Coastal Master Naturalist: Estuaries

November 6, 2010

Dr. Steven Rumrill, Research Program Coordinator

- South Slough National Estuarine Research Reserve
- University of Oregon – Institute of Marine Biology
- Oregon State University – Marine Resource Management

Coastal Master Naturalist / Estuaries

12:00 noon — **Seminar**: ***Overview of the Ecology of Pacific Northwest Estuaries***

1:00 PM — **break**

1:15 PM — **Natural History of the South Slough**:
Loop tour through exhibits & SSNERR Classroom / Diversity of Clams, Crabs, Eelgrass

2:00 PM — **Seminar**: ***Natural History and Restoration of Native Olympia Oysters***

3:00 PM — **Field Trip**:

1. **Hinch Road Bridge / Salt Marshes & Restoration**
2. **Hidden Creek Overlook / Estuary Conservation**
3. **Coos Head / Ocean Estuary Interface**
4. **Charleston Marina / Native & Non-native Invertebrates**
5. **Distant Water Dock / Mariculture & Eelgrass**

5:00 PM — **Return to: SSNERR Interpretive Center**

Overview of the Ecology of Pacific Northwest Estuaries

Outline:

1. Definition of Estuary
2. Formation and Classification of Pacific Northwest Estuaries
3. Physical Characteristics of Estuaries
4. Biogeochemistry and Nutrient Cycling
5. Ecology of Major Estuarine Habitats
    - *Salt marshes*
    - *Eelgrass Beds*
    - *Tideflats*
    - *Water column*
    - *Artificial Surfaces*
6. Habitat Alteration, Loss, and Restoration
7. Potential Effects of Climate Change on Estuaries

Definition of Estuary: *where rivers meet the sea*

L. *Aestuarium*

- tidal inlet of the sea

L. *Aestus*

- tide, boiling, seething, raging, agitation

Arm or inlet of the sea where freshwater mixes with saltwater

***Coos Estuary, OR*:** Mouth of Coos Bay / high-energy surf-zone and low-energy tidal waters protected by North Spit

Definition of Estuary: *where rivers meet the sea*

Land-margin ecosystem at the interface between steep or deltaic river valley and the nearshore Pacific Ocean

Semi-enclosed coastal water body with a free connection to the sea, within which seawater is diluted with freshwater

***Salmon River Estuary, OR*:**

Definition of Estuary: *where rivers meet the sea*

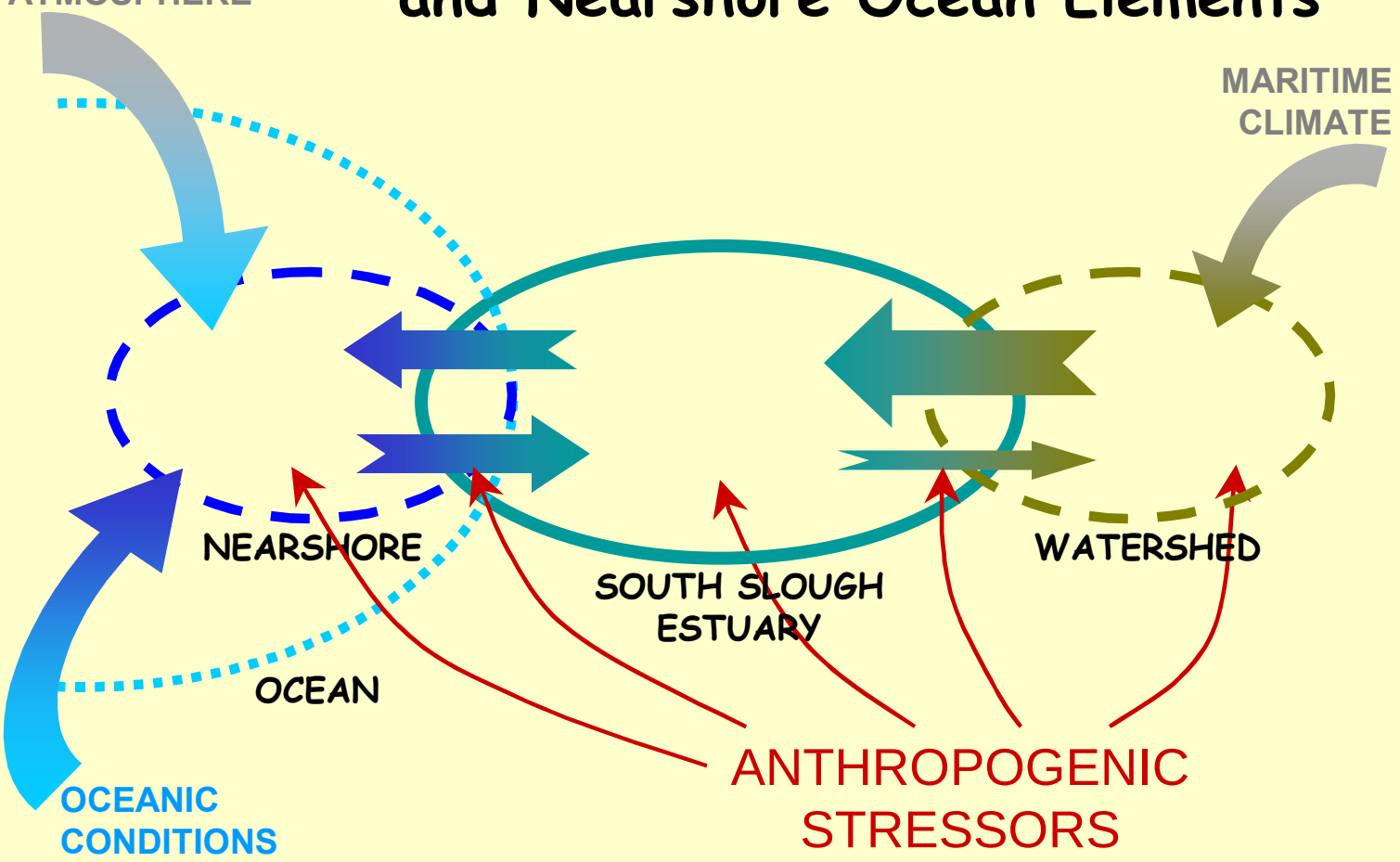
Inlet of the sea that reaches into a river valley as far as the upper limit of tidal rise

Holistic – entire land-margin ecosystem where there is an interaction of ocean water, fresh water, land, and the atmosphere

***Klamath River Estuary, CA*:** Breach of river mouth and discharge of estuarine waters into surf zone

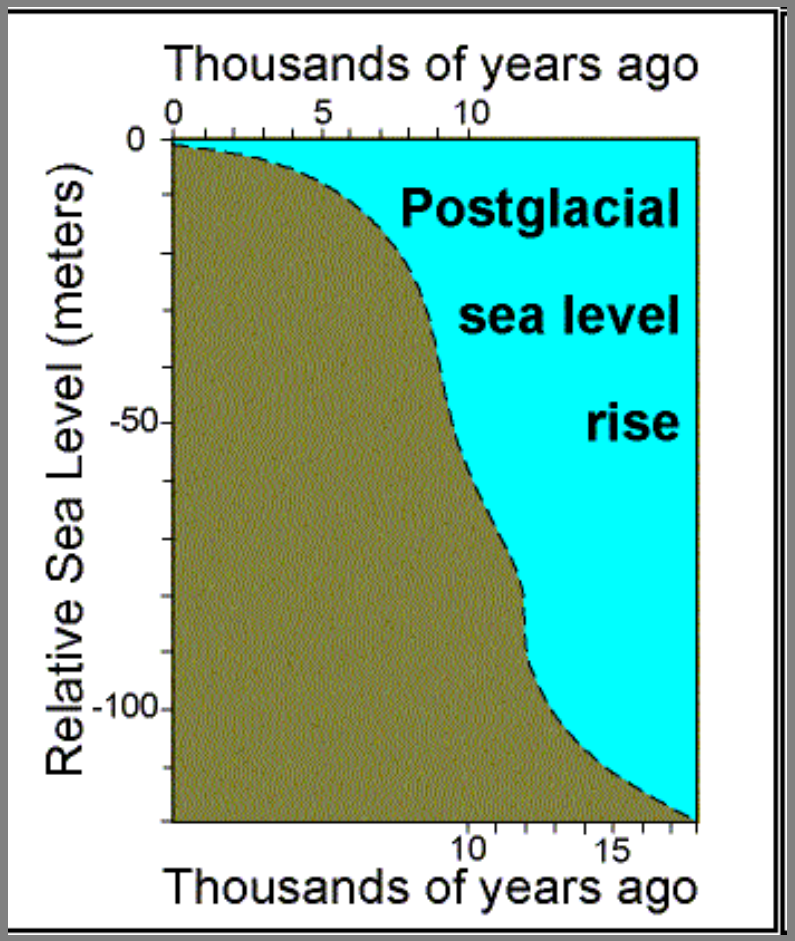
PACIFIC NORTHWEST ESTUARIES

Interface Model for Links Between Watershed, Estuary, and Nearshore Ocean Elements



Formation and Classification of Estuaries:

Most modern estuaries were formed during the Holocene (recent) epoc by the flooding of river-eroded valleys or glacial-scoured valleys when sea level began to rise about 10,000 to 15,000 years ago

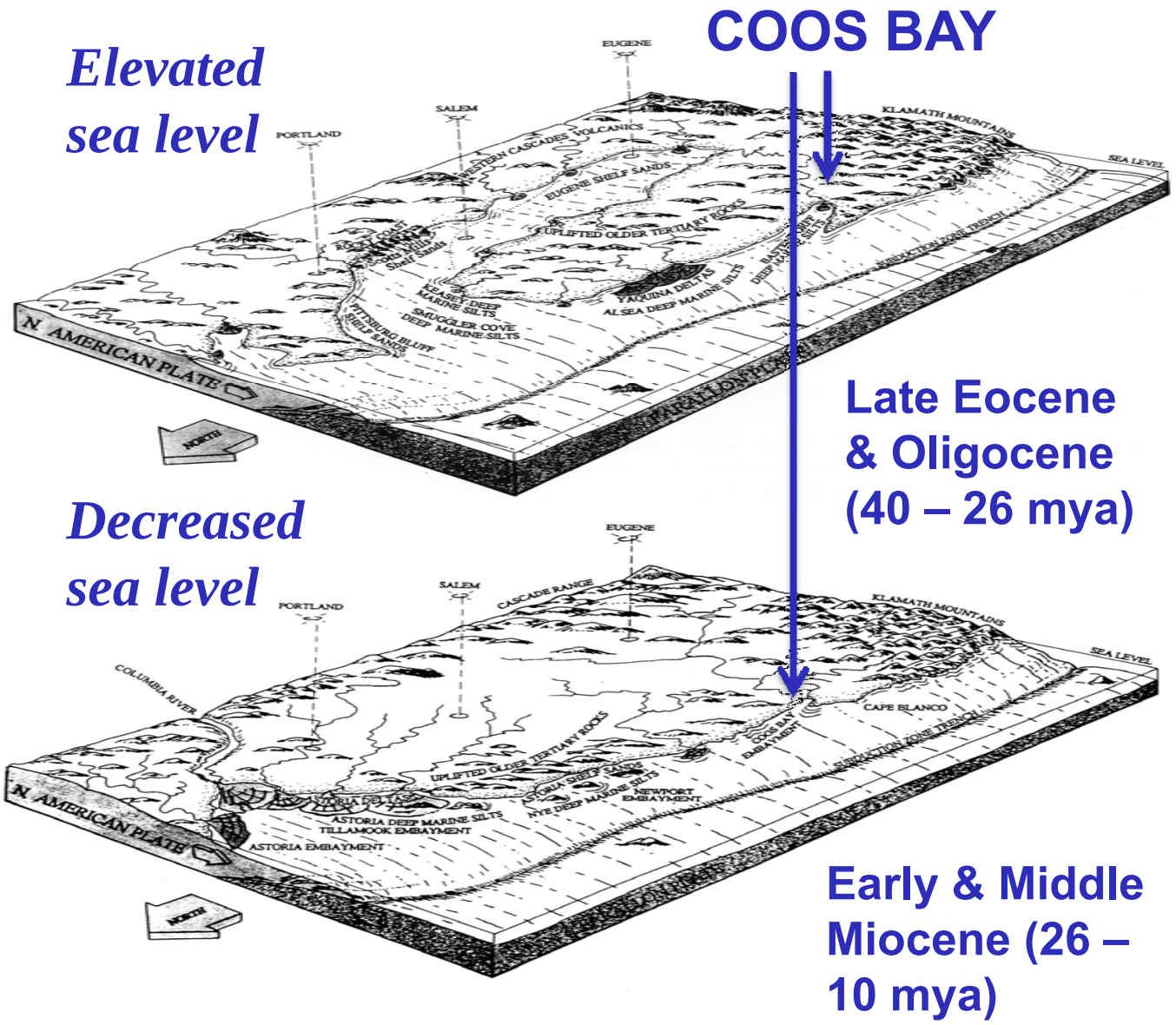


Holocene = warm, postglacial period characterized by glacial retreat and sea level rise

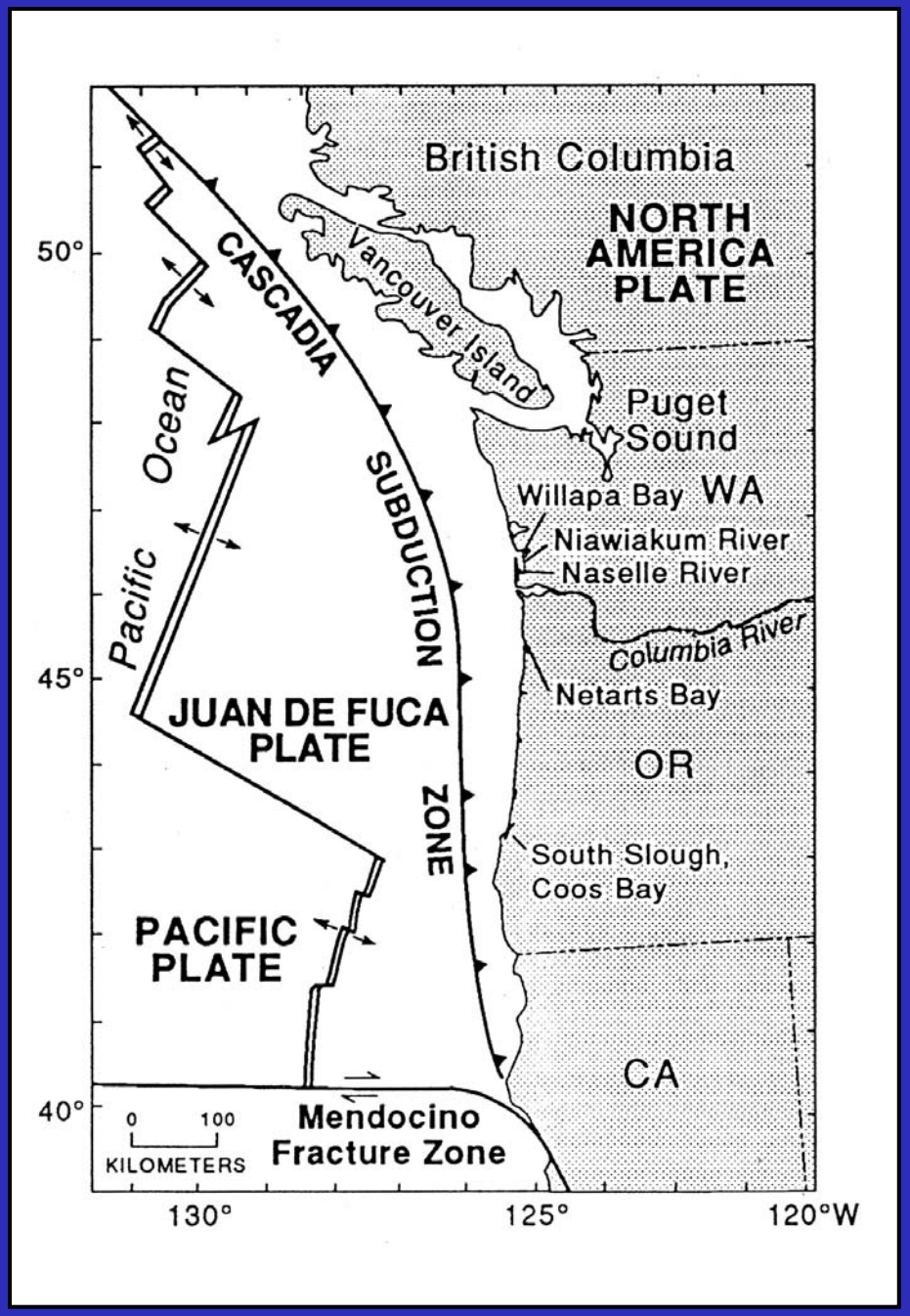
Tertiary Formation of Marine Sediments (65 – 2 mya)

Marine landscape of the Oregon shoreline in the Eocene and Oligocene (40-26 mya), and middle Miocene (26-10 mya).

Note deposition and formation of the Bastendorff shales and deep marine silts within the Coos Bay embayment.



Adapted from Orr and Orr, 1999

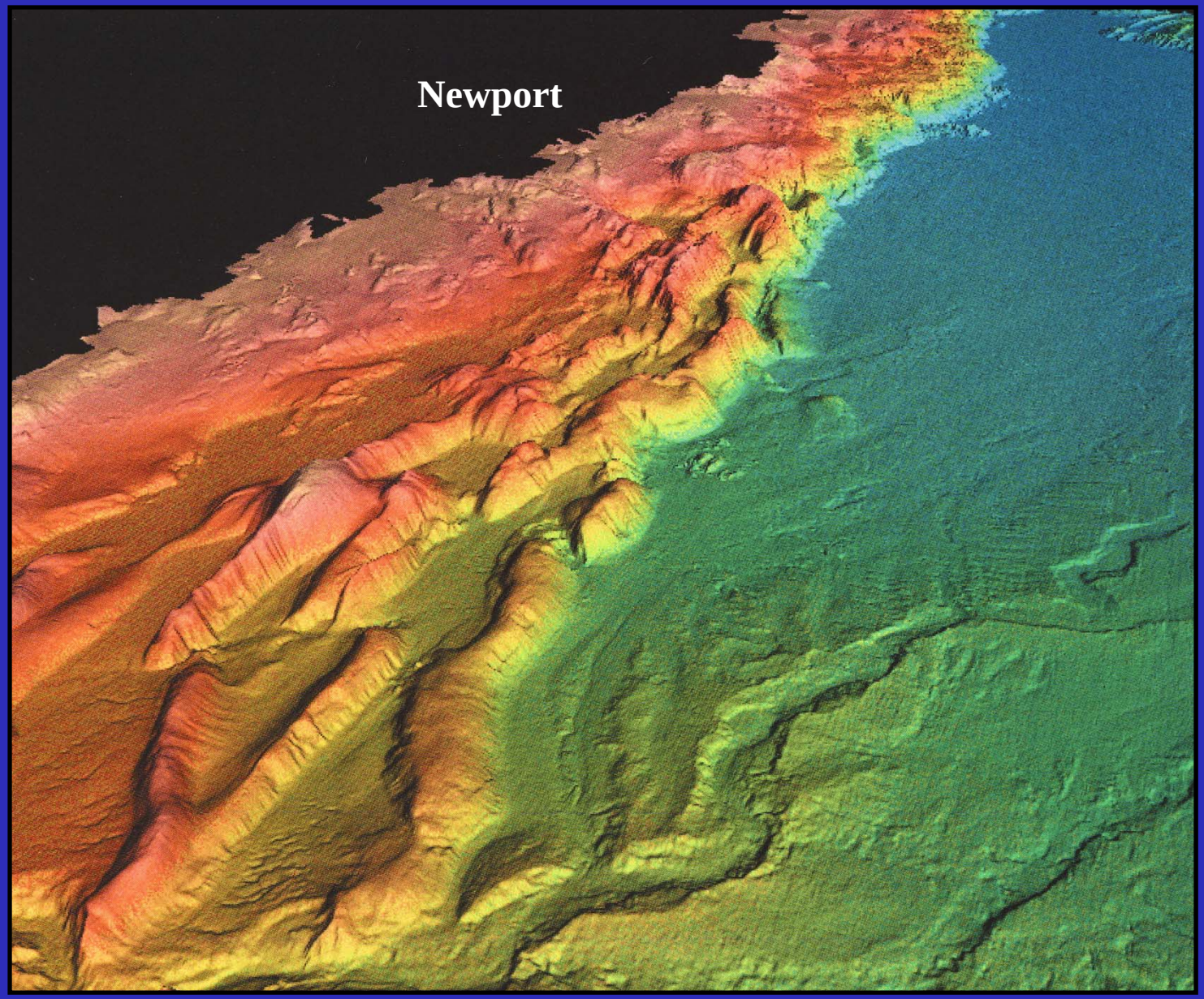


Geologic Process that Contribute to Formation of Estuaries:

Tectonic Movements of Coastal Plates along the Cascadia Subduction Zone

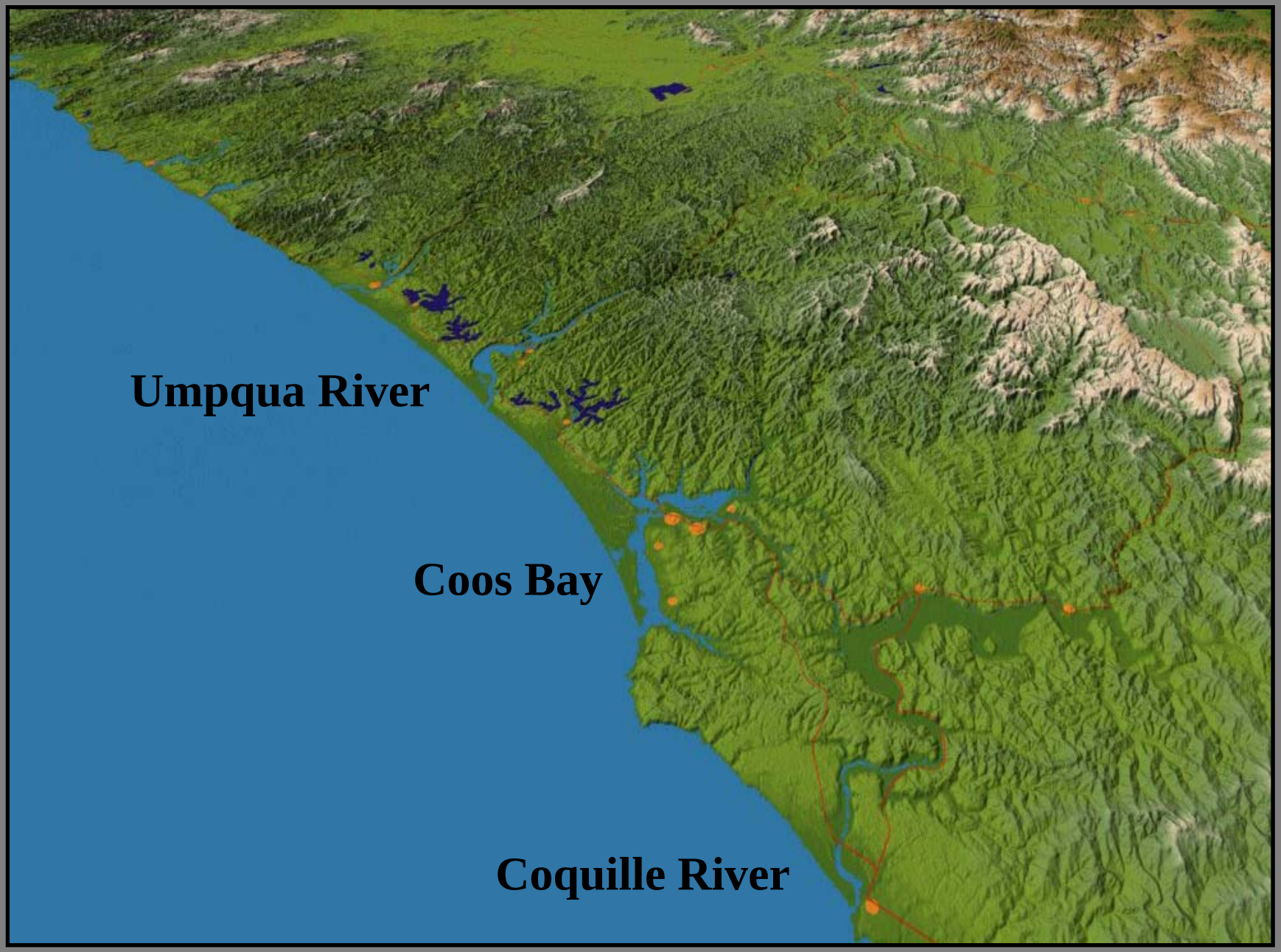
Lateral Displacement of the Juan de Fuca Plate results in Compression along the Oregon Continental Margin

OREGON CONTINENTAL MARGIN



Lateral techtonic compression creates pressure ridges, valleys, and coastal uplift

Drowned River Mouth Estuaries & Oregon Coast Range Mountains



Geologic Formation and Classification of Pacific Northwest Estuaries

PNW Estuaries formed in Late Pleistocene (28,000 to 15,000 years ago) and Holocene (15,000 to 10,000 years ago)

Drowned River Valley Estuaries:

- **Coos, Yaquina, Tillamook**

Lagoon / Bar-built Estuaries:

- **Netarts Bay, Sand Lake**

Fjord-type Estuaries:

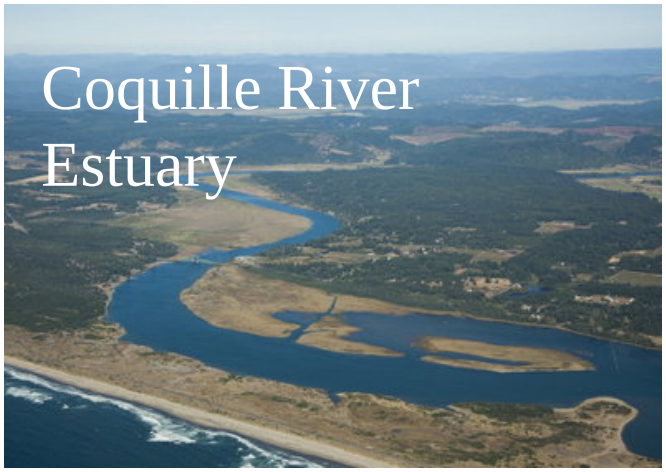
- **Hood Canal, Saanich Inlet**

Sounds:

- **Puget Sound, Barkley Sound**

Tectonic Estuaries:

- ***San Francisco Bay***
- ***Tomales Bay***



Coos Bay: A Pacific Northwest Drowned River Mouth Estuary

Digitial Elevation Model

North Bend

Coos Bay

Charleston

N
W
E
S

10 0 10 20 Kilometers

Coos Watershed

608 mi^2 / 158,645 ha

Coos Estuary

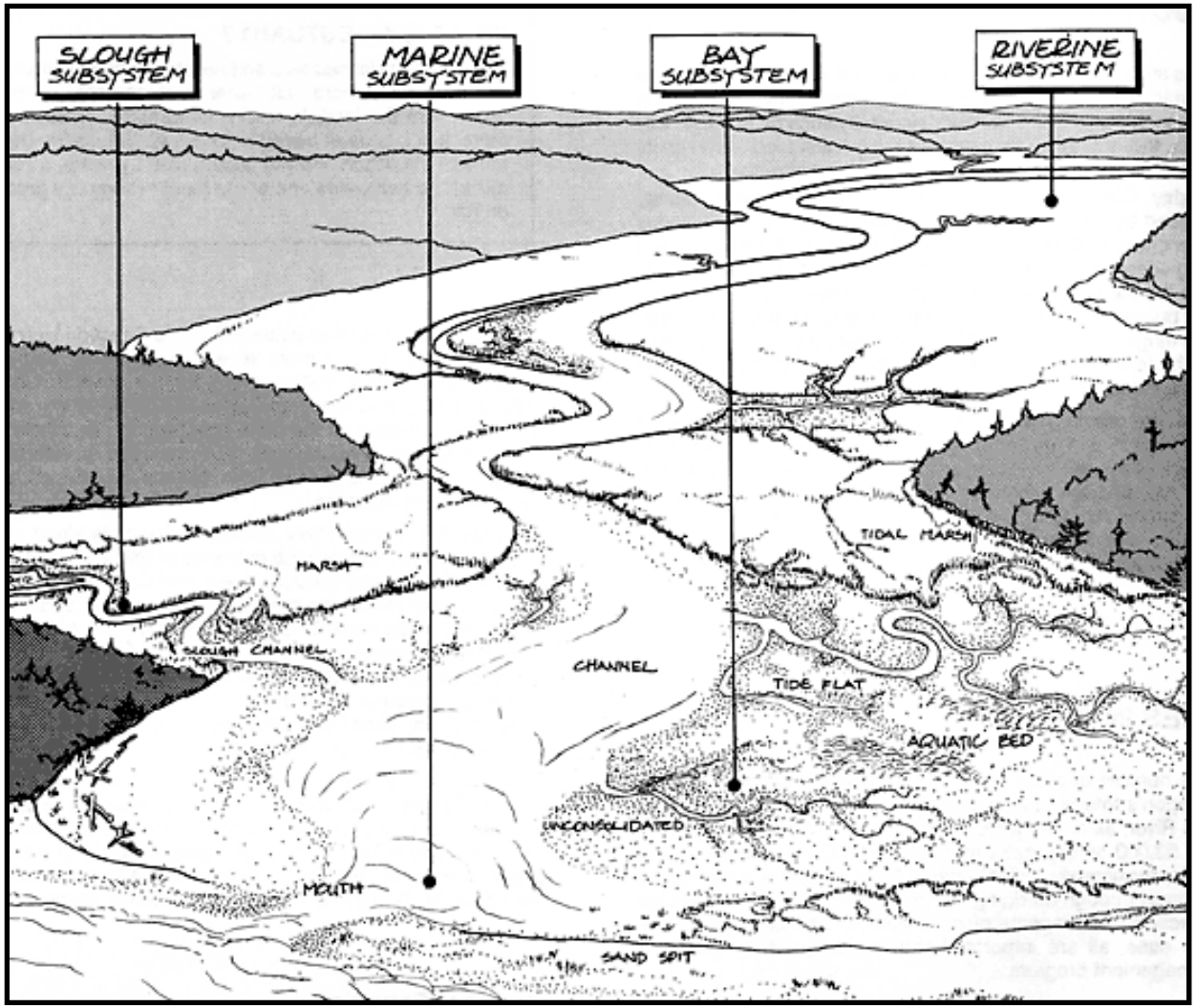
21 mi^2 / 5,010 ha

Rainfall

60 in yr^{-1}

110 in yr^{-1}

Classification / Estuarine Sub-systems:



MARINE:

open area dominated by ocean water and winds

BAY:

open area with SW/FW mixing and winds

SLOUGH:

elongated tidal inlet

RIVERINE:

elongated area characterized by FW inputs from river, creek, or FW stream

Physical Characteristics of Pacific Northwest Estuaries

Transition zone between fresh-water and salt water

Marine characteristics:

- **Brackish water (SW)**
- **Tides (semi-diurnal)**
- **Waves (tsunami influence)**
- **Marine nutrients & sediments**

Riverine characteristics:

- **Freshwater discharges (FW)**
- **Precipitation & groundwater**
- **Terrestrial nutrients & OM**
- **Sediment transport**

South Slough / Coos Bay Estuary

COOS ESTUARY, OREGON: Essential Facts & Figures

Typically well-mixed water column:

(partially stratified in winter)

Sediment inputs: 1.6 million yd^3 yr^{-1}

Wet surface area:

5,010 ha

Tidal prism volume:

765 million m^3

Tidal range:

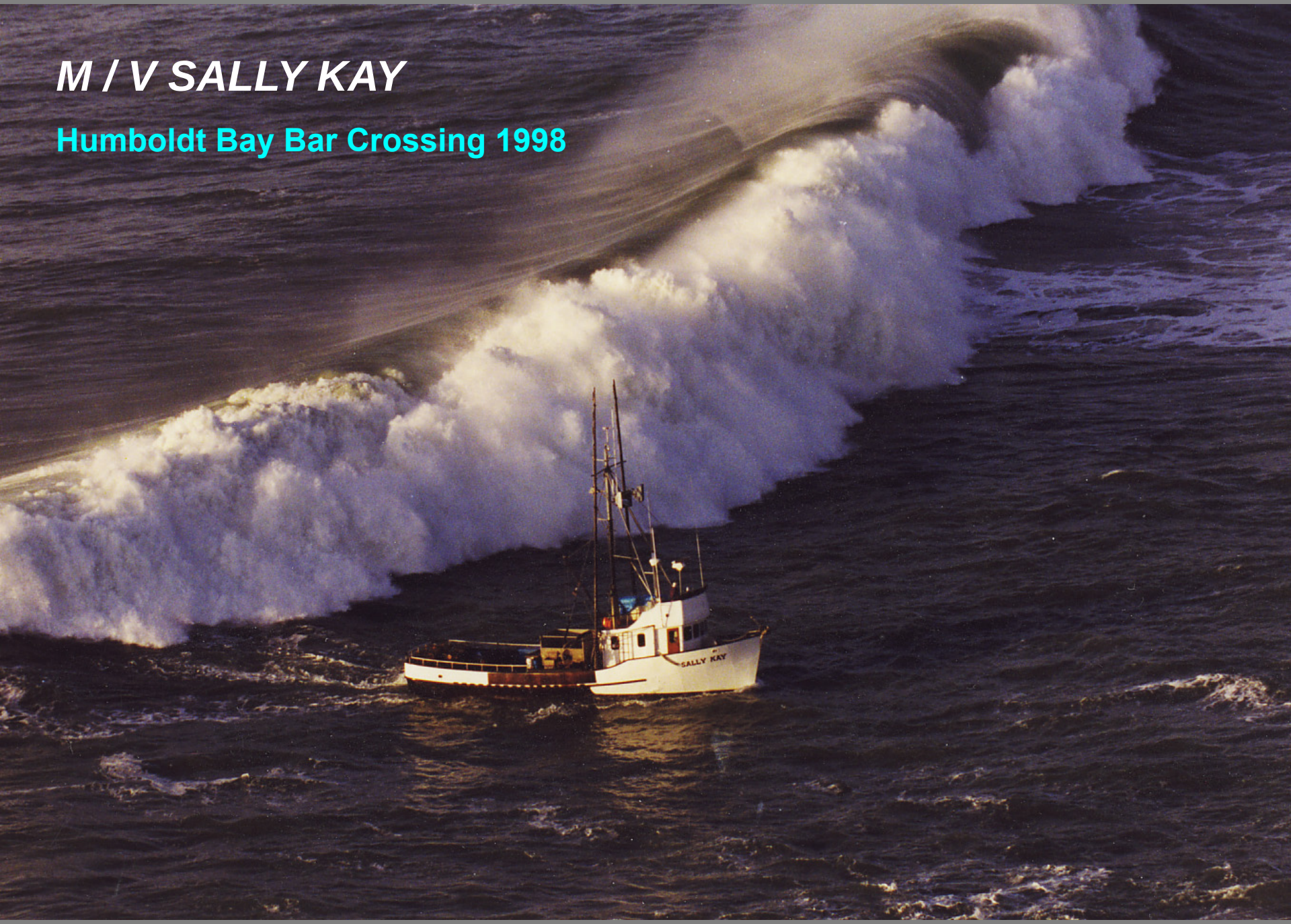
+3.3 m to -0.9 m

Navigation channel:

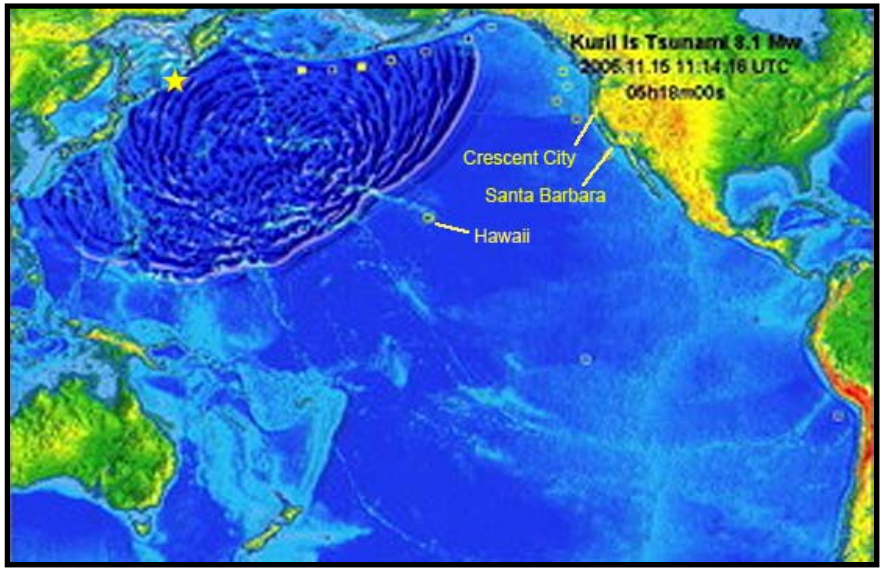
10-15 m / 40-45 ft

Tidal currents:

1.1 to 1.7 ms^{-1}

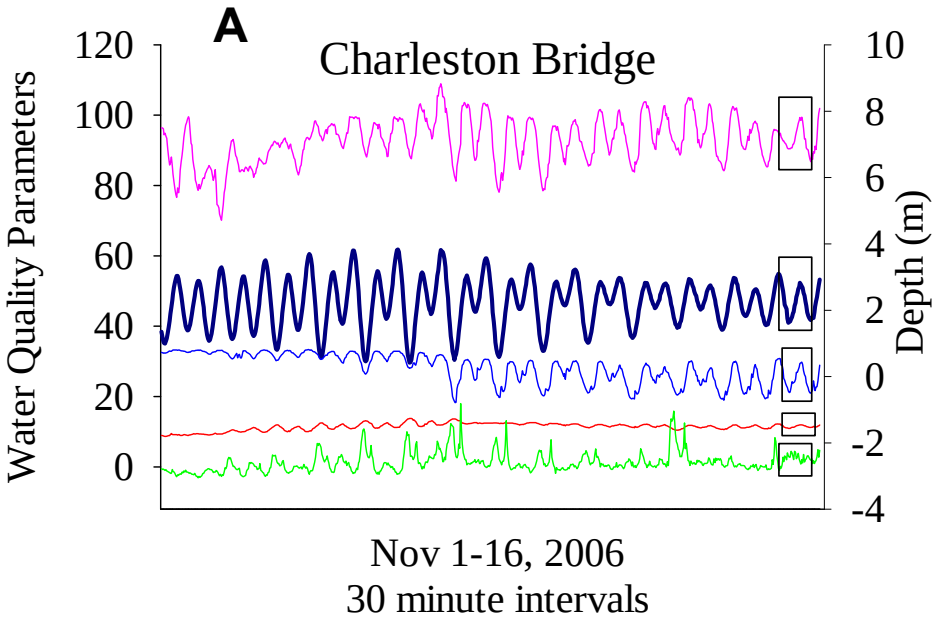

M / V SALLY KAY
Humboldt Bay Bar Crossing 1998
SALLY KAY

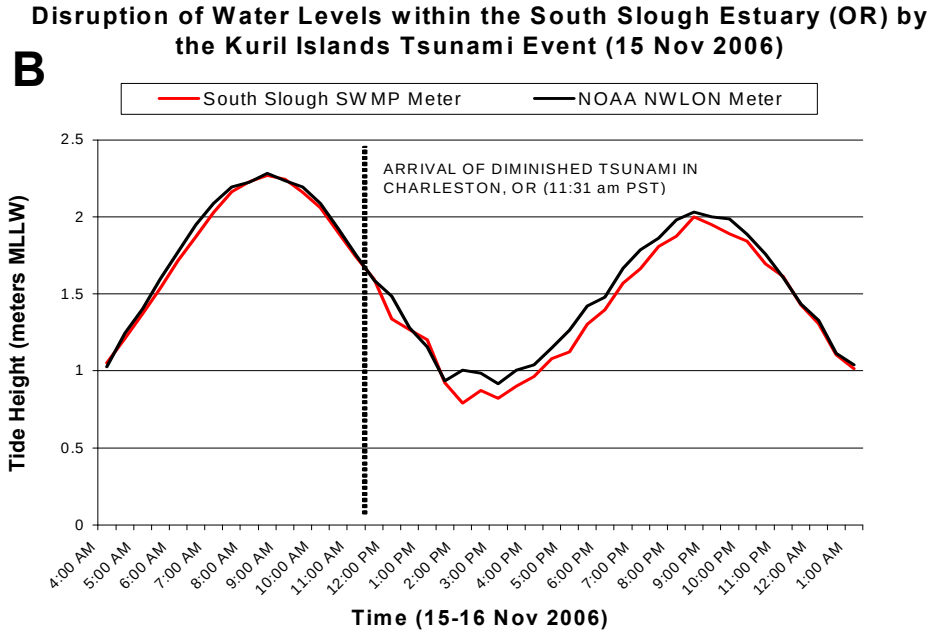
Kuril Islands Tsunami (15 Nov 2006)



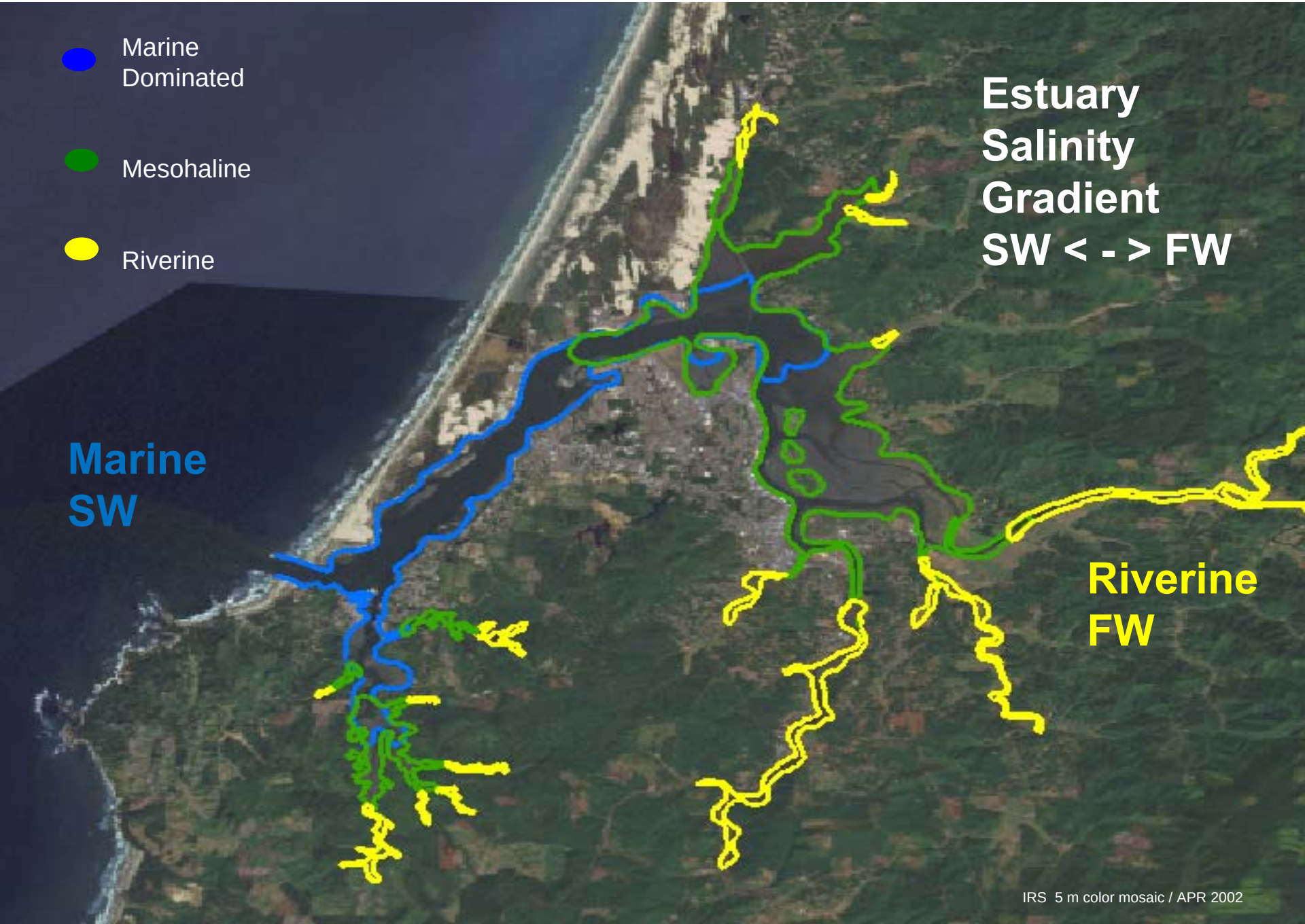
A. Time-series measurements of water quality parameters (dissolved oxygen, depth, salinity, temperature, turbidity) at the Charleston SWMP station, South Slough, OR. Boxes identify time period for detection of the small-scale tsunami event in South Slough.

B. Localized disruption of water levels in South Slough

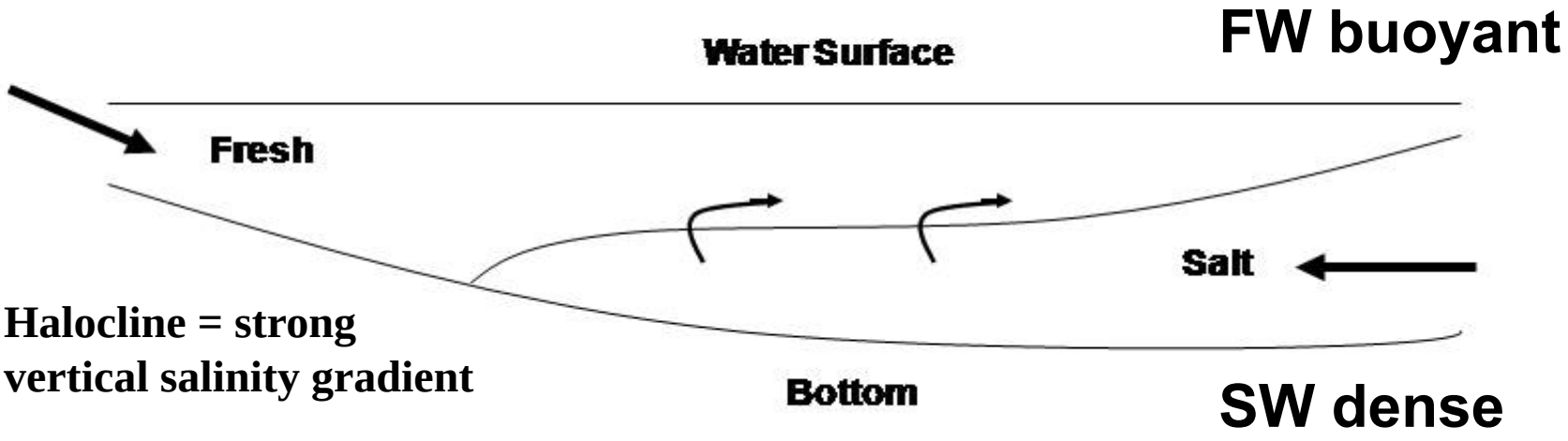


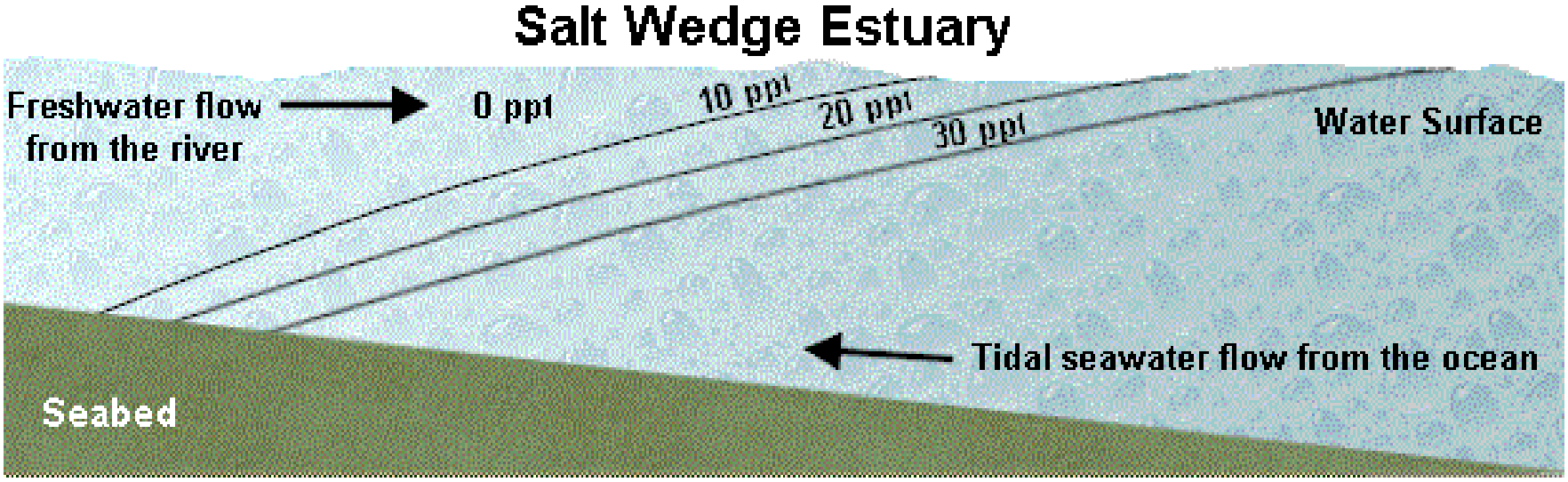


COOS ESTUARY, OR Spatial Extent and Location of Hydrologic Regions



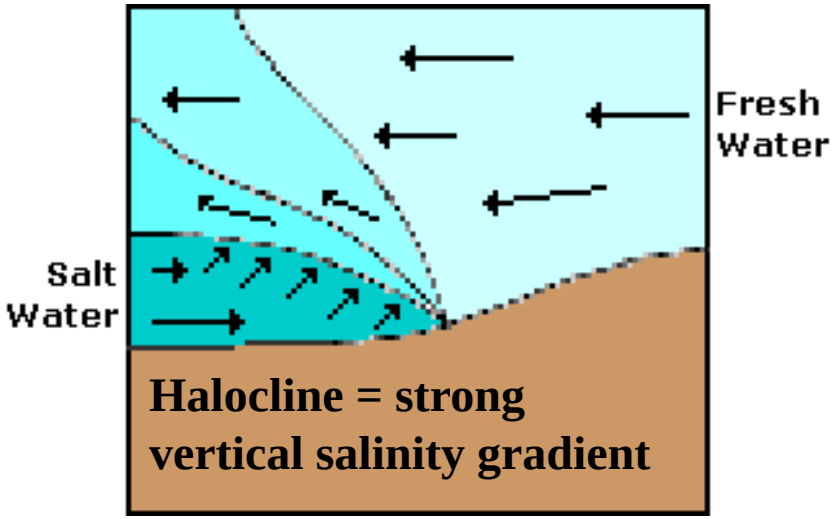
Physical Characteristics / Estuarine Salinity Wedge:

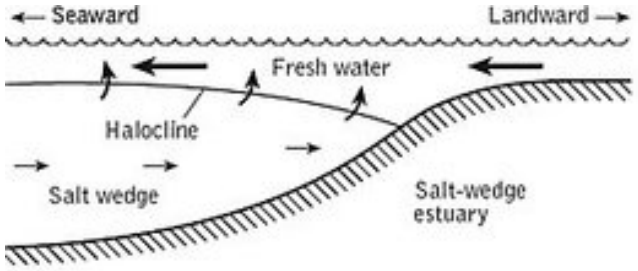




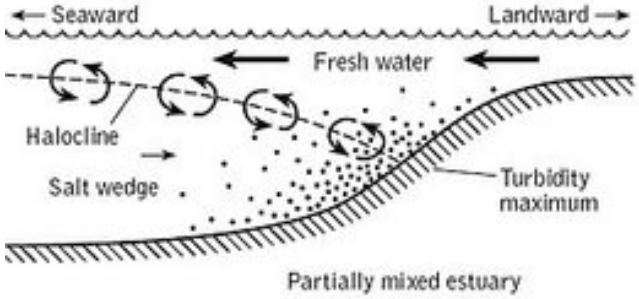
Physical Characteristics / Estuarine Mixing Types:

Salt Wedge Estuary / Stratified

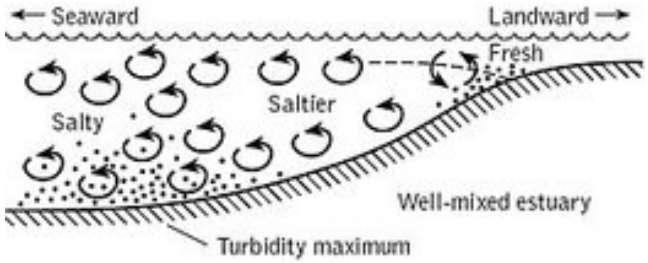


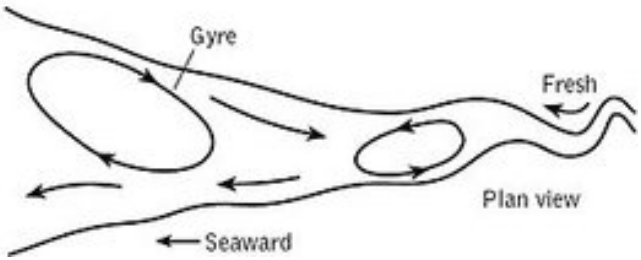


Partially-mixed Estuary

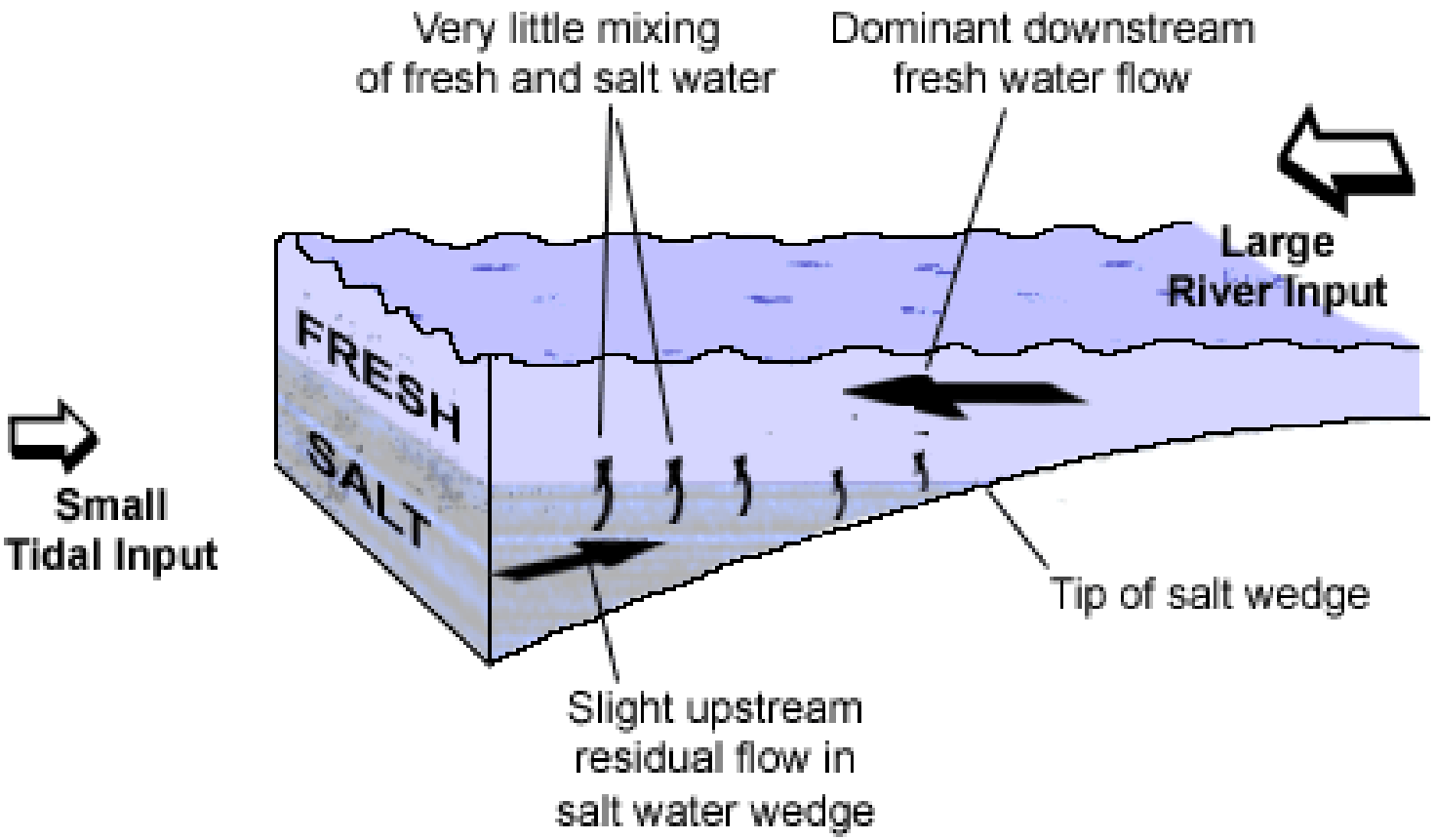


Well-mixed Estuary / Not Stratified



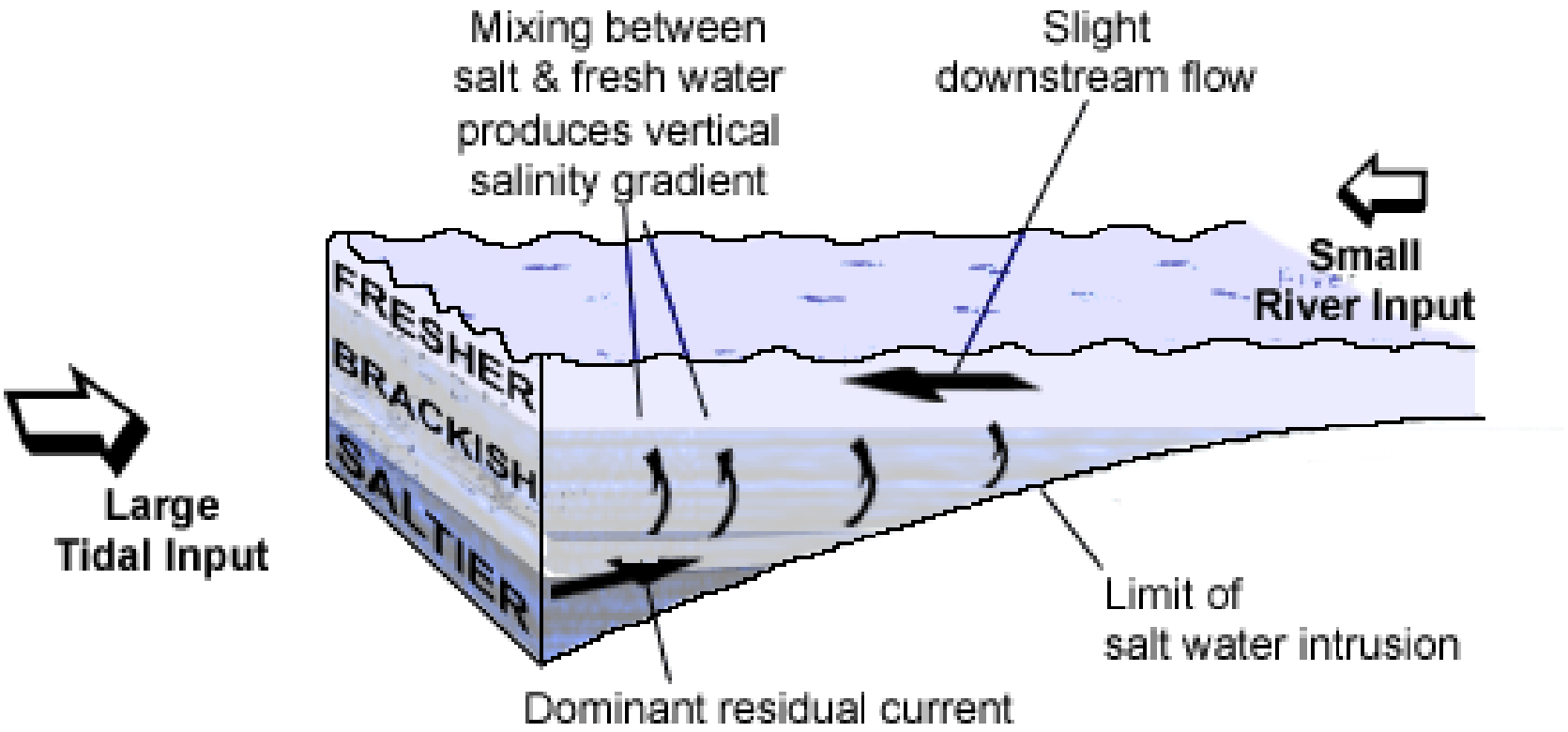


Buoyancy Mixing in Estuaries:



A Salt Wedge Estuary

Buoyancy Mixing in Estuaries:



A Partially Mixed Estuary

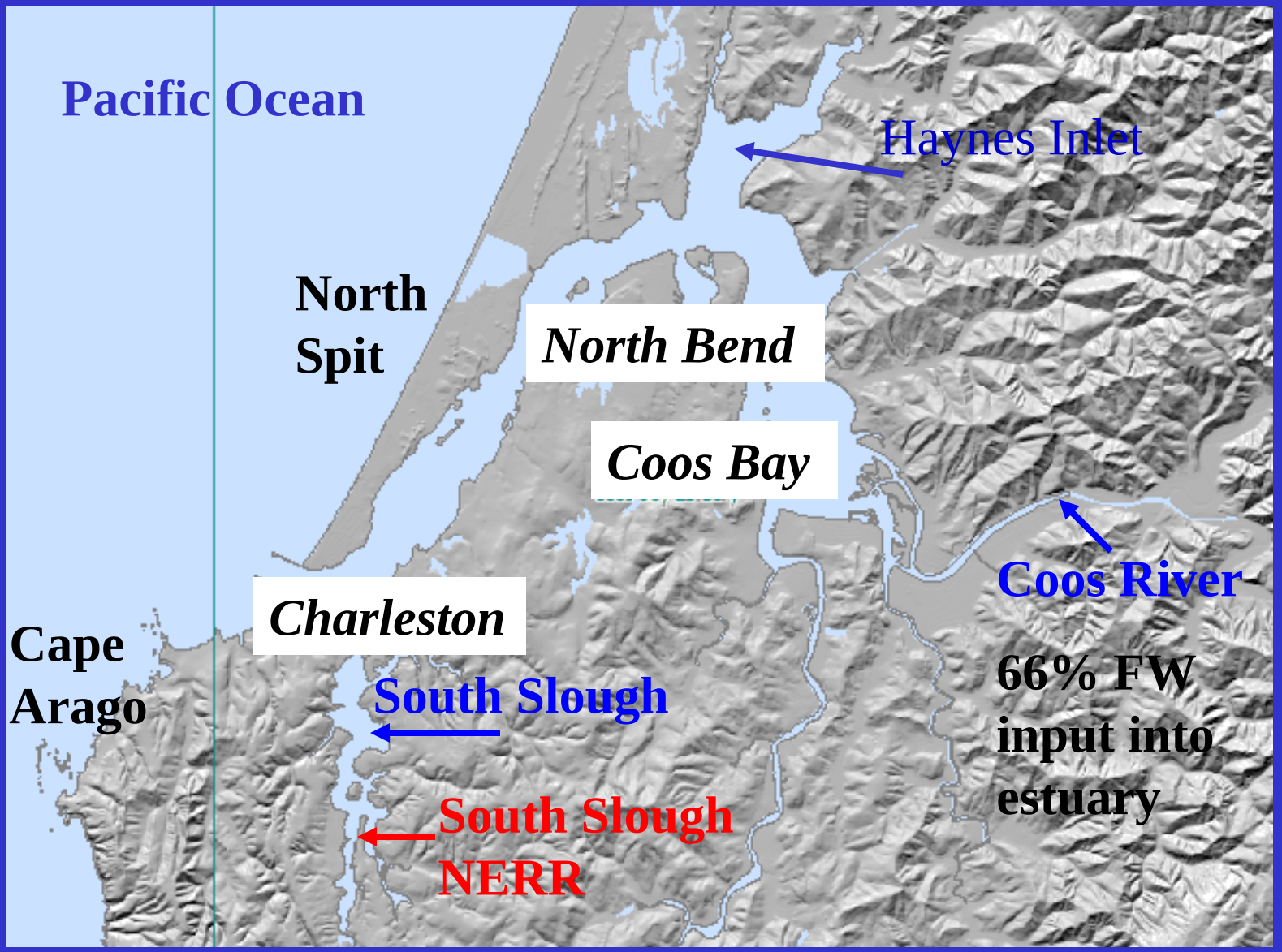
Water Balance in Estuaries:

Positive Estuary:
Combined freshwater input from rivers, streams, groundwater, and rainfall exceeds evaporation

Neutral Estuary:
Balance between freshwater input and evaporation

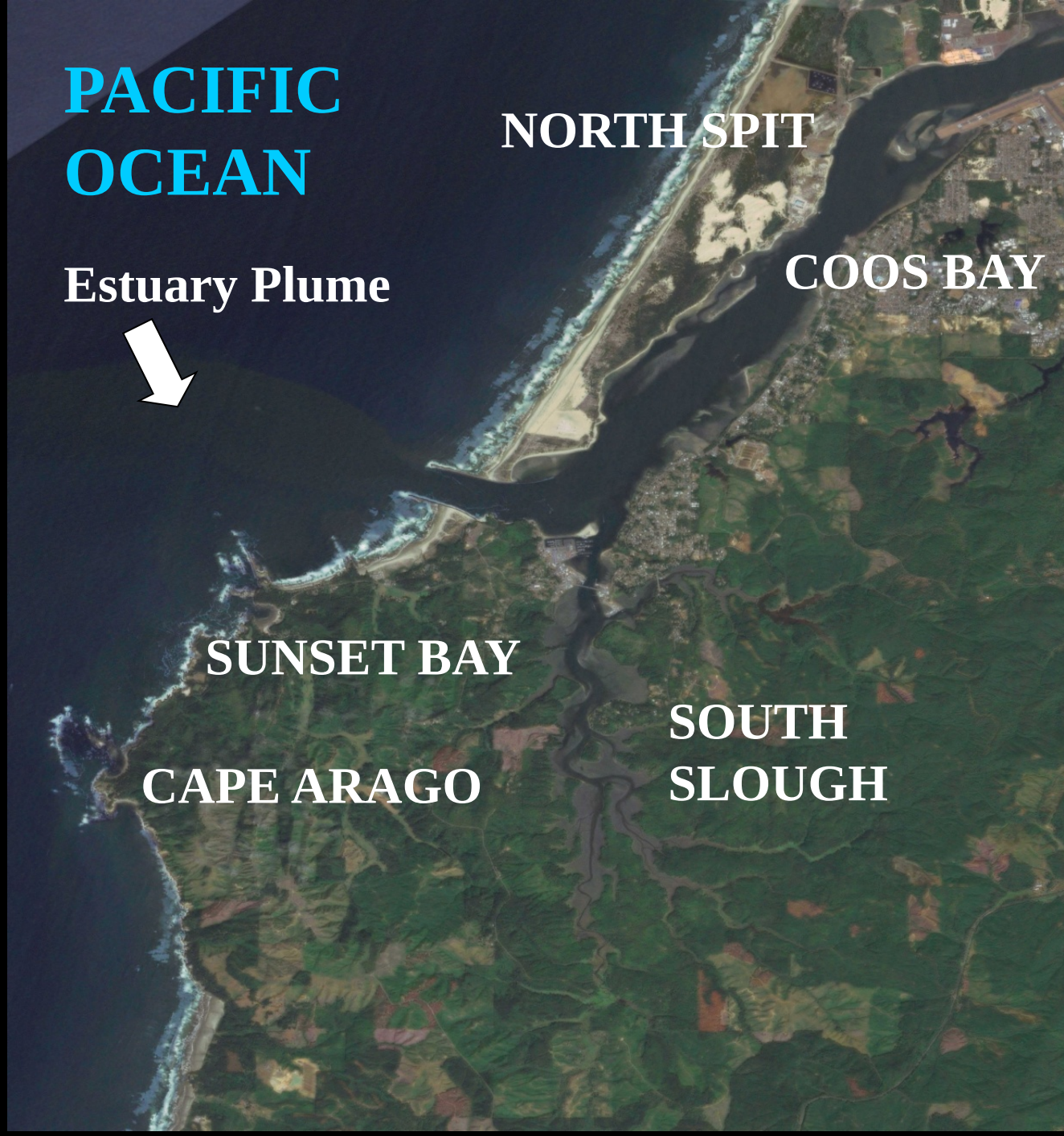
Negative Estuary:
Evaporation exceeds freshwater input (arid areas)

COOS ESTUARY: Fresh Water Inputs into the Tidal Basin



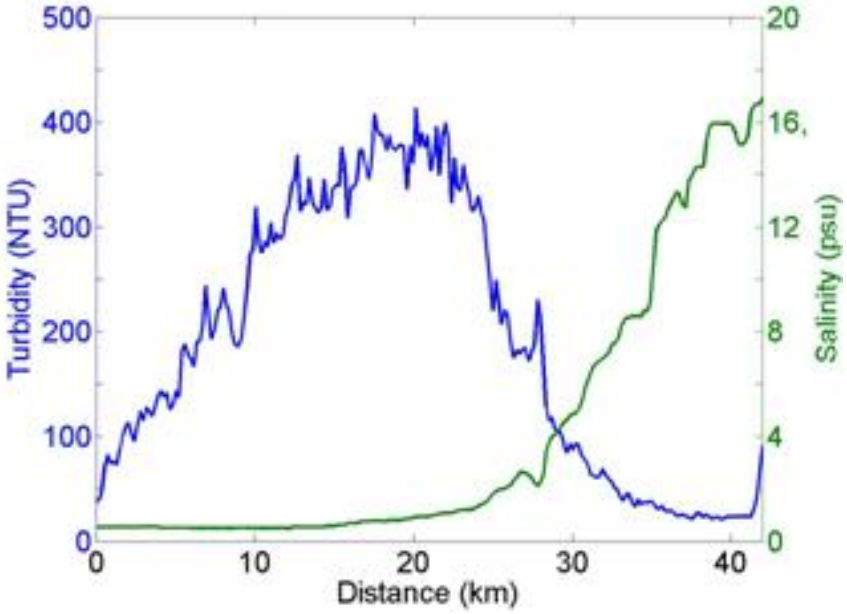
Coos Bay:

Linked Ocean, Estuary, and Watershed Ecosystem



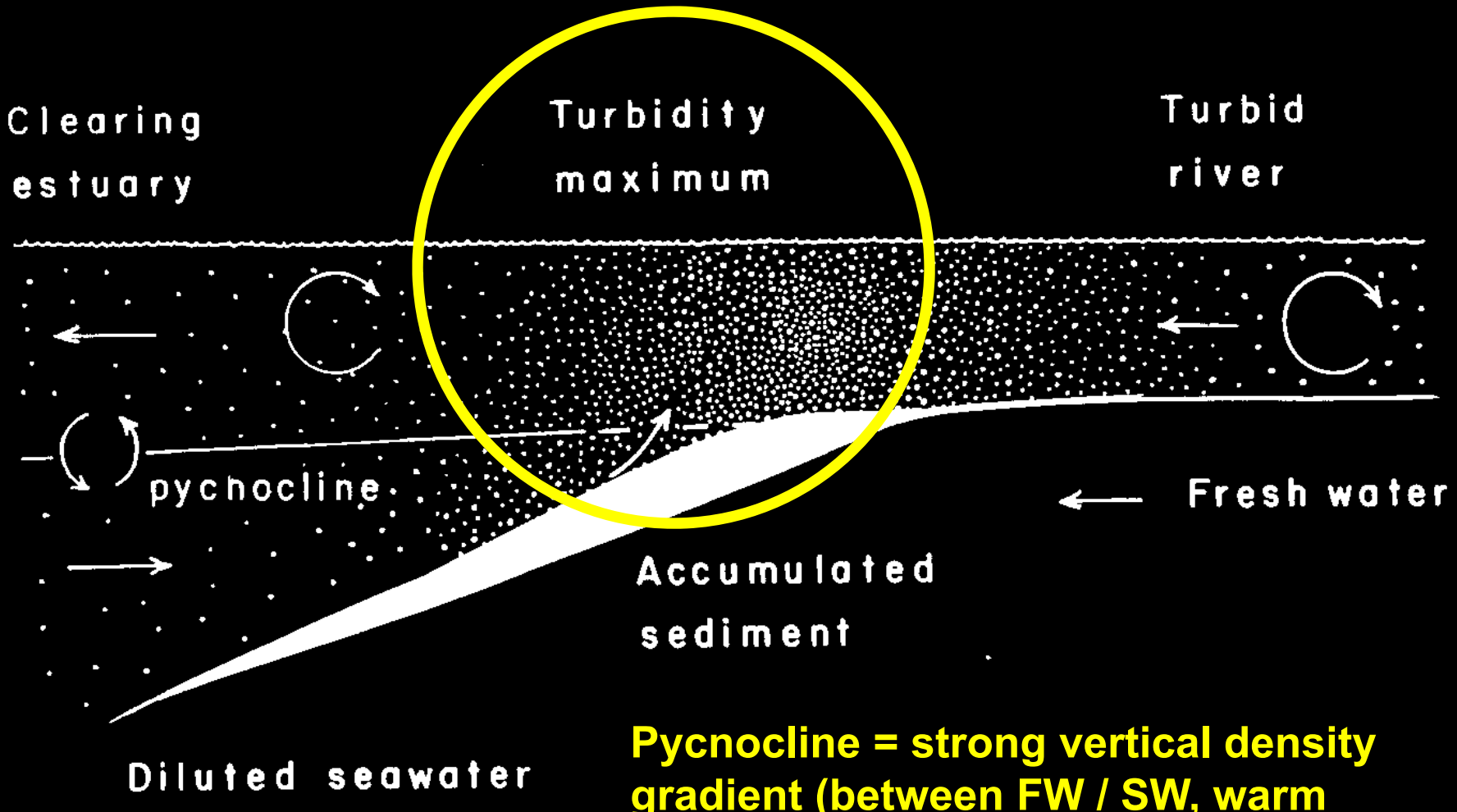
Estuarine Sediment Transport / Turbidity Maximum Zone:

Sediment is transported into estuary by creeks and streams



Estuarine Turbidity Maximum zone is formed in mid estuary

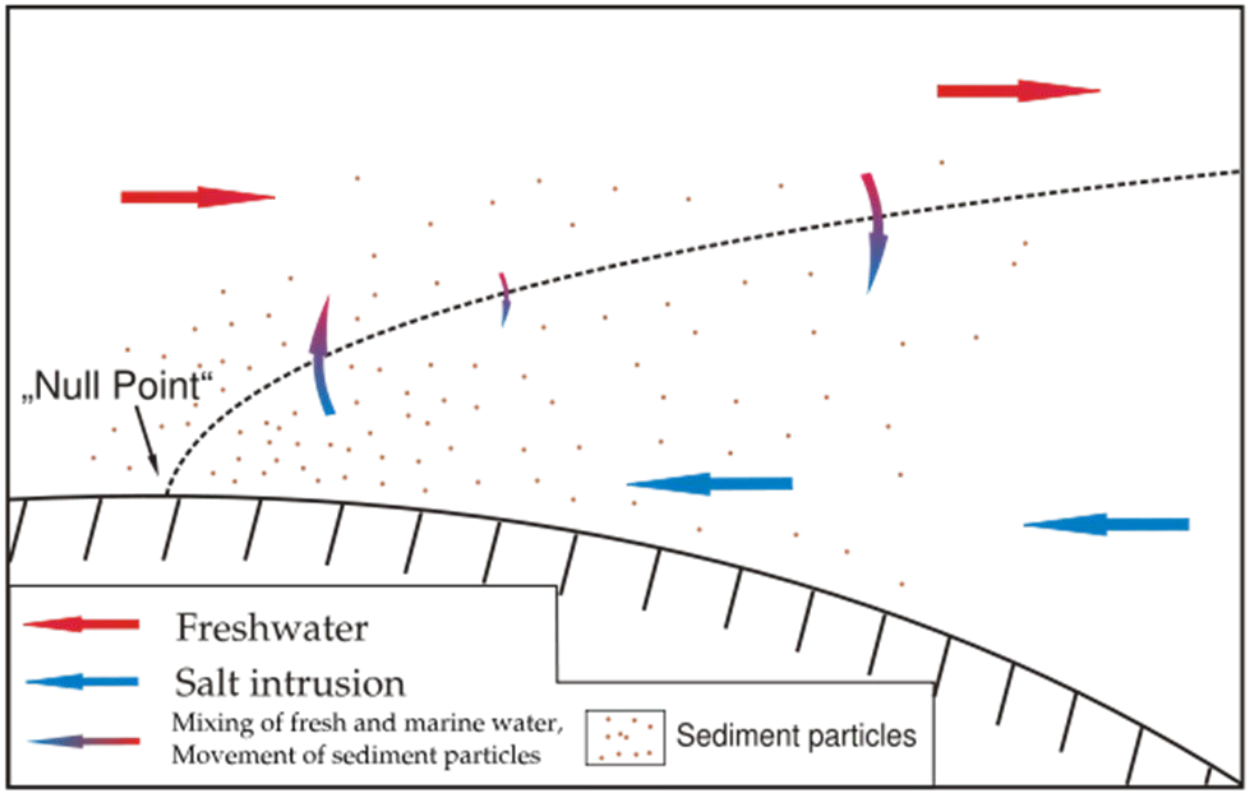
Formation of Estuarine Turbidity Maximum:



Pycnocline = strong vertical density gradient (between FW / SW, warm surface / cold deep water, etc.)

Formation of Estuarine Turbidity Maximum:

The formation of a turbidity maximum by the vertical gravitational circulation in a partially mixed estuary



Suspended sediments accumulate at “Null Point” in estuary where outflow of buoyant freshwater is balanced by inflow of dense seawater

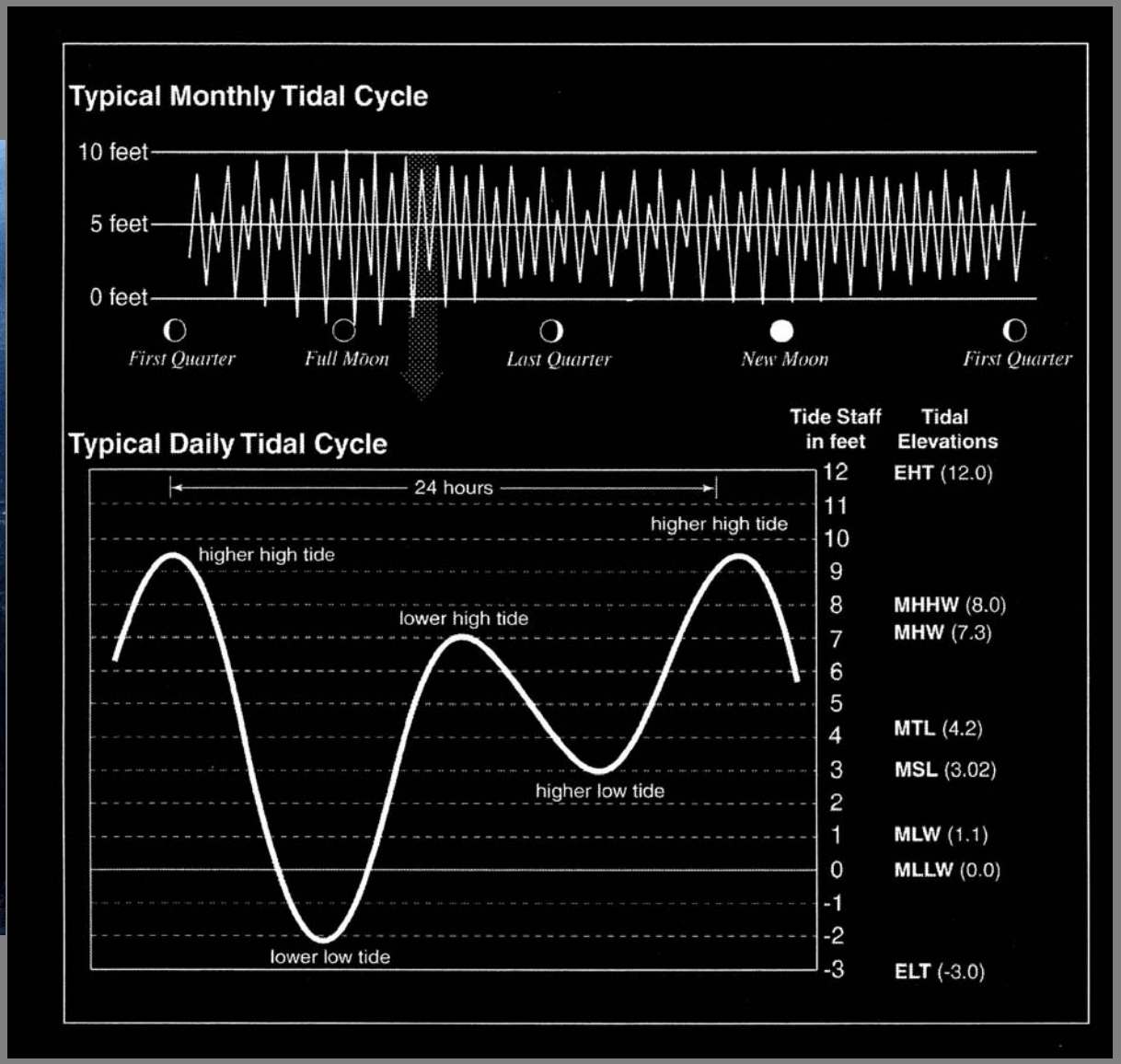
Semi-Diurnal Tidal Cycle within the Coos Estuary & South Slough

SOUTH SLOUGH:

Wet Surface Area = 783 ha

Estimated Tidal Prism:

9.34 million m^3



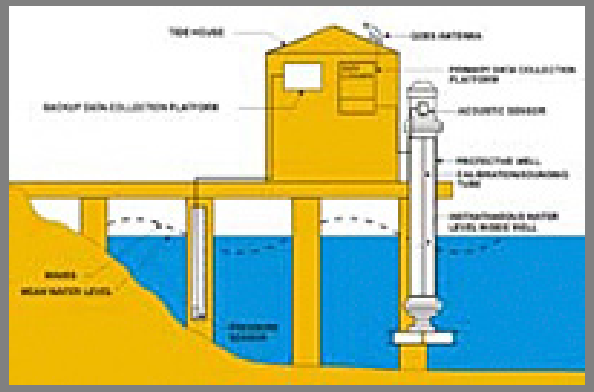
NOAA / National Water-Level Observational Network:

REAL-TIME MEASUREMENT OF TIDAL ELEVATION

GOES:
Geostationary
Operational
Environmental
Satellite

Telemetry
Antenna &
Solar Panel

Acoustic
Pinger Water
Level Gauge



NOAA / National Water-Level Observational Network:

REAL-TIME MEASUREMENT OF TIDAL ELEVATION

Real-time, Predicted, and Historic Tides are Available On-line:

Water-levels

Winds

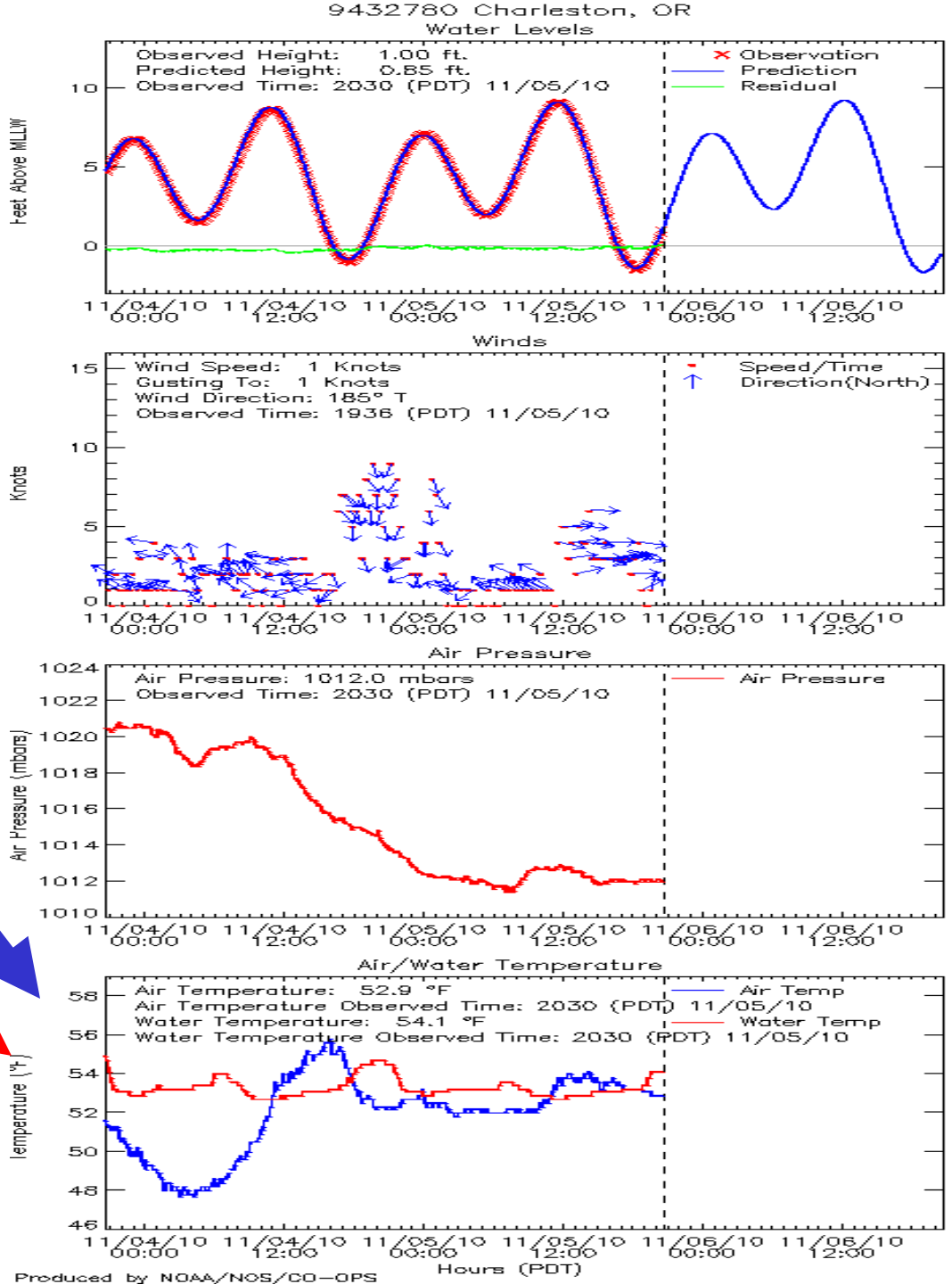
Air Pressure

Air Temperature /

Water Temperature

TidesOnline

www.tidesonline.nos.noaa.gov



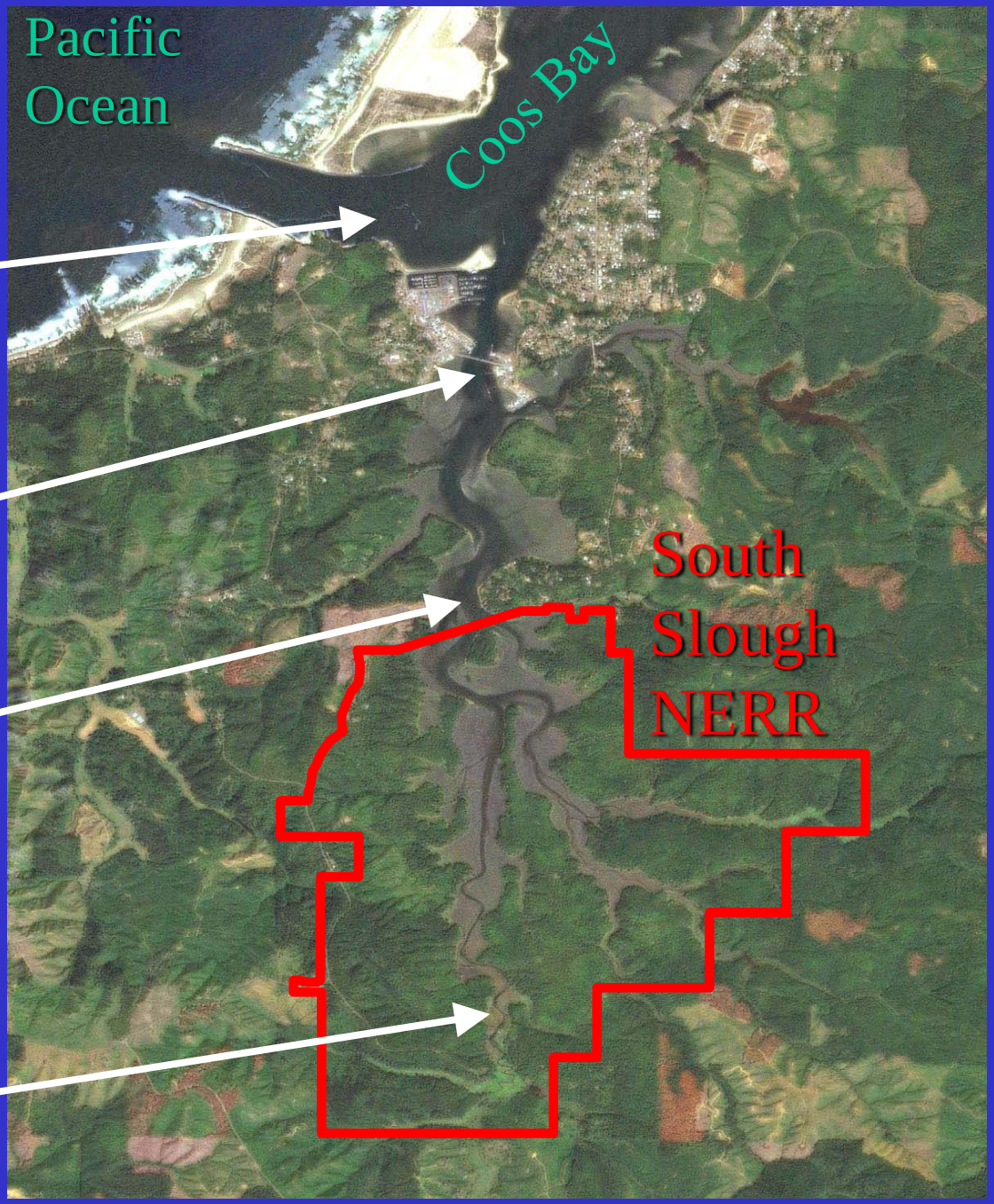
South Slough Estuarine Gradient

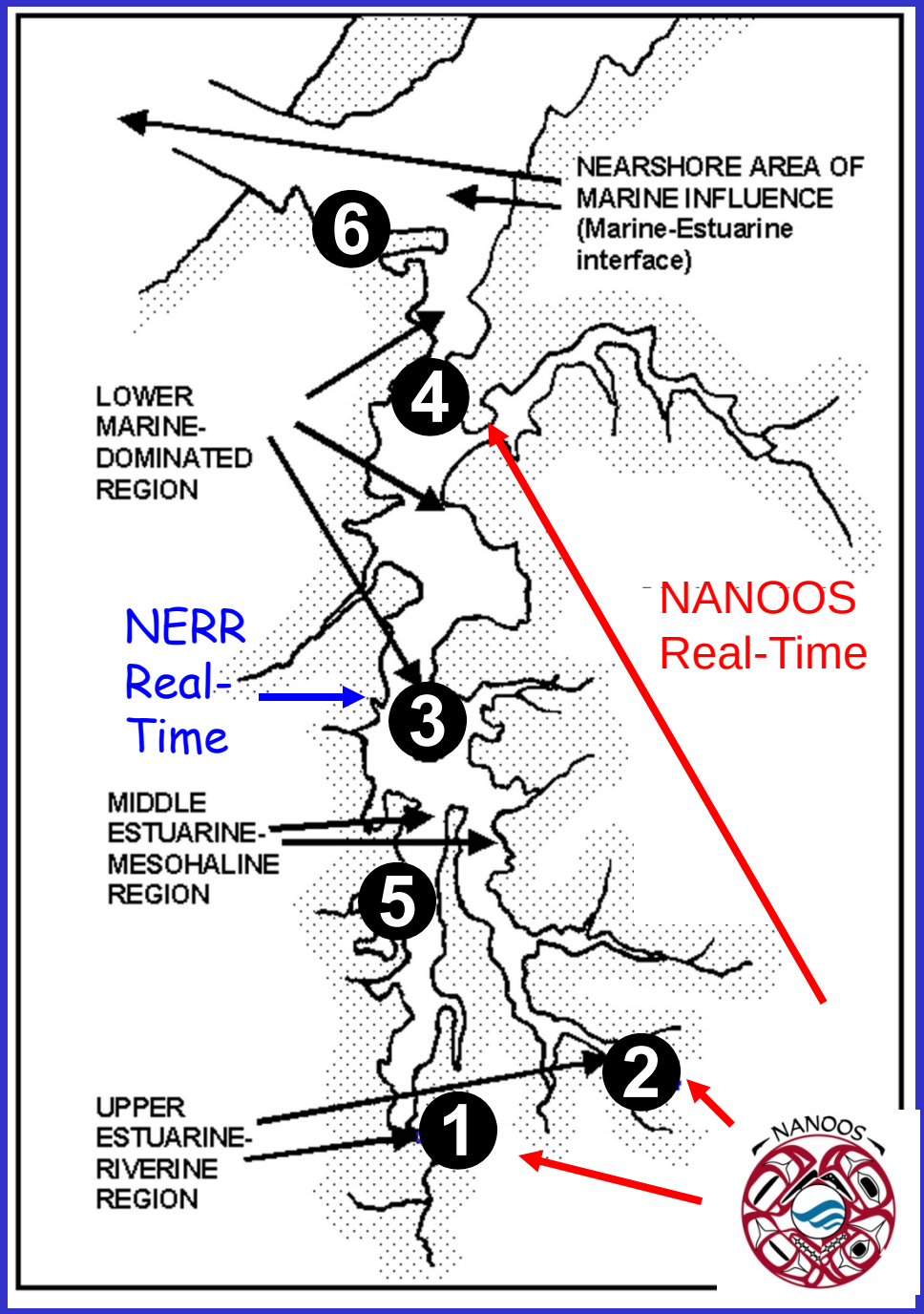
MARINE / BAY
Boathouse

MARINE DOMINATED
Charleston

MESOHALINE
Valino Island

RIVERINE
Winchester Creek





South Slough NERR SWMP Monitoring Sites

Estuarine Water Parameters / Datasondes

1 – Winchester Arm
2 – Sengstacken Arm
3 – Valino Island
4 – Charleston Bridge
5 – Sloughside Pilings (temp)
6 – OIMB Boathouse (future)

Meteorological Station

6 – OIMB / ECOS Lab

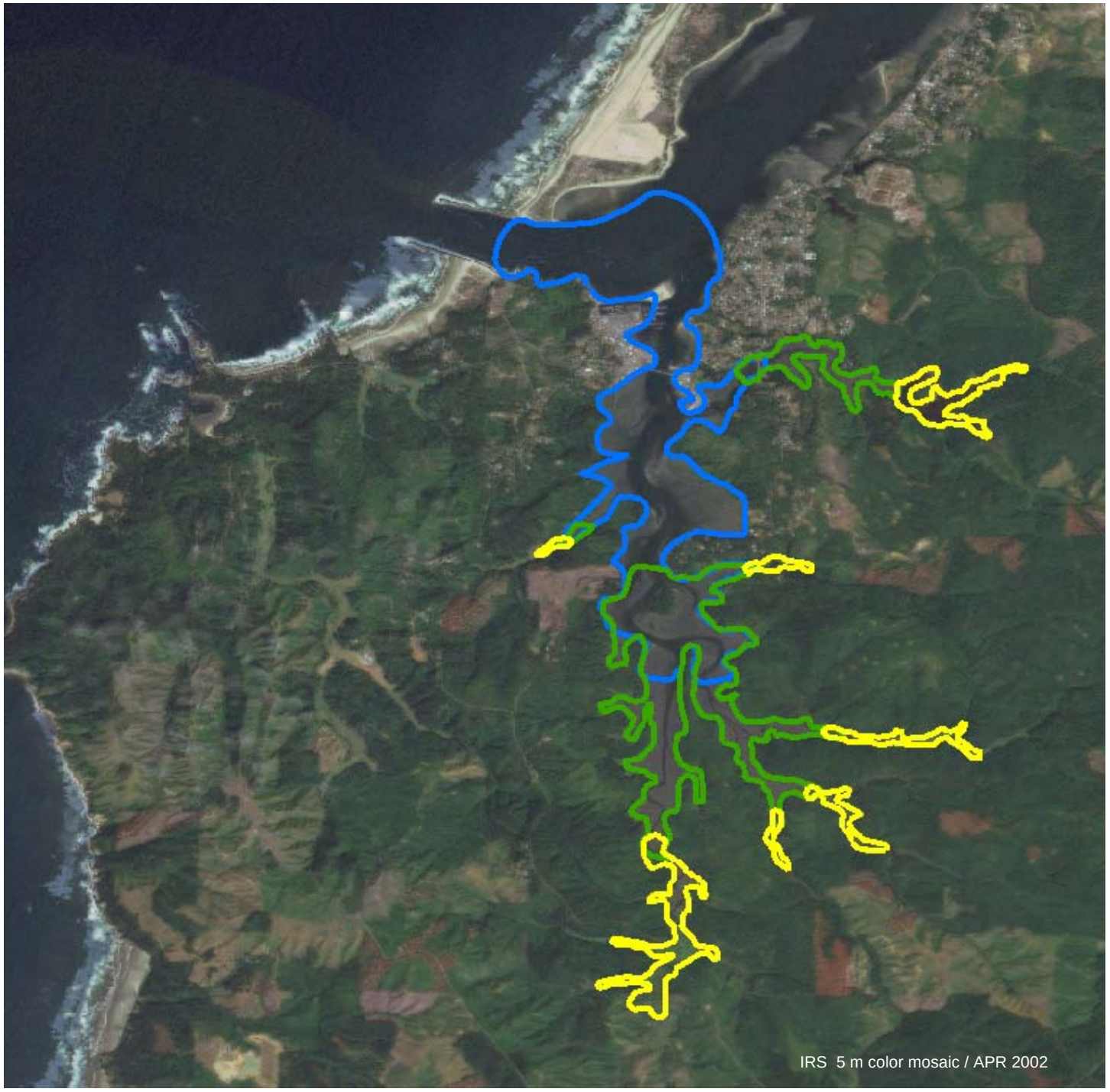
Estuarine Nutrients

Automated Sampler:
4 – Charleston Bridge

Van Dorn Samples:
1 – Winchester Arm
3 – Valino Island
4 – Charleston Bridge
6 – OIMB Boathouse

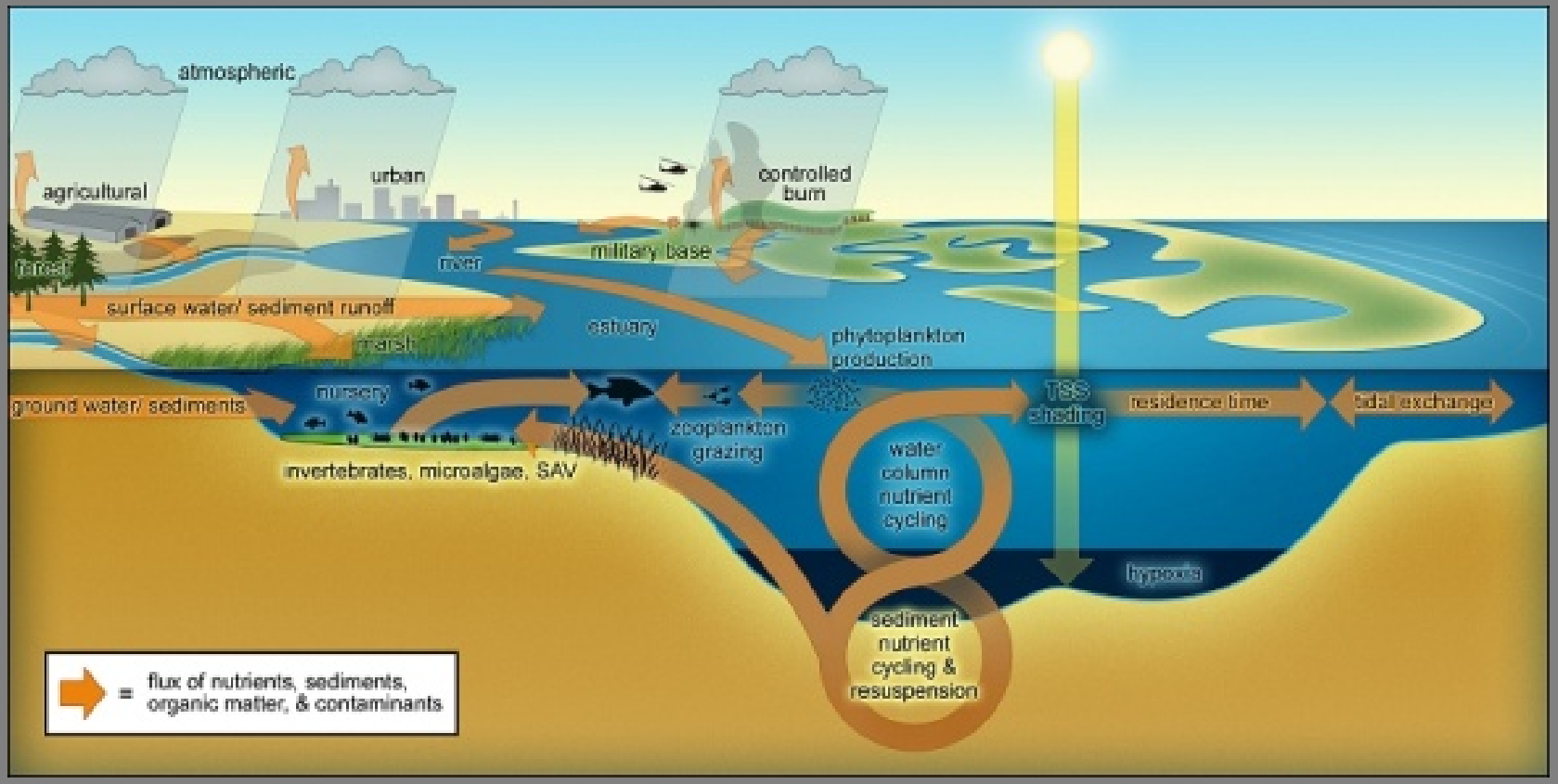
SOUTH SLOUGH ESTUARY, OR

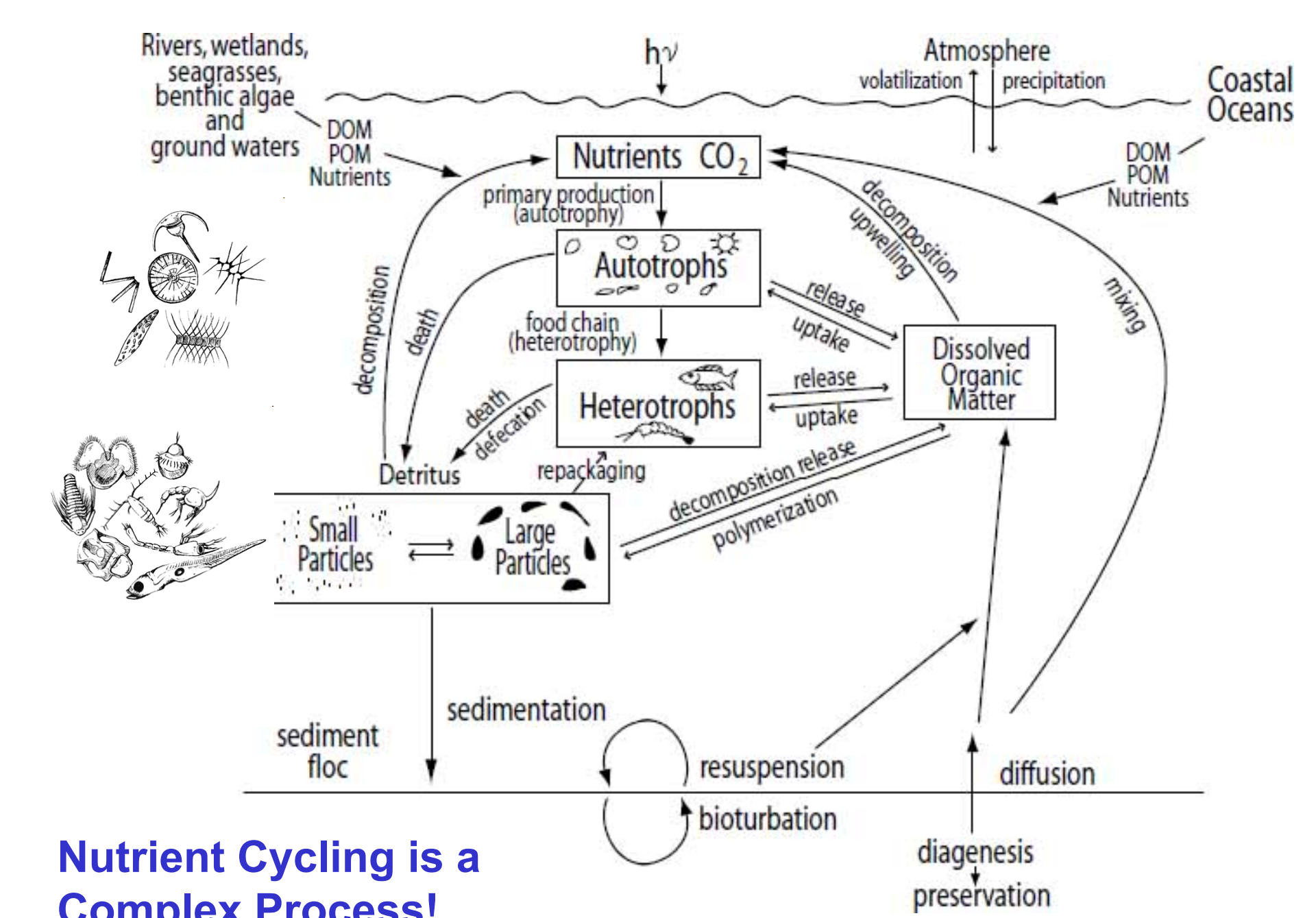
Location and spatial extent of three distinct hydrographic regions located along the estuarine gradient of the South Slough



Biogeochemistry and Nutrient Cycling in Estuaries:

- Sediments, nutrients, and organic materials flux through the estuarine system
- Biochemical processes recycle and transform nutrients and organic compounds during residence time and transport

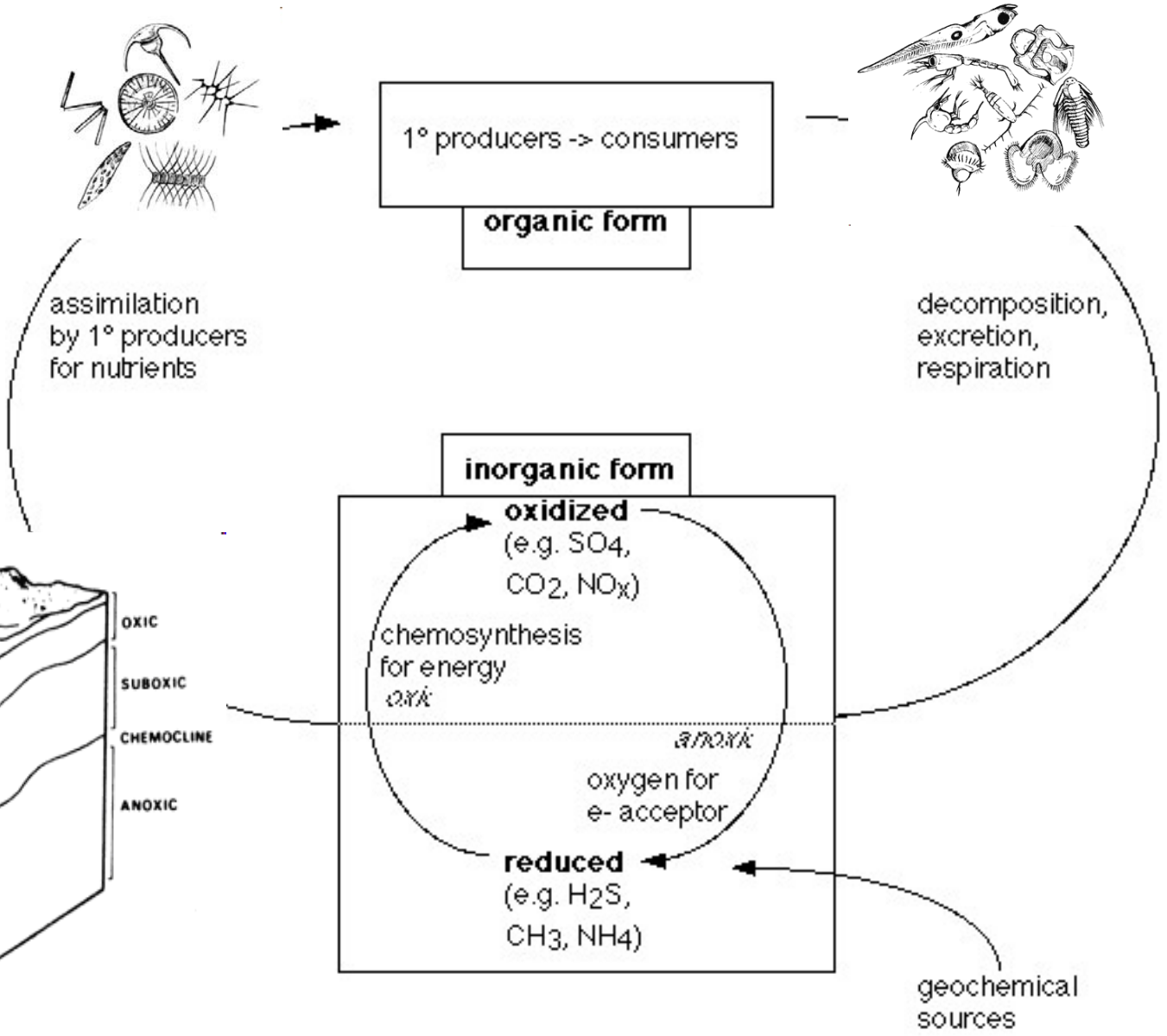


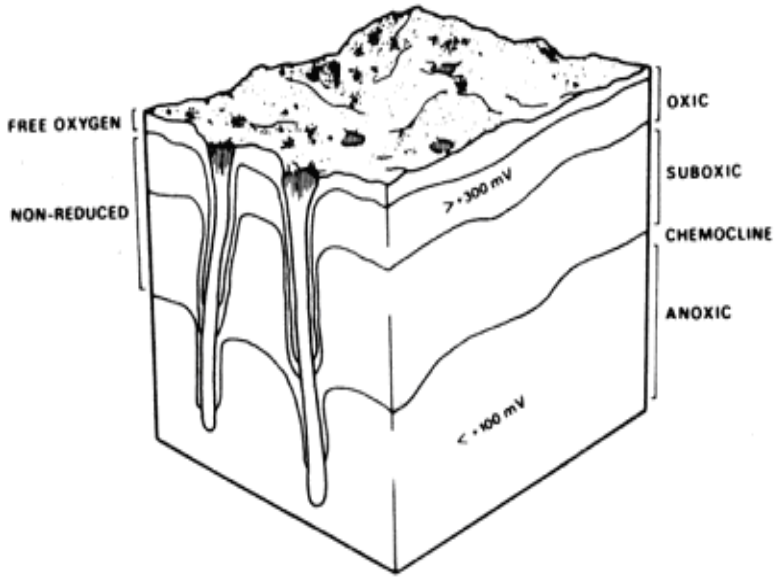


Nutrient Cycling is a Complex Process!

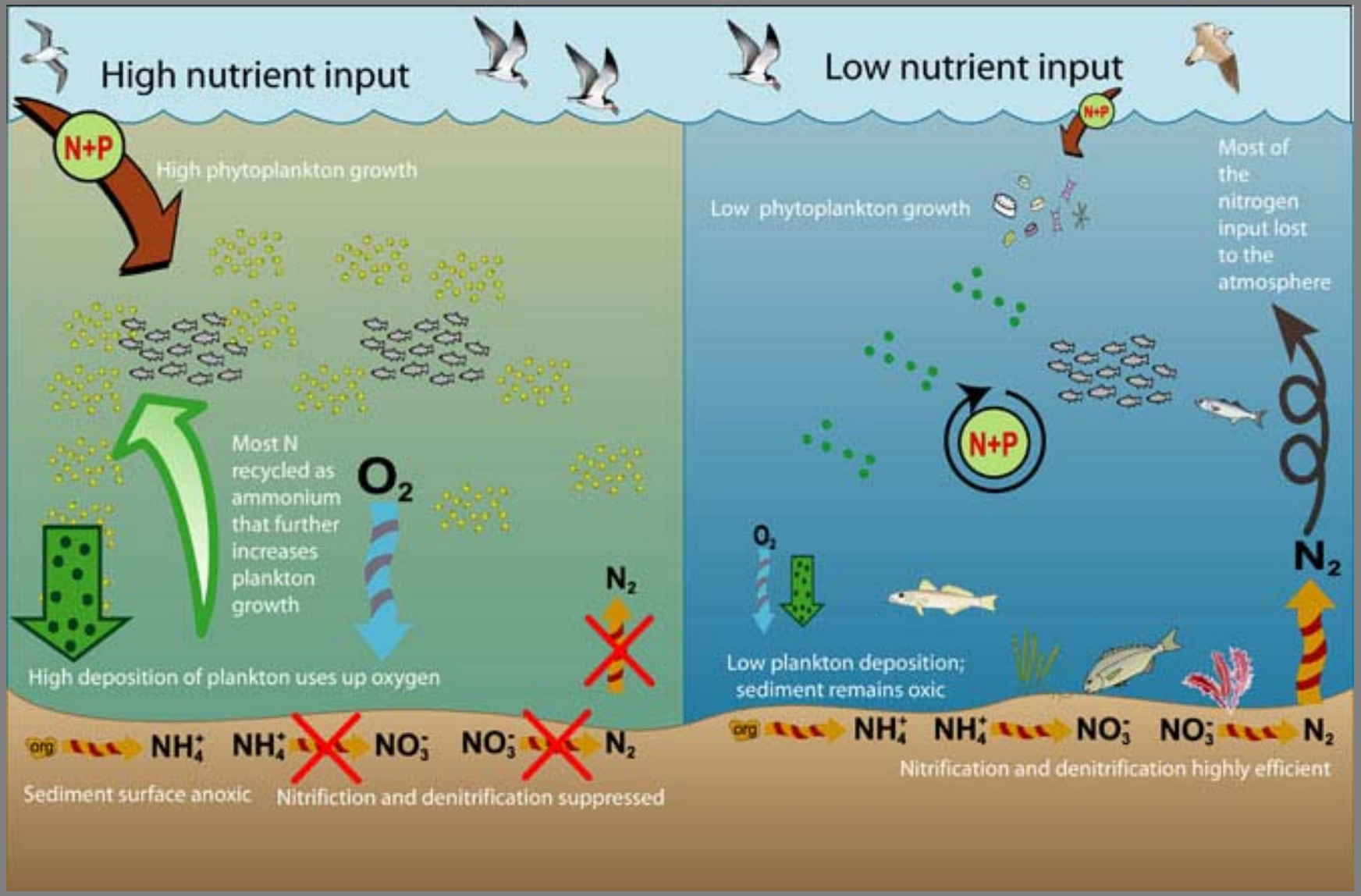
Nutrient Cycling:

Inorganic nutrients are oxidized when oxygen is present, and reduced when oxygen is absent





Nutrient Loading can cause Eutrophication and Low Dissolved Oxygen Concentrations



Ecology of Major Estuarine Habitats:

1. Tidal Fresh Marshes & Wetlands
2. Salt Marshes
3. Sandflats & Mudflats
4. Burrowing Shrimp Beds
5. Oyster Beds
6. Eelgrass Beds and Benthic Algae
7. Tidal Channels
8. Open Water
9. Gravel, Cobble, Rip-rap, & Bedrock
10. Bridge Supports, Pilings & Floating Docks

Pickleweed (*Salicornia virginica*)

Ecology of Major Estuarine Habitats:

Tidal Fresh Marshes & Wetlands

Salt Marshes

Lyngbye's sedge (*Carex lyngbyei*)

Saltgrass (*Distichlis spicata*)

Emergent Salt Marsh Biotic Assemblage

Emergent Salt Marsh

Carex lyngbyei

Distichlus spicata

Deschampsia caespitosa

Jaumea carnosa

Juncus balticus

Salicornia virginica

Triglochin maritimum

Ecology of Major Estuarine Habitats:

Sandflats & Mudflats

Polychaete worm
(*Nereis succinea*)

Sandpipers forage for invertebrates in the tideflats

Caprellid amphipod
(*Caprella californica*)

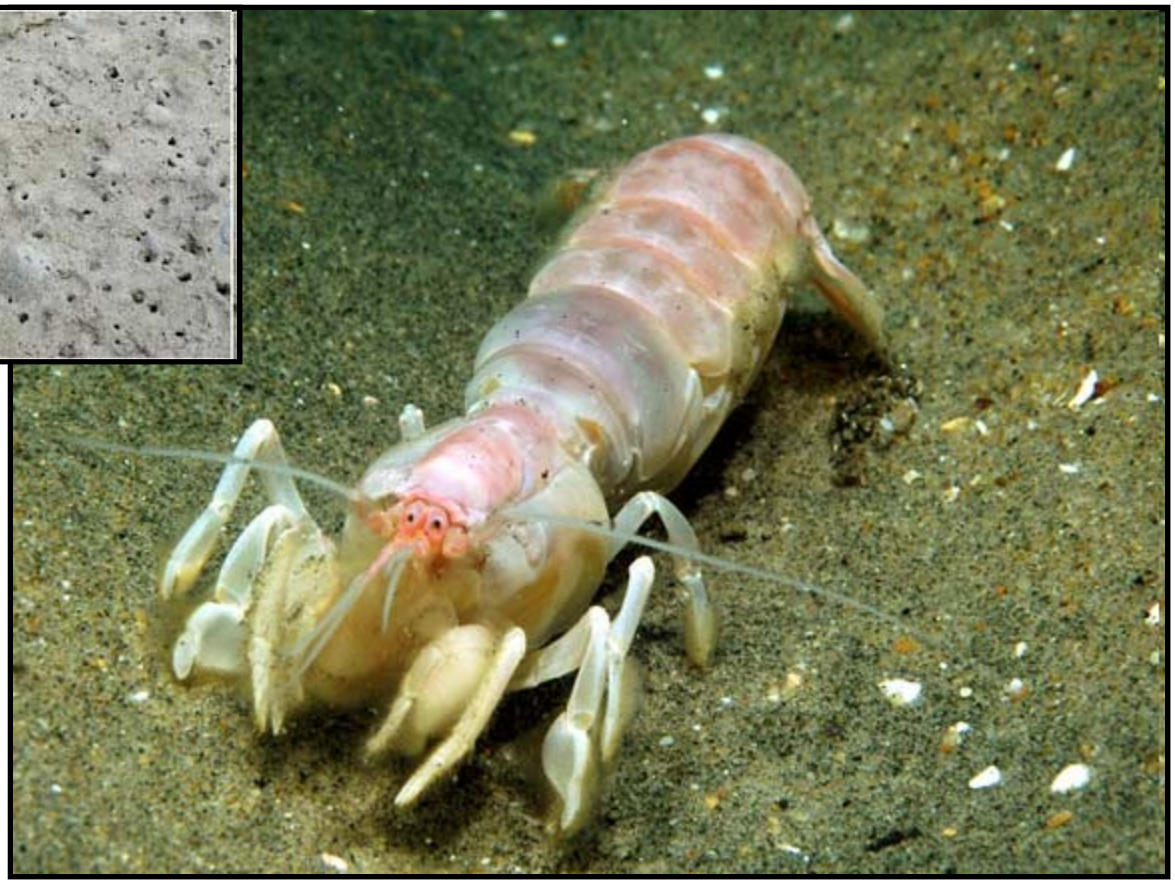
Recreational Clamming and Collection of Burrowing Shrimp are Important Activities during Low Tides

Gaper clam (*Tresus capax*)

Ecology of Major Estuarine Habitats:

Burrowing Shrimp Beds

Ghost shrimp construct deep burrows in soft sediments and recirculate water to feed



Ghost shrimp (*Neotrypaea californiensis*)

Coos Bay, OR: Commercial Mariculture of Pacific Oysters (*Crassostrea gigas*)

Oyster harvest (1940 to 2007)

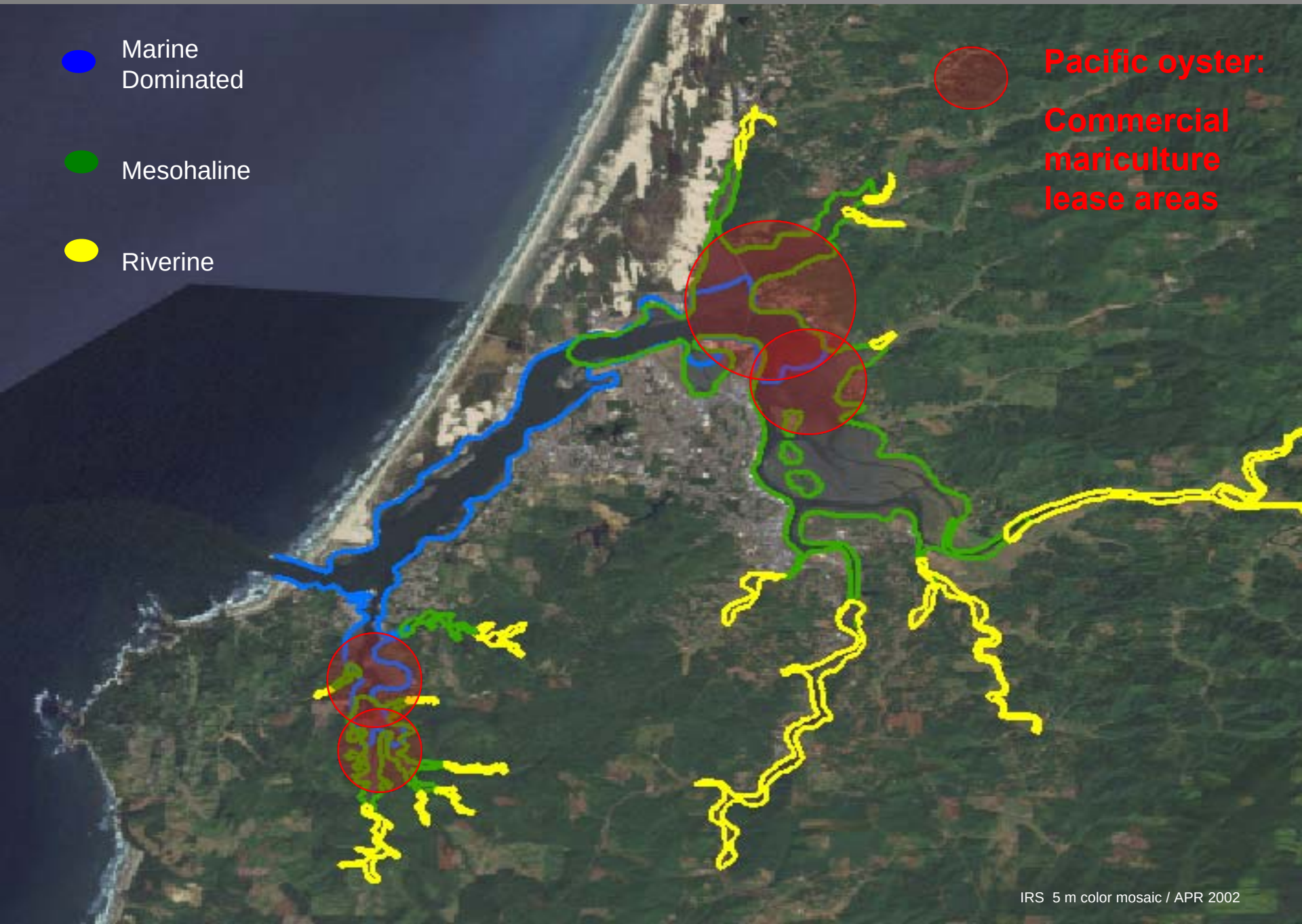
Oyster transport barge

Bottom culture on tideflats

- **4 commercial growers**
- **Highest annual oyster production in Oregon**

Shore-based packing facility

COOS ESTUARY, OR Hydrologic Regions and Oyster Mariculture Operations



Ecology of Major Estuarine Habitats:

Eelgrass Beds and Benthic Algae

Zostera marina

Ulva sp.

Eelgrass (*Zostera marina*):

Perennial terrestrial flowering plant with long blades, roots/rhizomes, and seeds

Tolerates brackish water to full saltwater

Beds become established in gravel, mud, sandy-mud substrata

Form open extensive beds, narrow fringing beds, or isolated patches

Ecological engineering species that create biogenic habitat

Eelgrass (*Zostera marina*): Tideflat Ecological Engineer and Essential Functions in Pacific Northwest Estuaries

Primary Production & Detritus

Sediment Trap & Nutrient Exchange

Water Quality Improvement

Habitat for Juvenile Fish & Shellfish

Zostera marina: Conceptual model of controlling factors (from Thom *et al.*, 2003)

CONTROLLING FACTORS → **STRUCTURE** → **FUNCTIONS**

PRIMARY:

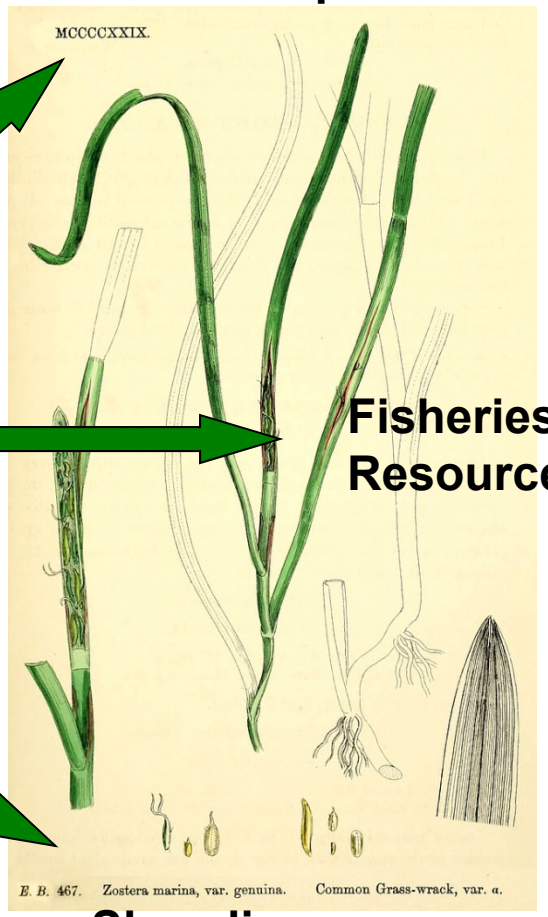
- Light (3 moles PAR d^{-1})
- Temperature (7-13 °C)
- Substratum (sand/mud/gravel)
- Nutrients (mod soil / low water col.)
- Water Motion (3 m s-1 tidal / 80 cms-1 burst)

SECONDARY:

- Bioturbation
- Dessication
- Mechanical Damage
- Plant Competition
- Disease/Herbivory

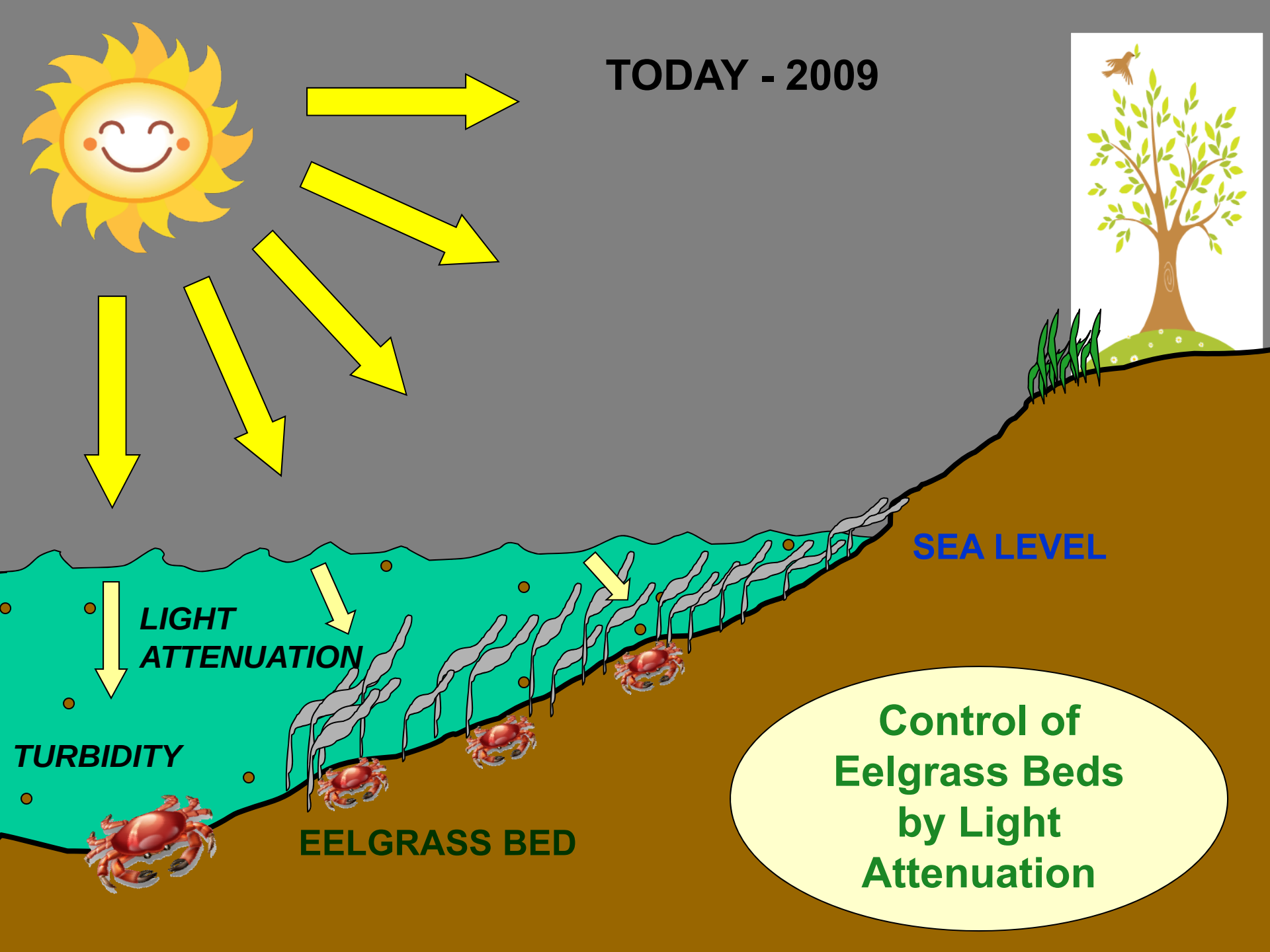
Eelgrass Biomass (& associated community)

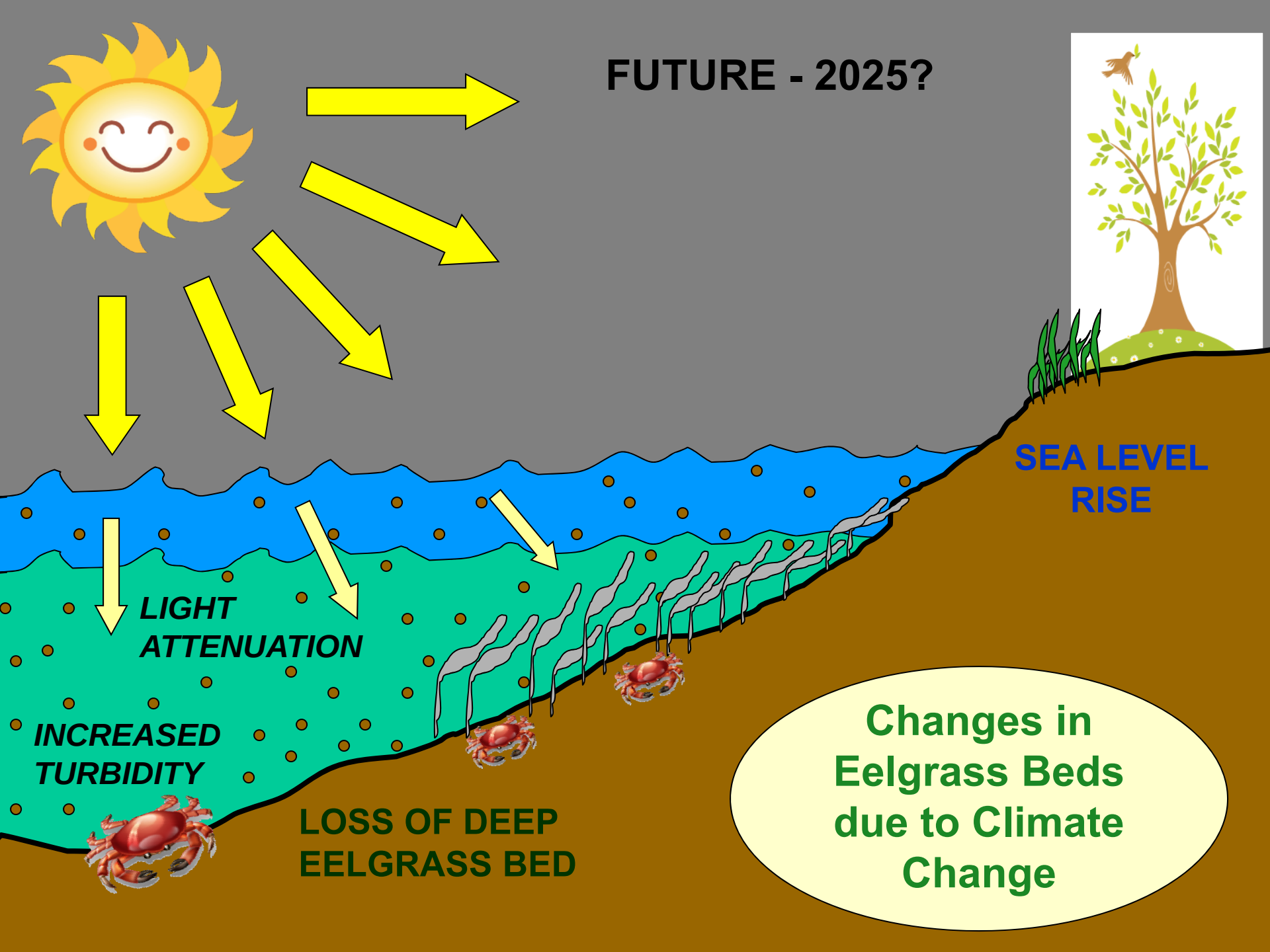
Carbon Export



Fisheries Resources

Shoreline Stabilization


TODAY - 2009
SEA LEVEL
LIGHT ATTENUATION
TURBIDITY
EELGRASS BED
Control of Eelgrass Beds by Light Attenuation


FUTURE - 2025?
SEA LEVEL RISE
LIGHT ATTENUATION
INCREASED TURBIDITY
LOSS OF DEEP EELGRASS BED
Changes in Eelgrass Beds due to Climate Change

Ecology of Major Estuarine Habitats:

Tidal Channels & Drainage Creeks

High tide:
Sloughside Pilings marsh

Low tide:
Sloughside Pilings marsh

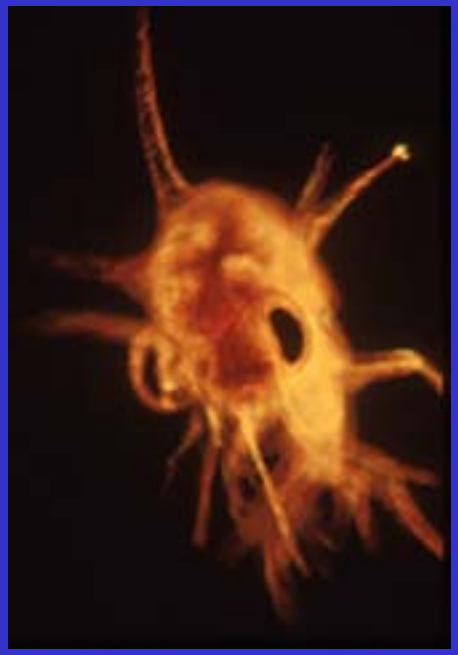
Ecology of Major Estuarine Habitats:

Tidal Channels & Open Water

Dungeness crab (*Cancer magister*)

Red Rock crab (*Cancer productus*)

Life Stages of *Cancer* Crabs



Planktonic Zoea larva

Late Stage Megalops

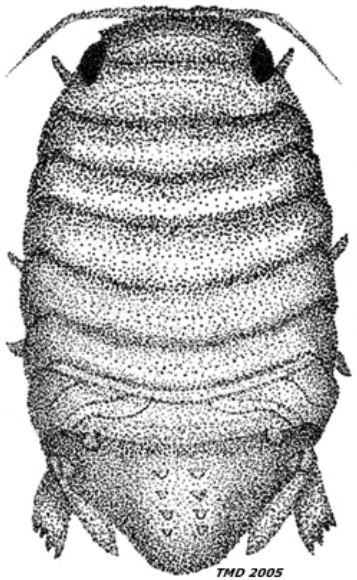
Adult *Cancer productus*

Recently Settled Megalopae and Early Juveniles

Juvenile Crab in Algae Bed

Ecology of Major Estuarine Habitats:

Gravel, Cobble, Rip-rap, & Bedrock



New Zealand Burrowing Isopod (*Sphaeroma quoyanum*)

Burrows in sandstone bedrock: (*Sphaeroma quoyanum*)

North Jetty Repair / Coos Bay (2002)

Ecology of Major Estuarine Habitats:

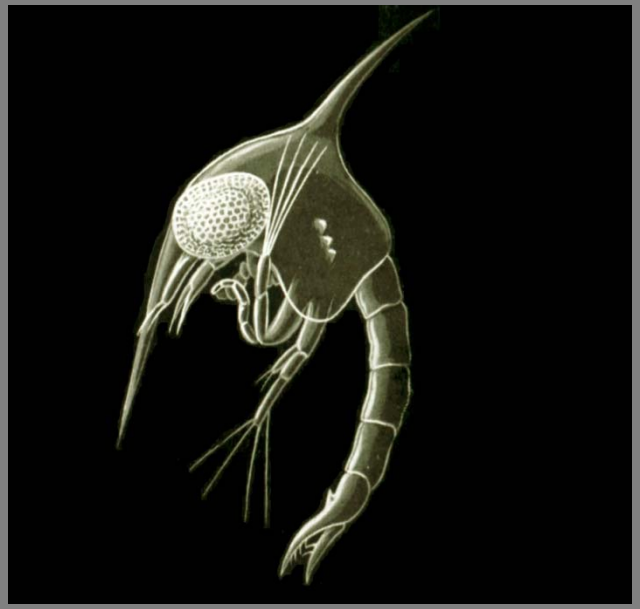
Bridge Supports, Pilings & Floating Docks

Mixed epifouling community of tunicates, hydroids, sponges, barnacles, algae

Colonial Tunicate: *Didemnum vexillum* / A New Invader in Oregon Estuaries

Didemnum **spreads rapidly and out-competes native invertebrates**

European Green Crab: *Carcinus maenas* / A Recent Invader in Oregon Estuaries (1997)



Carcinus **became established in San Francisco, CA, and rapidly spread north by dispersal of planktonic zoea larvae**

Maritime Commerce: Primary Modern Vector for Introduction of Non-Native Species from Distant Shores

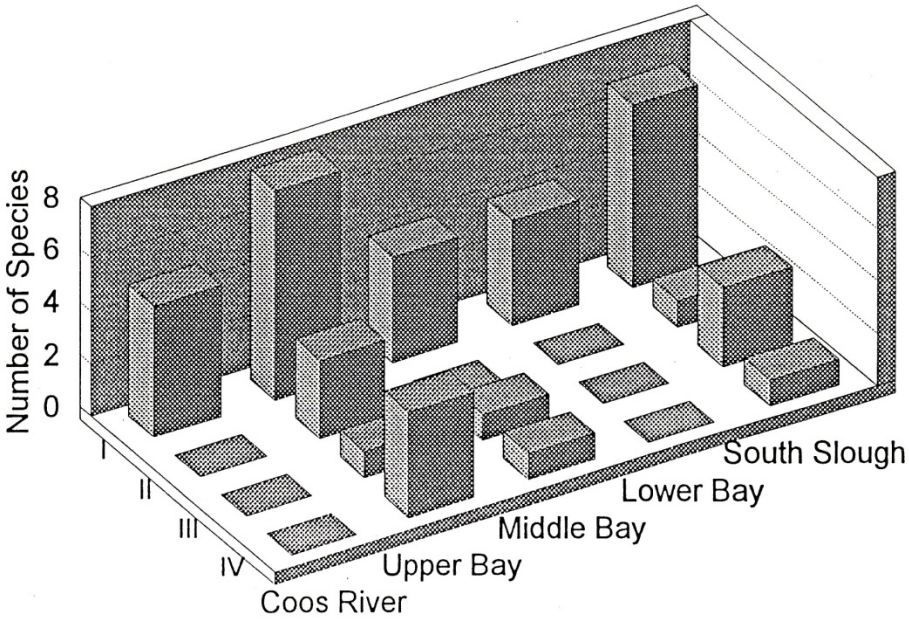
Cargo ships discharge ballast water that contains foreign species during port operations in estuaries

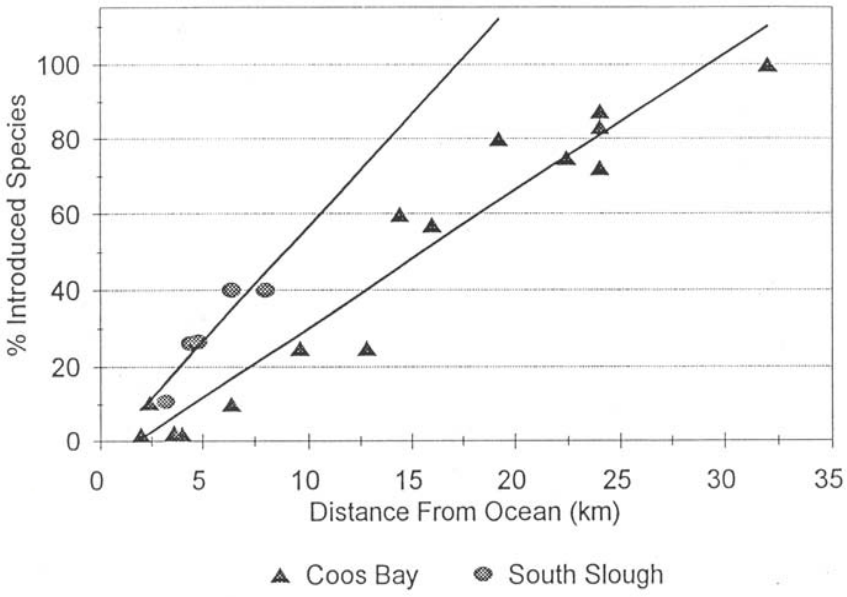
Polychaete worm (*Eteone longa*): introduced to Coos Bay via ballast water transport from Asia and the North Atlantic

Colonization by Estuaries by Non-Native Species:

Coos Bay is colonized by over 100 non-indigenous aquatic species, most historically from wood hull ships

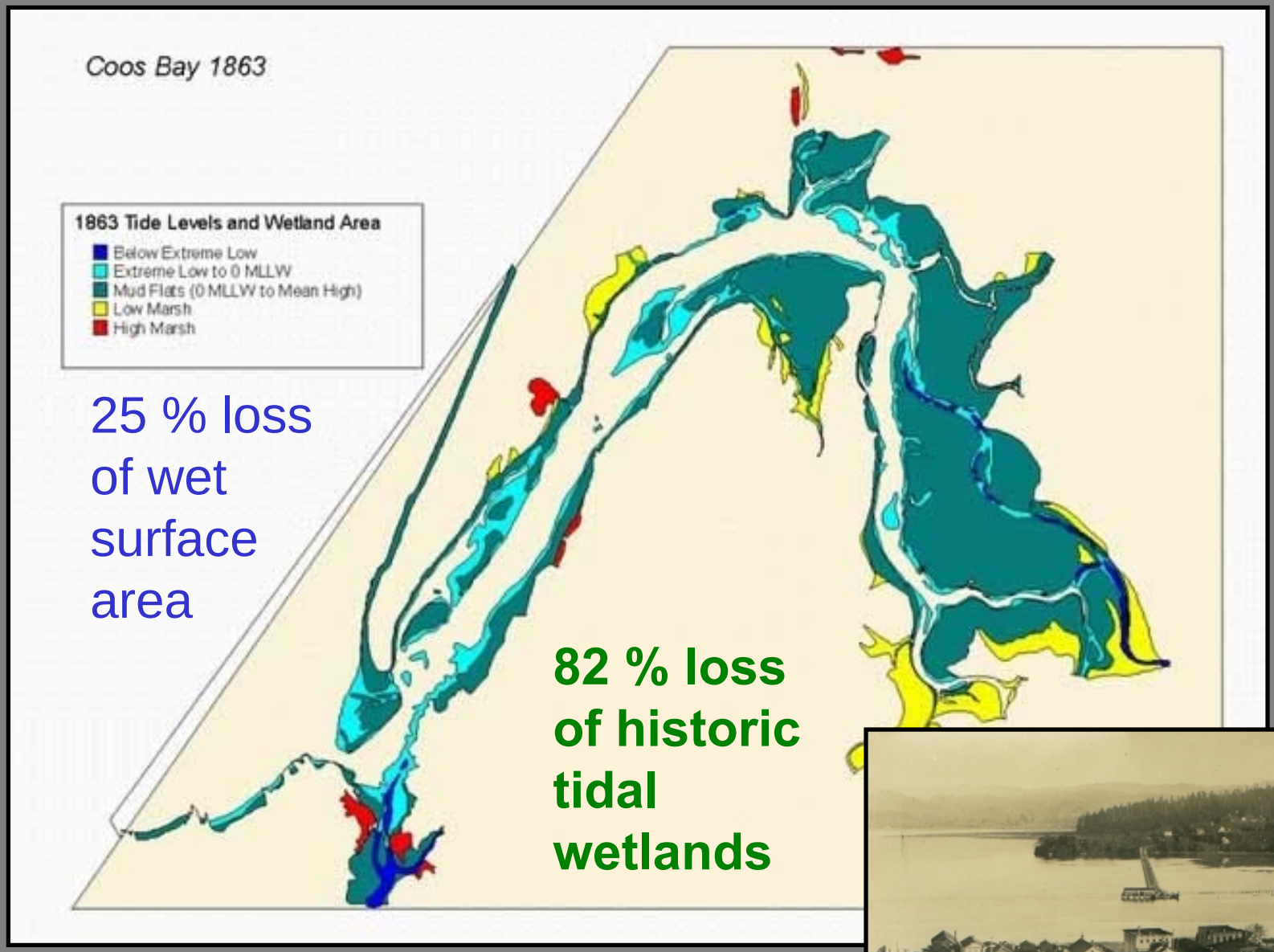
Greater #s of NIS occur further up the estuary





Proportion of estuarine invertebrate community contributed to Coos Bay and the South Slough by introduced species as a function of distance from the ocean (from Hewitt, 1993).

Abundance of introduced invertebrates in five regions of Coos Bay according to their affinities with specific introduction vectors: I=Wooden hulled vessel fouling, II=Atlantic oyster culture, III=Pacific oyster culture, IV=Modern introduction mechanisms (from Hewitt, 1993).



Historic Alteration of the Coos Bay Estuary

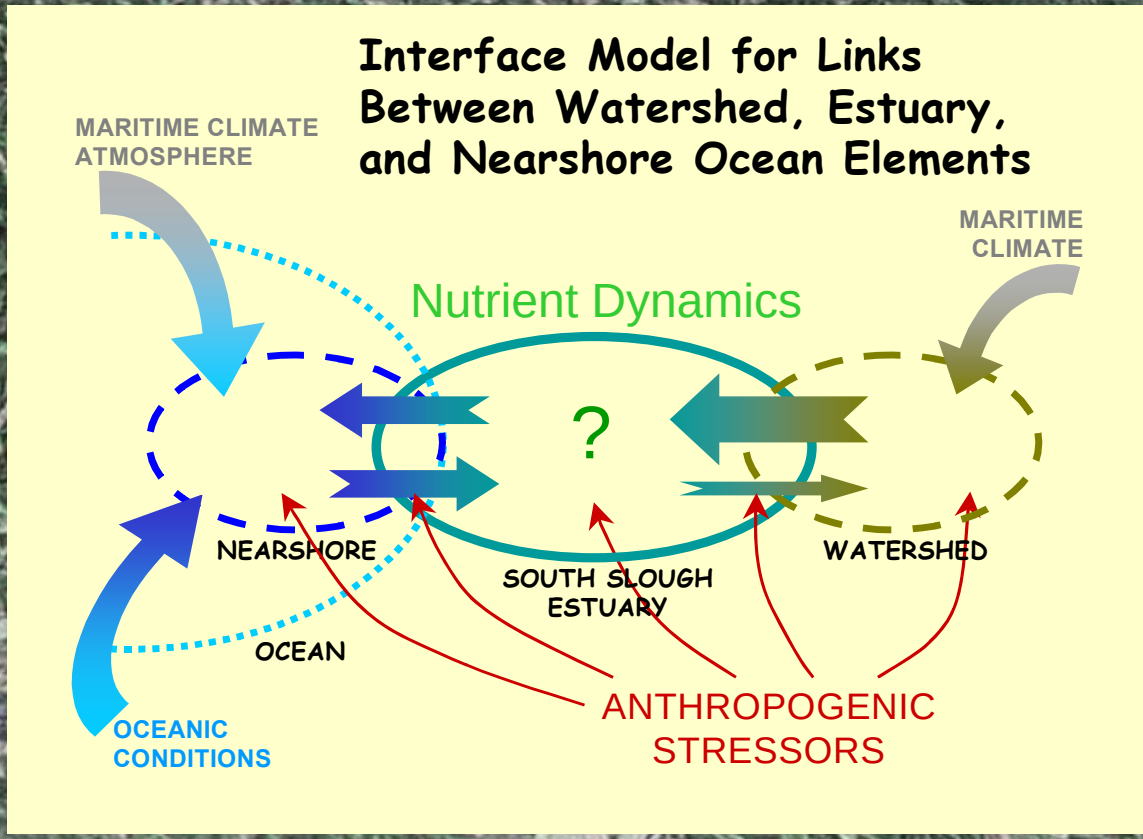
South Slough NERR:

Winchester Tidelands Restoration Project / Kunz Marsh

- Dike Removal and Experimental Correction for Subsidence

- Monitoring to Evaluate Effectiveness of Restoration Actions

Application of the Interface Model to the South Slough Estuarine Sub-System



Nearshore

Estuary

Watershed

Central Question:

"To what extent are chlorophyll and nutrients driven by ocean forcing and upwelling versus watershed inputs within the South Slough estuary?"

Approach:

1. ***Seasonal Baseline Monitoring of Chl a & Nutrients along Estuarine Gradient***
2. ***Diel Assessment of Tidal Forcing during Flood and Ebb Tides***
3. ***Nutrient Dynamics during Upwelling Events***

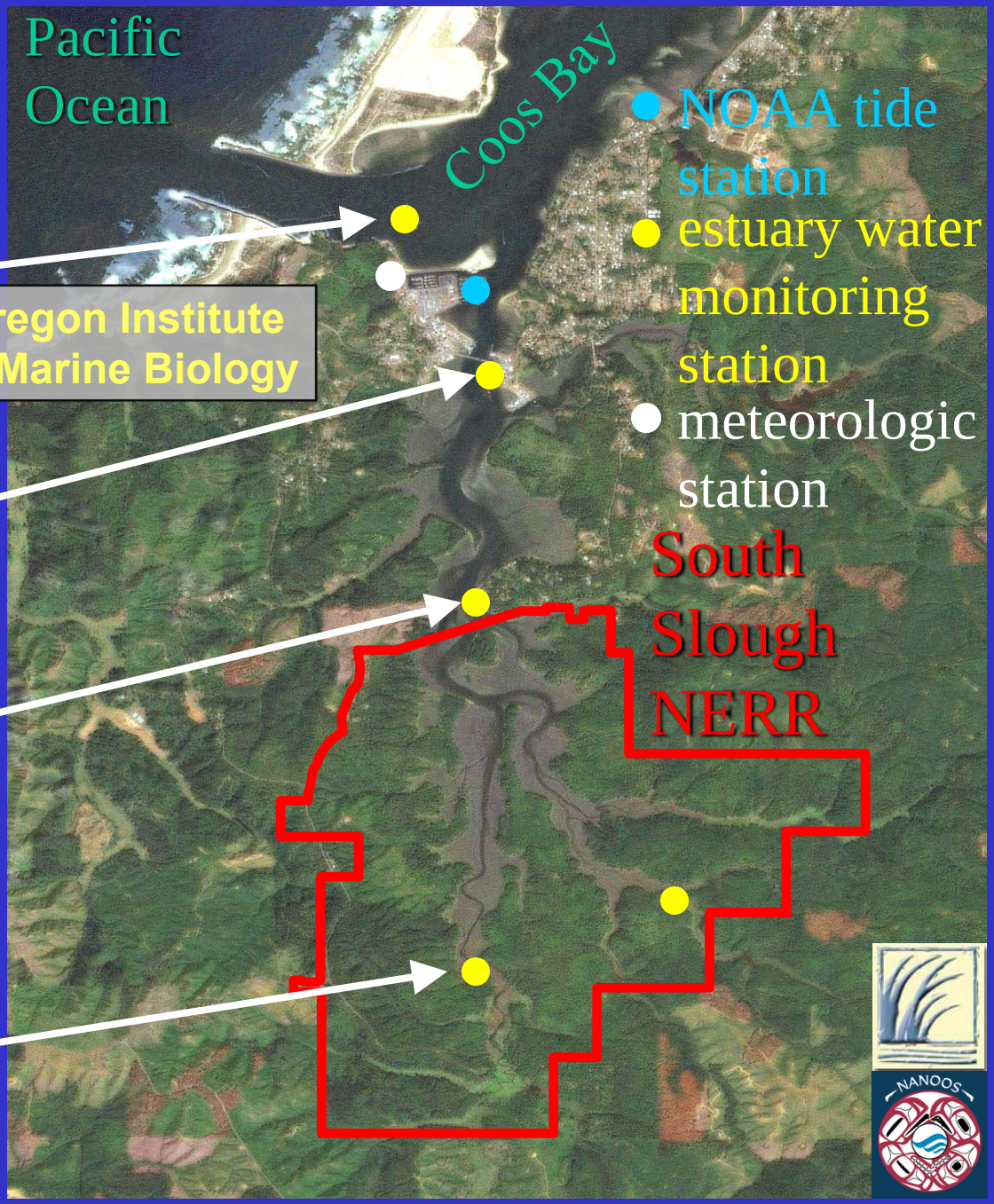
Location of Monitoring Stations along the South Slough Estuarine Gradient

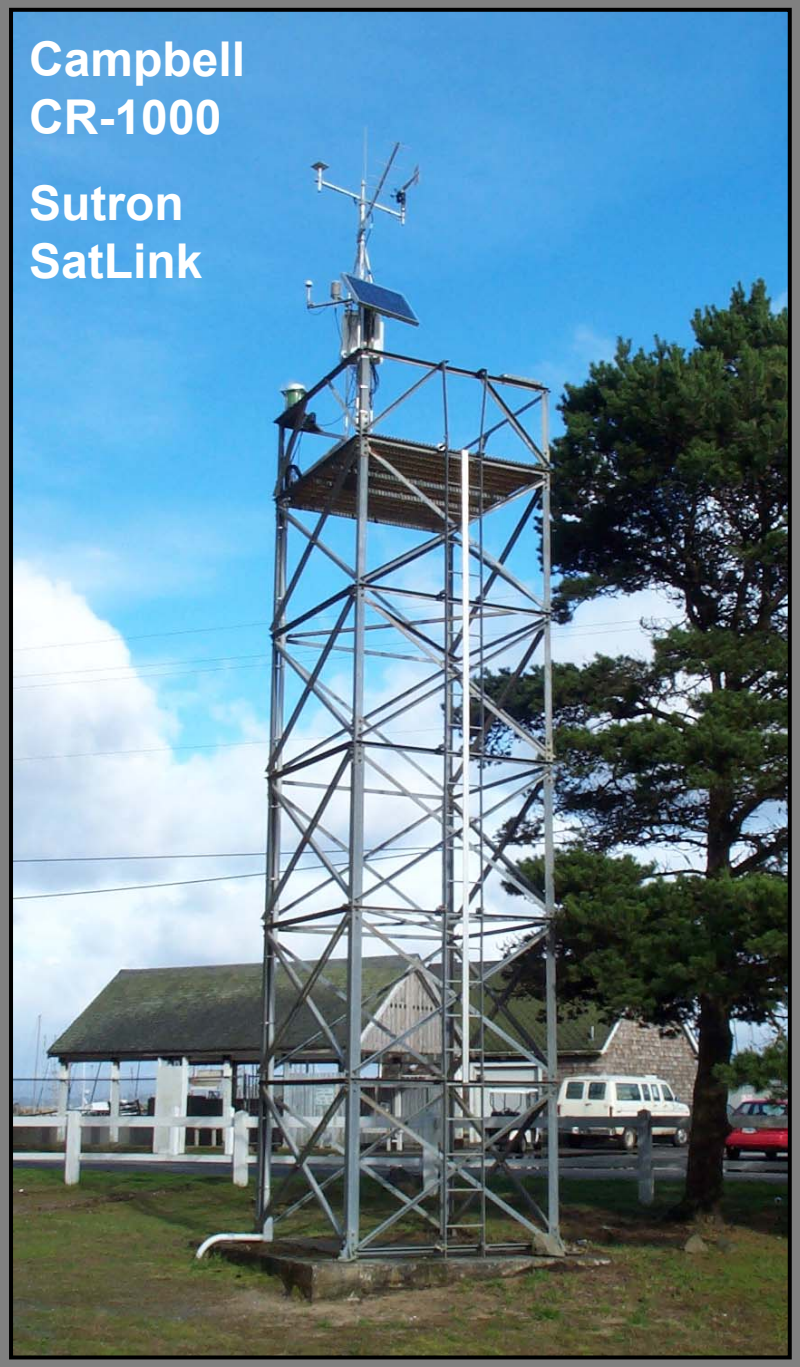
MARINE / BAY
Boathouse

MARINE DOMINATED
Charleston

MIXING ZONE
Valino Island

RIVERINE
Winchester Creek

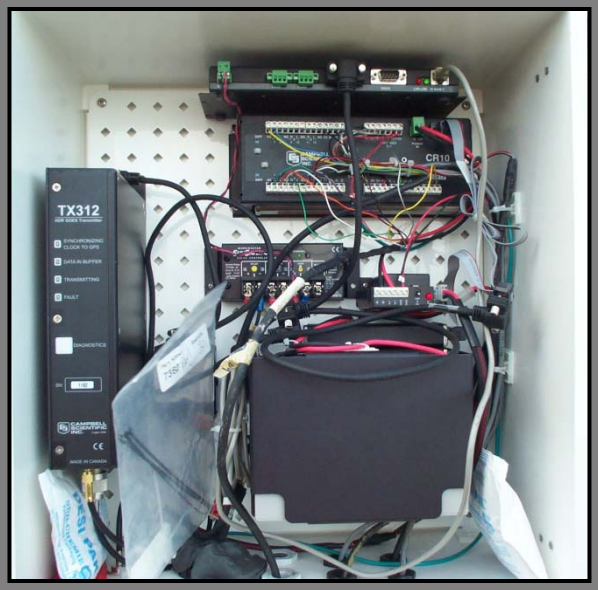




South Slough NERR / SWMP Meteorologic Station

Charleston, OR

GOES Satellite Transmission System



Parameters (5 sec):

- air temp
- wind velocity
- wind direction
- relative humidity
- barometric pressure
- precipitation
- photosynthetically active radiation

12 V-DC

60 W solar

UNIVERSITY OF OREGON

South Slough NERR System-Wide Monitoring Program / Charleston Dock Station, OR

Near Real-time Data available on-line:

NERRS Centralized Data Management Office

http://nerrs.noaa.gov

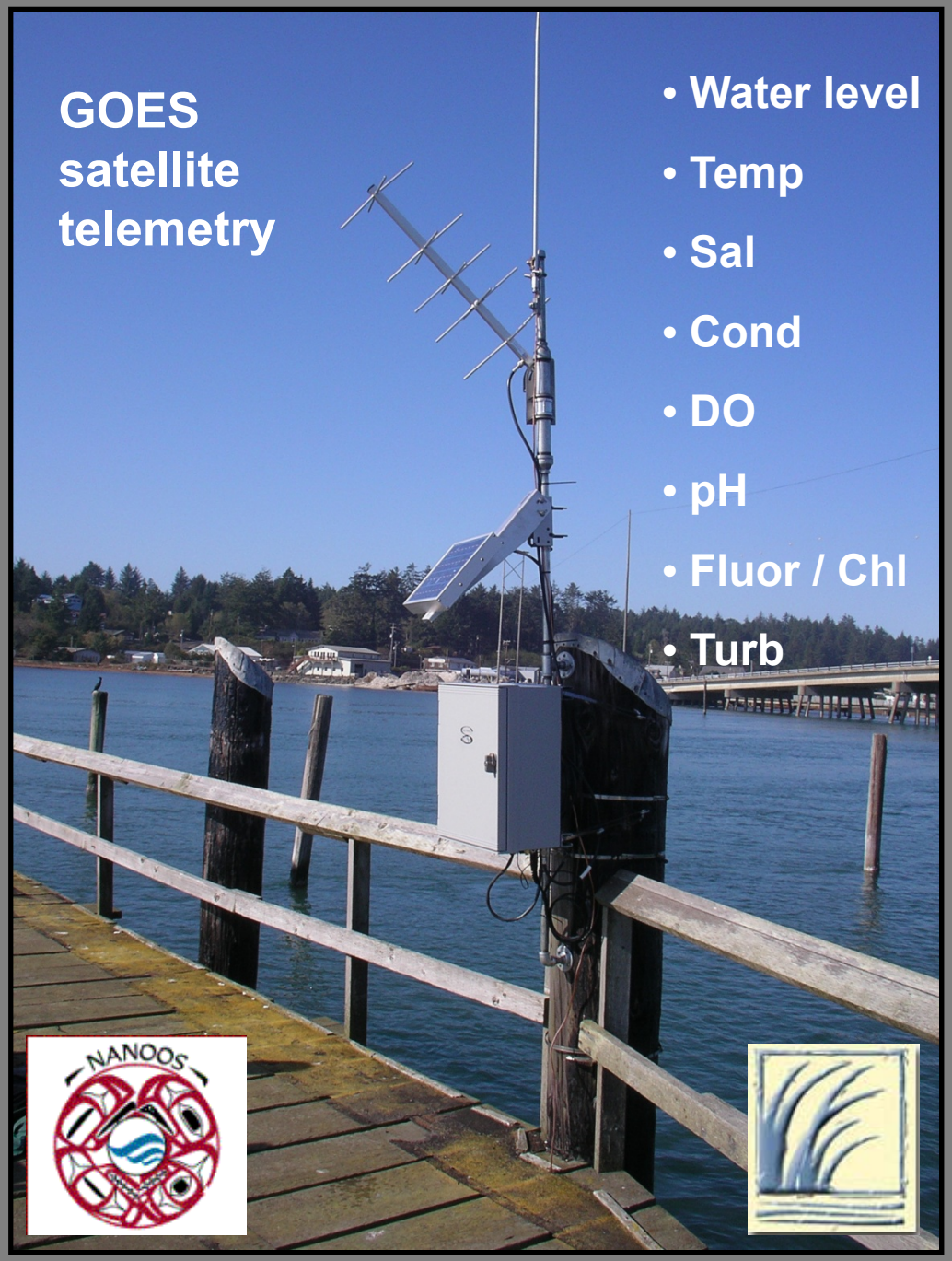
http://cdmo.baruch.sc.edu

National Weather Service

www.weather.gov/oh/hads

Northwest Association of Networked Ocean Observing Systems

www.nanoos.org



National Estuarine Research Reserve System-Wide Monitoring Program

YSI-6600 EDS Datasonde
Probe array
SatLink / GOES

Continuous measurements of water parameters:

- Temperature
- Salinity/Conductivity
- Dissolved Oxygen
- pH
- Turbidity
- Chlorophyll/fluorescence
- Water level

YSI 605091 pH/ORP sealed gel probe

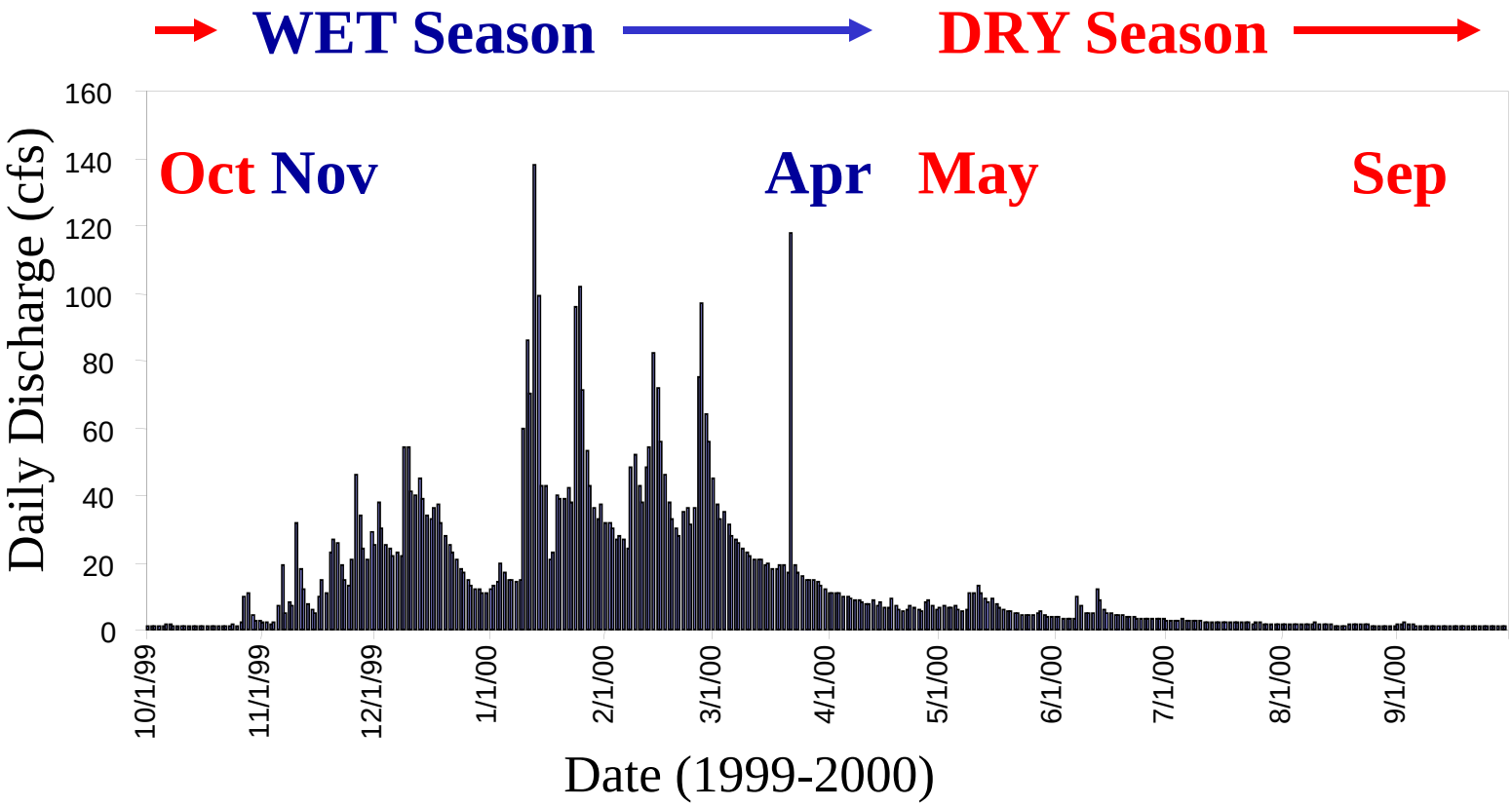
Res = 0.01 pH unit

Nutrients-HT & LT discrete grabs & diel tidal sampling (2 hr X 25 hr)

Monthly measurements:

- Nitrogen: NO_2, NO_3, NH_4, DIN
- Phosphorus: PO_4 (ortho-phosphate)
- Plant Pigments: Chl *a*, phaeophytin
- Bacteria (total coliforms)

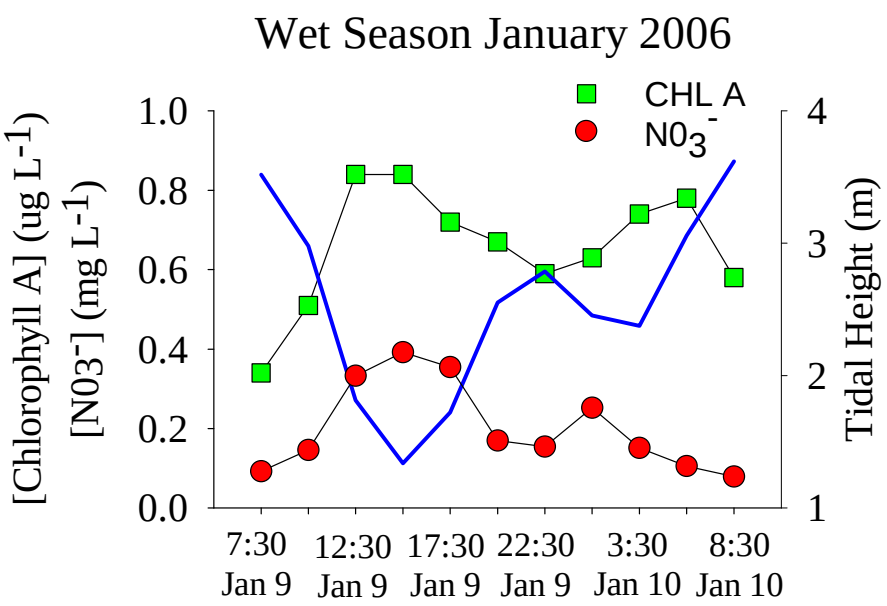
Seasonal Cycle Determined by Rainfall and Stream Discharge

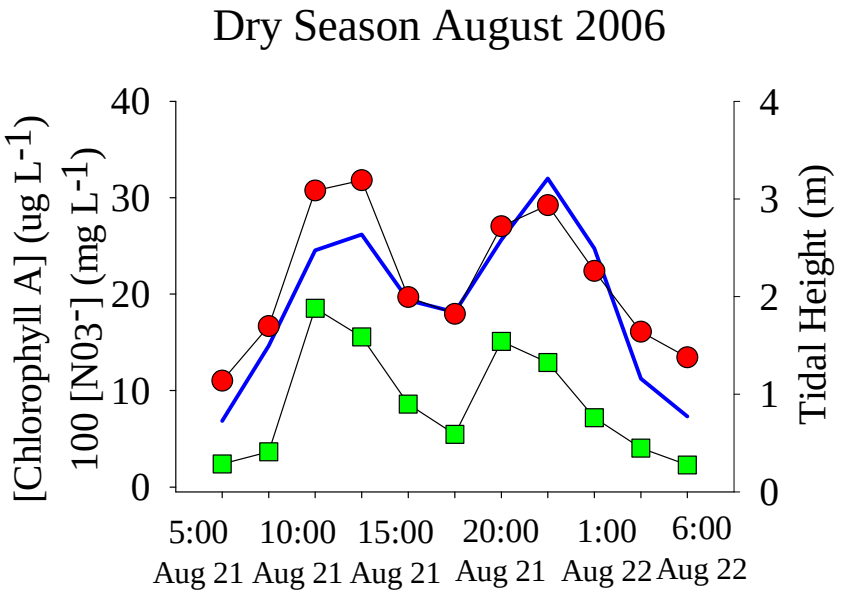


Pulsed discharge of freshwater from Winchester Creek into the South Slough Estuary, OR. Values indicate daily discharge (cfs) during the water year from October 1999-September 2000.

Tidal Changes in Nitrate and Chlorophyll-a Concentrations at the Charleston Bridge SWMP Station during the Wet and Dry Seasons

note: dry season nitrate scaled up 100X



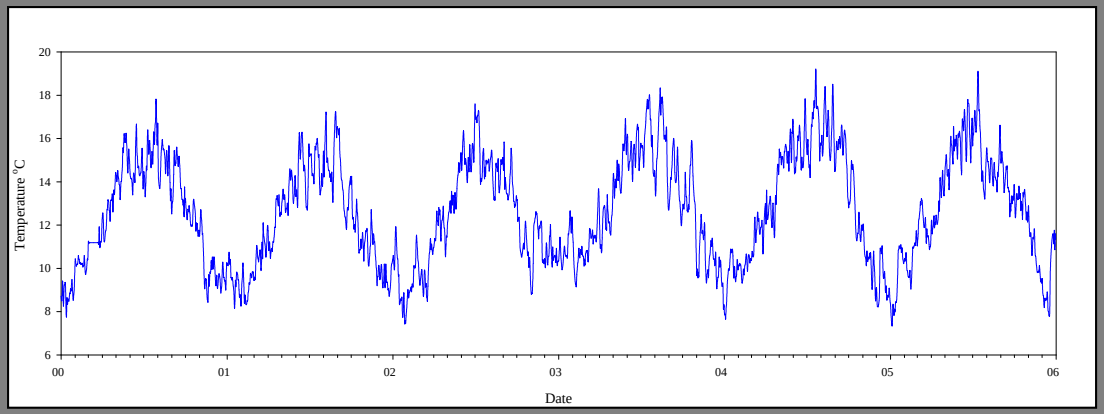


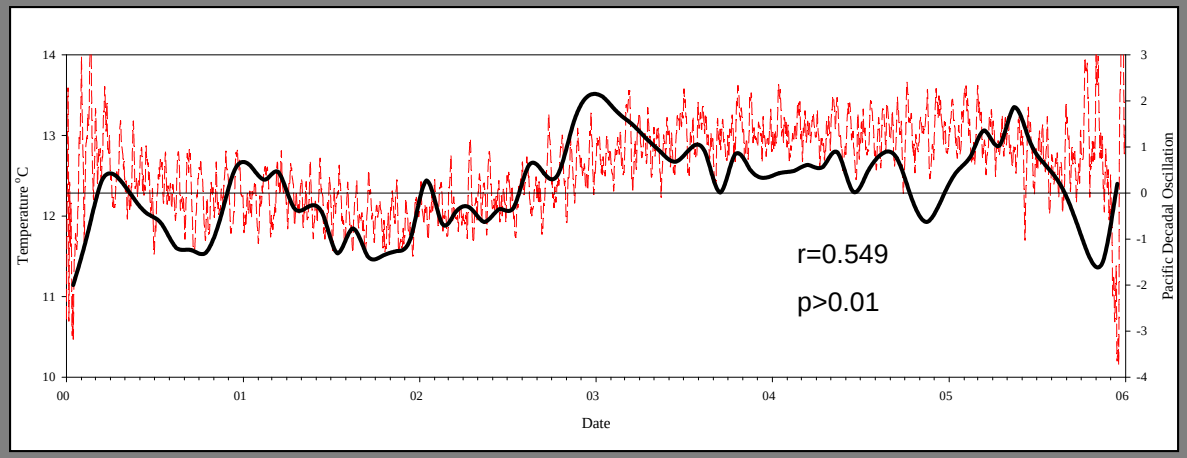
Out-of-Phase with Tide: ⟺ **In-Phase with Tide:**

- **Peak Chl-a & NO3 values at low tide**
- **Watershed delivery of nutrients**
- **Peak Chl-a & NO3 values at high tide**
- **Ocean delivery of nutrients**

South Slough, OR: Climatic & Ocean Forcing of Estuarine Water Parameters (2001-06)

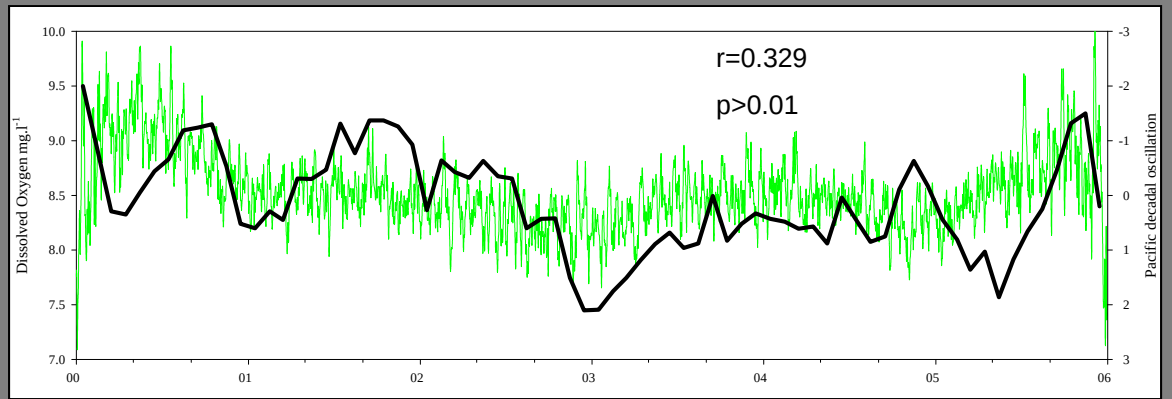
Seasonal cycle: Daily averaged temperatures



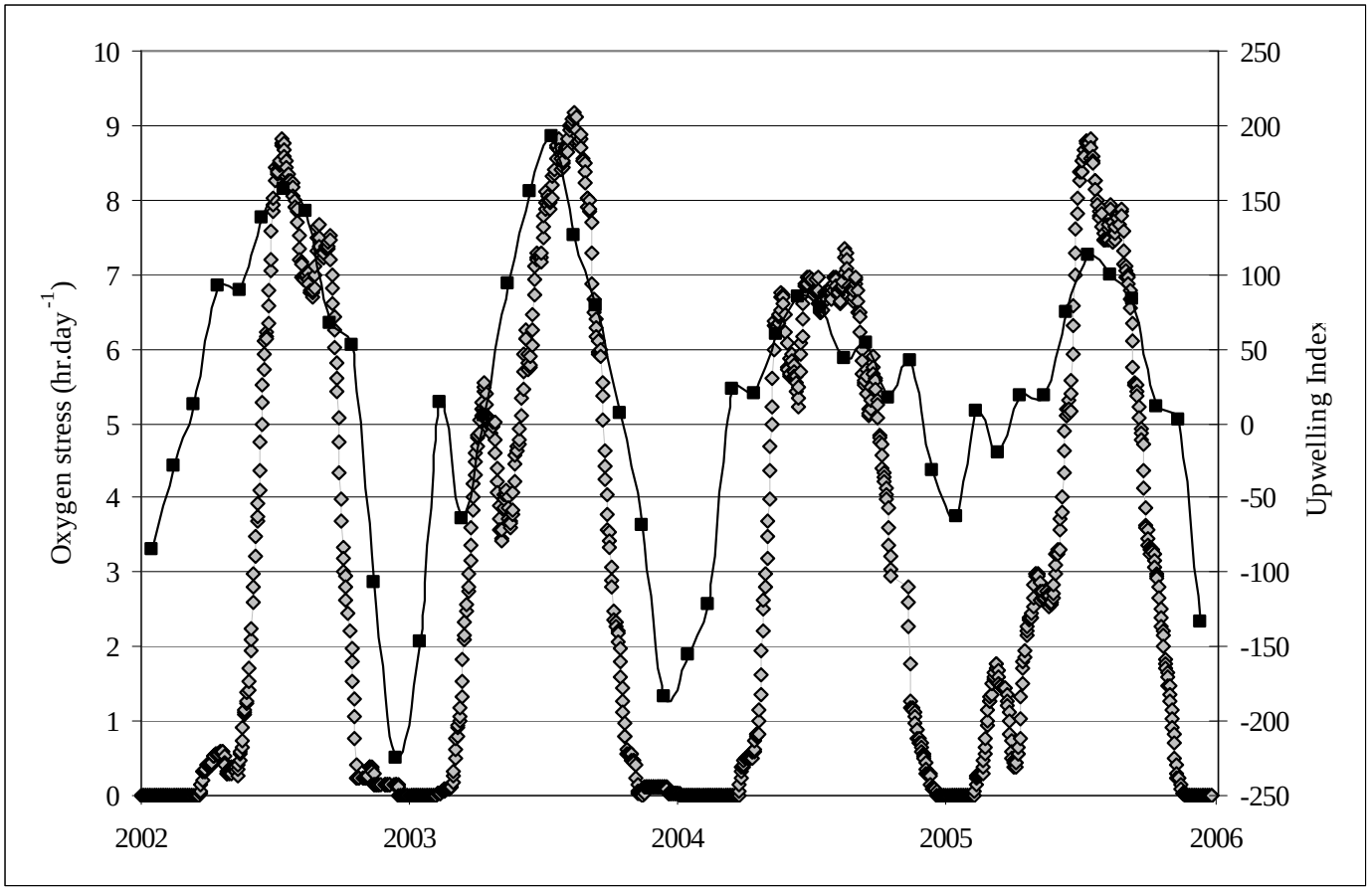


Regional Ocean Influence: Seasonally adjusted temperature

Regional Ocean Influence: Seasonally adjusted dissolved oxygen



SOUTH SLOUGH ESTUARY, OR: Relationship between Oxygen Stress, Temperature, and Pacific Ocean Upwelling



◇ **Oxygen stress = < 5 mg/L**

■ **Upwelling Index**

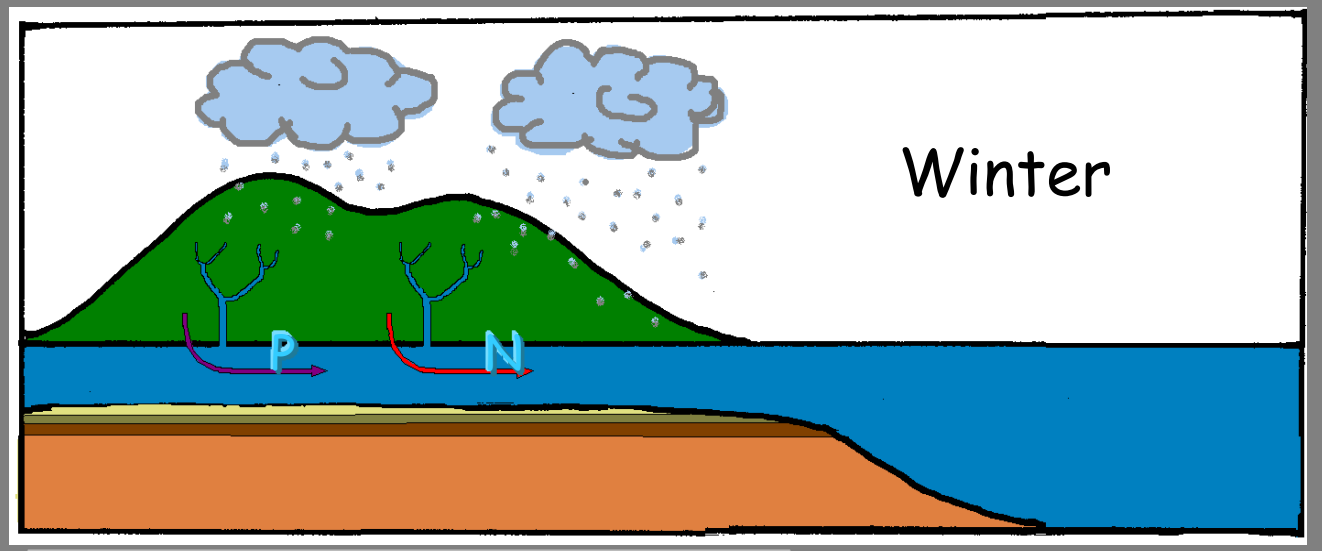
O2 stress with temperature r = 0.855

O2 stress with upwelling r = 0.711

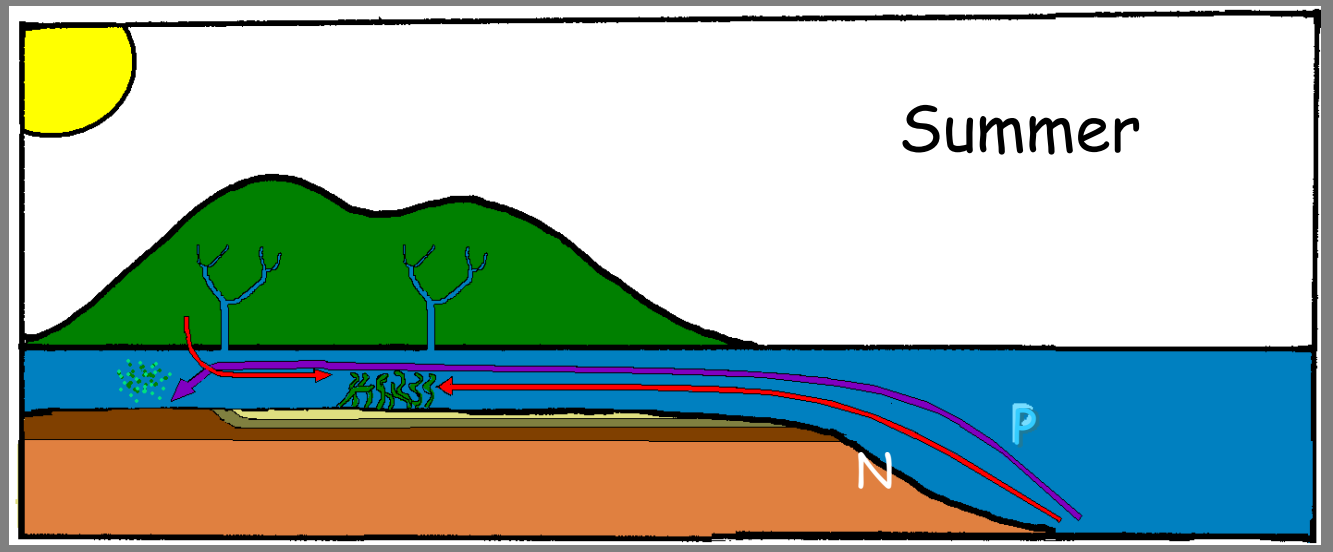
O2 stress with lag upwelling r = 0.742

Conceptual Model for Seasonal Changes in Delivery of Nitrate and Phosphorus to the South Slough Estuary

Watershed Delivery in Wet Season

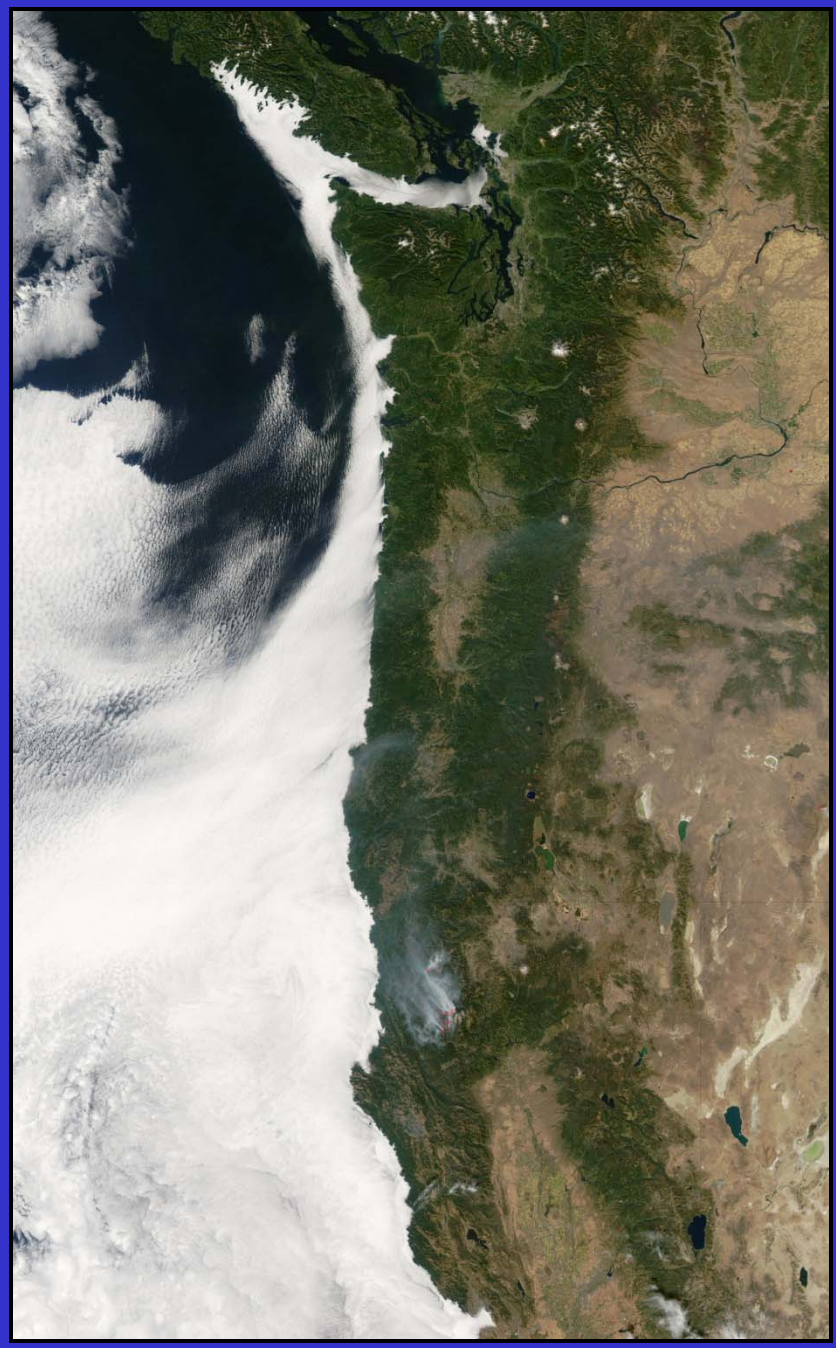


Ocean Delivery in Dry Season



<u>Note</u>: Extensive eelgrass beds (*Zostera marina*) located in the South Slough function as sinks for nitrogen. Phosphorus delivery stimulates phytoplankton blooms and oxygen stress.

Wind-driven upwelling during late spring and summer delivers cold nutrient-rich water to the shoreline where it is advected into the estuaries by flooding tides

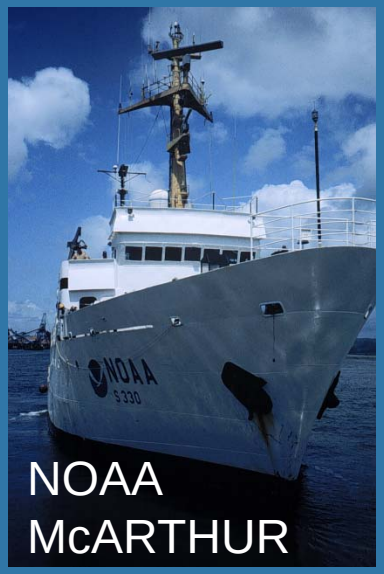


What is the extent and influence of estuarine production on the nearshore region immediately outside Oregon's drowned river mouth estuaries?

Umpqua River

Coos Bay

Coquille River



NOAA
McARTHUR

Coos Bay

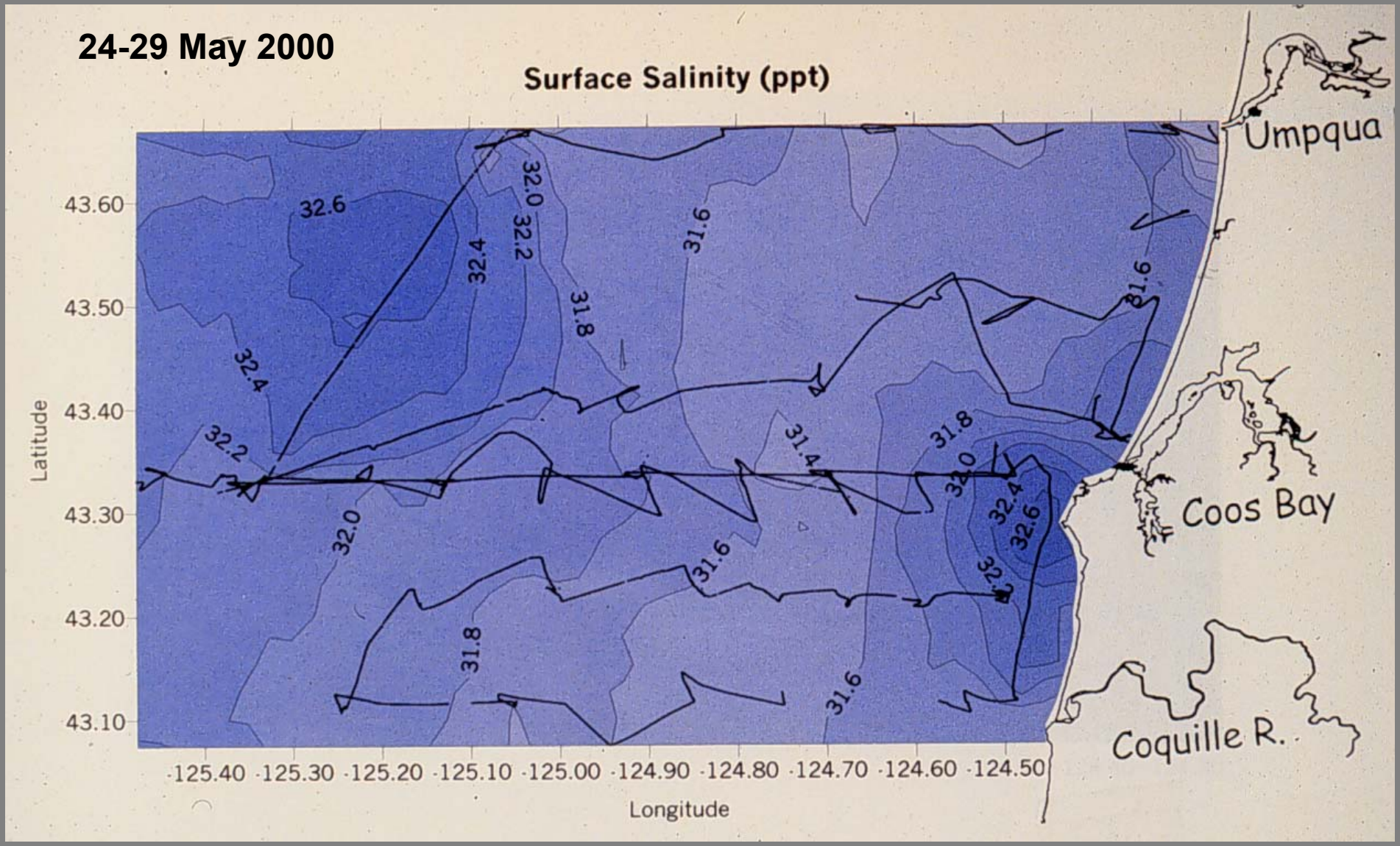
Umpqua Estuary

Ocean Transects

NOAA McARTHUR:

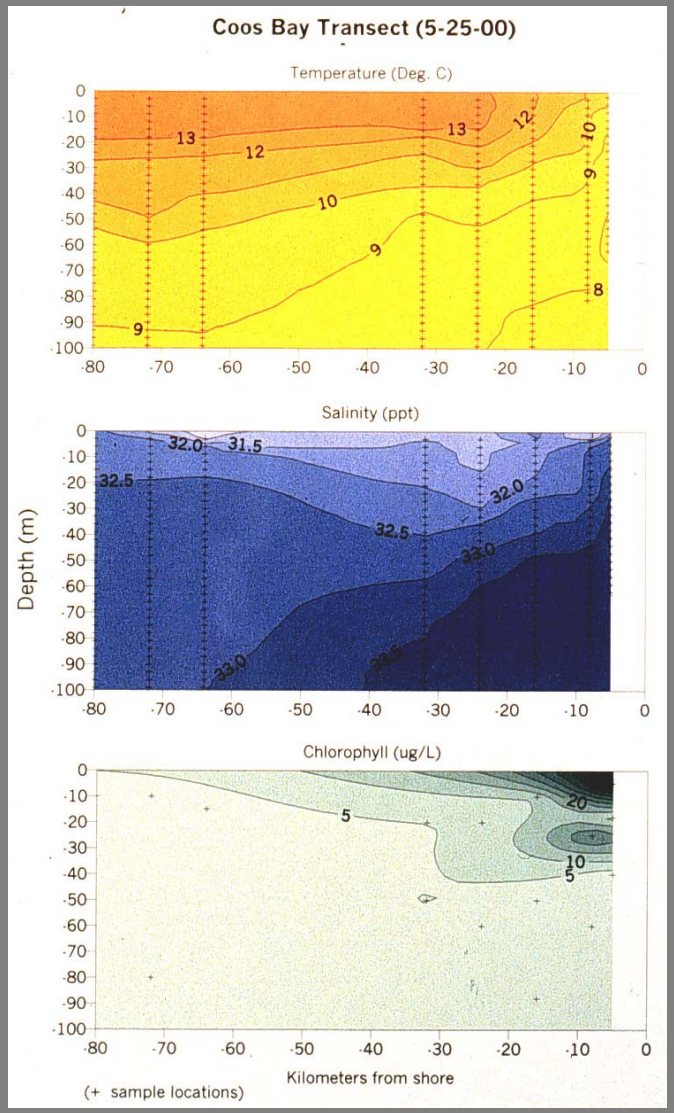
Study Links between Estuaries and Pacific Ocean

Nearshore Surface Salinities off the Mouths of Three Oregon Estuaries

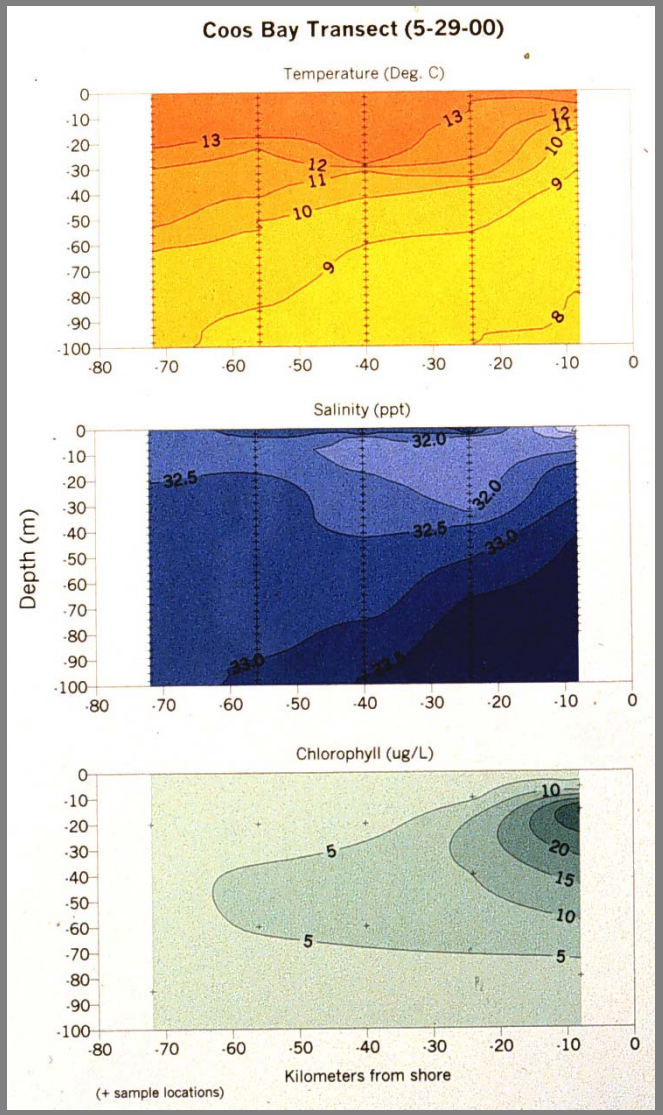


Export of Chlorophyll from the Coos Estuary

Upwelling Event



Upwelling Relaxation



Acidification of Ocean Water

Atmospheric carbon dioxide

CO_2

CO_2 + H_2O → H_2CO_3 → H^+

Hydrogen ion

Dissolved carbon dioxide

Water

Carbonic acid

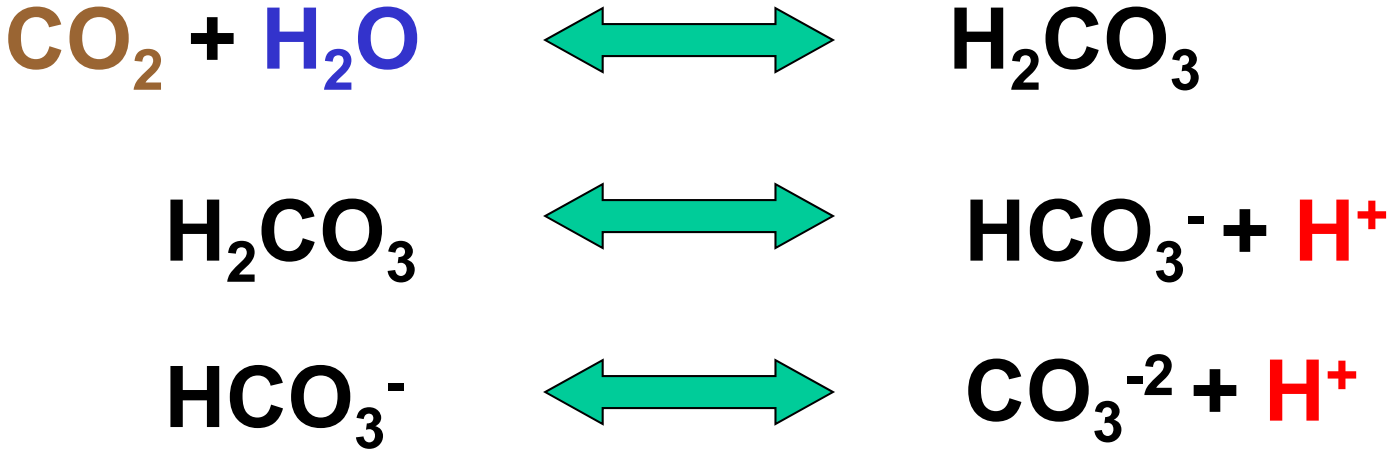
HCO_3^-

Bicarbonate

CO_3^{-2}

Carbonate

Ocean Carbonate System Reactions



Release of H+ results in decreased pH

(= increased acidity) of surrounding water

CO_2 Carbon dioxide

H_2O Water

H^+ Hydrogen ion

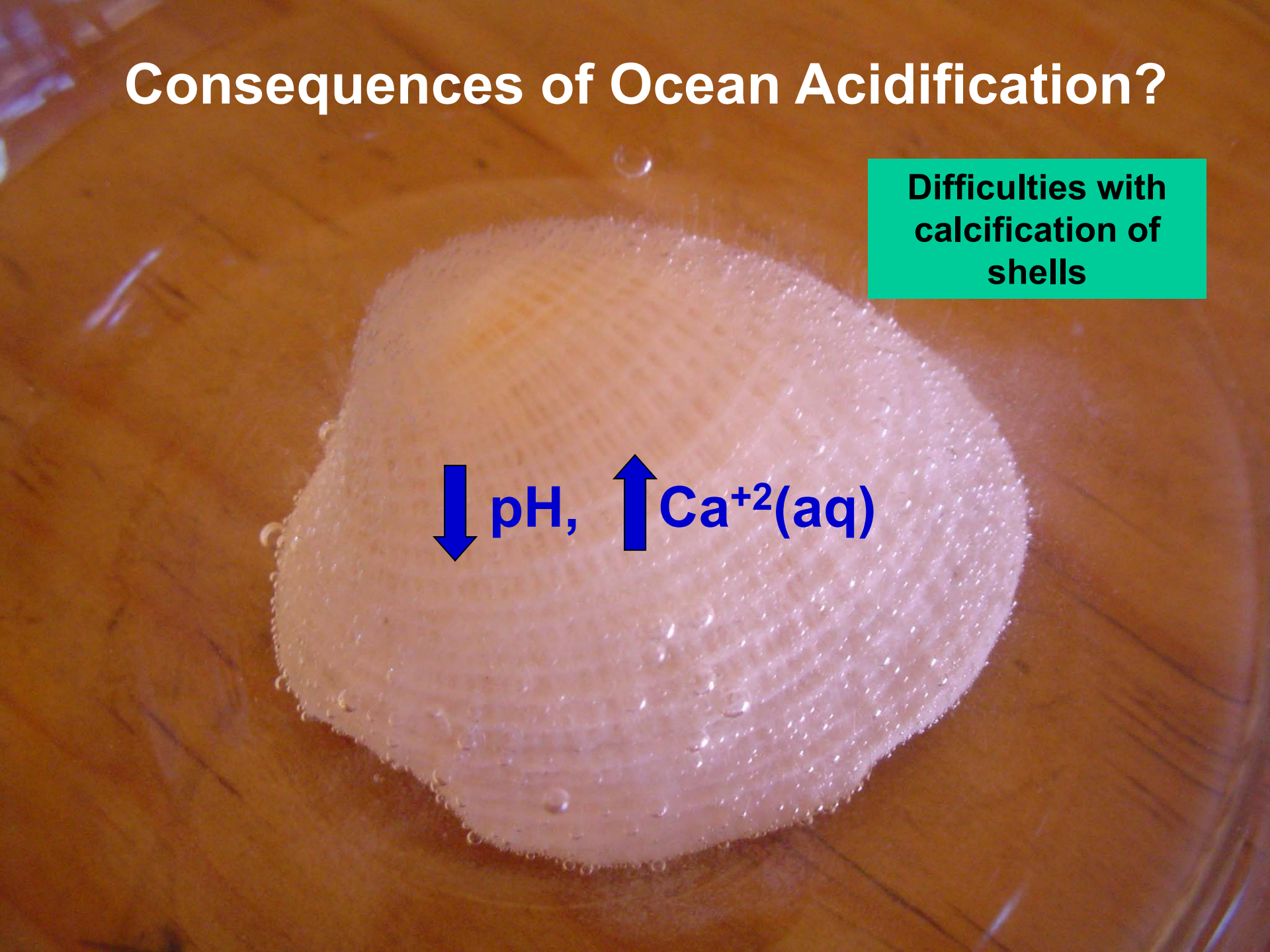
H_2CO_3 Carbonic acid

HCO_3^- Bicarbonate

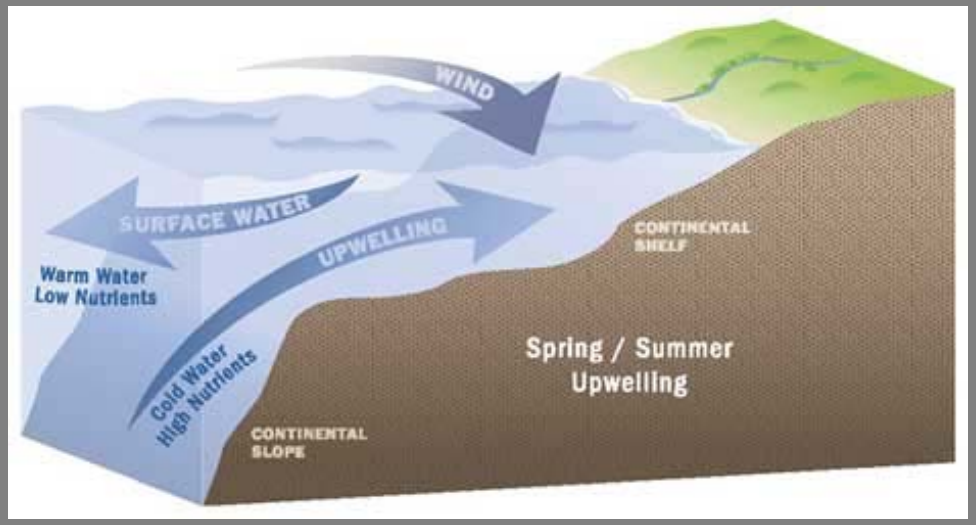
CO_3^{2-} Carbonate

Consequences of Ocean Acidification?

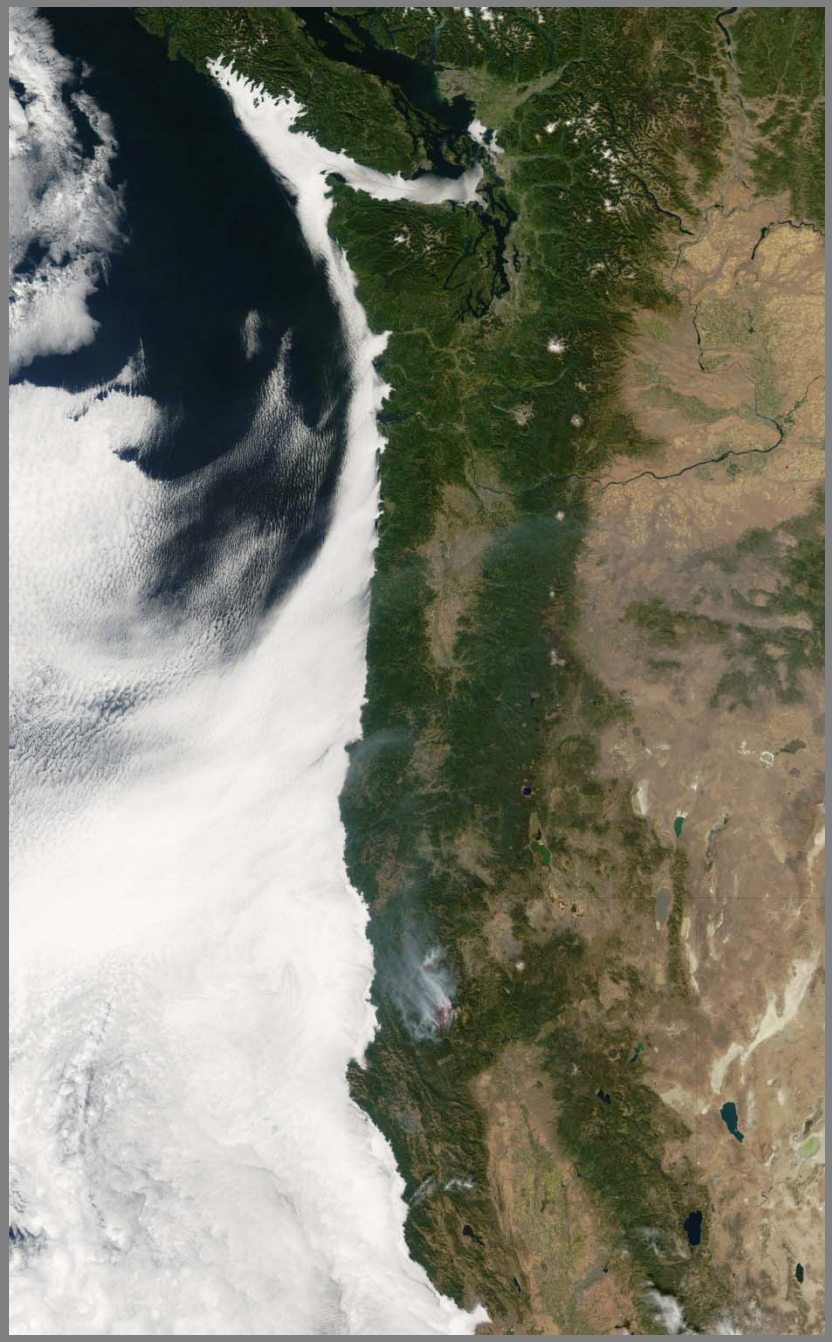
Difficulties with calcification of shells



Wind-driven upwelling during late spring and summer delivers cold, low DO, low pH, nutrient-rich water to the shoreline



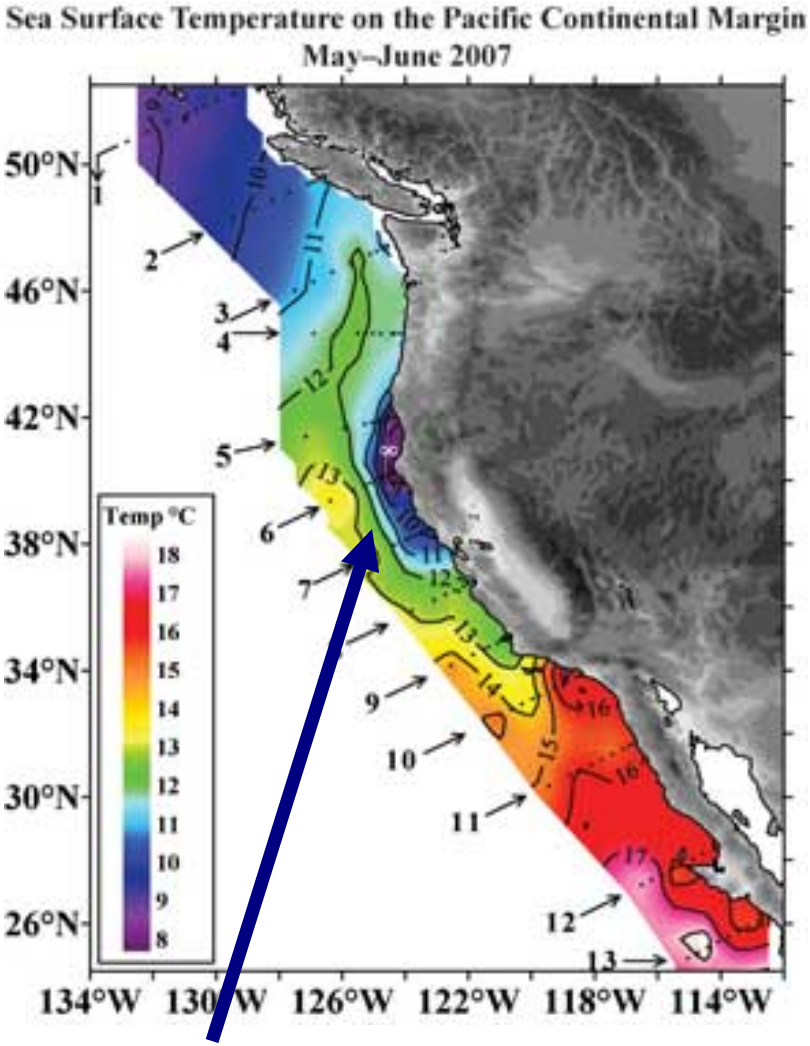
<u>General Question</u>: How does acidification of the nearshore ocean waters influence carbonate chemistry and pH dynamics in Pacific northwest estuaries?



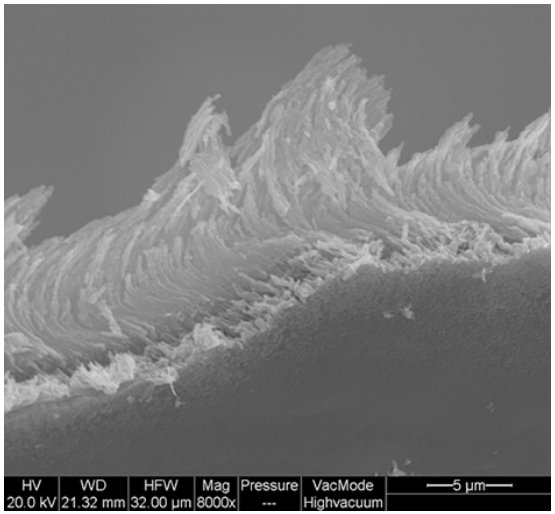
Southern Oregon / Northern California: An Ocean Acidification Hot Spot

Intense upwelling brings deep cold water to the surface nearshore:

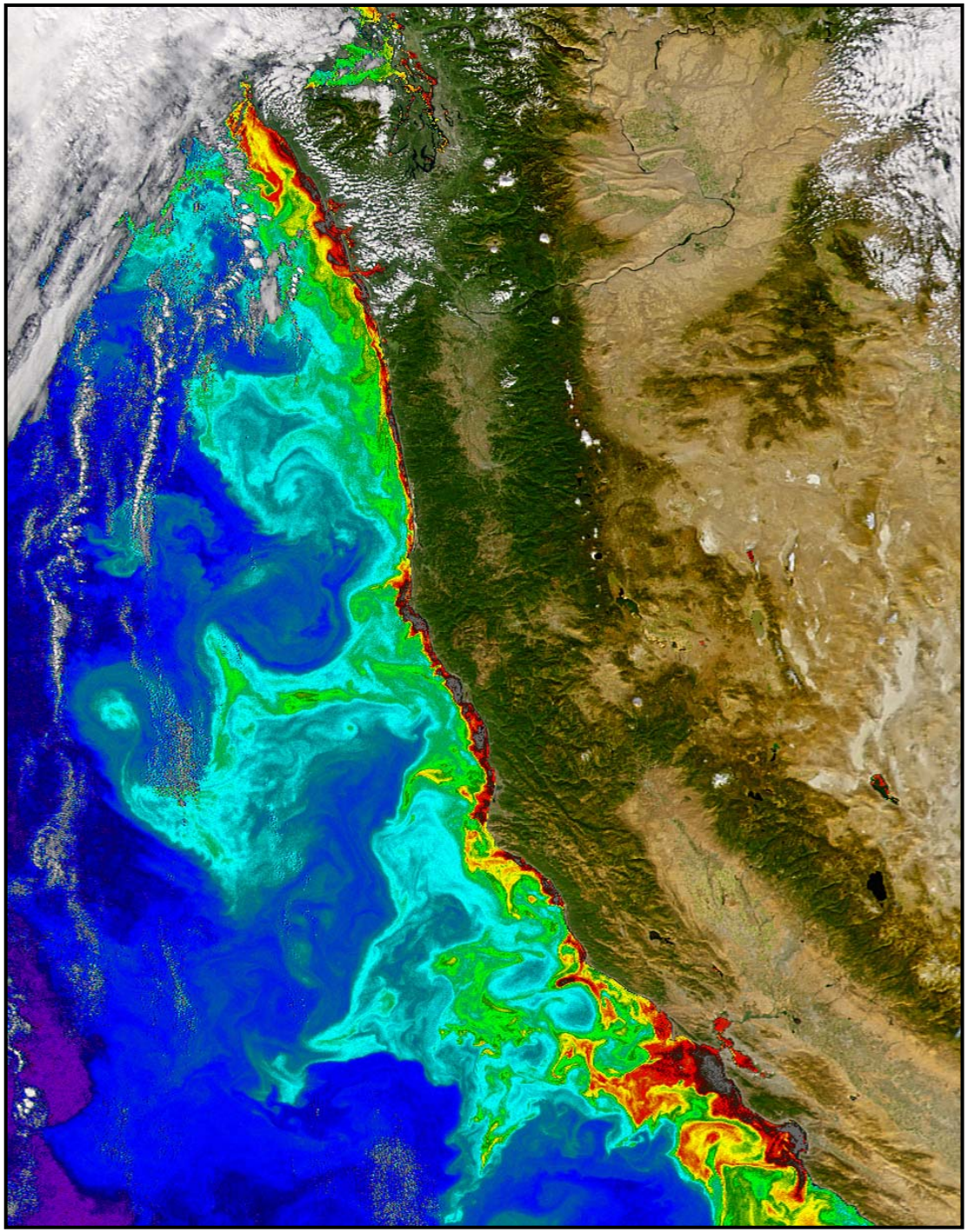
- **Low dissolved oxygen**
- **High nutrients**
- **Low pH**
- **Low aragonite saturation state**



Pteropod shell after exposure to acidified seawater



Low pH / low Ω aragonite water at surface results in exposure of nearshore marine organisms to corrosive seawater

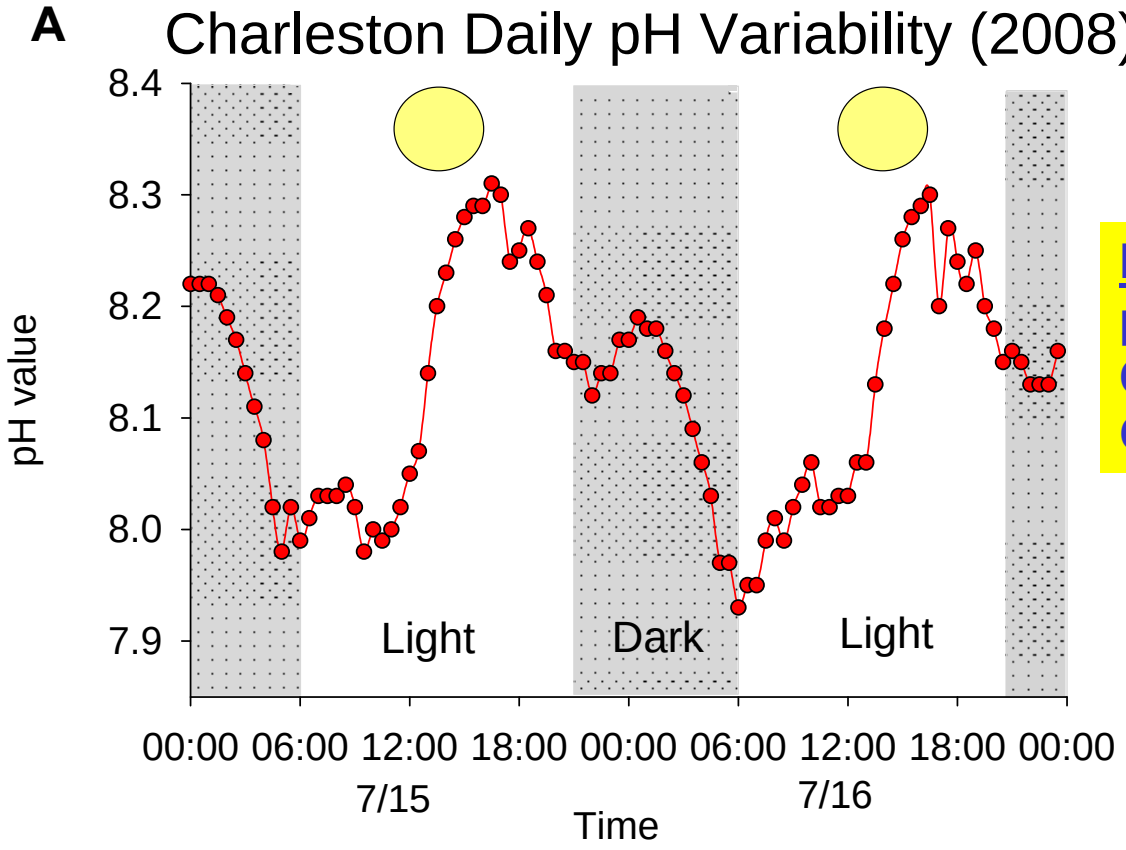


High biotic productivity associated with upwelling extends into estuaries

Does the South Slough estuary also exhibit long-term trends toward elevated pCO2 and decreased akalinity?

Daily Cycle of pH Changes within the South Slough Estuary: Charleston Bridge / 15-17 July 2008

A



Estuary pH values fluctuate on a daily cycle:

Daylight: produce O_2 / utilize CO_2 — **highest pH in light (early afternoon)**

lowest pH at dark (pre-dawn)

Daily pH cycle is driven by photosynthesis and respiration by estuarine phytoplankton, macroalgae, benthic diatoms, and eelgrass beds

Eelgrass: *Zostera marina*

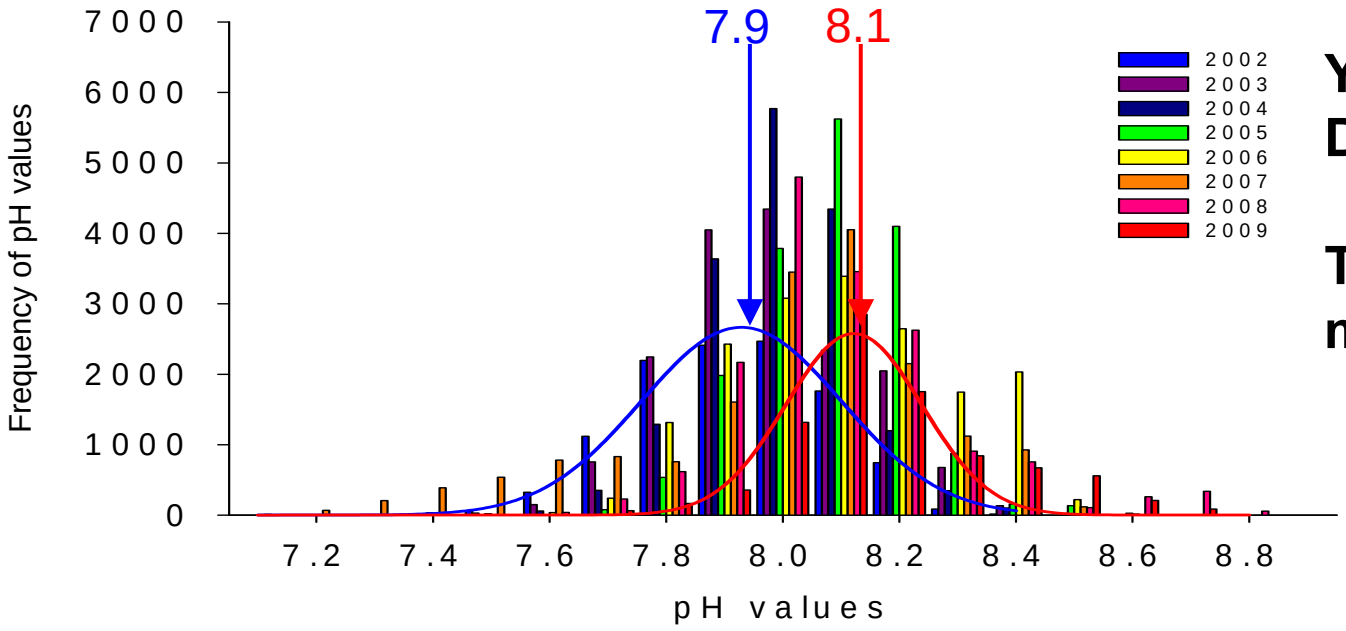
Time-series data reveal a long-term shift toward increased pH values within the marine-dominated region of the South Slough

Annual averages:

2002 / pH 7.9

2009 / pH 8.1

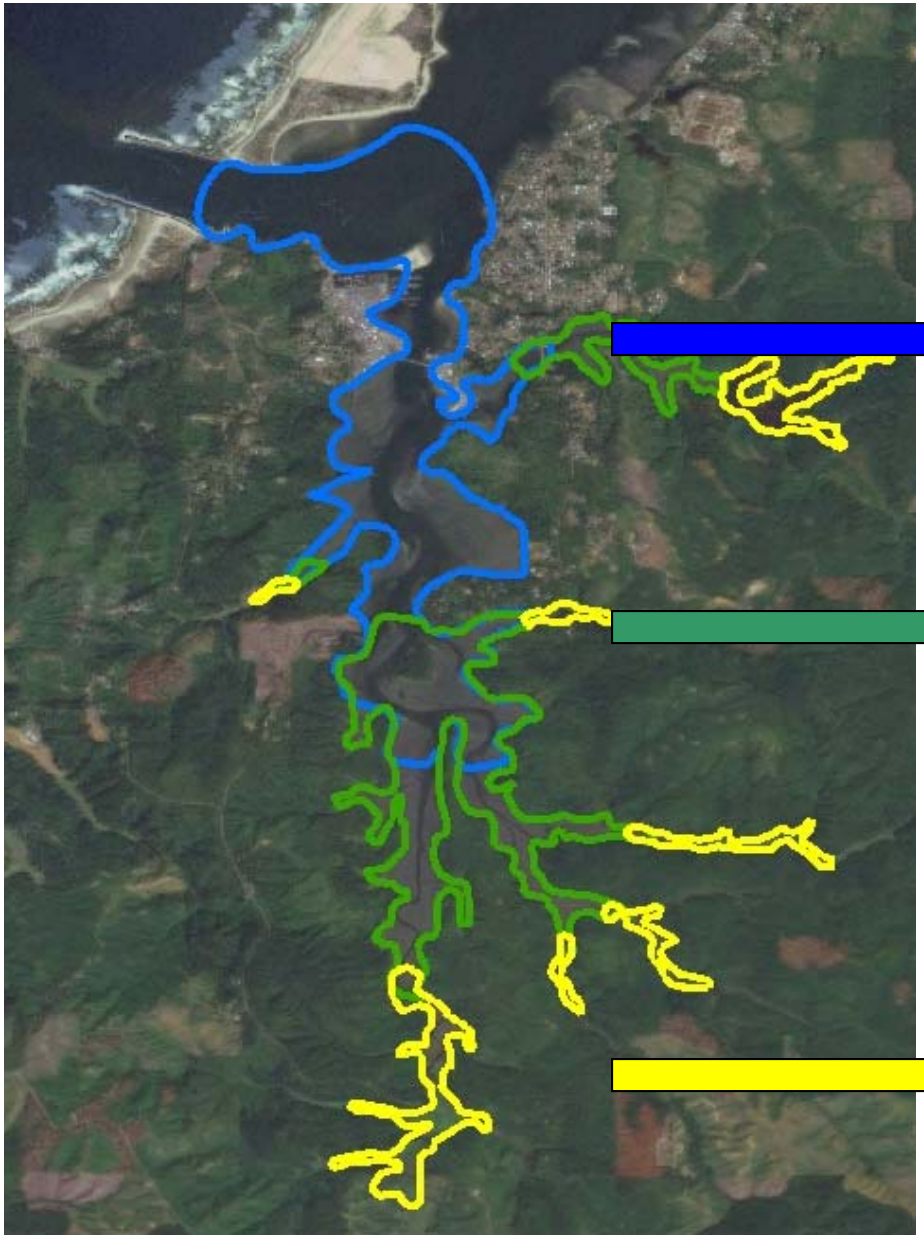
Charleston Bridge

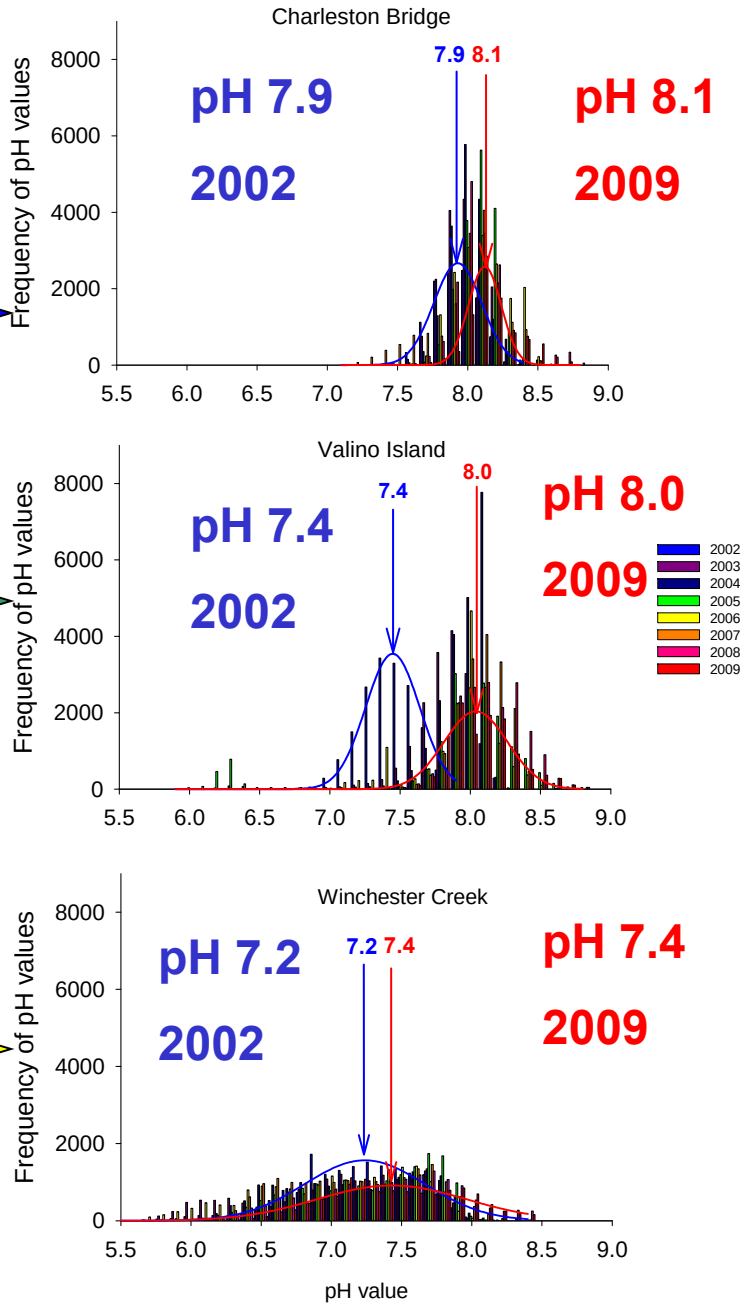


YSI-6600 EDS Datalogger

Total n = 208,400 pH measurements

South Slough: Changes in pH Values along the Estuarine Gradient

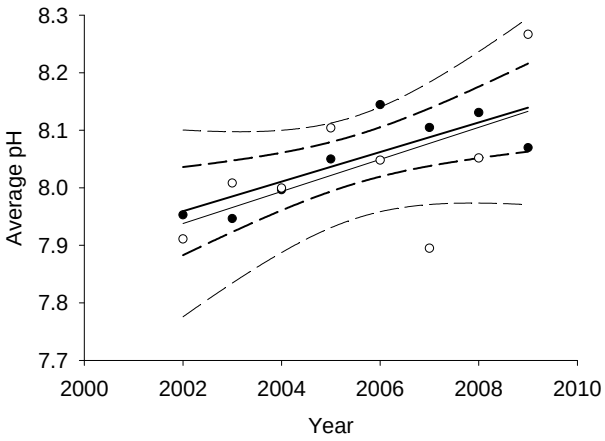


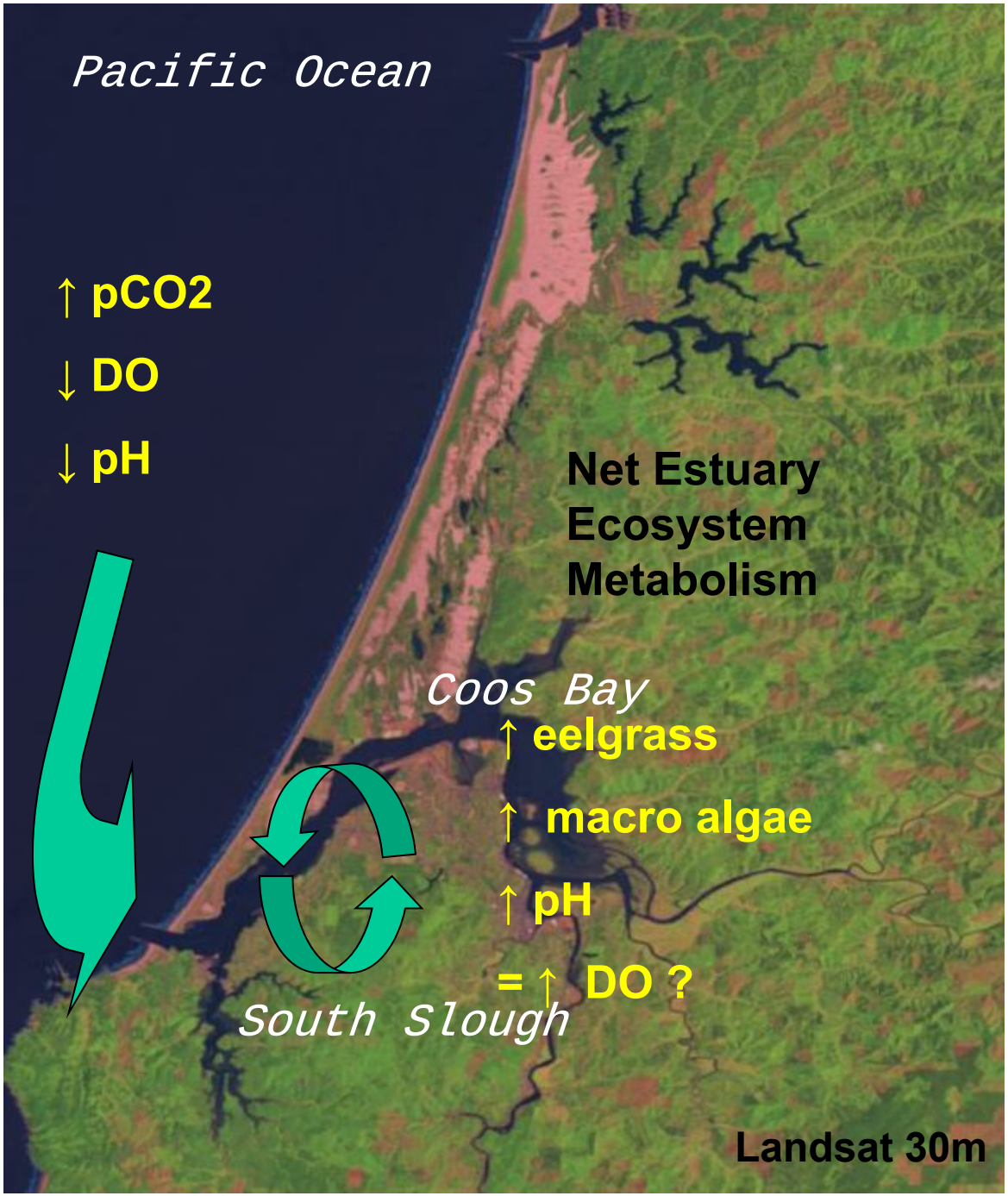


Coos Bay / South Slough Estuary

Working Hypothesis:

Long-term (8 yr) trend toward increased pH values is due to localized increases in production by eelgrass and algae, coupled with increases in the intensity of upwelling and ocean delivery of nutrients





Overview of the Ecology of Pacific Northwest Estuaries

Outline:

1. Definition of Estuary
2. Formation and Classification of Pacific Northwest Estuaries
3. Physical Characteristics of Estuaries
4. Biogeochemistry and Nutrient Cycling
5. Ecology of Major Estuarine Habitats
    - *Salt marshes*
    - *Eelgrass Beds*
    - *Tideflats*
    - *Water column*
    - *Artificial Surfaces*
6. Habitat Alteration, Loss, and Restoration
7. Potential Effects of Climate Change on Estuaries

PNW estuaries are diverse, dynamic, and complex

The End!