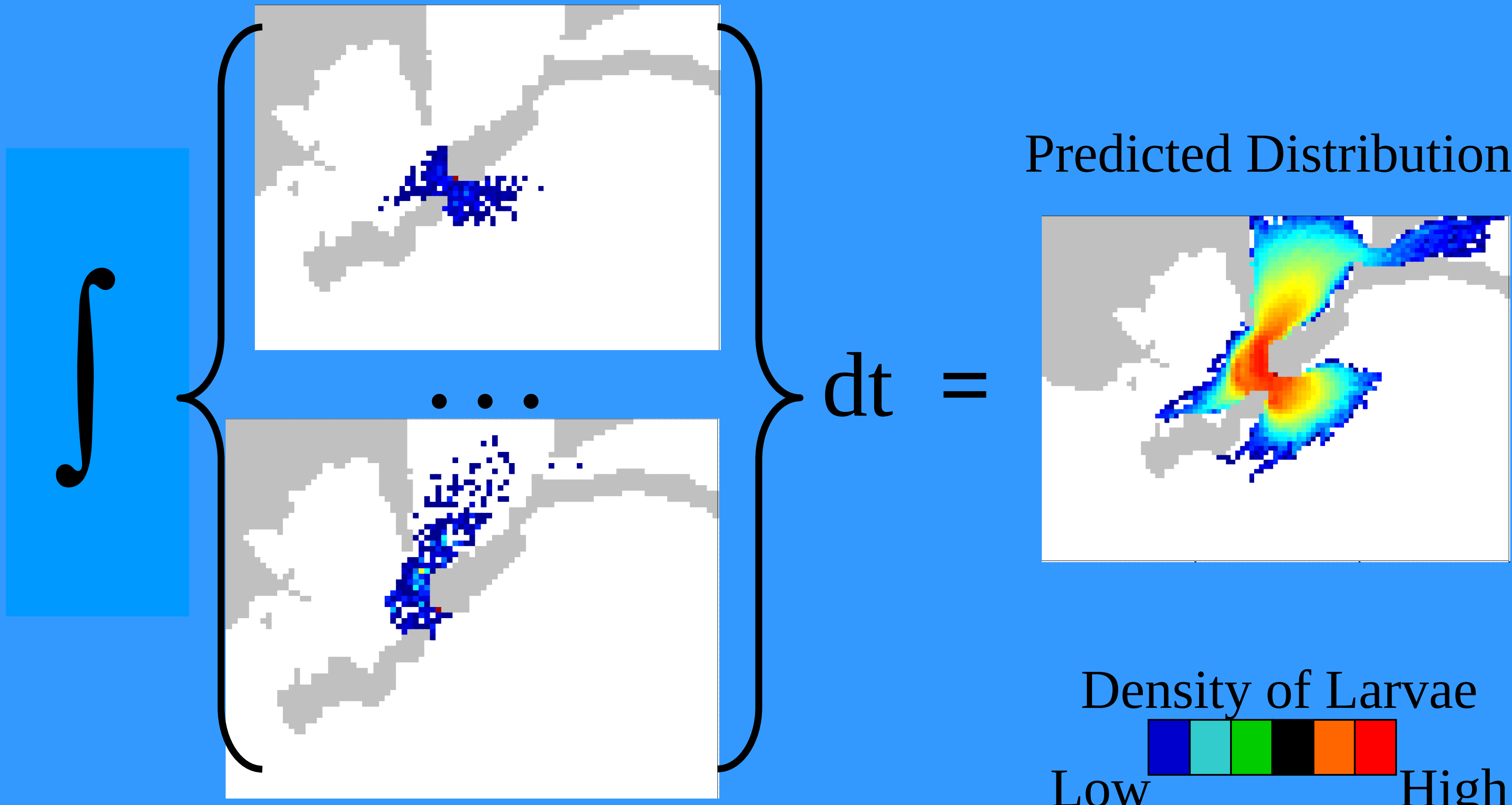
Source: Channel Region



Hydrodynamic Model

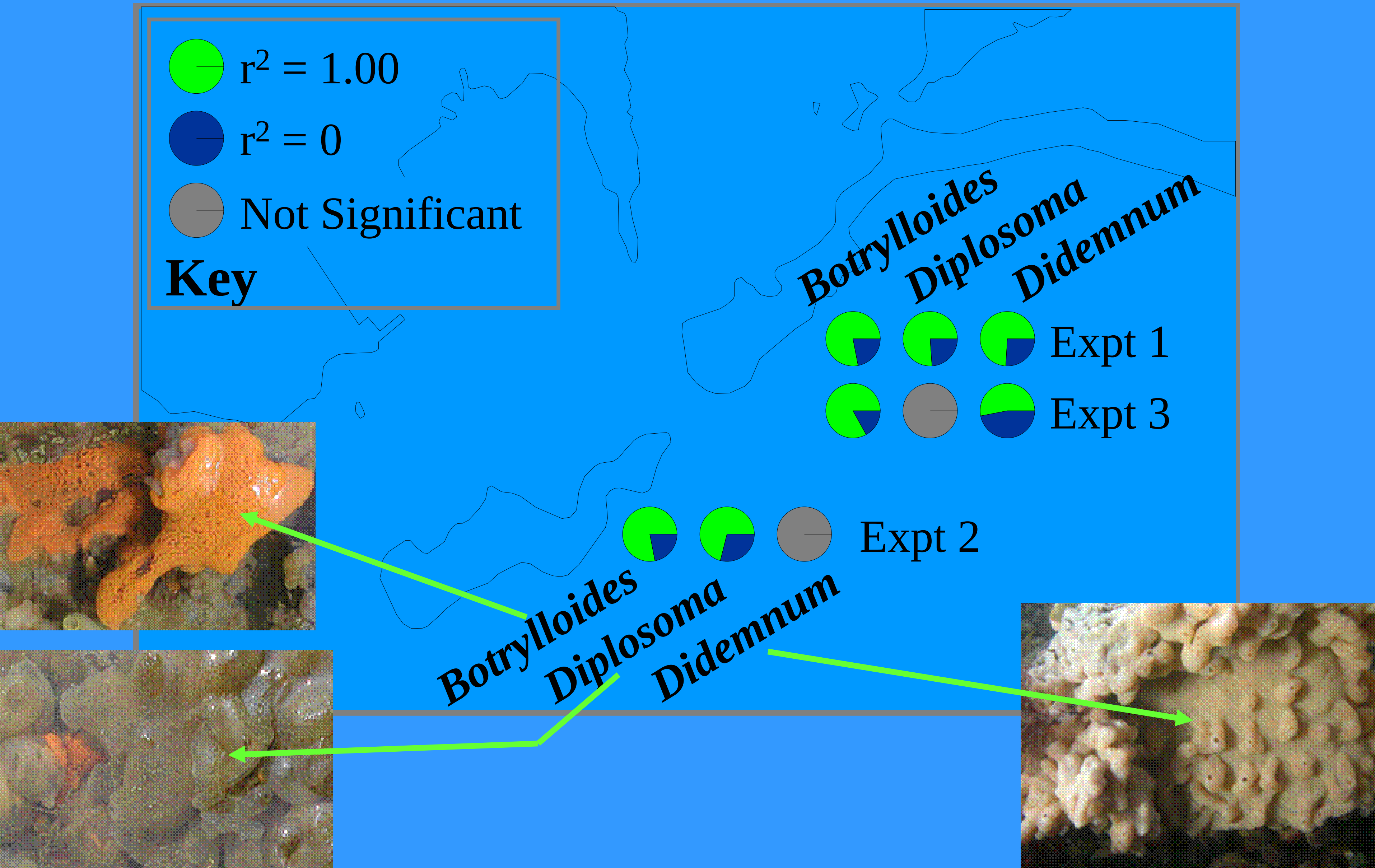
Estimated Larval Density

Cumulative Larval Distribution



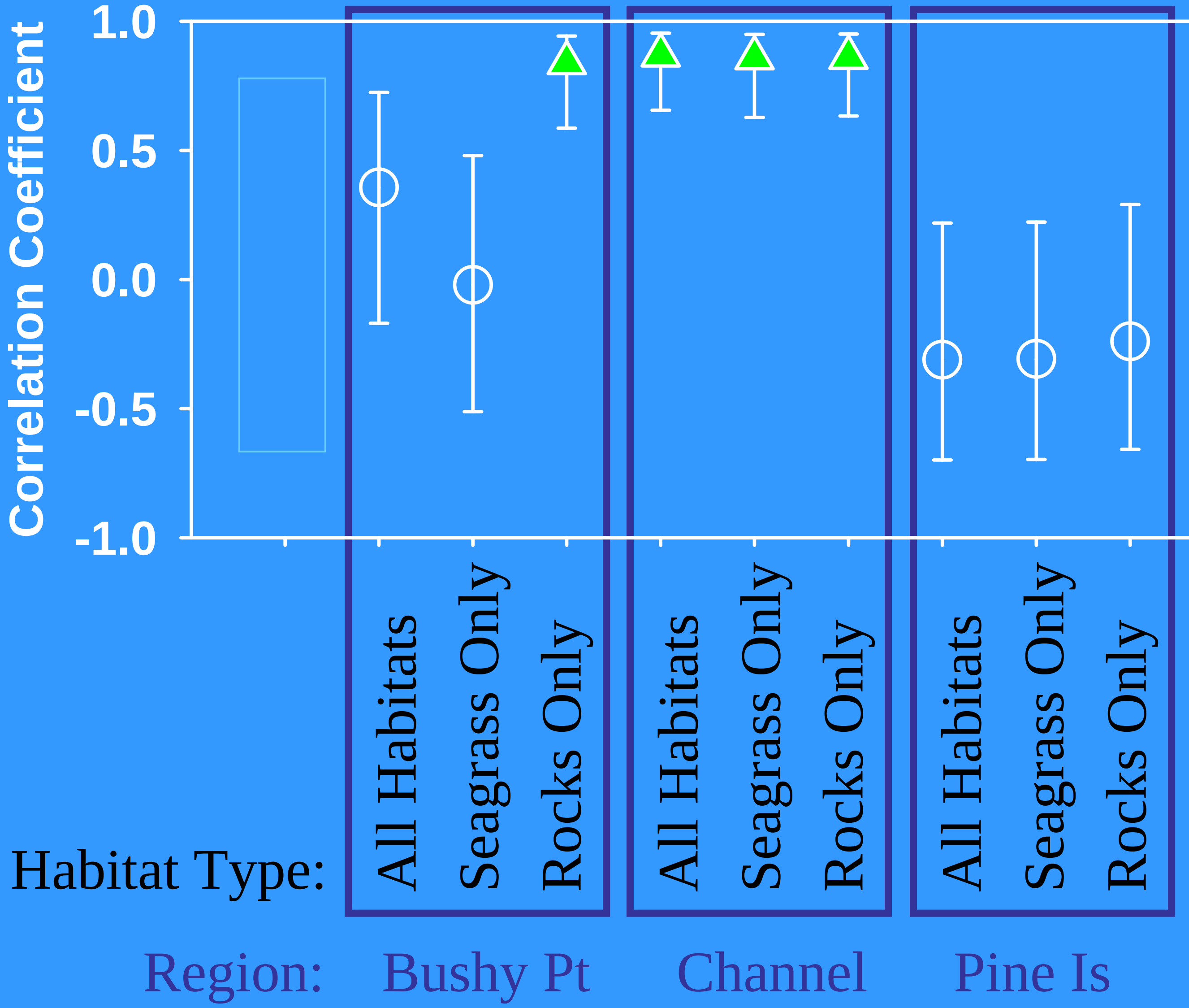
Source: Channel Region

Comparisons of Model Predictions to Experimental Data on Larval Recruitment Patterns and Rates



The Relative Contribution of Different Adult Source Habitats to Observed Recruitment Patterns

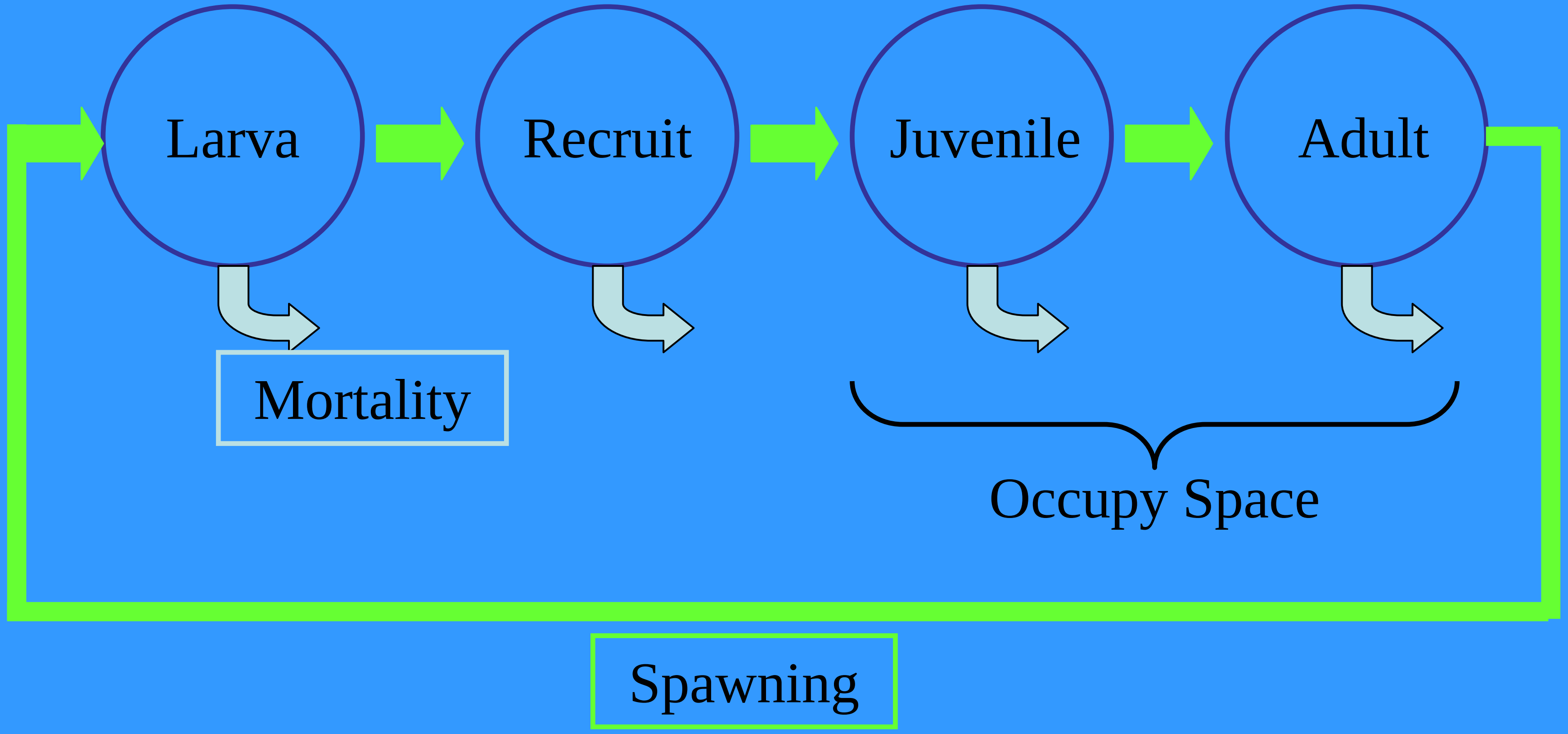
Experiment 1 - *Diplosoma*



Symbol: *r*
Error bar:
+/- 95%CI

$r^2 = 0.70$
to 0.76
$p < 0.001$

Life Stage-Based Population Model



Permits developing different scenarios/predictions related to:

1. Climate change influences on population dynamics, competitive interactions, etc.
2. Effects of current and projected changes in coastal land use
3. Effects new invaders into coastal systems
4. Interactions between stressors

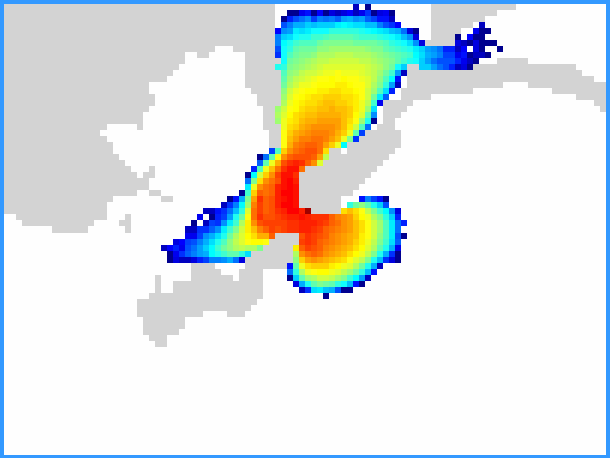
Example: Effects of habitat modification on larval dispersal patterns

Larval Sources

Unmodified Shoreline

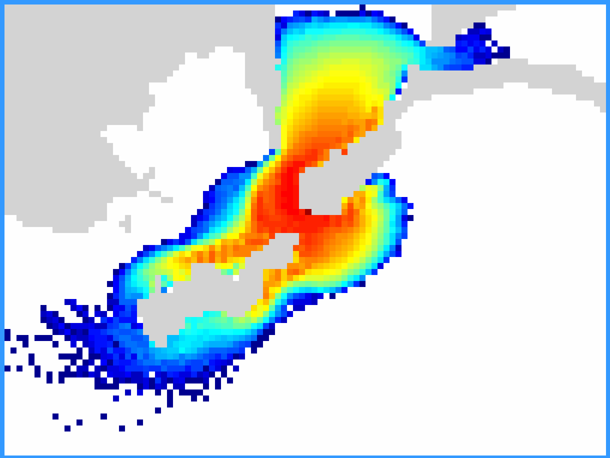
Heavily Modified Shoreline

Example: Model predictions of larval dispersal in unmodified and modified shorelines



Unmodified Shoreline:

Natural dispersal pattern



Heavily Modified Shoreline:

Extended dispersal pattern

Future Directions:

1. Additional field studies to simulate predicted temperature changes and population/community responses of native and non-native species

2. Reciporcal transplant experiments to determine interactive effects of water warming and existing stresses on the degree to which native communities may be altered by the increased success of newly introduced species.

3. Measurement and modeling of water quality, placement of marinas, docks and other alterations of the coastal zone on population/community dynamics

4. Continued development of a stressor-response model which can be easily used by managers to discern which coastal habitats appear to be more vulnerable to the multiple stressors

5. Examine the uncertainities of the model predictions and how model results be extrapolated both spatially and temporally and how the model can be tested and validated.

Thank You!

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