INTERACTIONS WITH NON-INDIGENOUS SPECIES POSE AN IMPEDIMENT TO RECOVERY OF NATIVE OLYMPIA OYSTERS

(*Ostrea conchaphila*)

WITHIN COOS BAY, OREGON, USA

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- ***South Slough National Estuarine Research Reserve***

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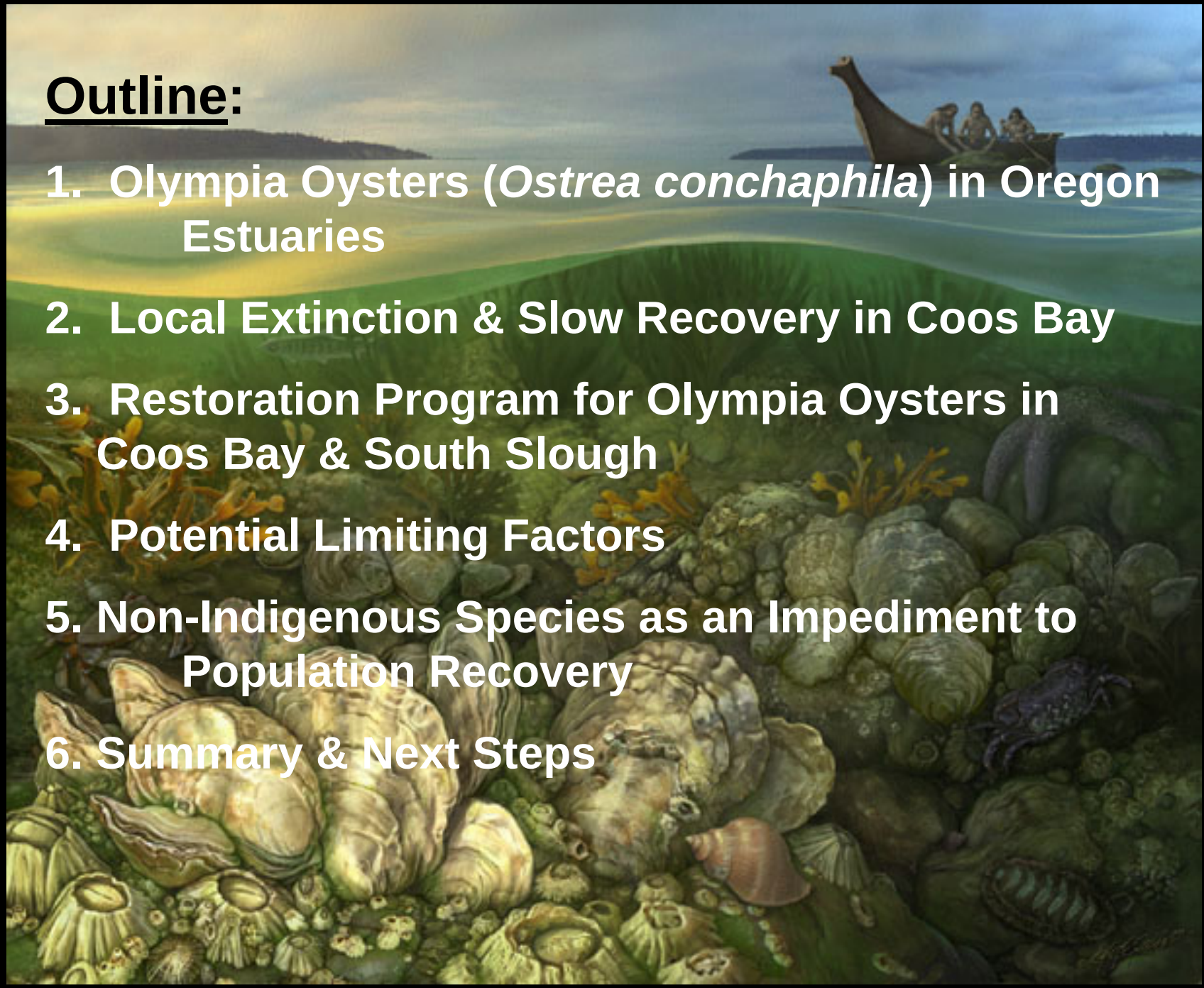
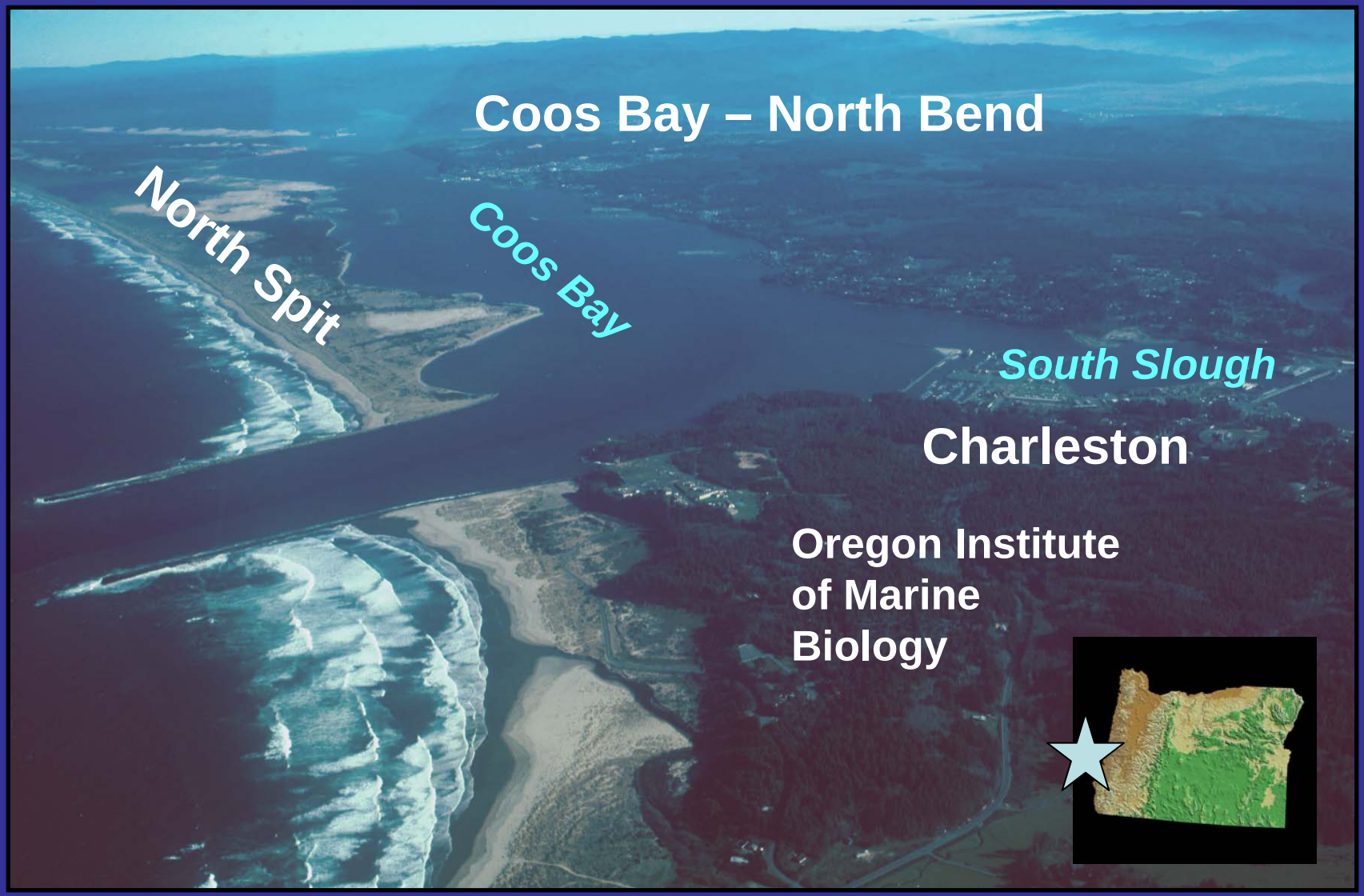


Outline:

1. Olympia Oysters (*Ostrea conchaphila*) in Oregon Estuaries
2. Local Extinction & Slow Recovery in Coos Bay
3. Restoration Program for Olympia Oysters in Coos Bay & South Slough
4. Potential Limiting Factors
5. Non-Indigenous Species as an Impediment to Population Recovery
6. Summary & Next Steps

LOCATION OF STUDY AREA: COOS BAY, OREGON, USA

Coos Bay: A Drowned River-Mouth Estuary



Olympia oysters
Ostrea conchaphila

- **Native from Alaska to Baja California**
- **Historically extensive in Coos Bay / dredge spoils**
- **Local extinction due to sedimentation & tsunami / 1700-1800s**
- **Reintroduced from outside source / 1940-50s**

Pacific oysters
Crassostrea gigas

- **Native from Russia to China**
- **Imported to North America from Japan / 1903**
- **Cultured in Coos Bay 1910s - present**
- **Mariculture operations include bottom, stake, and rack culture**

Olympia oysters (*Ostrea conchaphila*):

Appearance: Small (4-7 cm) epibenthic bivalves, non-motile with left valve typically cemented to shell or other hard substrata.

Reproduction & Growth: Protandric hermaphrodite, multiple spawning in spring and summer, internal fertilization with brooded embryos, release of planktonic veliger larvae.

Habitat: Lower intertidal to shallow subtidal, attachment to hard surfaces in sheltered waters, often on adult shells. Forms sparse to dense clusters or beds on bottom.

Feeding: Filter-feeder / suspension-feeder, consumes phytoplankton and protists.

Predators: Seastars, crabs, boring gastropods, polychaetes, fish, birds, humans.

History of Olympia Oysters in Oregon Estuaries

Netarts Bay:

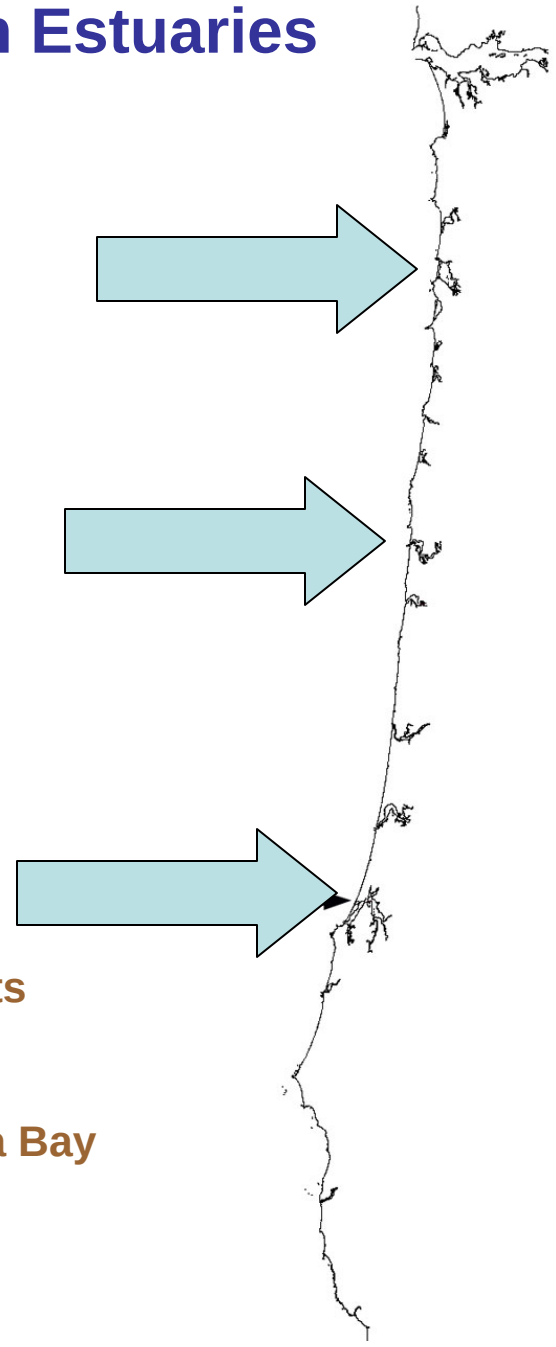
- Extensive commercial fishery 1860's
- Low numbers by 1930's
- Exotic snail predator 1957 (*Ocenebra*)
- Absent in 1992
- Restoration work in 2006-08

Yaquina Bay:

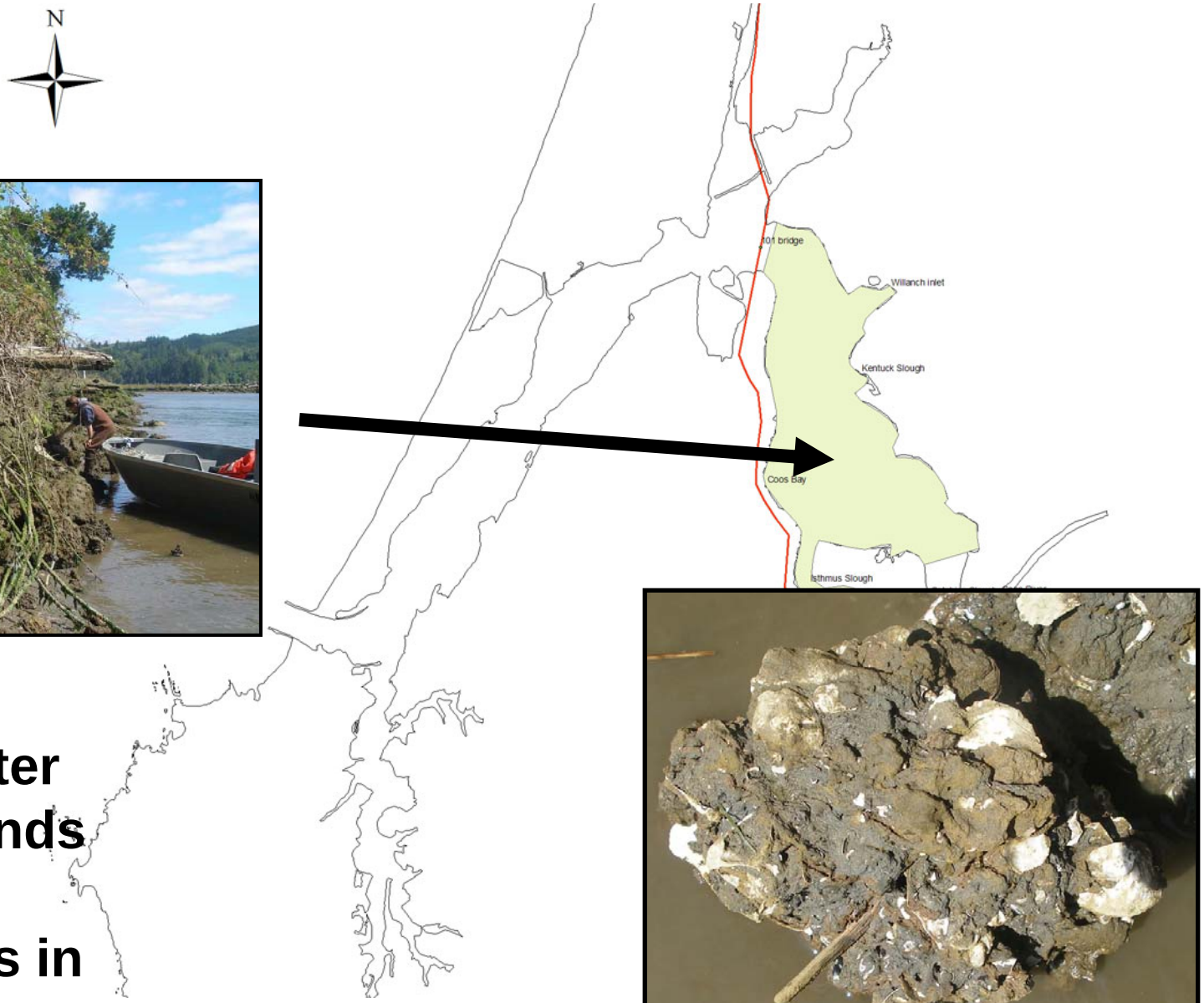
- Extensive commercial fishery 1860's to 1890's
- Commercial harvest ended by 1940's
- Slow recovery of natural populations 2006-08

Coos Bay:

- Extensive historic populations and shell deposits
- Local extinction prior to European settlement
- Reintroduction with Pacific oysters from Willapa Bay 1950's
- Slow recovery of natural populations 1987-2008
- Restoration work initiated in 2008



Recent Shell Deposits of *Ostrea conchaphila* in Coos Bay, OR

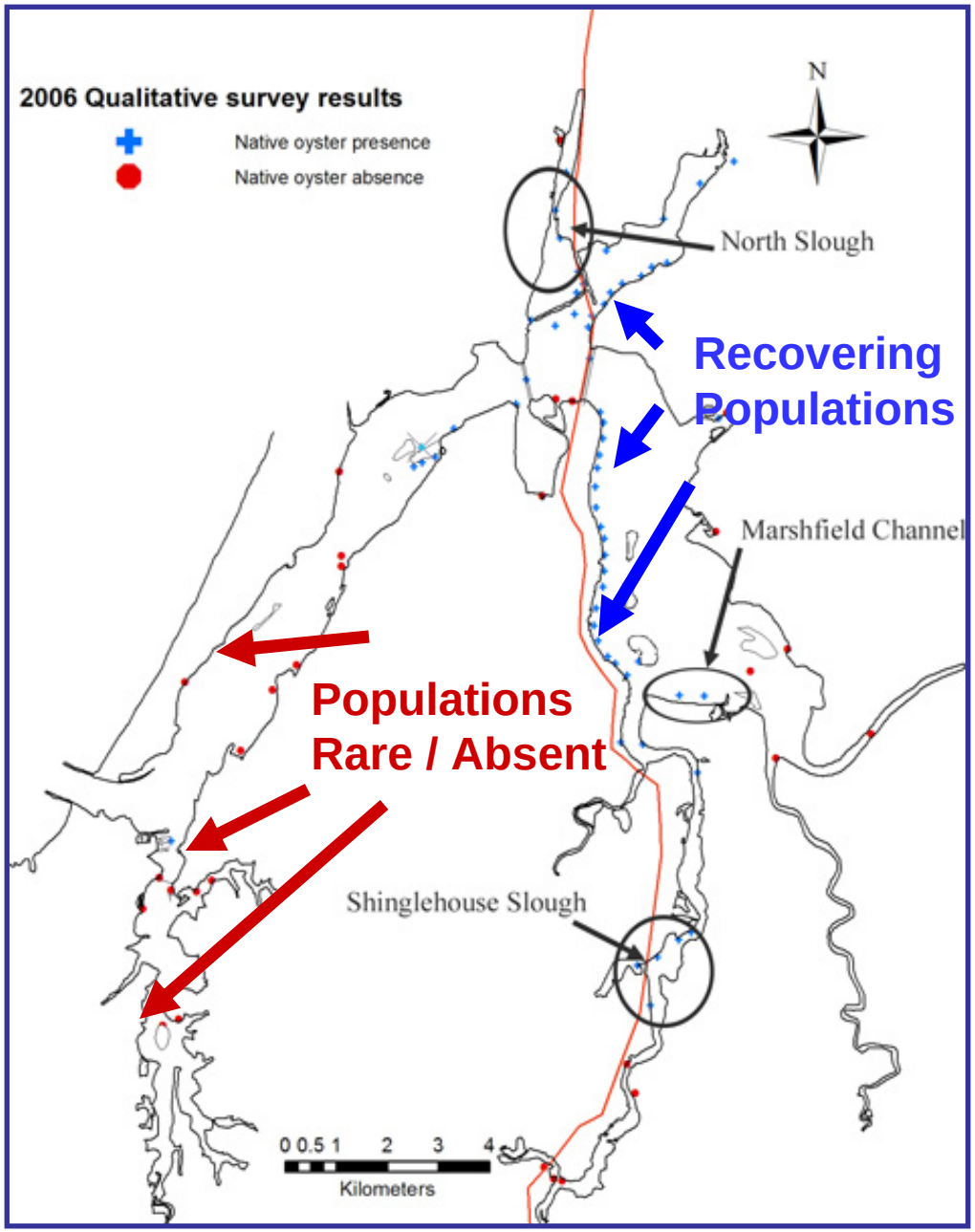


Extensive Olympia oyster shells in islands formed by dredge spoils in Coos Bay

***Ostrea conchaphila* shell**

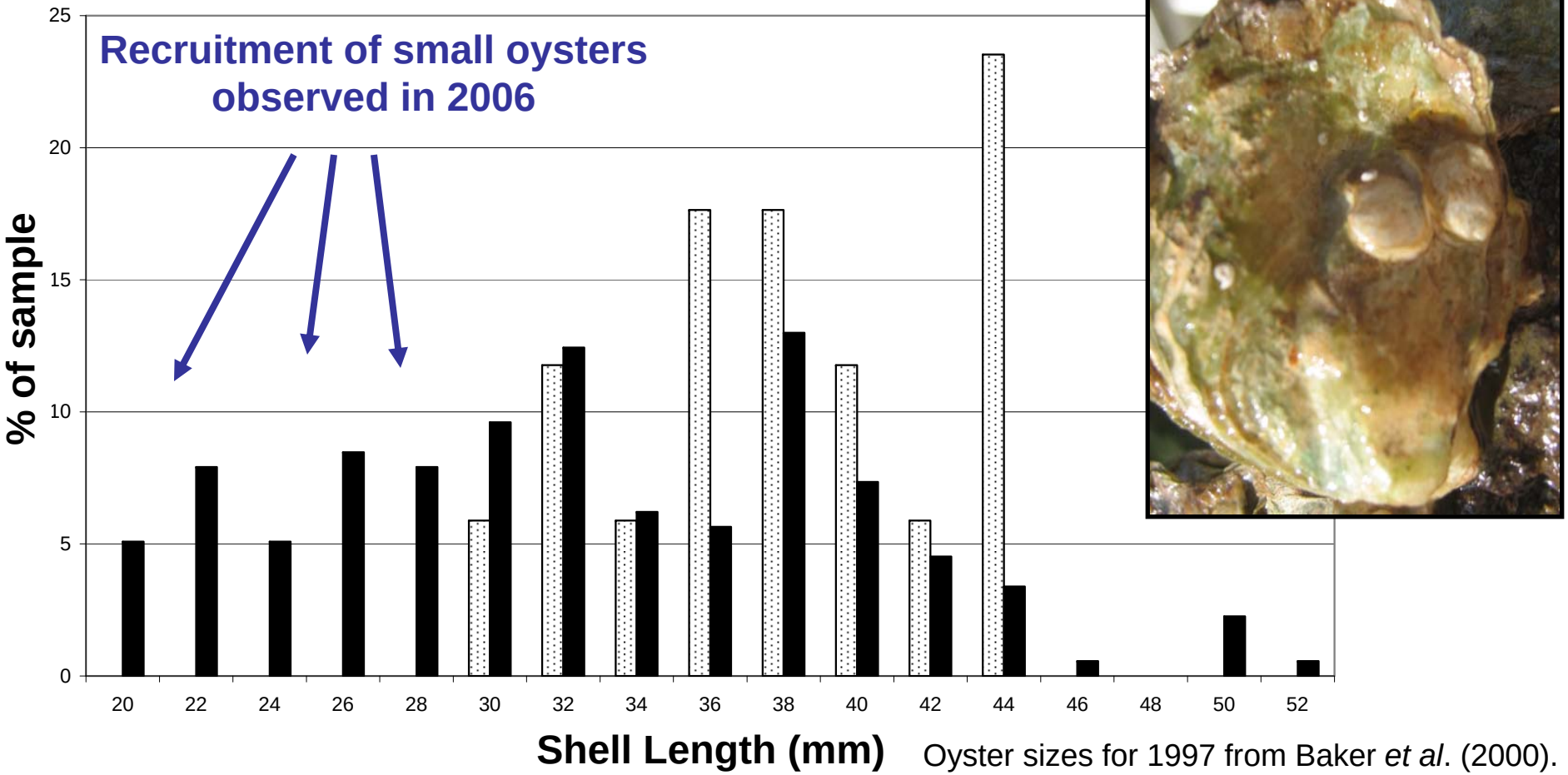
Coos Bay, OR:

Distribution of *Ostrea conchaphila* populations (2006). Circles indicate substantial changes in distribution from 1996-97 surveys.



Ostrea conchaphila: Size distribution of adult oysters for Coos Bay surveys conducted in 1997 and 2006.

1997 survey □ 2006 survey ■



Oyster sizes for 1997 from Baker *et al*. (2000).

South Slough Olympia Oyster Restoration Project: 2006-2015

Components:

History of Native Oysters in Oregon Estuaries (2006-07)

Genetic Identity of Broodstock Oysters (2006-07)

Distribution and Recovery of Olympia Oysters in Coos Bay (1997 & 2005-06)

Recruitment of Olympia Oysters to Fouling Panels and Shells (2004-05)

Characterization of Estuarine Water Quality Conditions (2005-15)

Culture, Settlement, and Out-planting of Juvenile Oysters (2008-12)

South Slough Olympia Oyster Restoration Project: 2006-2015

Components (continued):

Common-Garden Experiment to Investigate Local Adaptation (2009-2014)

Monitor Oyster Survival, Growth, and Reproduction (2008-2010)

Ecological Interactions with Predators and Competitors (2008-2010)

Alteration of Hydrodynamics by Oyster Clusters (2008-09)

Estimation of Larval Production, Retention, Export, and Settlement (2009-2015)

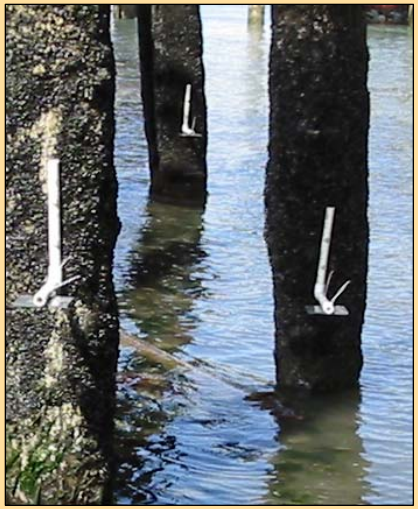
Initiation of Larger-scale Oyster Restoration Study Areas (2012-15)

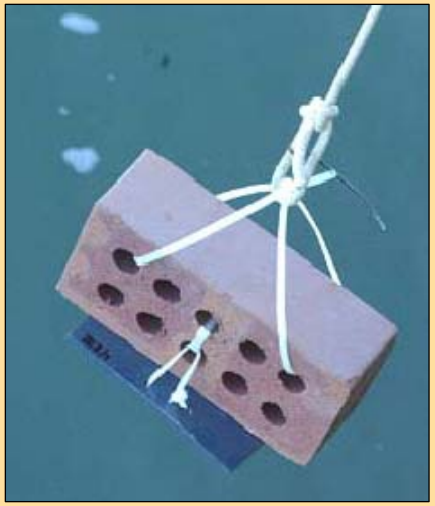
What factors may limit the recovery of Olympia oysters in Coos Bay and the South Slough?

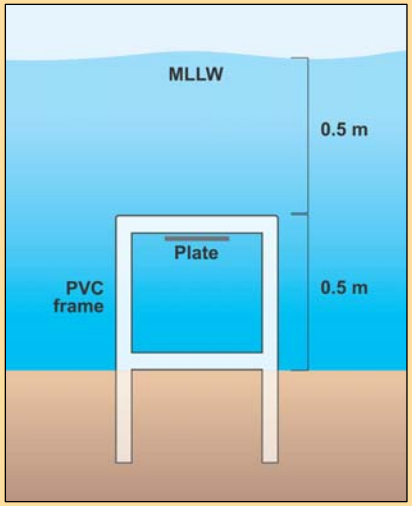
- Ambient physical conditions (temperature / salinity)
- Larval supplies (growth, survival, retention)
- Availability of appropriate substratum for larval settlement
- Recruitment of post-larvae into established populations
- Survival and growth of adult oysters
- Predation by crabs and snails
- Overgrowth by native and non-indigenous tunicates



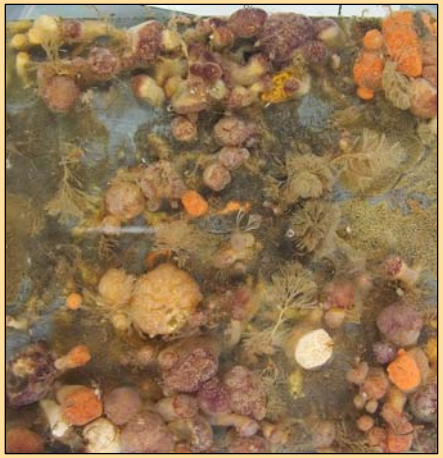

Broad-Scale Assessment of Estuarine Invasive Species in Coos Bay

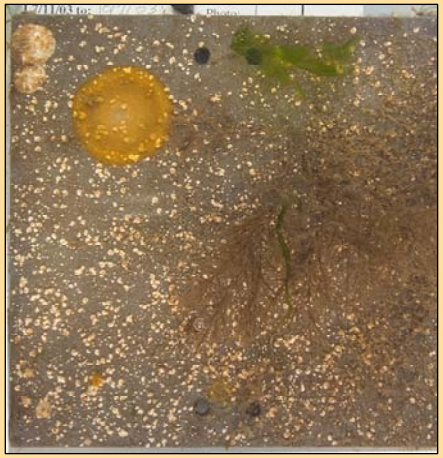






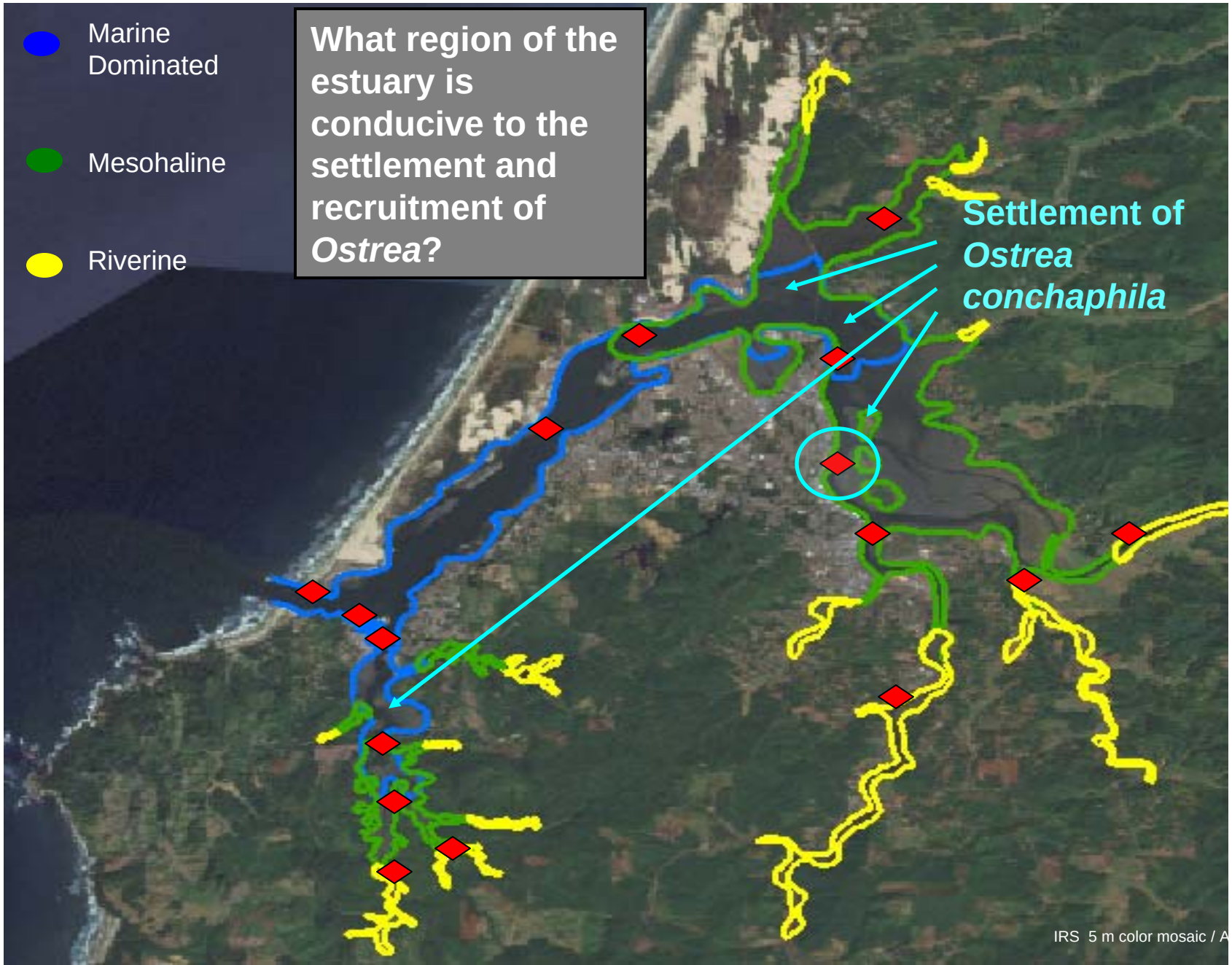
Fouling panel deployment from docks, piers, and on soft-sediment frames throughout estuarine habitats (2004)



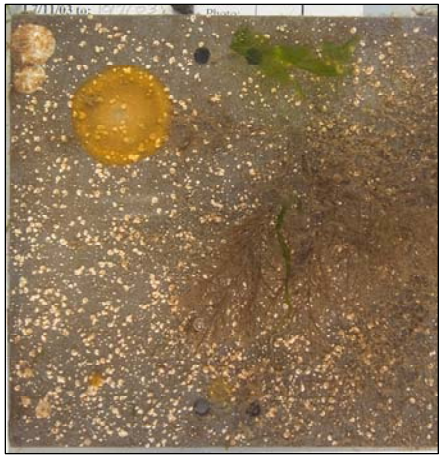


Recovery of panels after 90-100 days, followed by digital photos, preservation, and taxonomic identification

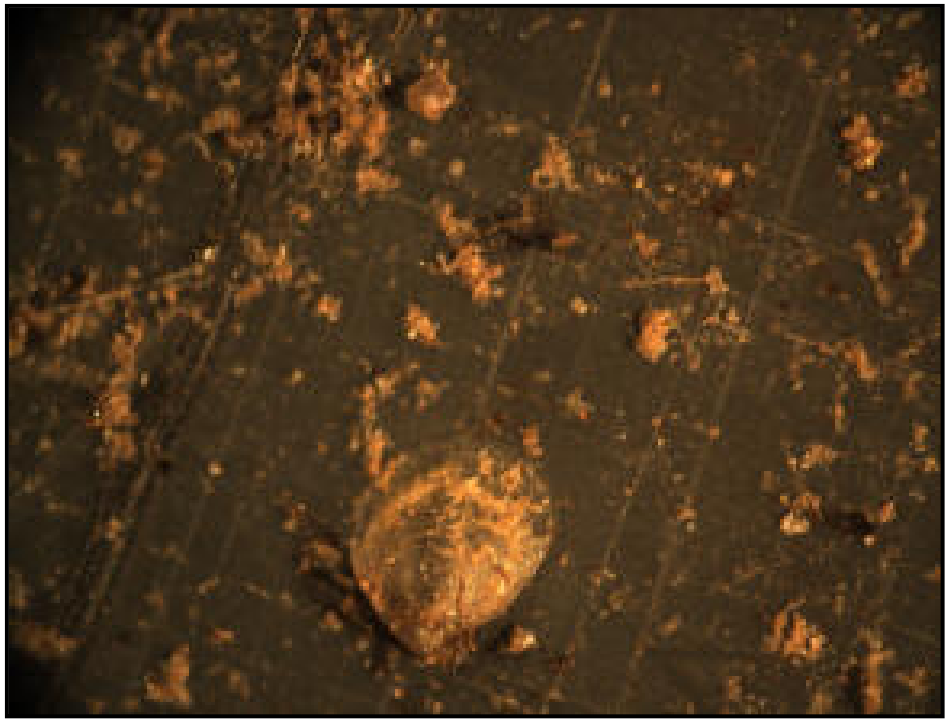
COOS ESTUARY, OR Monitoring Stations for Epifouling Invasive Invertebrates



Coos Bay, OR: Juvenile Native Oysters Recruited to PVC Fouling Panels Deployed off the Port of Coos Bay – Citrus Dock in the Mesohaline Region of the Estuary



PVC plate deployed in Coos Bay for 90-100 days in 2004



Juvenile *Ostrea conchaphila* attached to PVC plate

Which species of crabs prey upon adult Olympia oysters?

NO

A. *Cancer magister*

YES

C. *Cancer productus*

NO

B. *Cancer antennarius*

YES

D. *Carcinus maenas*

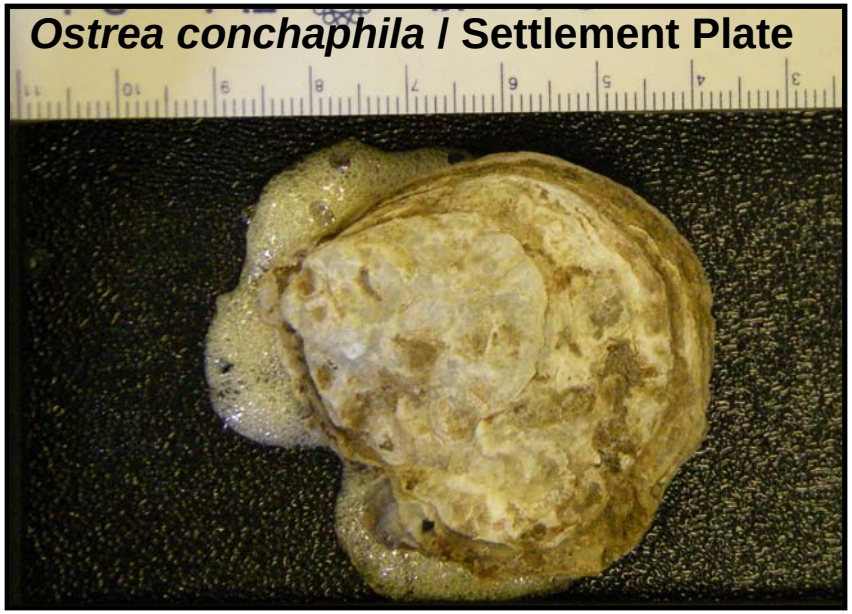
Overgrowth Competition by Epifouling Organisms


Ostrea & fouling community

- Tunicates
- Bryozoans
- Sponges
- Hydroids
- Barnacles
- Mussels
- Anemones

Oyster Epifouling Plates:

- Living Adult Oysters
- Gorilla Glue Adhesive
- Deployed at 11 Locations in Coos Bay and South Slough
- Seasonal monitoring of Epifouling Organisms


Ostrea conchaphila / Settlement Plate

Ostrea conchaphila: Overgrowth Competition by Non-indigenous Tunicates

Colonial:

Didemnum spp.

Botryllus schlosseri

Botrylloides violaceus

Solitary:

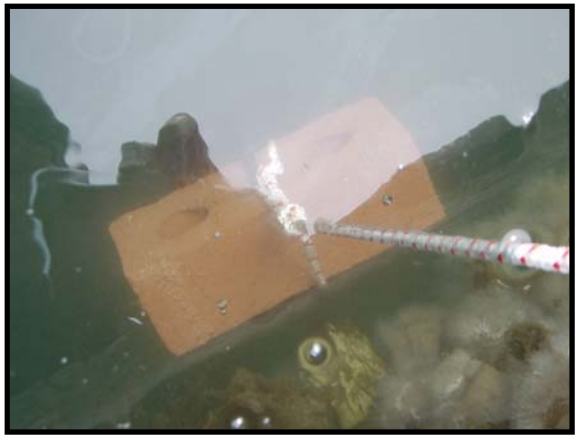
Styela clava

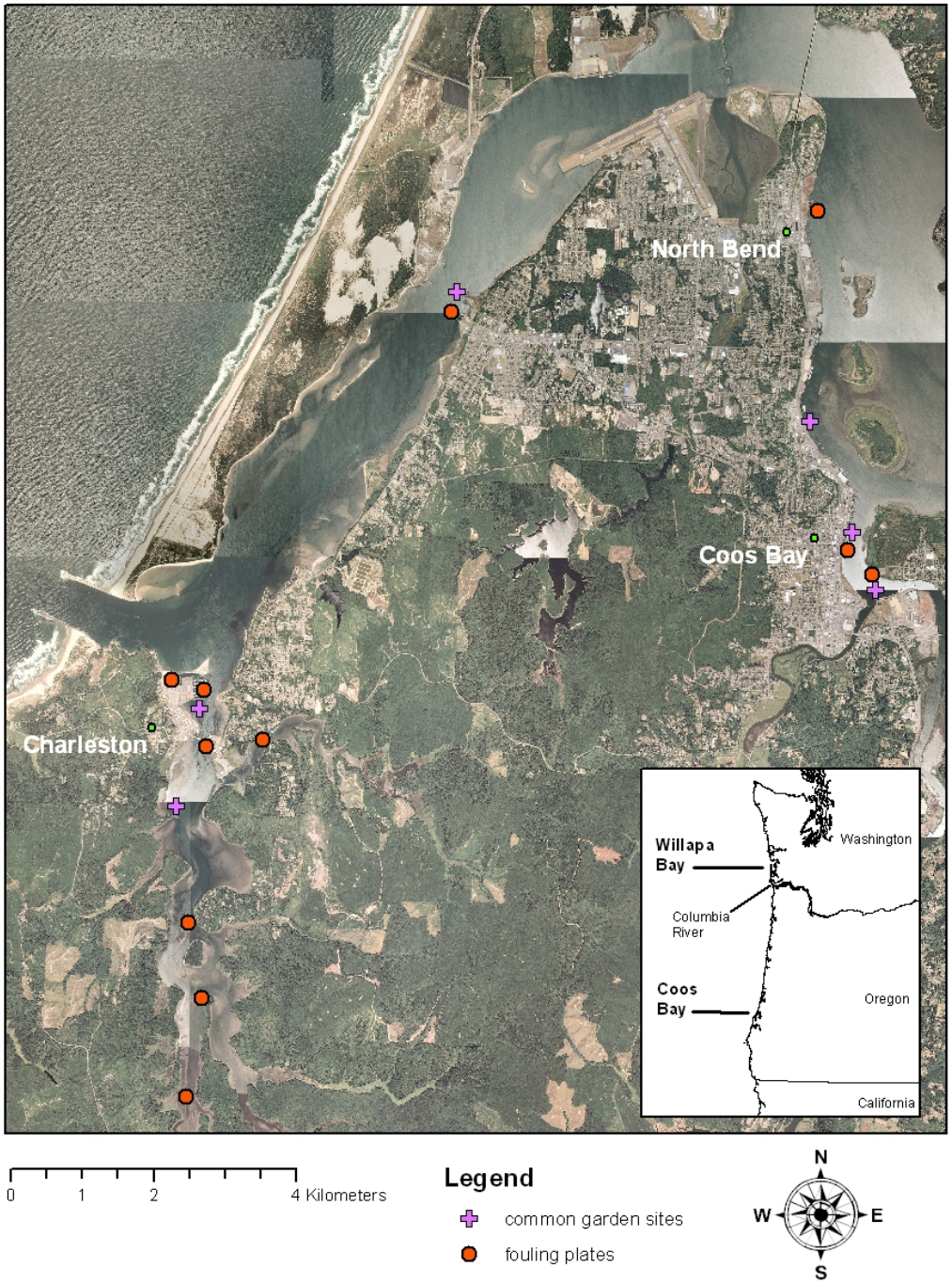
Molgula manhattenensis

Ciona intestinalis

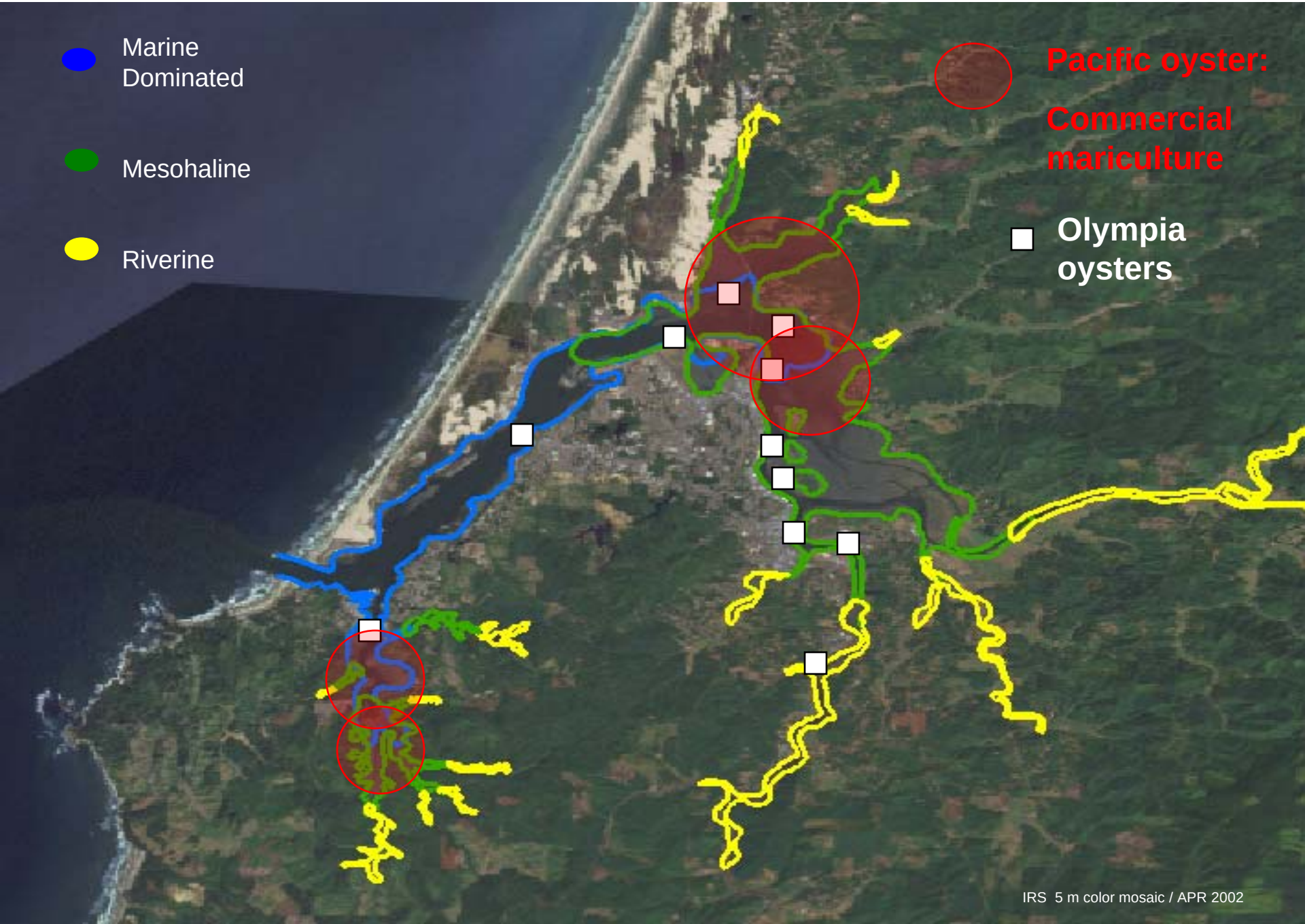
Ciona savignyi

Deployment of Oyster Plates and Common-Garden Bags in Coos Bay and South Slough, OR





COOS ESTUARY, OR Hydrologic Regions and Distribution of Olympia Oysters



COOS ESTUARY, OR Hydrologic Regions and Oyster Mariculture Operations

Pacific oysters: Coos Bay

Source – Sink Hypothesis

Pacific oyster: Commercial mariculture

Production of native Olympia oyster larvae occurs from recovering populations in Coos Bay.

Do the shells of commercial Pacific oysters provide a settlement site in the mid intertidal zone that is ultimately fatal for juvenile Olympia oysters?

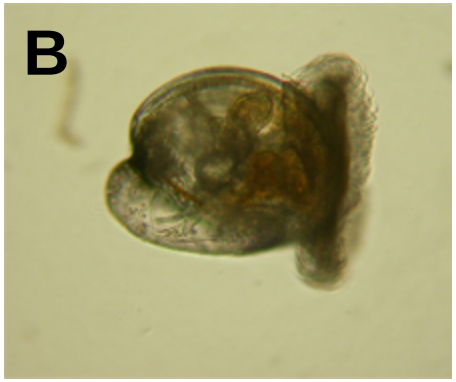
IRS 5 m color mosaic / APR 2002

Larval Settlement and Recruitment of Olympia Oysters to Shells

Female oysters brood larvae about 10-12 days

A

B



Planktonic veliger larva swims and feeds for about 8-10 days

Larvae settle and attach to shells as surface for growth

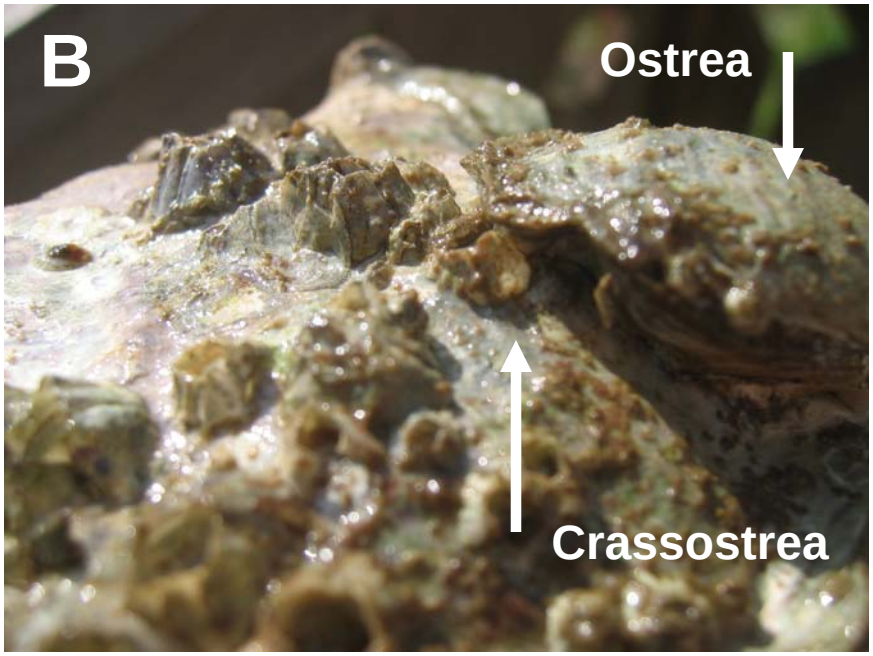
C

Ostrea conchaphila: Larval Settlement and Recruitment on Shells of Living Pacific Oysters (*Crassostrea gigas*)

Juvenile recruitment on adult Olympia oysters / *Ostrea*

<u>Outcome</u>: Good / Successive Generation

Juvenile recruitment on adult Pacific oysters / *Crassostrea*



<u>Outcome</u>: Good / Available Substrate

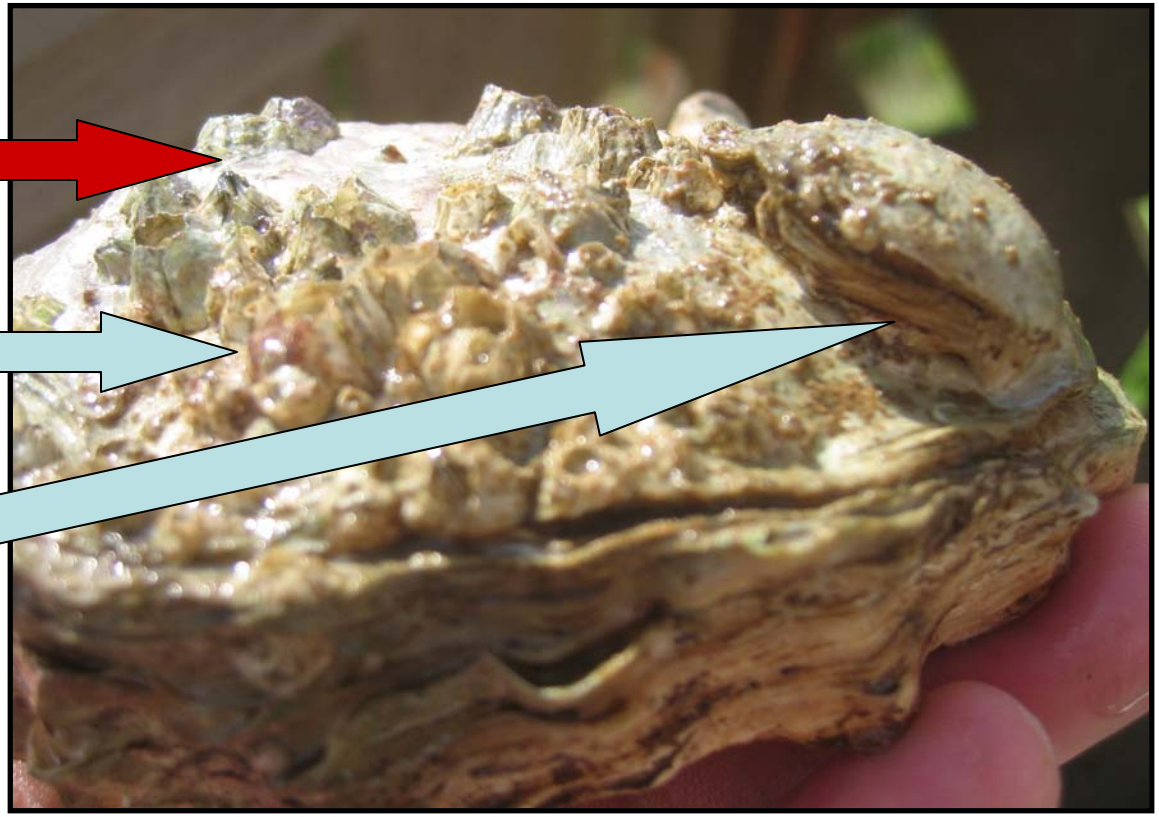
Bad / Harvested and Removed from Population

Examination of Pacific oyster (*Crassostrea gigas*) shells from mariculture facility for attached Olympia oysters (*Ostrea conchaphila*) / Aug 2008

Adult Pacific oyster

Juvenile Olympia oyster

Adult Olympia oyster



About 3 - 4% of Pacific oyster shells have attached Olympia oysters.

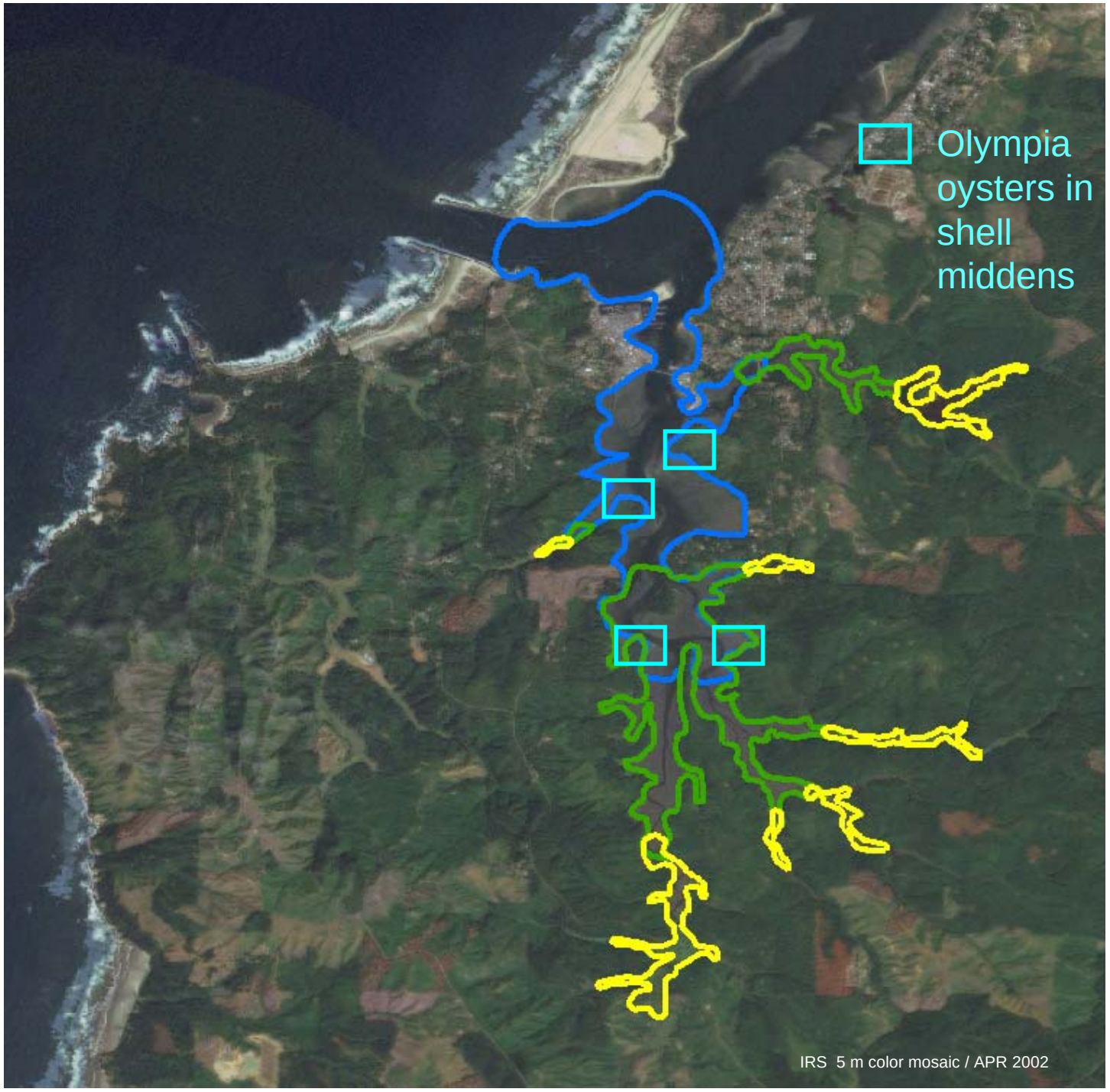
What % of the local Olympia oyster population is lost due to mariculture harvests?

Shell Type	Number Examined
Pacific *Crassostrea gigas*: adult	Pile A: 386 shells Pile B: 525 shells
Attached Olympia *Ostrea conchaphila*: adult & juvenile	Pile A: 15 shells (4%) Pile B: 18 shells (3%)

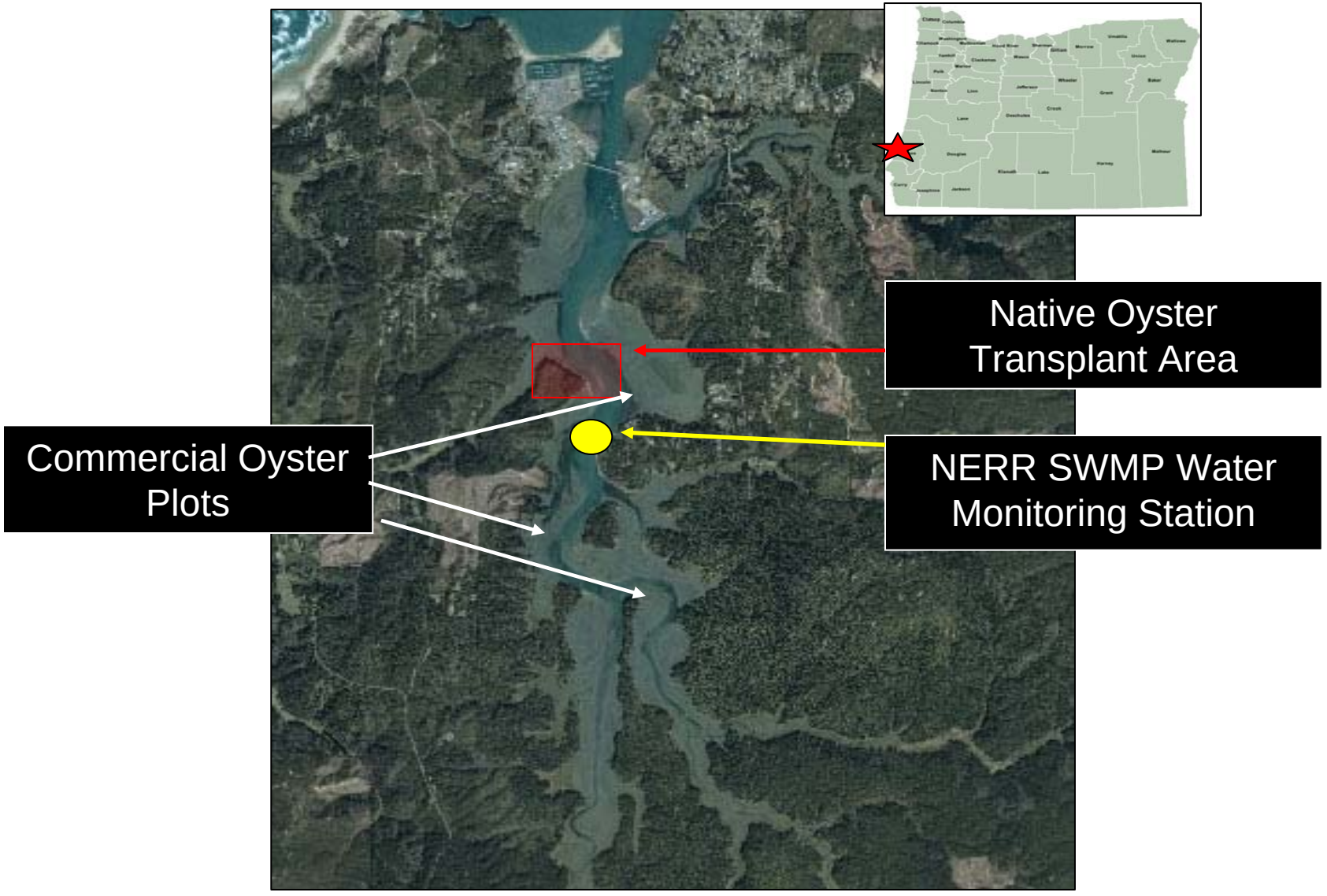
SOUTH SLOUGH ESTUARY, OR

Location and spatial extent of three distinct hydrographic regions located along the estuarine gradient of the South Slough tidal basin

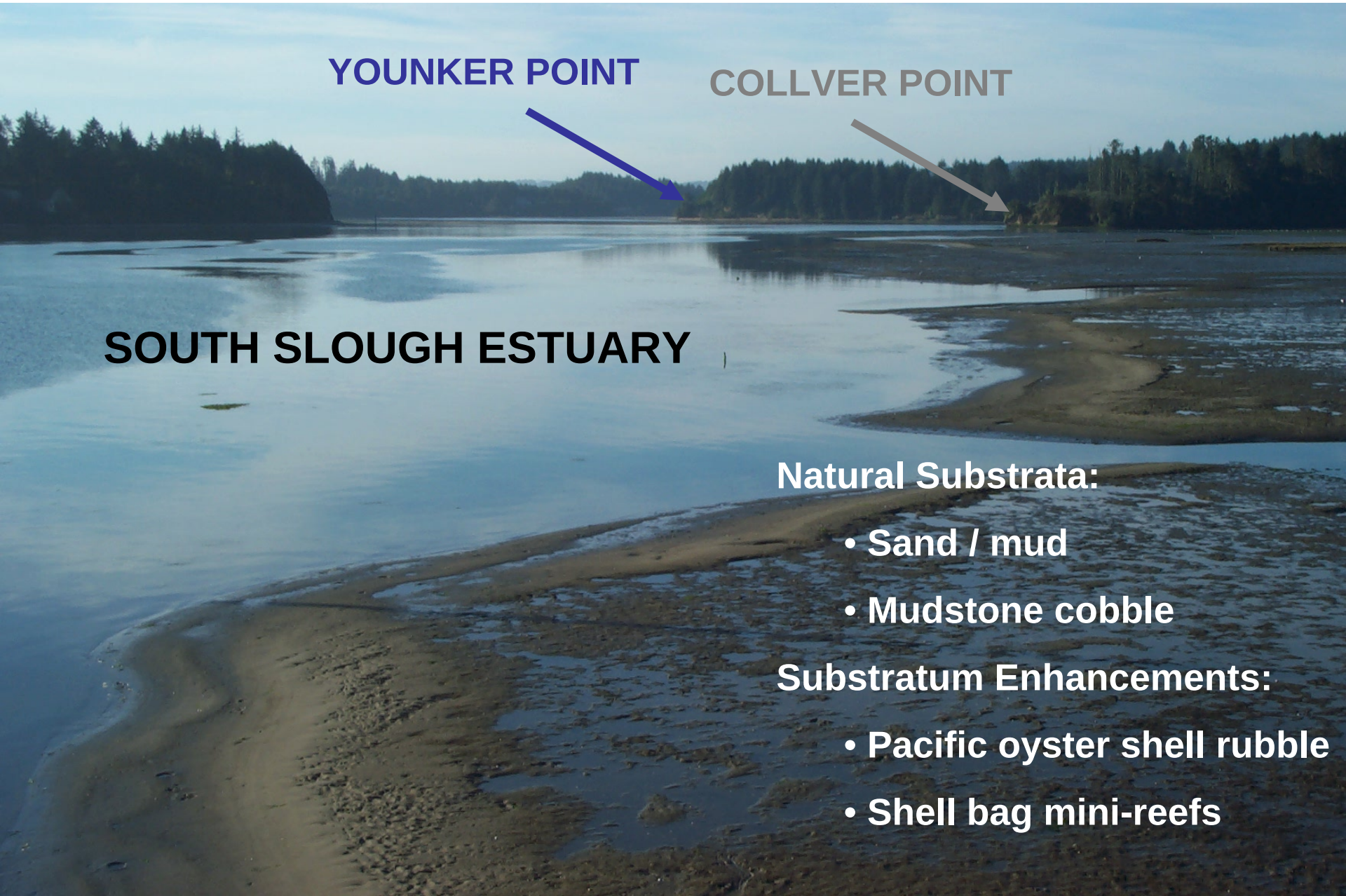
- Marine-Dominated
  31-20 psu
- Mesohaline
  28-15 psu
- Riverine
  21-0 psu



Project Area: Restoration of Native Olympia Oysters Within The South Slough Estuary, Oregon



Location of Olympia oyster out-planting sites in the South Slough estuary 2008



Re-establishment of Olympia Oysters in the South Slough Estuary: Common Garden Experiment

Evidence for local adaptation?

Broodstock Source

A. Willapa Bay, WA

B. Coos Bay, OR

Oyster Cultch

(shell with juveniles)

22 Oyster Bags Outplanted into the South Slough Estuary in 2008

Ecological Performance

- **Survival**
- **Growth**
- **Onset of Reproduction**
- **Reproductive Output**
- **Susceptibility to:**
  - **predation**
  - **overgrowth competition**
  - **sedimentation**

Summary:

1. Native Olympia oysters were historically abundant in some Oregon estuaries, but not all estuaries

2. Populations of Olympia oysters are making a slow recovery in parts of Coos Bay, but they are virtually absent from some regions

3. The genetic signature and shell morphology of Coos Bay oysters is nearly identical to oysters from Willapa Bay, WA, and a common-garden field experiment has been initiated to investigate local adaptation

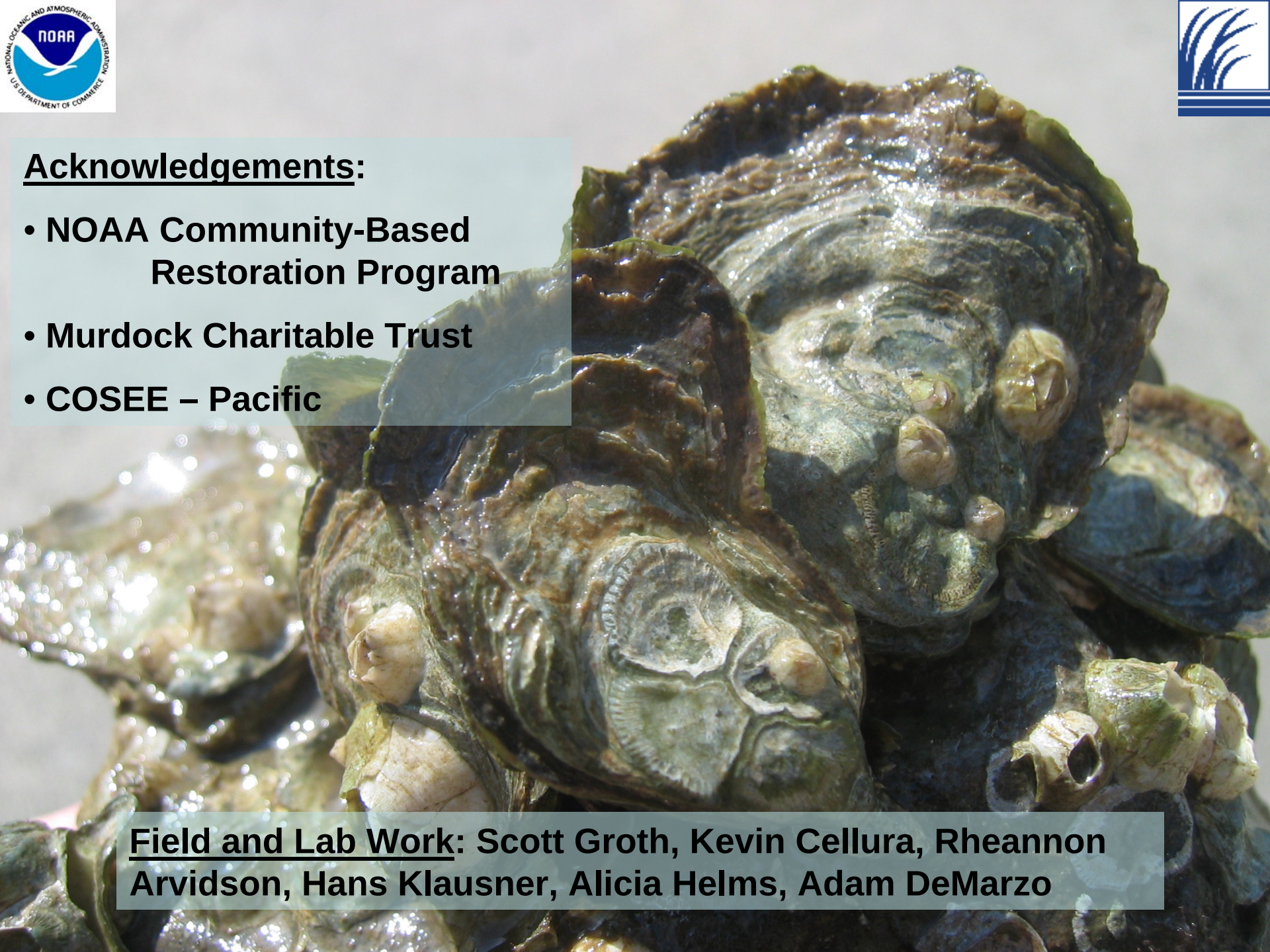
4. Interactions with non-native crabs, tunicates, and sponges pose an impediment to survival and growth of Olympia oysters in Coos Bay

5. Hard substrata is limited, and settlement of Olympia oyster larvae on Pacific Oyster shells is a potentially important source of incidental mortality when the commercial oyster plots are routinely harvested every 2-3 years *

6. Results generated by small-scale experimental oyster restoration plots will be used to guide larger-scale oyster restoration efforts in South Slough and Coos Bay in the future

Additional Thoughts and Considerations:

1. **Do Pacific oysters have a net positive or negative impact on recruitment and reproductive success of Olympia oysters?**
2. **The "death assemblage" of shell piles suggests that 3-4 Olympia oysters are killed / 100 Pacific oysters harvested. How many Pacific oysters are harvested per year from Coos Bay? How many Olympia oysters are inadvertently removed as by-catch?**
3. **The "death assemblage" of shells also suggests that 3-4 Olympia oysters successfully settled and grew (some to maturity) per 100 Pacific oysters harvested. Would these attached Olympia oysters have been lost without the shell as substratum?**
4. **Living Pacific oysters are the primary hard substratum available in Coos Bay and may be an important factor in the recovery of Olympia oysters along the shoreline.**
5. **What % of the reproductive population of Olympia oysters resides on Pacific oyster shells versus rocks, rip-rap, and pilings?**



Acknowledgements:

- NOAA Community-Based Restoration Program
- Murdock Charitable Trust
- COSEE – Pacific

Field and Lab Work: Scott Groth, Kevin Cellura, Rheannon Arvidson, Hans Klausner, Alicia Helms, Adam DeMarzo

Where did the Olympia oysters that currently inhabit Coos Bay come from?

Genetic Identity of Broodstock Oysters:

Sample Collections from Coos Bay Populations

North Bend, Coos Bay, Isthmus Slough, Shinglehouse Slough / (D. Stick, S. Rumrill, S. Groth, D. Sowers / 2005)

Genetic Analysis / DNA Microsatellites

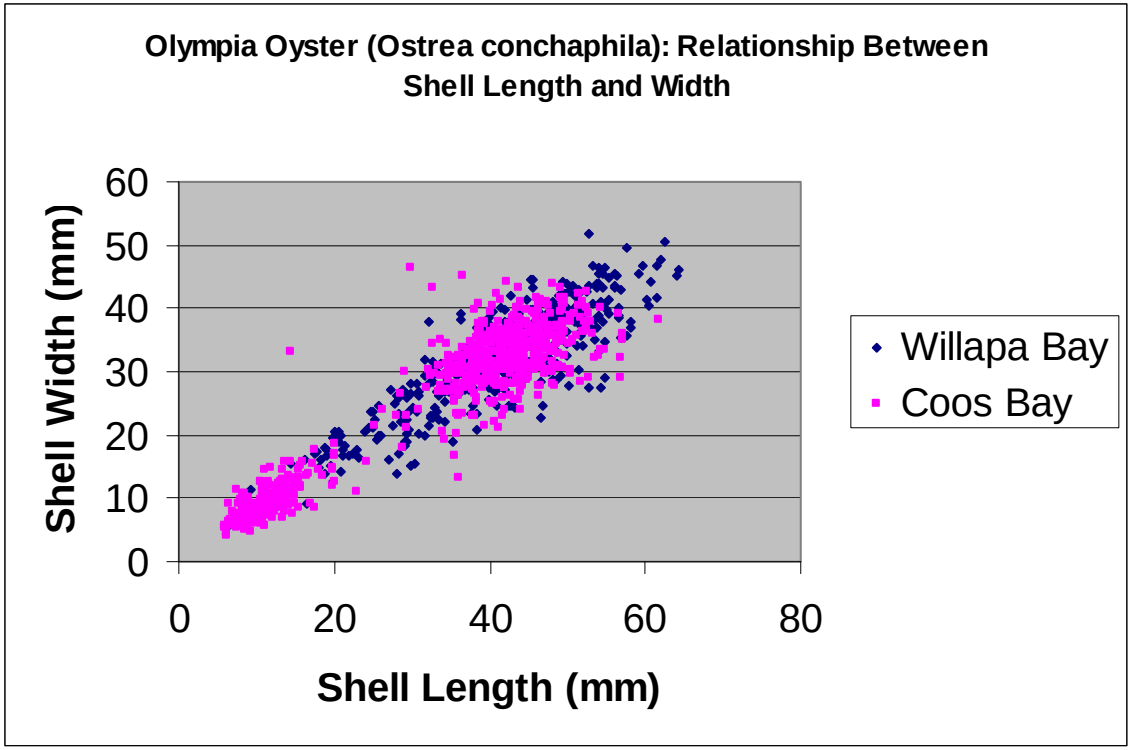
M. Camara, C. Langdon, D. Stick / 2006-07

Preliminary findings so far (2007) …

Genetic identity (DNA microsatellite variability) and phenotypic evidence (oyster body size and shape) indicate that specimens from Coos Bay are not distinctly different from populations in Willapa Bay, WA and Tomales Bay, CA.

Recommendation: Use local adults from Coos Bay and distant adults from Willapa Bay as broodstock for larval cultures and outplanting. Conduct a "common garden experiment" to assess importance of local adaptation.

Measurements of Oyster shell dimensions and variability



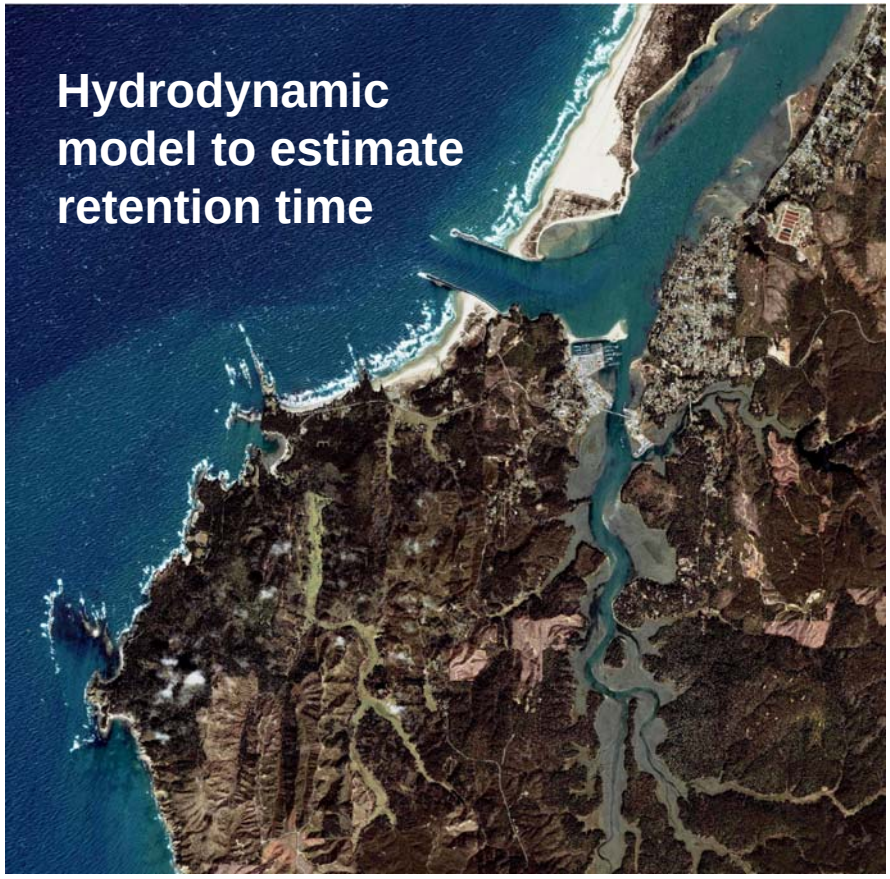
Variation due to:

- Location / estuaries
- Substratum
- Hydrodynamic environment
- Broodstock source

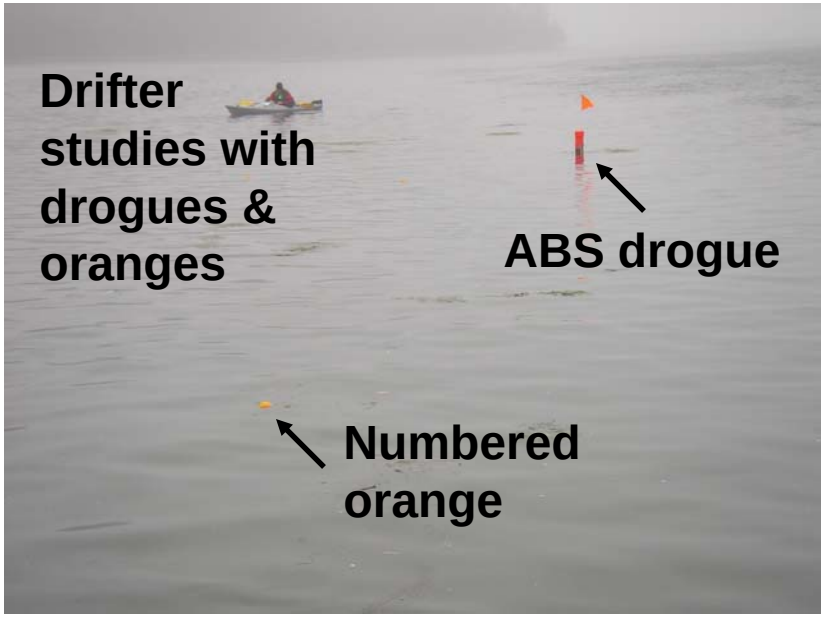
Are *Ostrea* larvae retained or exported from Coos Bay and the South Slough estuary?

Laboratory and field behavior of pediveliger larvae

Hydrodynamic model to estimate retention time



Dispersion and tidal current studies with Rhodamine WT dye and ADCP deployment

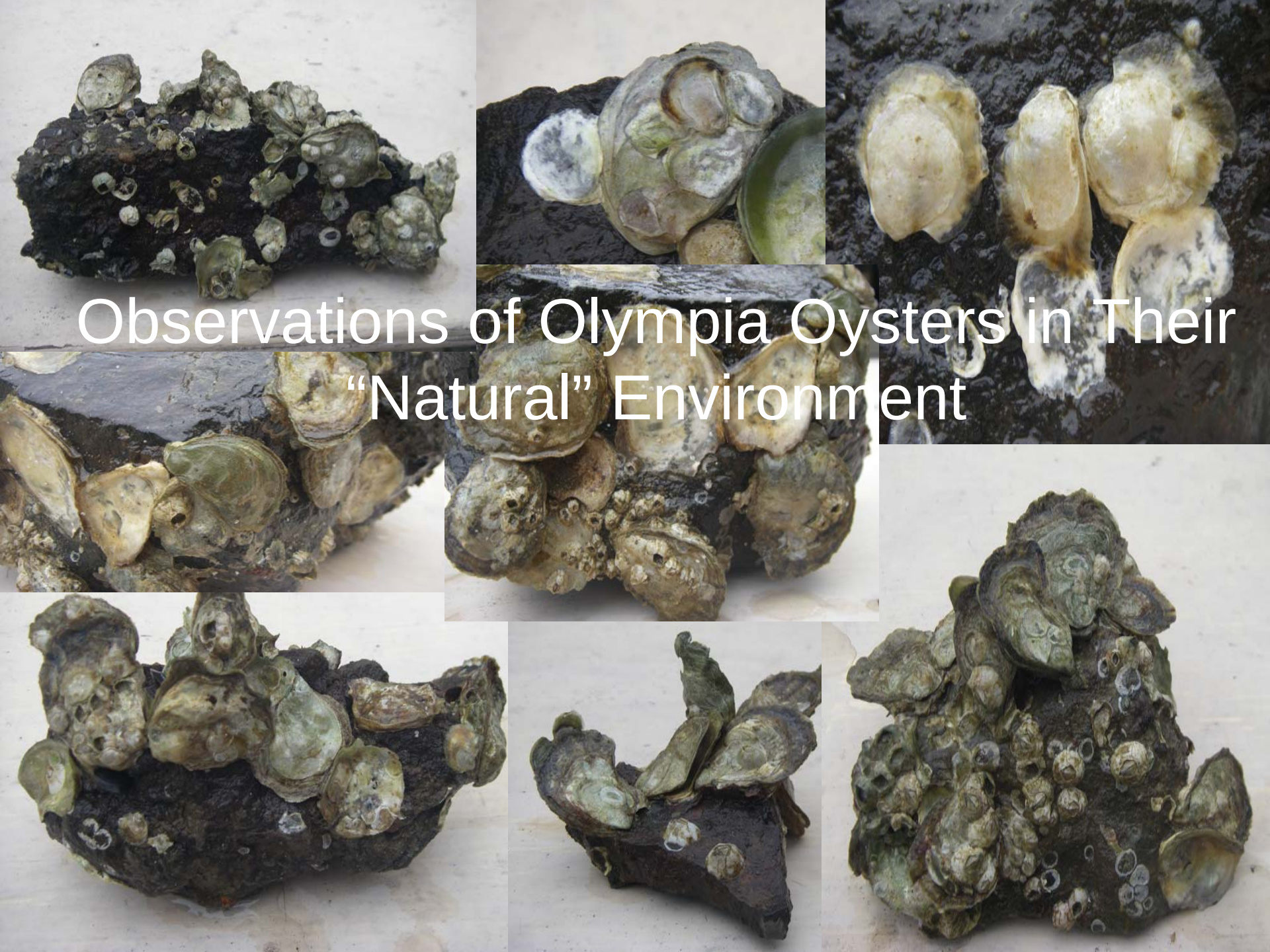


Populations of Native Olympia Oysters are Making a Slow Recovery in the Middle and Upper Regions of Coos Bay

Salinity range 10 to 30 psu (mesohaline to polyhaline hydrographic region)

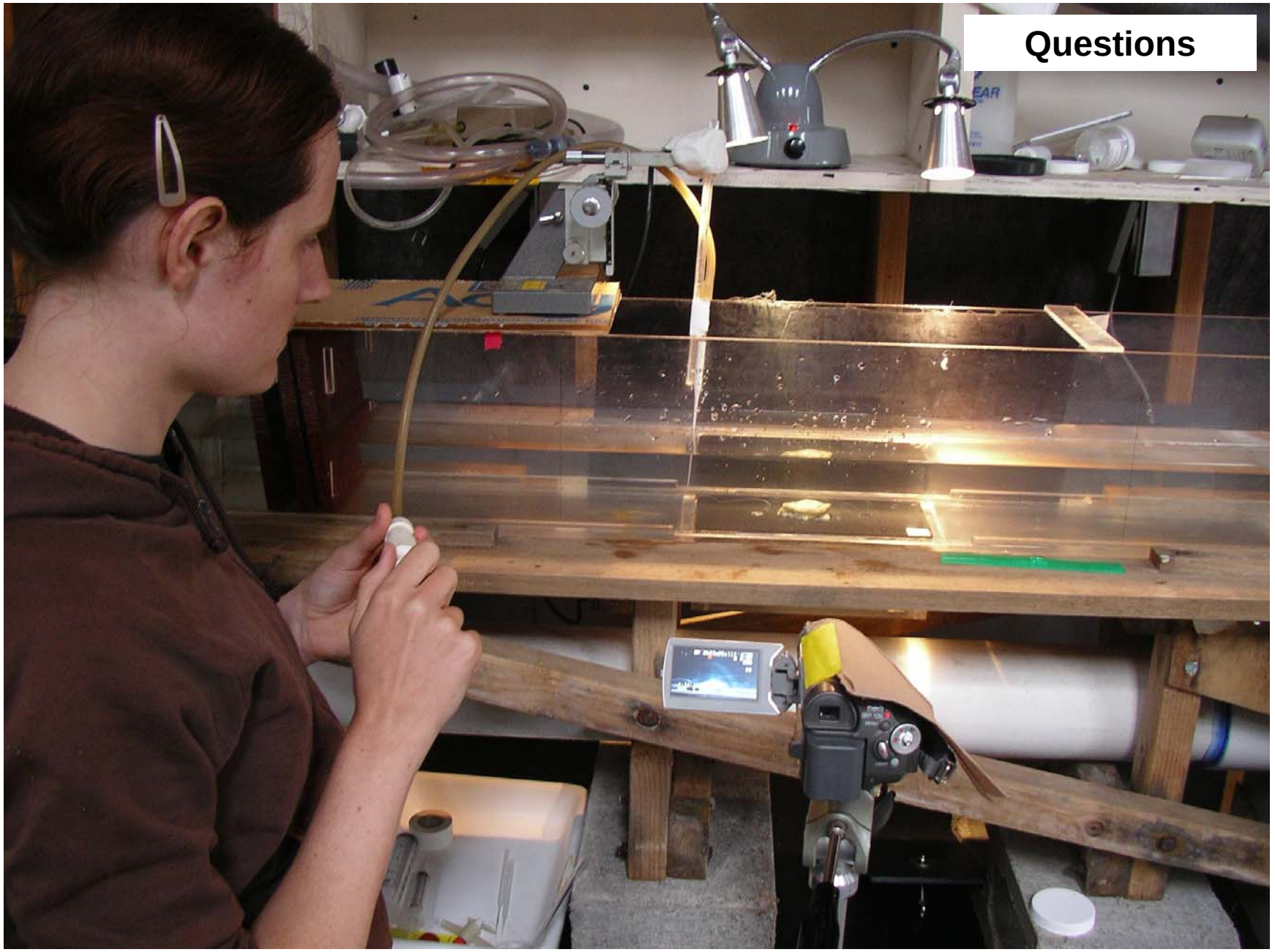
Availability of Suitable Surfaces for Settlement and Growth Appears to be an Important Limiting Factor

Suitable Hard Surfaces include Shell Rubble, Rocks, Gravel, Pilings, Rip-Rap, and Living Pacific Oysters (*Crassostrea gigas*)



Observations of Olympia Oysters in Their "Natural" Environment

Questions



Coos Bay: A Drowned River-Mouth Estuary (21 sq. miles)

Coos Bay

South Slough

Oregon Institute of Marine Biology

Cape Arago

South Slough National Estuarine Research Reserve

Designated 1974

4,800 ac research natural area

Habitats:

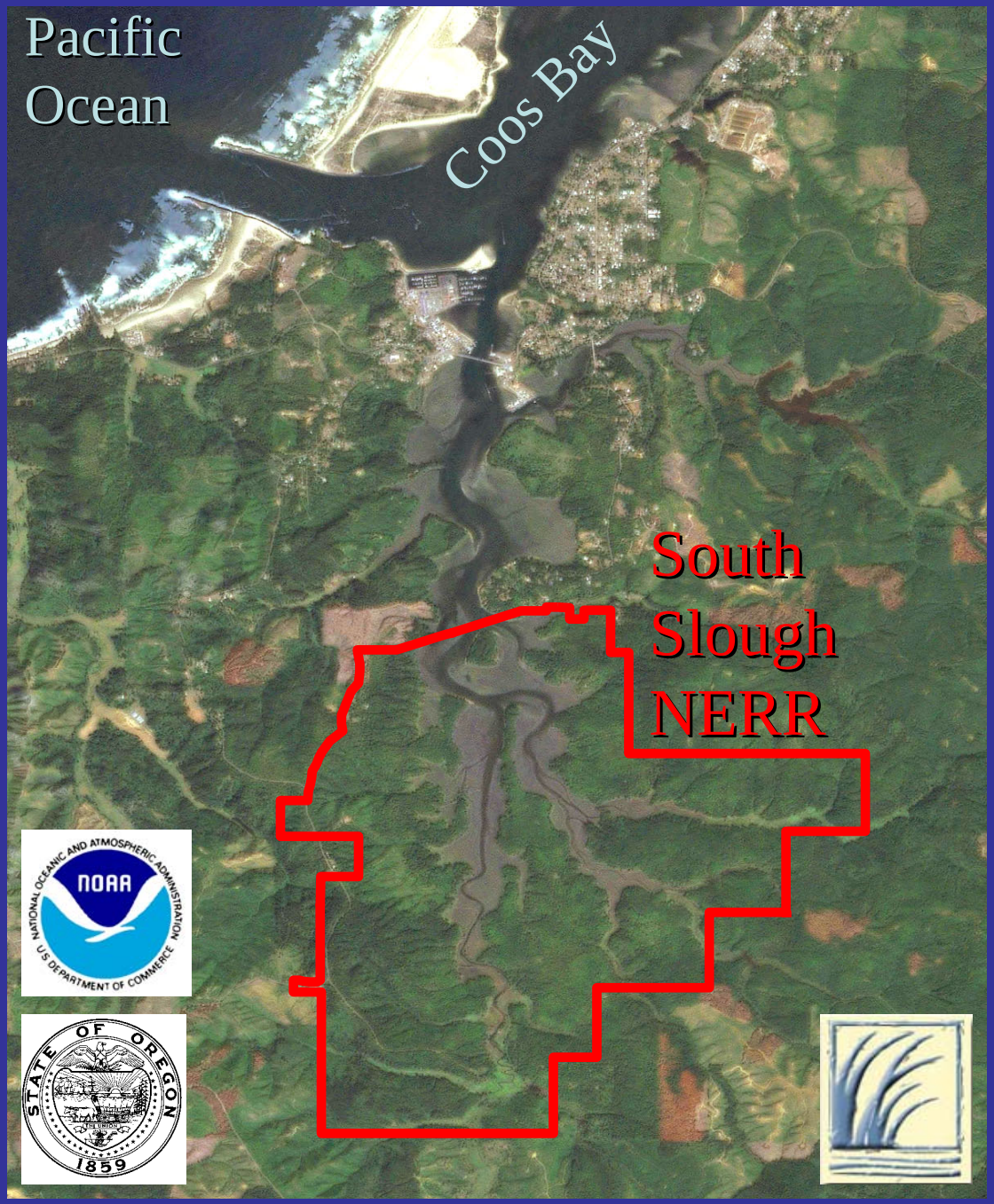
- estuary
- wetlands / riparian
- coastal forest

Land-Margin Ecosystem

Ocean

↳ Estuary

↳ River

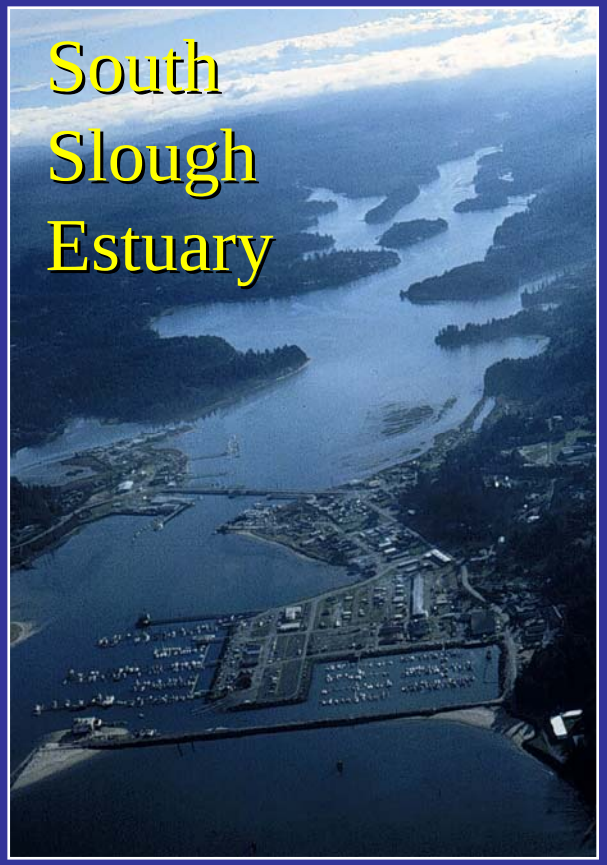


Commercial Mariculture of Pacific Oysters in South Slough NERR, OR

A. Bottom culture

B. Stake culture

C. Rack culture



Restoration of Olympia oysters in the South Slough Estuary

Vision: Successful establishment of self-sustaining populations of *Ostrea conchaphila* throughout the South Slough and Coos Bay, to the extent that native oysters can provide habitat and contribute to improved ecological functions

Project Goal: Increased understanding of intrinsic and ecological factors to facilitate and encourage recovery of self-sustaining populations in the estuarine tidal channels and tideflats

Objectives:

1. Determine the genetic identity of existing oyster populations in Coos Bay and identify appropriate broodstock sources (2006)
2. Establish an experimental population and conduct an on-site assessment of oyster survivorship, growth, and reproduction in South Slough (2007-09)

Poster: Jefferson County, WA

NOAA / Northwest Straits Marine Conservation Initiative

Conclusions:

1. New project to initiate restoration and recovery of *Ostrea conchaphila* populations in the South Slough estuary
2. Genetic identification of an appropriate source of broodstock in 2006-07
3. Culture, settlement, and out-planting of 15,000 to 22,000 oysters will occur in summer 2008
4. Field assessments to determine survival, growth, and reproduction in 2008-2010
5. Future work to determine larval export, retention, and interactions with predators, competitors, and eelgrass

Community Restoration Program

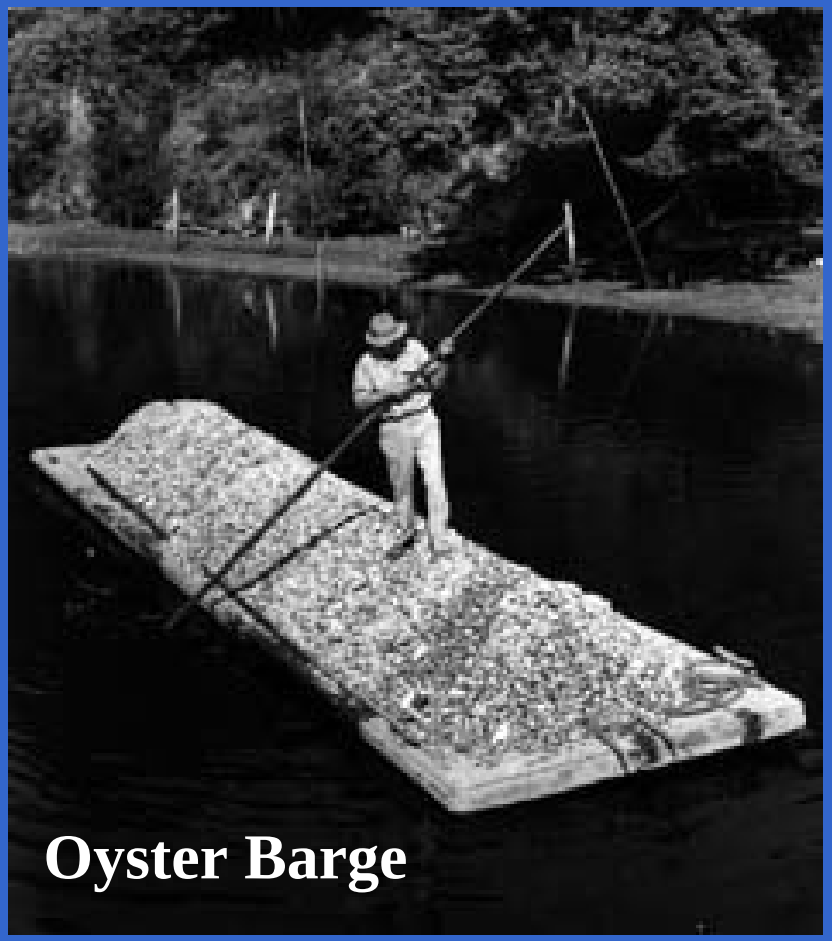
LARGE-SCALE RESTORATION OF OLYMPIA OYSTERS IN PUGET SOUND, WA

Over 7 million oysters spread out at 80 sites (1999-2006)

Survivorship rate at 29-95%

Re-establishment of naturally spawning populations at 8 sites

Harvest and Culture of Native Olympic Oysters (1850s-1920s)



Oyster Barge

Diked Culture Plots

Tong Harvest

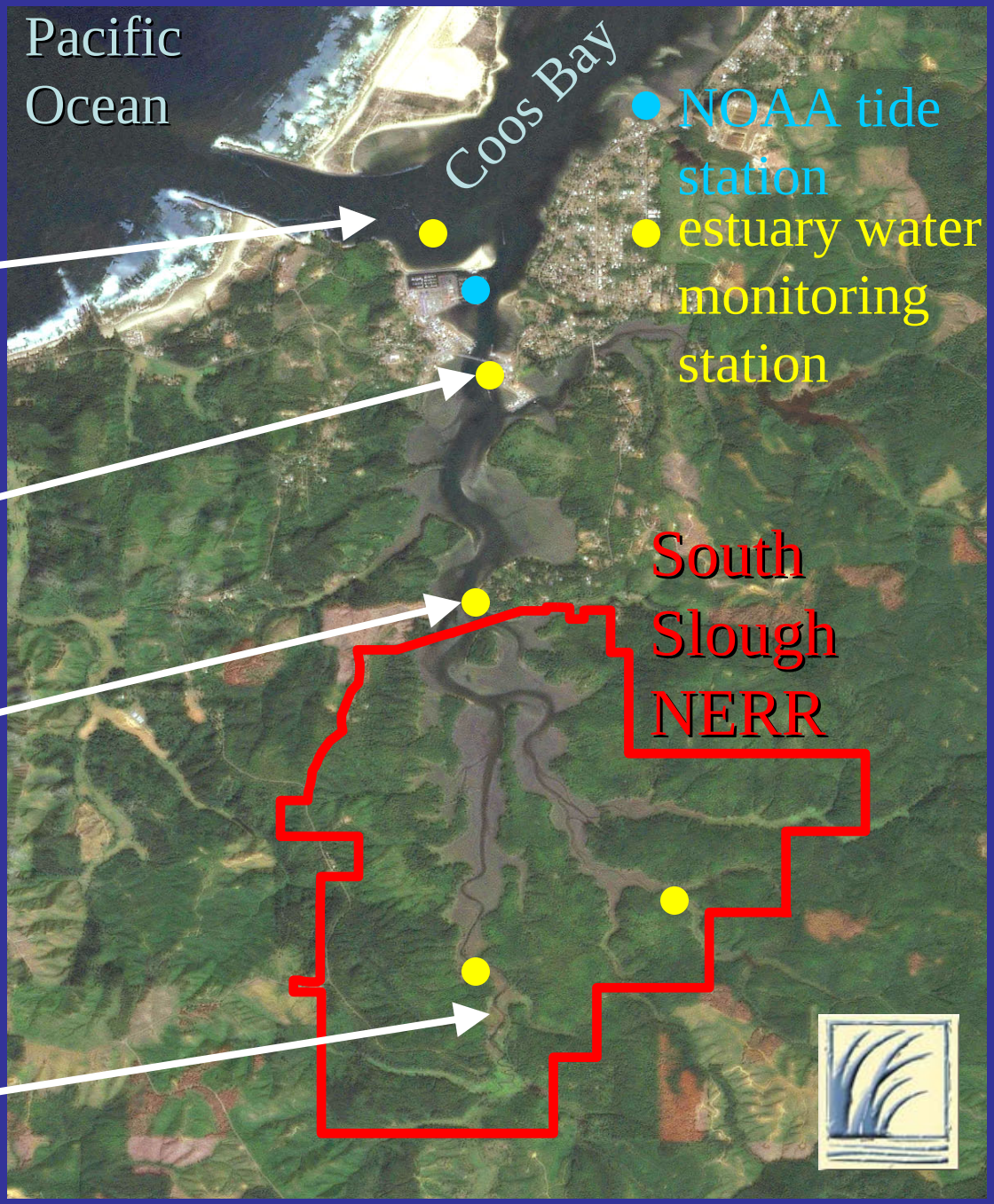
South Slough Estuarine Gradient

MARINE / BAY
Boathouse

MARINE DOMINATED
Charleston

MESOHALINE
Valino Island

RIVERINE
Winchester Creek



Marine Biogeographic Regions represented by the National Estuarine Research Reserve System

Gulf of Alaska

Puget Sound

Lower Columbia

Central California

Southern California

Great Lakes

Gulf of Maine

Mid Atlantic

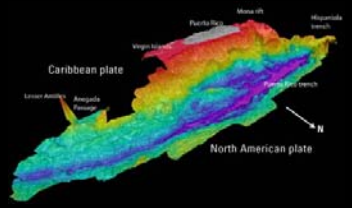
Delaware / Chesapeake

South Atlantic

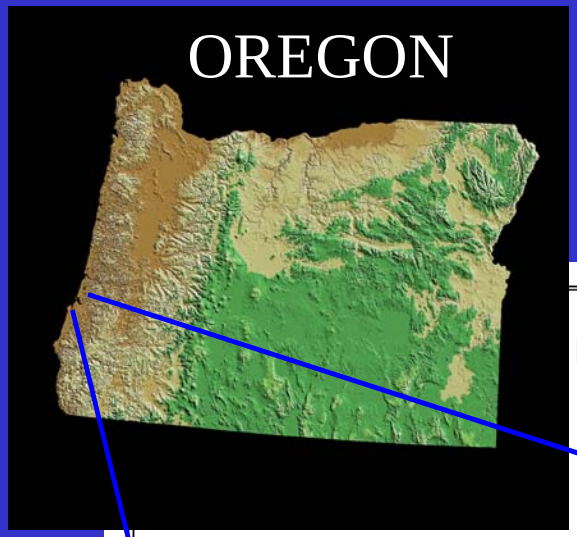
Gulf of Mexico

Caribbean

NERRS Biogeographic Regions are Sub-Sets of NOAA Large Marine Ecosystems



Coos Bay: A Pacific Northwest Drowned River Mouth Estuary



Digitial Elevation Model

N
W
E
S

10 0 10 20 Kilometers

Coos Bay

South Slough Tidal Inlet

Commercial oyster harvest since 1850s / Import of *C. gigas* 1920s

Coos Bay: A Drowned River-Mouth Estuary (21 sq. miles)

Coos Bay

South Slough

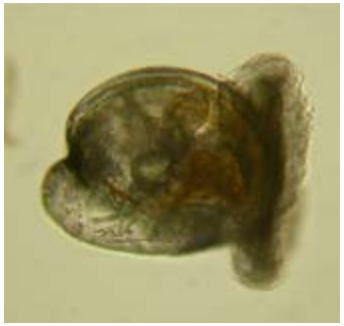
Oregon Institute of Marine Biology

Cape Arago

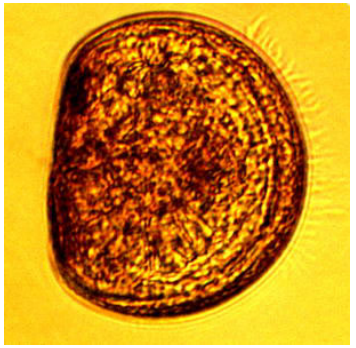
Life History of Pacific Oysters: *Crassostrea gigas*

Trochophore larva

Veliger larva

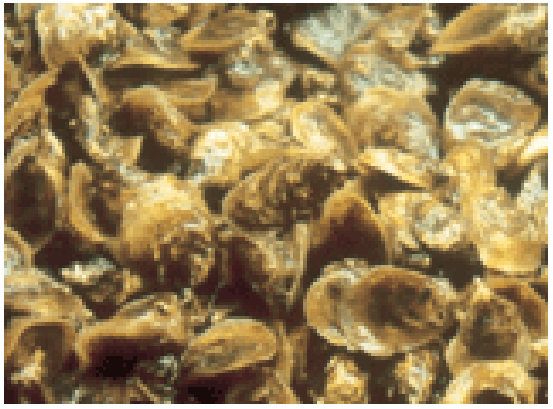


D-shell larva

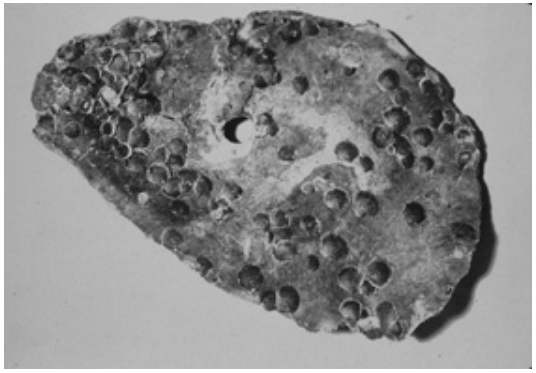


20-28 days in plankton

Settled juveniles



"Cultch" juveniles on adult shell



Adult oyster

Sperm Egg

Embryo

Ecology of oysters (*Crassostrea gigas*):

Appearance: Large (8-15 cm) epibenthic bivalves, non-motile with left valve typically cemented to substrata.

Reproduction & Growth: Protandric hermaphrodite, spawn in summer, external fertilization with planktonic veliger larvae. Post settlement growth about 25 mm per year.

Habitat: Mid intertidal to shallow subtidal, attachment to hard surfaces in sheltered waters, often on adult shells. Mariculture species.

Feeding: Filter-feeder / suspension-feeder, consumes phytoplankton and protists.

Predators: Seastars, crabs, boring gastropods, polychaetes, fish, birds, humans.

South Slough Estuary Olympia Oyster Restoration Project: 2006-2015

- **History of Native Oysters in Oregon Estuaries**

  Oregon Dept. Fish & Wildlife / SSNERR (S. Groth, S. Rumrill / 2006)

- **Genetic Identity of Broodstock Oysters**

  Oregon State University (M. Camara, C. Langdon, D. Stick / 2006-07)

- **Distribution and Recovery of Olympia Oysters in Coos Bay**

  Oregon Dept. Fish and Wildlife (S. Groth / 2005-06)

- **Recruitment of Olympia Oysters to Fouling Panels and Shells**

  SSNERR / SERC (C. deRivera, S. Rumrill / 2004-05)

- **Characterization of Estuarine Water Quality Conditions**

  SSNERR (S. Rumrill, A. Helms, A. DeMarzo / 2005-2010)

- **Culture, Settlement, and Out-planting of Juvenile Oysters**

  SSNERR / TNC (S. Rumrill, D. Vander Schaaf / 2008)

- **Monitor Oyster Survival, Growth, and Reproduction (2008-2010)**

  SSNERR (2008-10)

- **Ecological Interactions with Competitors, Predators, and Eelgrass (2008-2010)**

  SSNERR / MHS / COSEE (K. Cellura, R. Arvidson, S. Rumrill, P. Archer / 2008)

- **Estimation of Larval Production, Retention, Export, and Settlement (2009-2015)**

Distribution and Recovery of Olympia Oysters in Coos Bay

<u>Coos Bay, OR</u>: Map indicates the location of local landmarks and five study sites examined in 2006 during quantitative surveys of *Ostrea conchaphila* populations.