Understanding Ecological Thresholds in Aquatic Ecosystems through Retrospective Analysis

Thresholds and multiple stable states in southern New England shallow water communities

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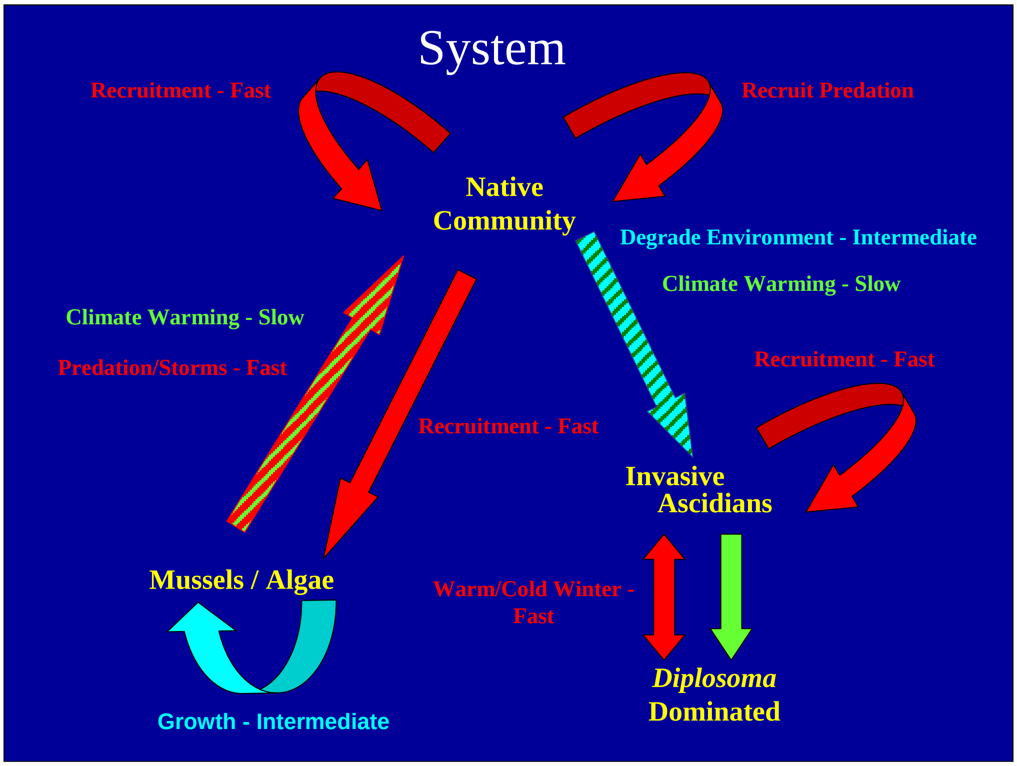
Approach

- Define System & Geographic Location
- Discuss the Underlying Data
- Present Examples of Modeling the System
- Describe Surprising Recent System Changes
- Discuss Possible Management Uses

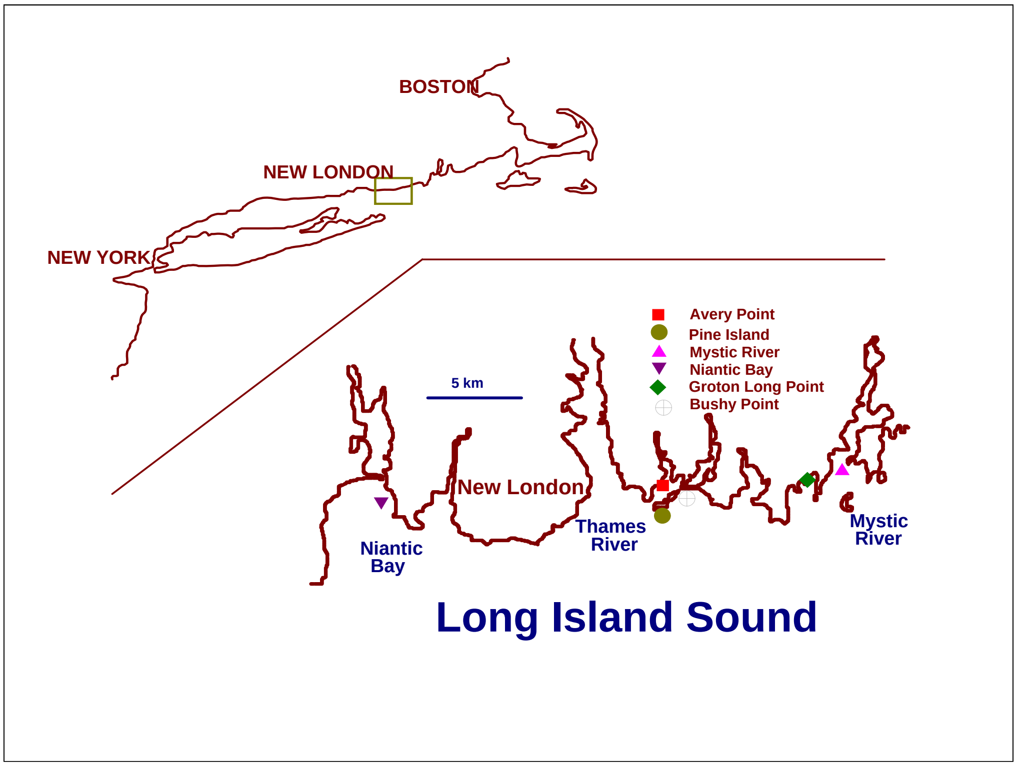
The researchers are studying sessile invertebrates in the southern New England area. As adults, all of these species are attached to some type of natural substrate, usually rocky areas. Planktonic water larvae connect the different parts of the system.



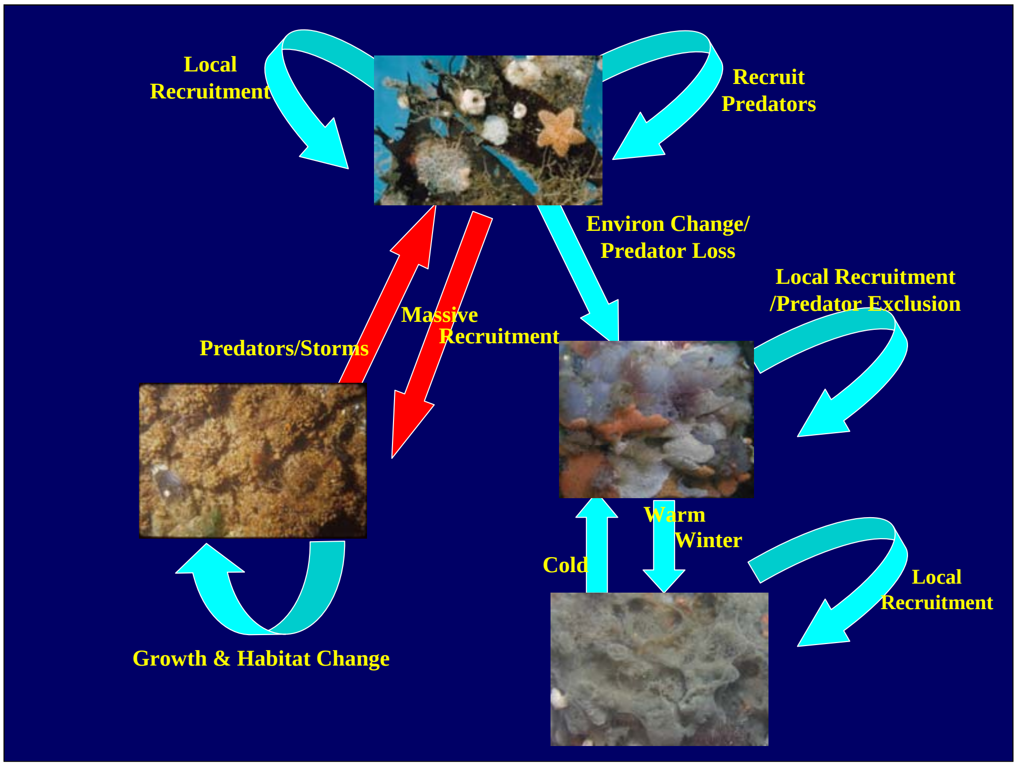
Three major transitions have occurred: invasion of the native community by mussels, introduction of new species into the community (they often dominate the community), and total domination of the community by an invasive species (temperature dependent).

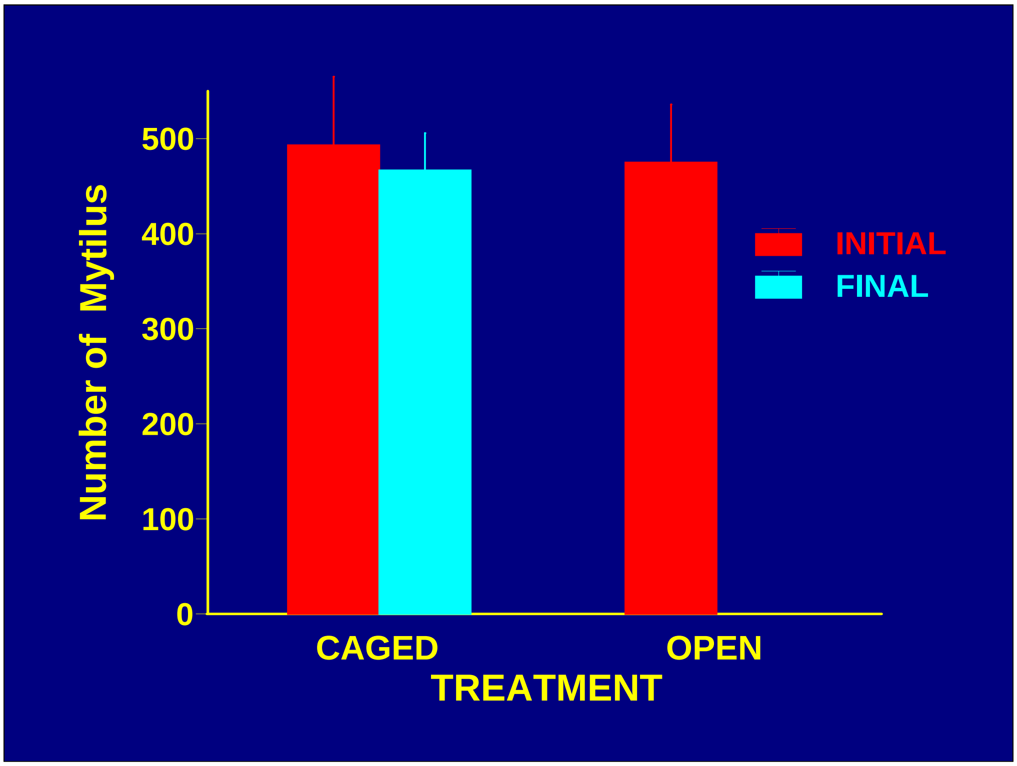
Ecological Significance of Thresholds

- 4 States varying in Dominance from Native to Invasive Species
- Invasive Species Associated with Human Impact
- Native Species Include Commercially-Important Species & Important Food Web Species
- Switches May Effect Biodiversity of Region

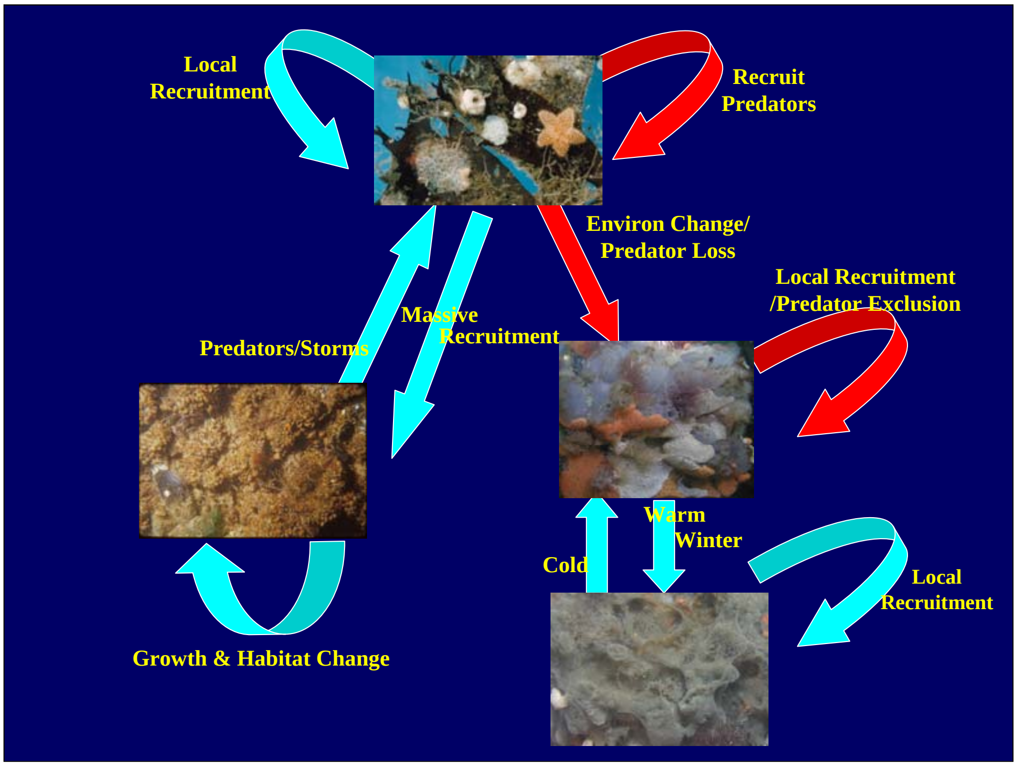

BOSTON
NEW LONDON
NEW YORK
Avery Point
Pine Island
Mystic River
Niantic Bay
Groton Long Point
Bushy Point
5 km
New London
Niantic
Bay
Thames
River
Mystic
River
Long Island Sound

Most of the work has been performed in the Poquonnock River.

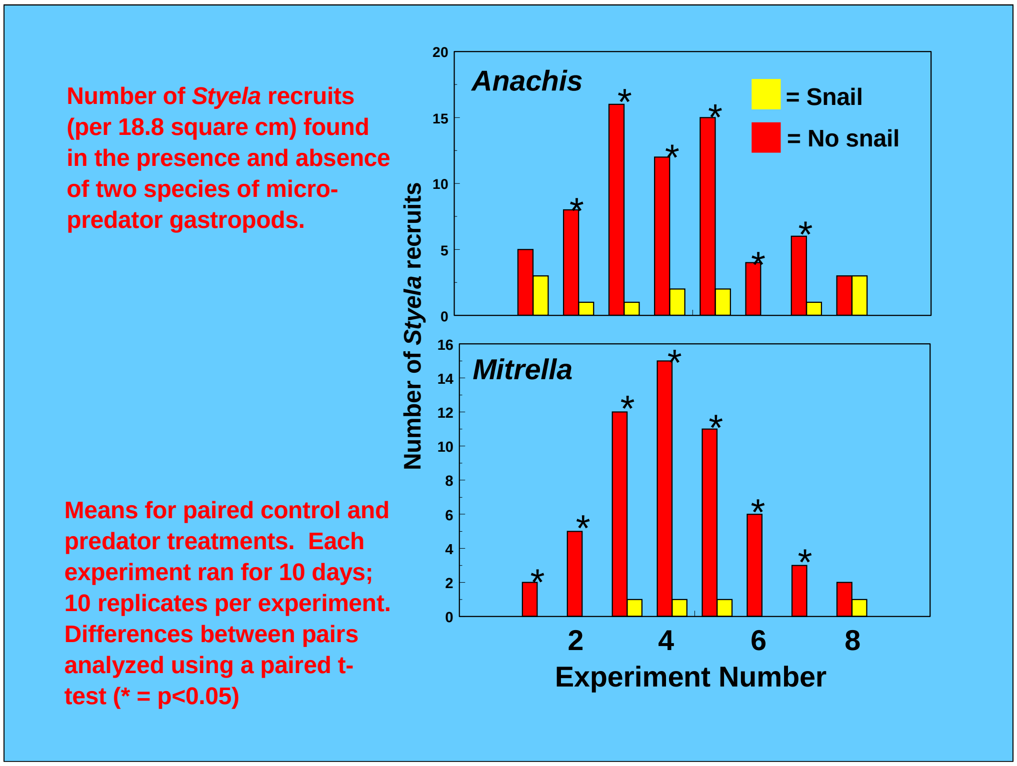

Local
Recruitment
Recruit
Predators
Environ Change/
Predator Loss
Local Recruitment
/Predator Exclusion
Massive
Recruitment
Predators/Storms
Warm
Winter
Cold
Local
Recruitment
Growth & Habitat Change



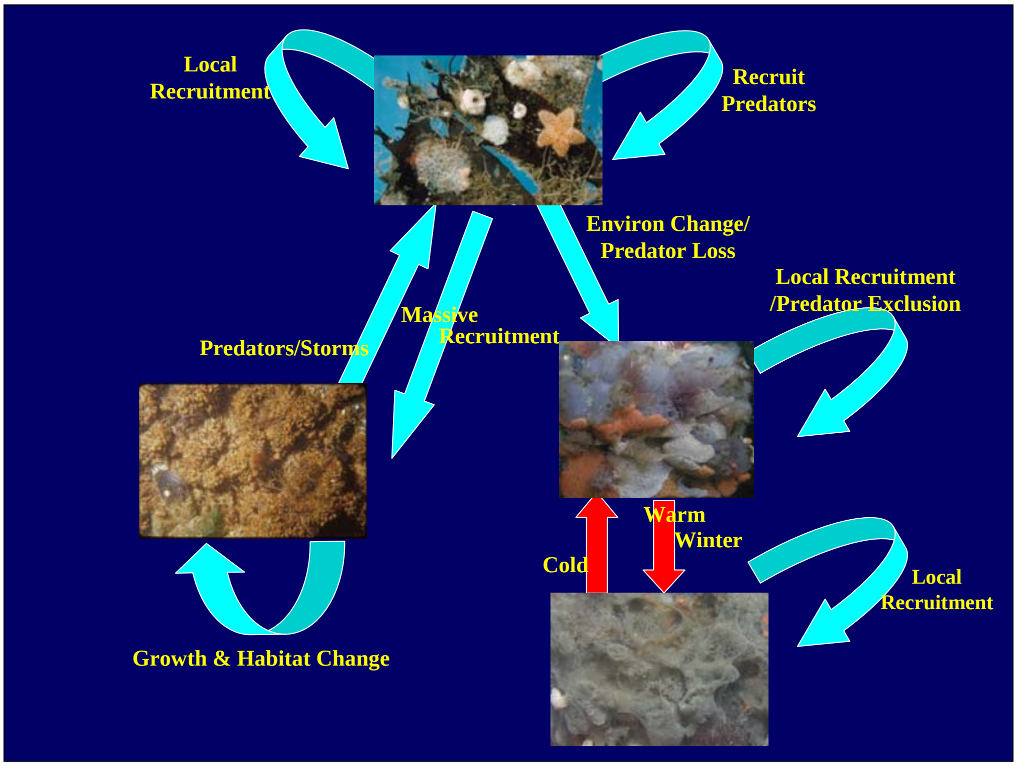
After the first invasion of mussels, the researchers found 500 mussels per panel (very densely packed). Within a week, all the mussels were removed.



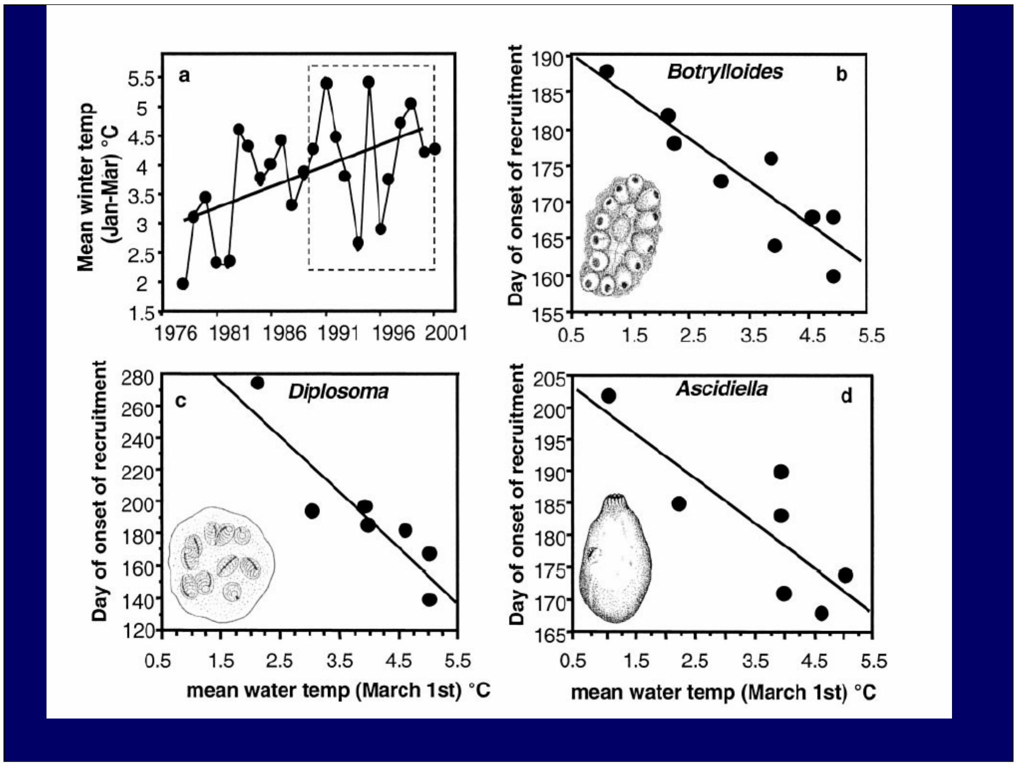
After the second invasion, the mussels were found to be scattered over a wide area. These mussels survived for several years.



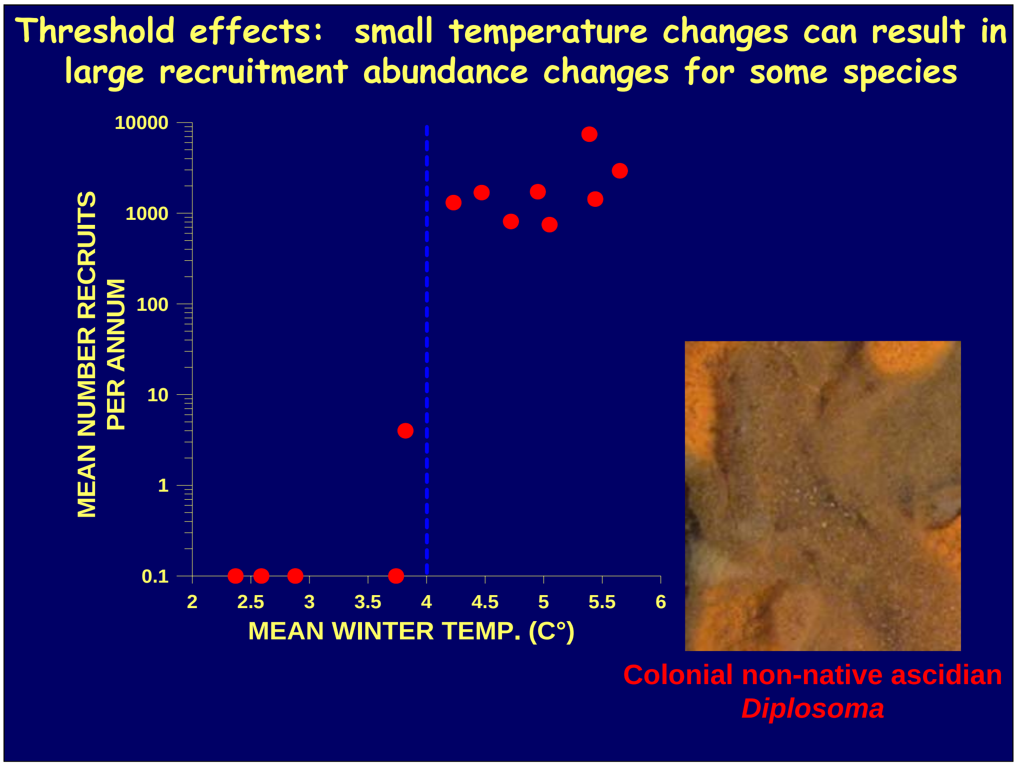
When snails are present, they remove the invasive ascidians. Because the snails remove them quickly, it can appear that these invasive ascidians are not invading the sites.



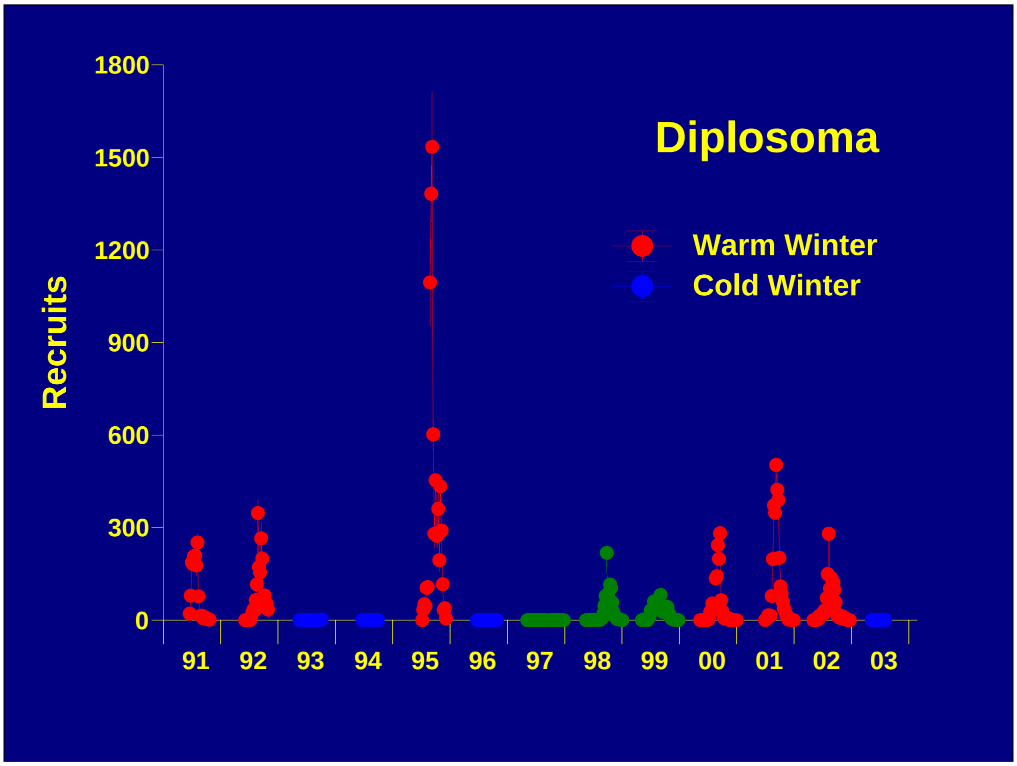
The largest number of invasive species are found in areas affected by humans. Temperature also plays a role.



The graph in the upper left-hand corner shows the temperature in Long Island Sound over the past 30 years. There is tremendous variability, but there also has been a gradual warming. The other graphs represent three species of invasive ascidians. The researchers determined the first day each year that the species first recruited. In the warm years, the species recruit much earlier. This occurs only in the invasive species.

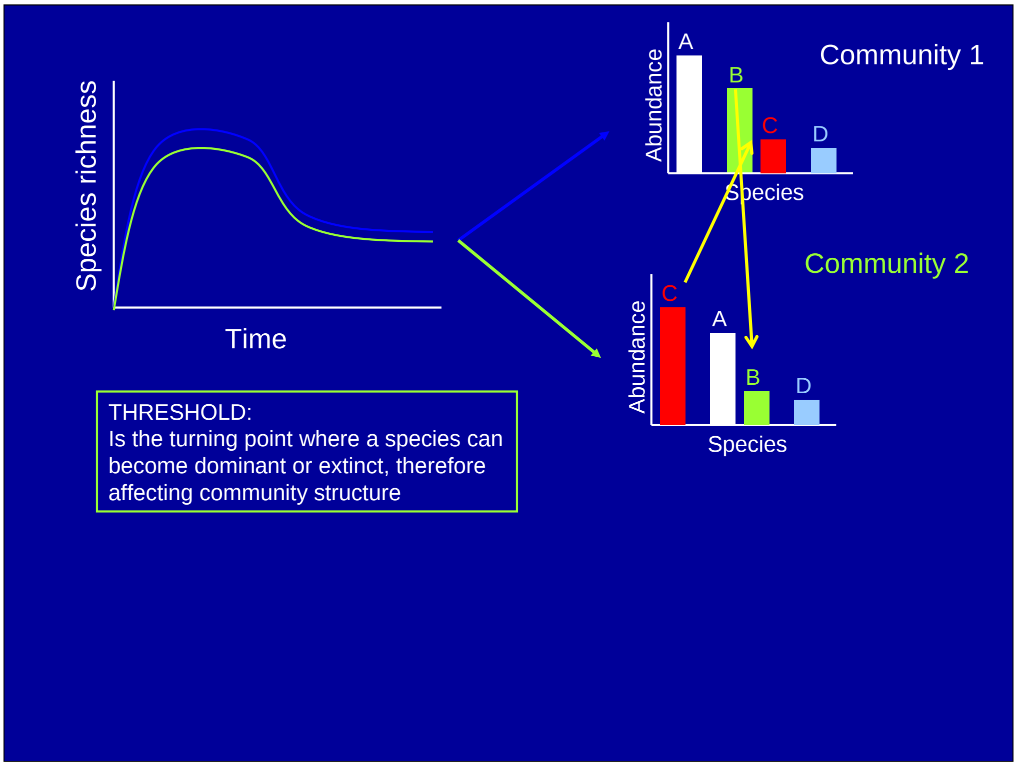


This graph shows that there essentially is no recruitment occurring when the mean temperature of the water is below 4°C. When the mean temperature is above 4°C, considerable recruitment occurs. Thus, climate change will allow more and more invasive species to flourish.


Diplosoma
Warm Winter
Cold Winter
Recruits
1800
1500
1200
900
600
300
0
91
92
93
94
95
96
97
98
99
00
01
02
03

Modeling Approaches

- **Population/Community Models**
- Spatially explicit, individual-based model driven by hydrodynamic model
- Landscape analysis and modeling


Species richness
Time
Abundance
A
B
C
D
Species
Community 1
Community 2
C
A
B
D
Abundance
Species
THRESHOLD:
Is the turning point where a species can become dominant or extinct, therefore affecting community structure

Three potential mechanisms that could give rise to spatial and temporal overlaps in species' population dynamics, and thus in community structure.

1. Invasive species
   - Can dominate habitats during particular years
   - e.g. *Diplosoma* sp.
2. Anthropogenic changes of the environment.
   - Human modifications of hard substrates
3. Disturbance
   - (a) Increase in winter temperatures as a function of global warming → affects the whole region.
   - (b) Localized effects of predation → affecting a locality.

Question

What are the effects of disturbance on thresholds?

(1) Do regional and local disturbances generate species dominance?
Regional disturbance simulates climate change effects (e.g. changes in temperatures).
Local disturbance simulates predation events.

(2) Can particular life history traits counter the effects of disturbance?
Can broadcasting spawners and brooders show similar dominance patterns?

MODEL

Lotka-Volterra model where species compete for space:

$n_{t+1} = n_t + T^*n_t^*([K- \Sigma\ Nt] / K)$

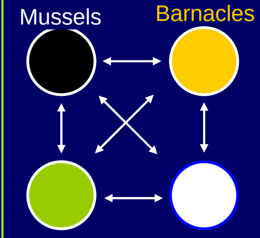
T = transition matrix containing life history traits and the distance among local communities.

•4 species, 4 local communities = 16 local populations.

•100 time steps each run, with 1000 runs for each scenario.

•Species simulate a range of life history stages of sessile invertebrates in Long Island Sound:

INITIAL CONDITIONS



Broadcast spawner	Broadcast spawner	Brooding solitary ascidian	Brooding colonial ascidian

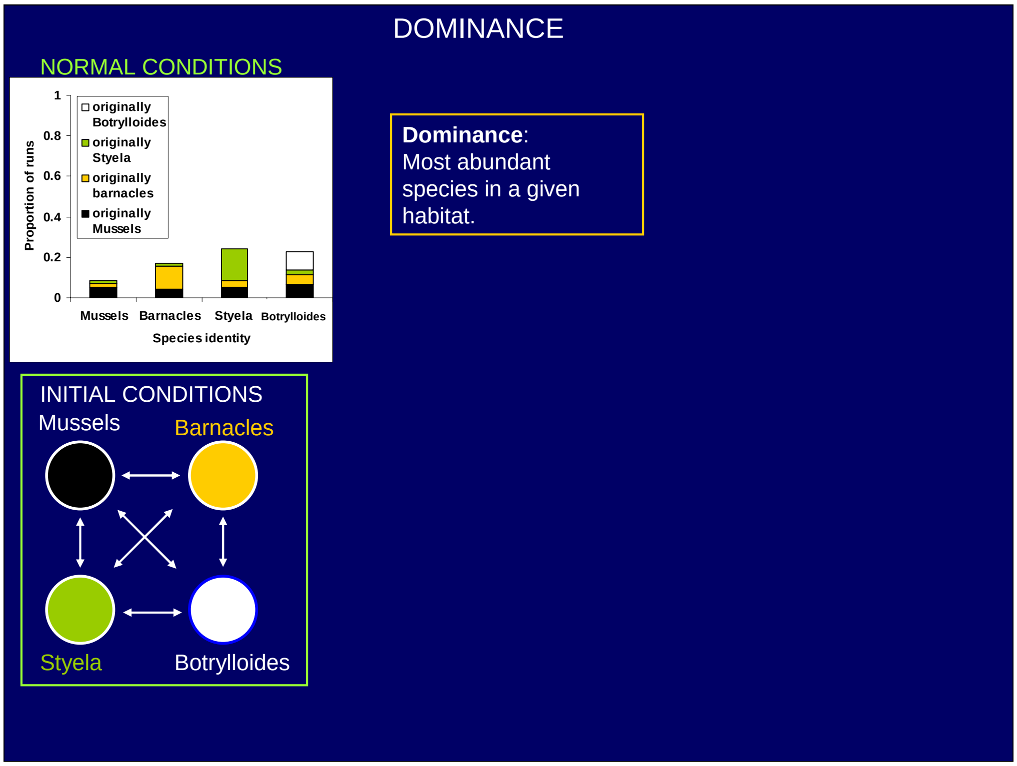
Mytilus edullis	*Balanus*	*Styela clava*	*Botrylloides violaceus*

Dispersal ability and local retention gradient

LOCAL AND REGIONAL DISTURBANCE EVENTS

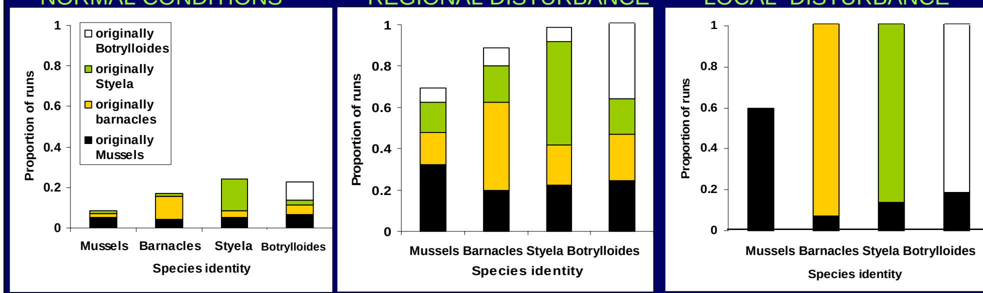
REGIONAL DISTURBANCE
Every 4 time steps, all of the populations within each of the 4 communities were reduced to 30% abundance.

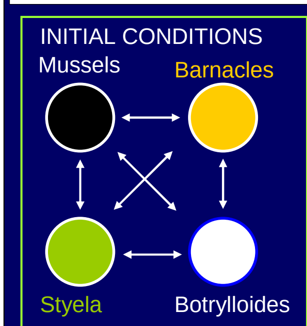
LOCAL DISTURBANCE
Every 4 time steps, all of the populations within one community are reduced to 30% abundance. But the community affected is randomly selected every time.


DOMINANCE
NORMAL CONDITIONS
Proportion of runs
1
0.8
0.6
0.4
0.2
0
originally Botrylloides
originally Styela
originally barnacles
originally Mussels
Mussels
Barnacles
Styela
Botrylloides
Species identity
Dominance: Most abundant species in a given habitat.
INITIAL CONDITIONS
Mussels
Barnacles
Styela
Botrylloides

DOMINANCE

NORMAL CONDITIONS | REGIONAL DISTURBANCE | LOCAL DISTURBANCE

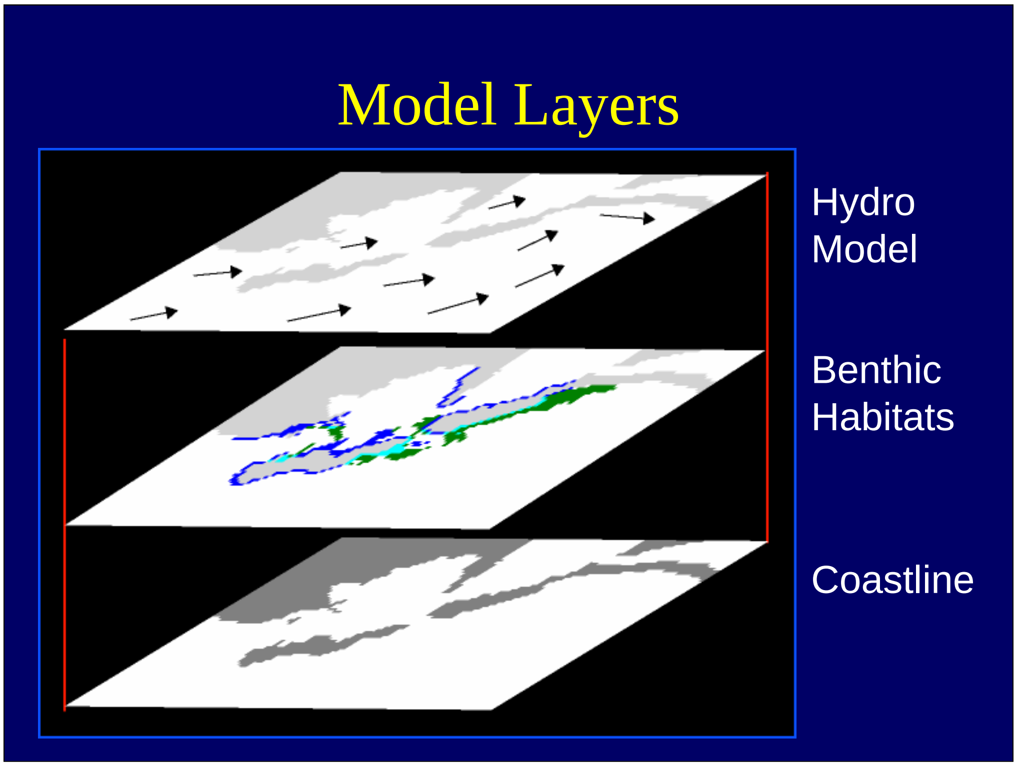


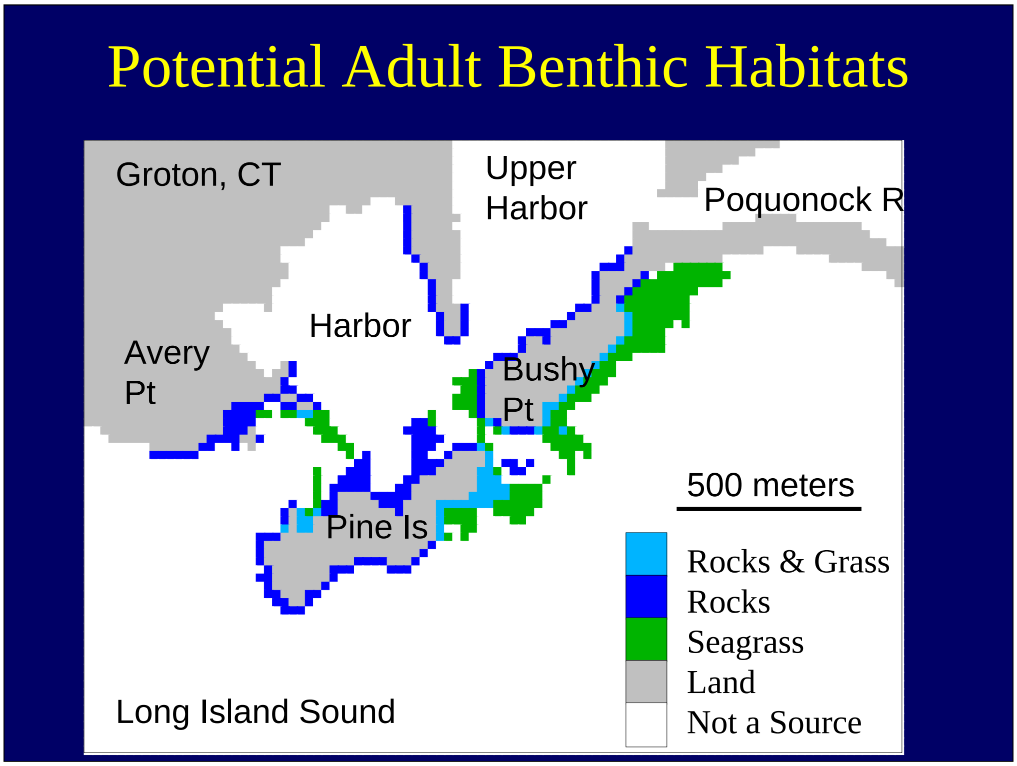


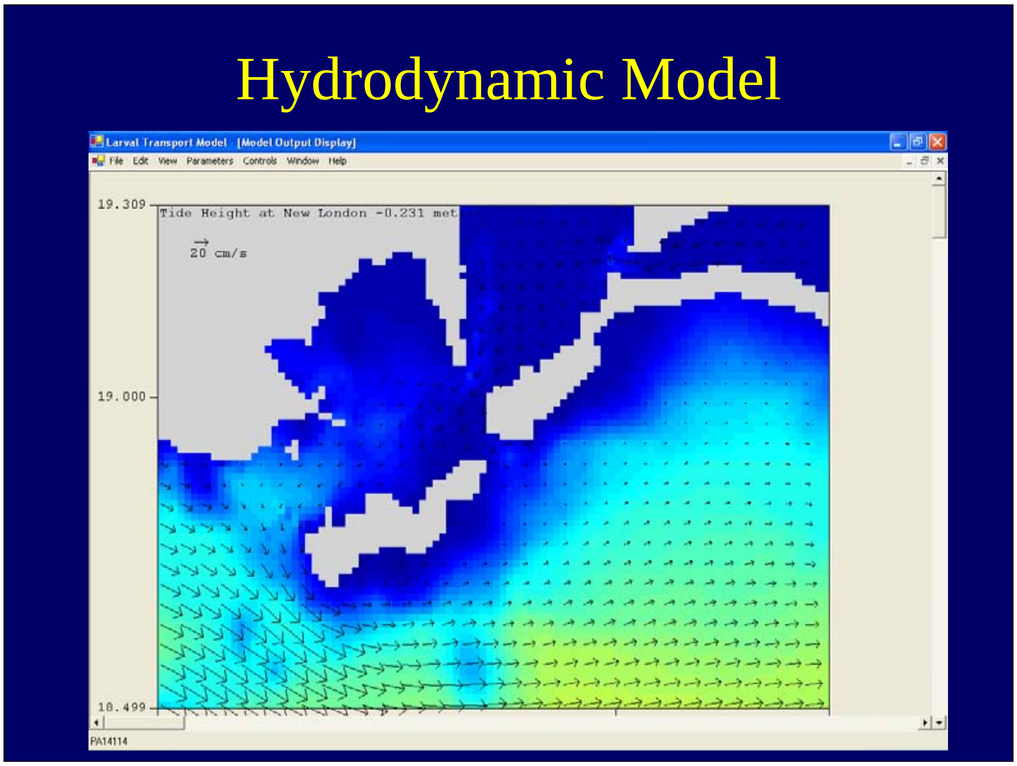
- **Normal conditions**
  Few dominance events
- **Regional disturbance**
  There are many dominance events with no clear pattern
- **Local disturbance**
  Species tend not to dominate outside of their original community. However, Mussel beds tend to be invaded and dominated by the other species.

Modeling Approaches

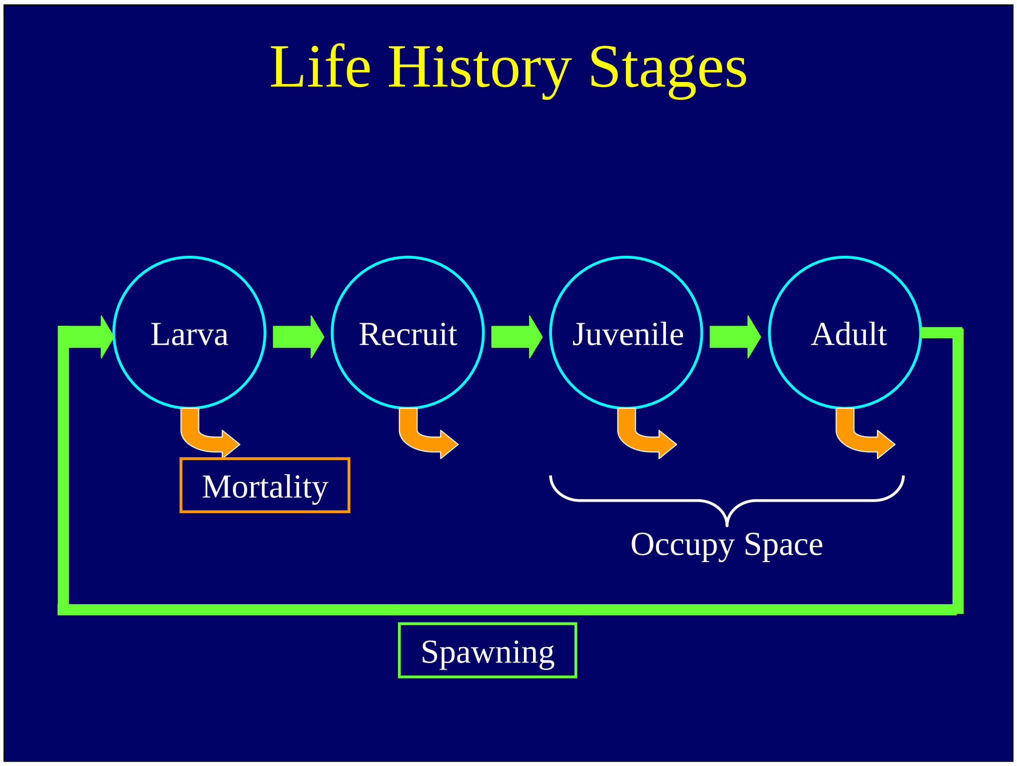
- Population/Community Models
- **Spatially explicit, individual-based model driven by hydrodynamic model**
- Landscape analysis and modeling

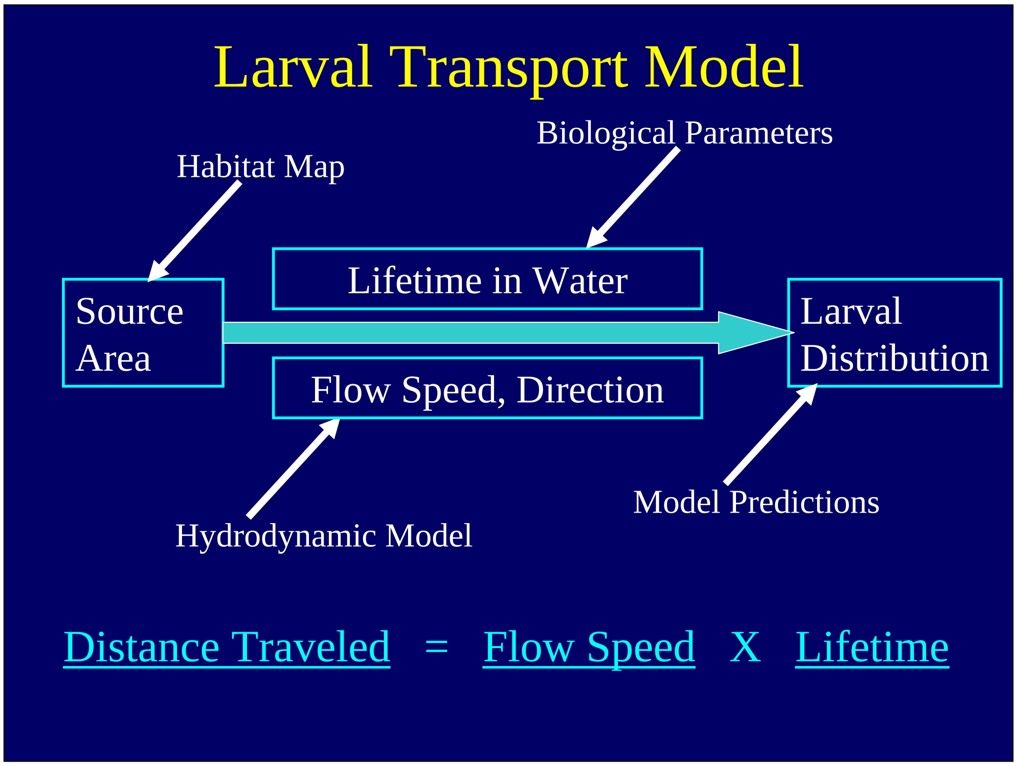

Model Layers
Hydro Model
Benthic Habitats
Coastline


Potential Adult Benthic Habitats
Groton, CT
Upper
Harbor
Poquonock R
Harbor
Avery
Pt
Bushy
Pt
Pine Is
500 meters
Rocks & Grass
Rocks
Seagrass
Land
Not a Source
Long Island Sound



Current direction and speed are tracked.


Life History Stages
Larva
Recruit
Juvenile
Adult
Mortality
Occupy Space
Spawning


Larval Transport Model
Biological Parameters
Habitat Map
Lifetime in Water
Source Area
Larval Distribution
Flow Speed, Direction
Hydrodynamic Model
Model Predictions
Distance Traveled = Flow Speed X Lifetime

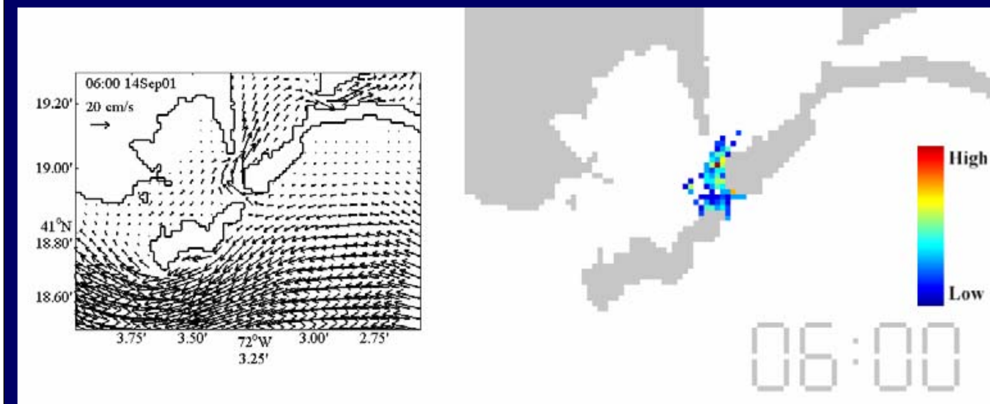
Model Larval Sources

Source Area:

The seagrass bed in the channel

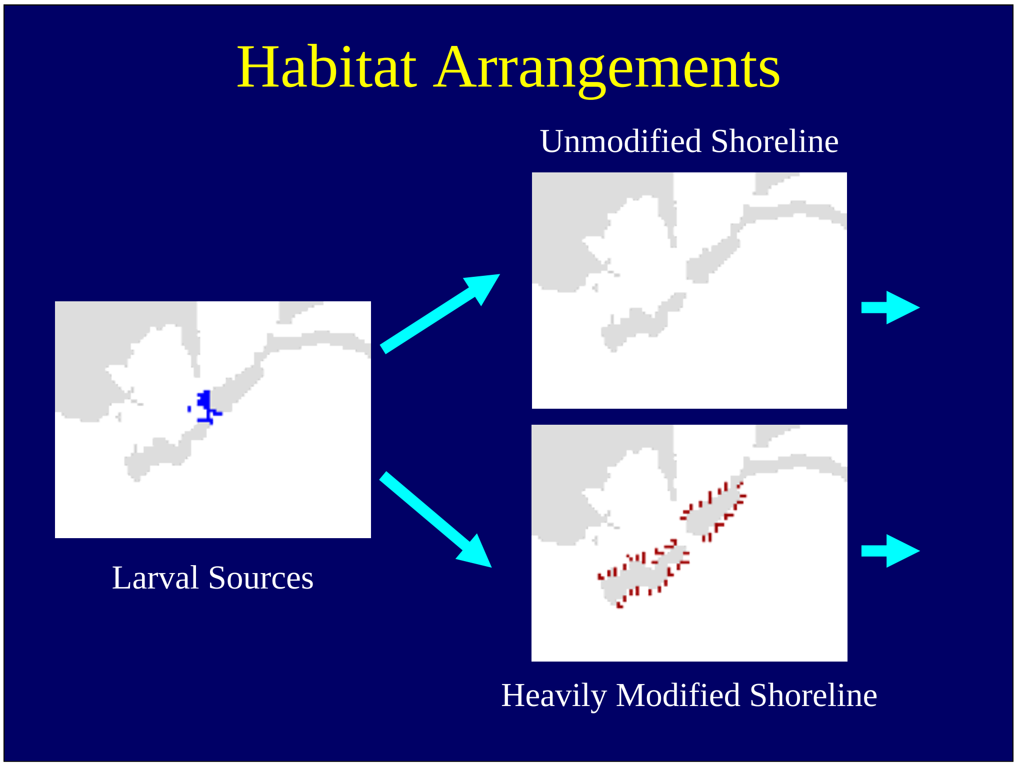
Habitat + Hydrodynamics -> Larval Distribution

Source: Channel Region

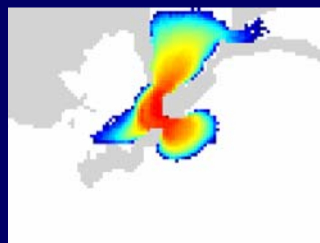


Hydrodynamic Model

Estimated Larval Density

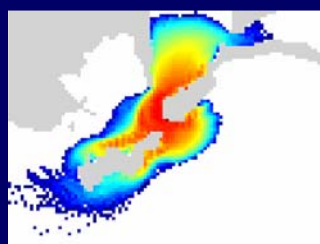

Habitat Arrangements
Unmodified Shoreline
Larval Sources
Heavily Modified Shoreline

Model Dispersal Patterns



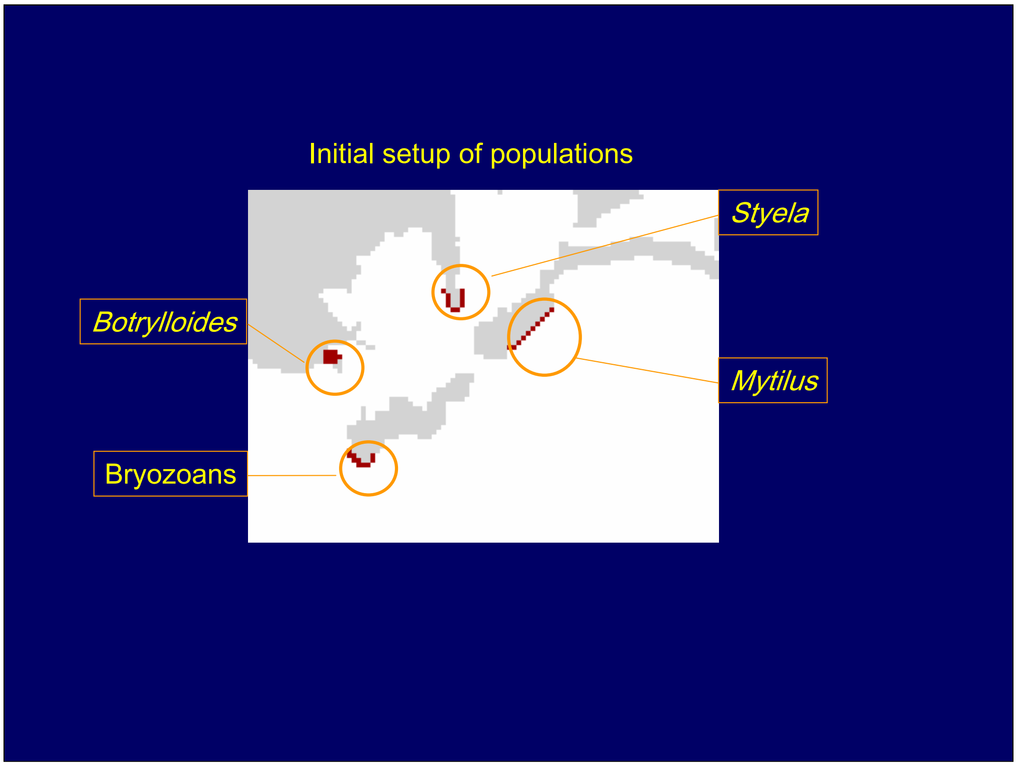
Unmodified Shoreline:

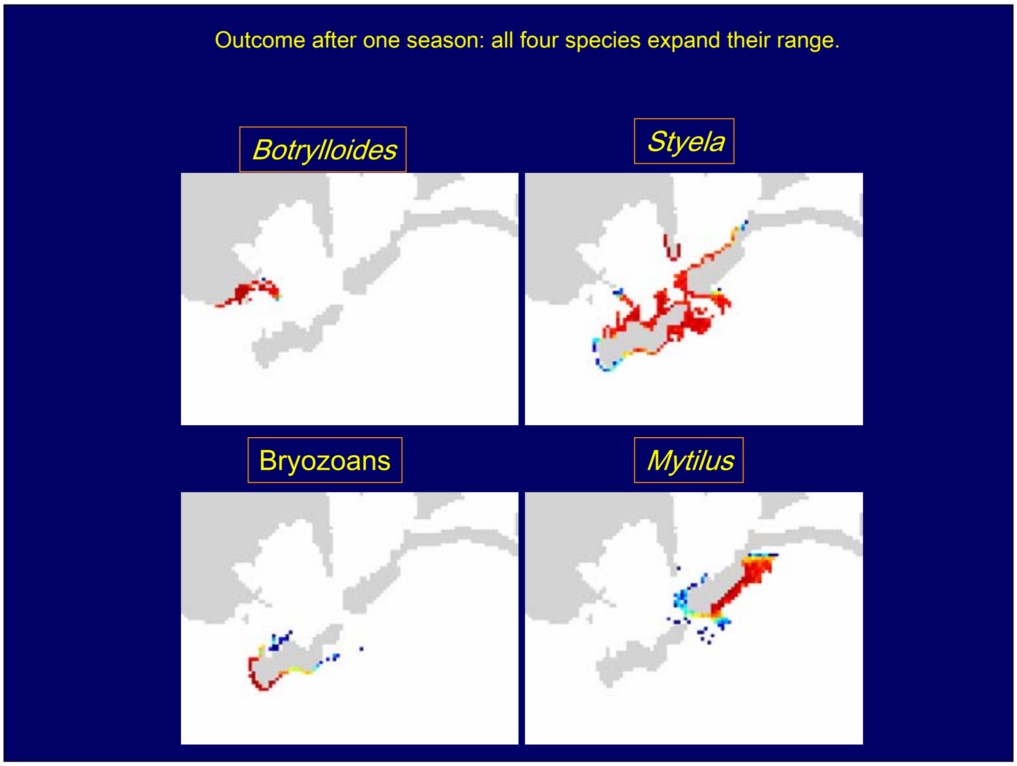
Natural dispersal pattern

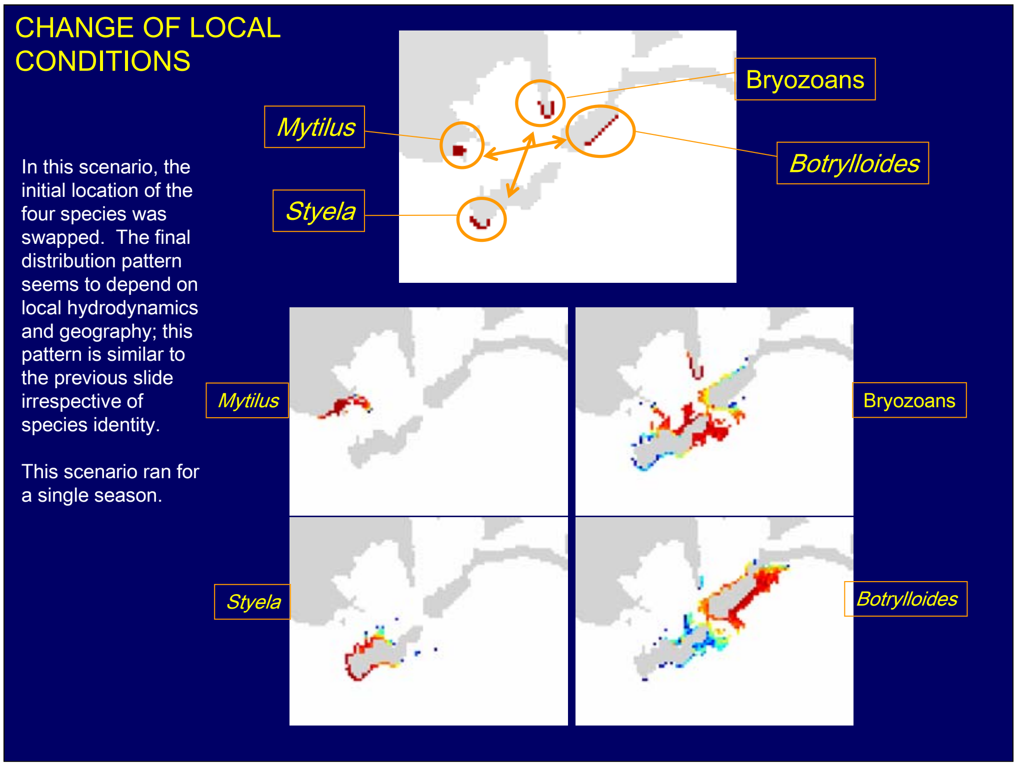


Heavily Modified Shoreline:

Extended dispersal pattern
where tidal effects are strong.


Initial setup of populations
Styela
Botrylloides
Mytilus
Bryozoans

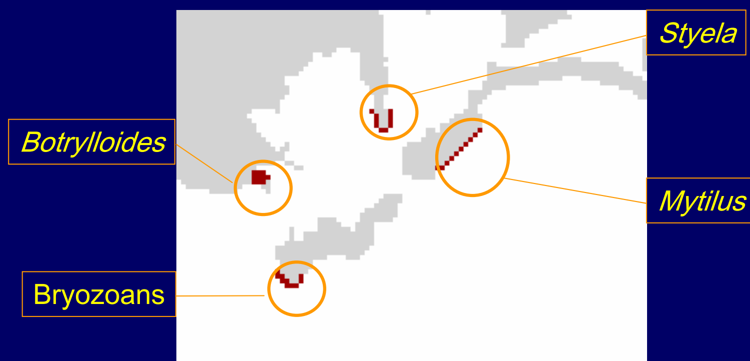

Outcome after one season: all four species expand their range.
Botrylloides
Styela
Bryozoans
Mytilus

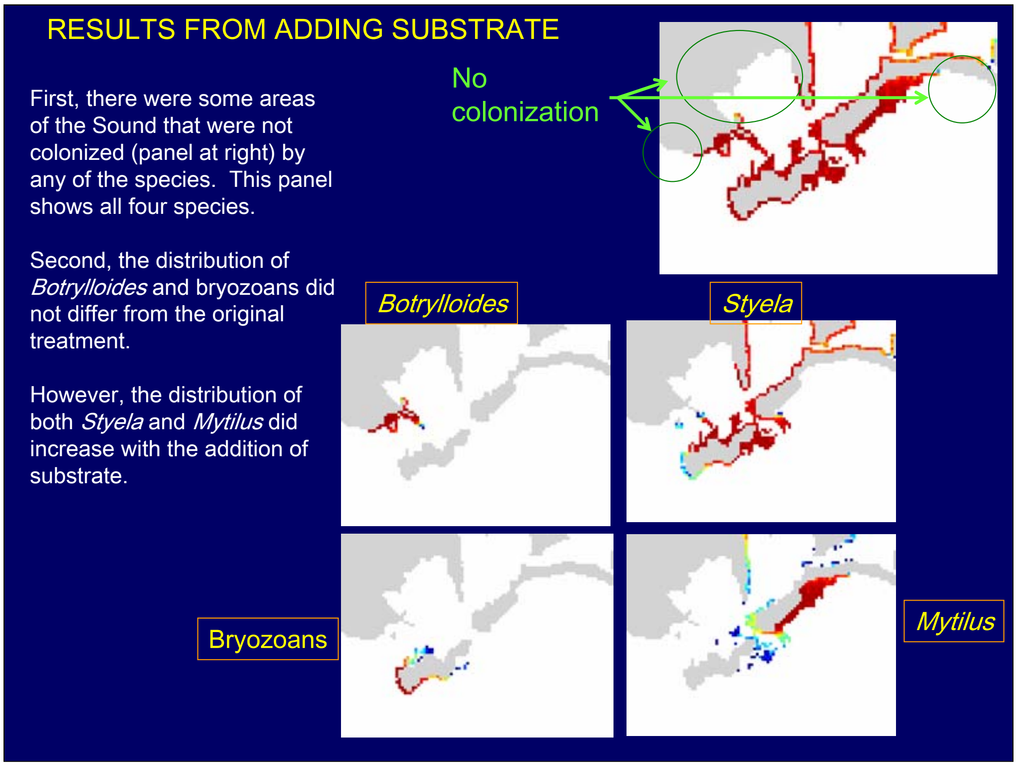

CHANGE OF LOCAL CONDITIONS
In this scenario, the initial location of the four species was swapped. The final distribution pattern seems to depend on local hydrodynamics and geography; this pattern is similar to the previous slide irrespective of species identity.
This scenario ran for a single season.
Bryozoans
Mytilus
Botrylloides
Styela
Mytilus
Bryozoans
Styela
Botrylloides

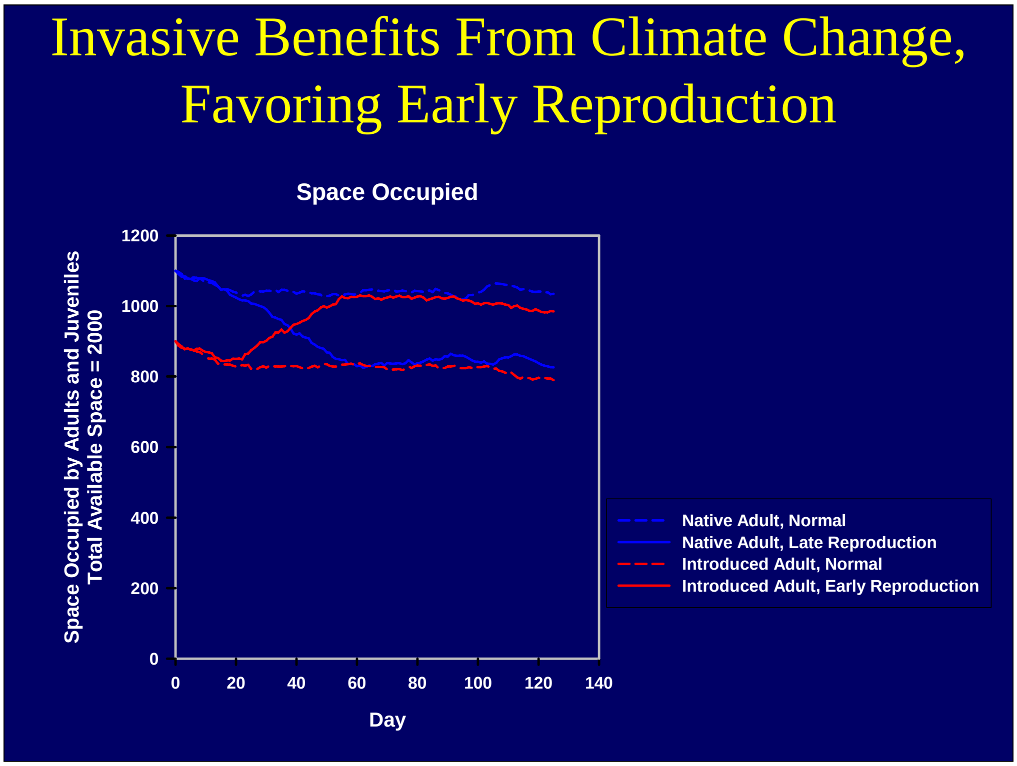
Increase in substrate: human alterations to the environment.

We were interested in asking the question, how do populations respond if the available surface area for colonization is increased (due to human modifications of the coastline). After the initial scenario, we added a 20 m perimeter around the shore that was available for colonization, and then we ran the simulation a second year.

Initial location of the four populations




RESULTS FROM ADDING SUBSTRATE
First, there were some areas of the Sound that were not colonized (panel at right) by any of the species. This panel shows all four species.
Second, the distribution of *Botrylloides* and bryozoans did not differ from the original treatment.
However, the distribution of both *Styela* and *Mytilus* did increase with the addition of substrate.
No colonization
Botrylloides
Styela
Bryozoans
Mytilus


Invasive Benefits From Climate Change,
Favoring Early Reproduction
Space Occupied
Space Occupied by Adults and Juveniles
Total Available Space = 2000
1200
1000
800
600
400
200
0
0
20
40
60
80
100
120
140
Day
Native Adult, Normal
Native Adult, Late Reproduction
Introduced Adult, Normal
Introduced Adult, Early Reproduction

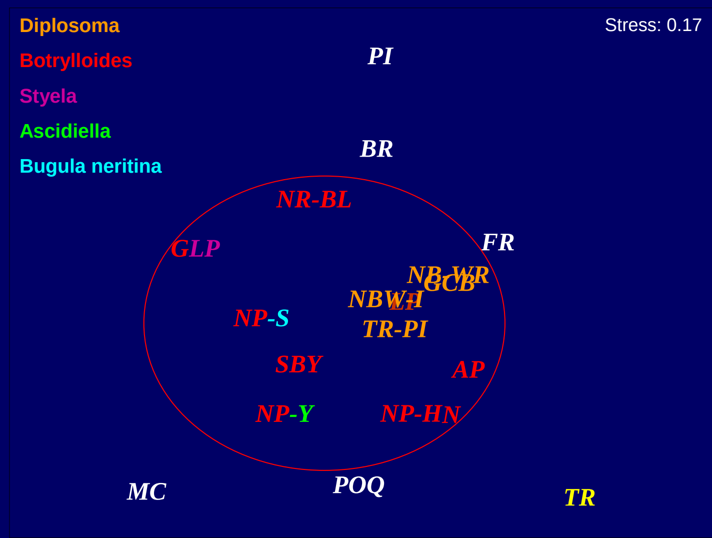
Invasive Benefits From Disturbances and Climate Change

Modeling Approaches

- Population/Community Models
- Spatially explicit, individual-based model driven by hydrodynamic model
- **Landscape analysis and modeling**

MDS Plot of Fouling Communities In Southern New England Study Sites- Fouling inverts only

Avery Point	AP
Branford	BR
Flat Rock	FR
Groton City Beach	GCB
Groton Long Point	GLP
Lord's Point	LP
Mumford Cove	MC
Noank	N
Waterford Island-Niantic Bay	NB-WI
Niantic Bay Wigwam Rock	NB-WR
Newport Harbor	NP-H
Newport Shipyard	NP-S
Newport Yacht	NP-Y
Niantic River Boat Launch	NR-BL
Pine Island	PI
Poquonock	POQ
Stonington Boat Yard	SBY
Thames River	TR
Thames River Powder Island	TR-PI

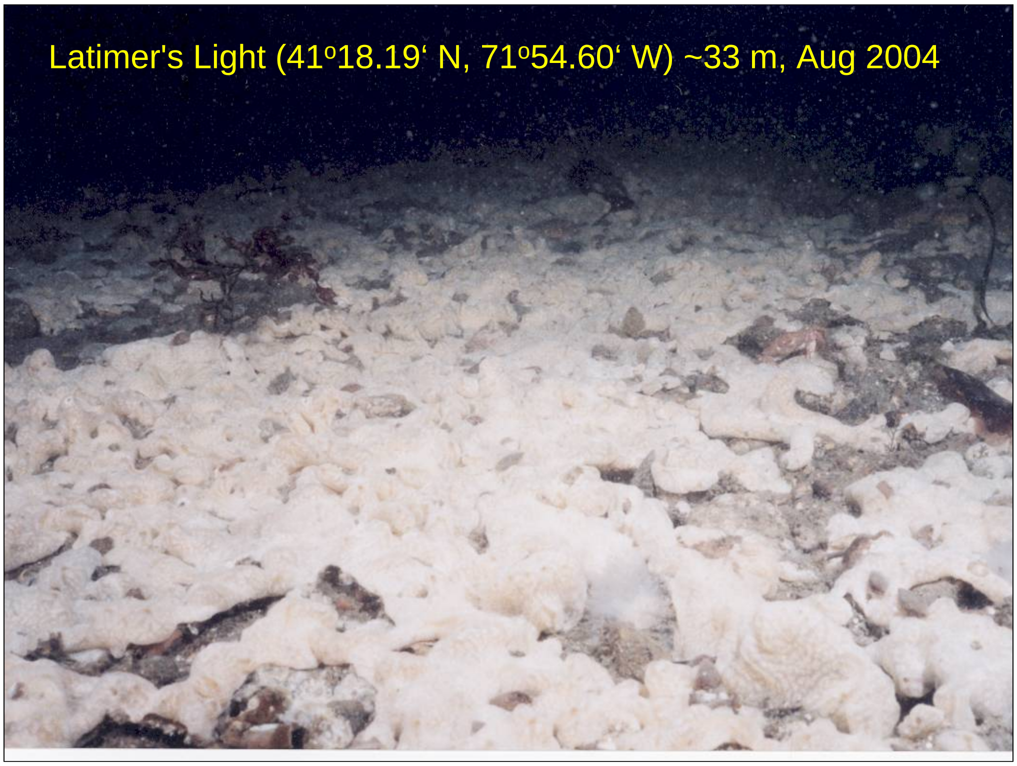


Sites in the center of the plot (in circle) may be more disturbed areas – those in the periphery seem to be less disturbed areas (e.g. open coast, small coves, isolated sites where overall richness may be higher but cover lower

Note that the sites in the center of the plot are in less disturbed areas; those on the periphery appear to be more disturbed.

Surprising Results

- Invasion of the system by a new species – *Didemnum* sp.
- Dominance of some deep water areas by *Didemnum* – 1-10 km^2 known to date
- *Didemnum* potential new stable state



This is a site on the eastern end of Long Island Sound where *Didemnum* completely covers the sound bottom

.

Potential Management Uses

- Models designed to test management scenarios
- Models applicable to management at local and regional scales
- Landscape modeling and analyses to identify approaching threshold conditions

Discussion

A participant asked if the invaders represented in the graphs (*Botrylloides*, *Diplosoma*, and *Ascidiella*) were preyed upon. Dr. Osman answered that they all are preyed upon. Colonial species are not as vulnerable, however. The participant asked if there would be a new group of predators if the invaders shifted from spring to fall recruitment. Dr. Osman responded that the predators are native and, from the data gathered, there does not appear to be any seasonal difference. Space is an important issue. New species tend to appear earlier and take up much of the available space.

Another participant asked if the temperature threshold was included in the modeling. Dr. Osman replied that the temperature was not included in the modeling completed to date. He and his colleagues intend to incorporate temperature in future models.