Farming Shellfish in a Changing Ocean:

Understanding the Effects of Acidified Seawater on the Pacific Northwest Shellfish Industry

Pacific Coast
SHELLFISH GROWERS ASSOCIATION
Partners with Mother Nature
sustainably farmed
oysters, clams, mussels, scallops

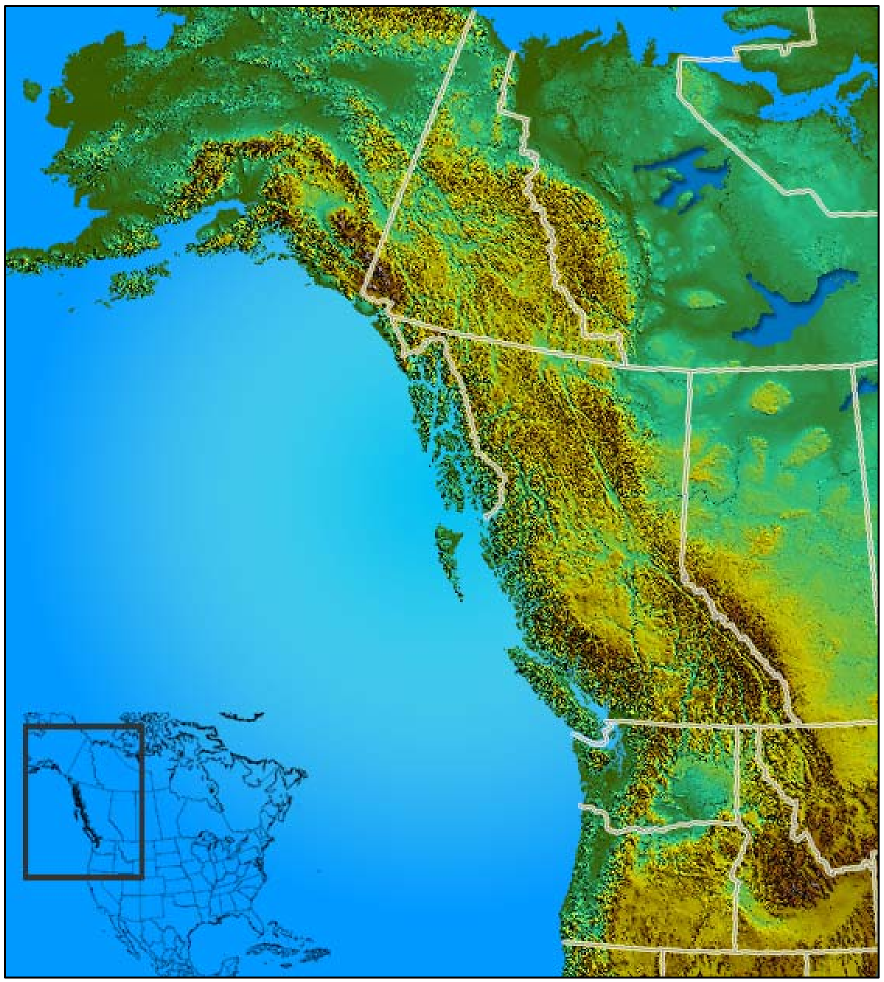
Pacific Northwest Shellfish Industry

- Commercial harvest of shellfish in the Pacific Northwest dates from the 1860s

- Currently provides over 3000 family wage jobs for workers in WA, OR, CA, AK, and Hawaii

- Farm gate value of $110 million per year, representing a total contribution of $278 million annually to rural coastal communities

Pacific Coast Shellfish Growers Association (PCSGA)

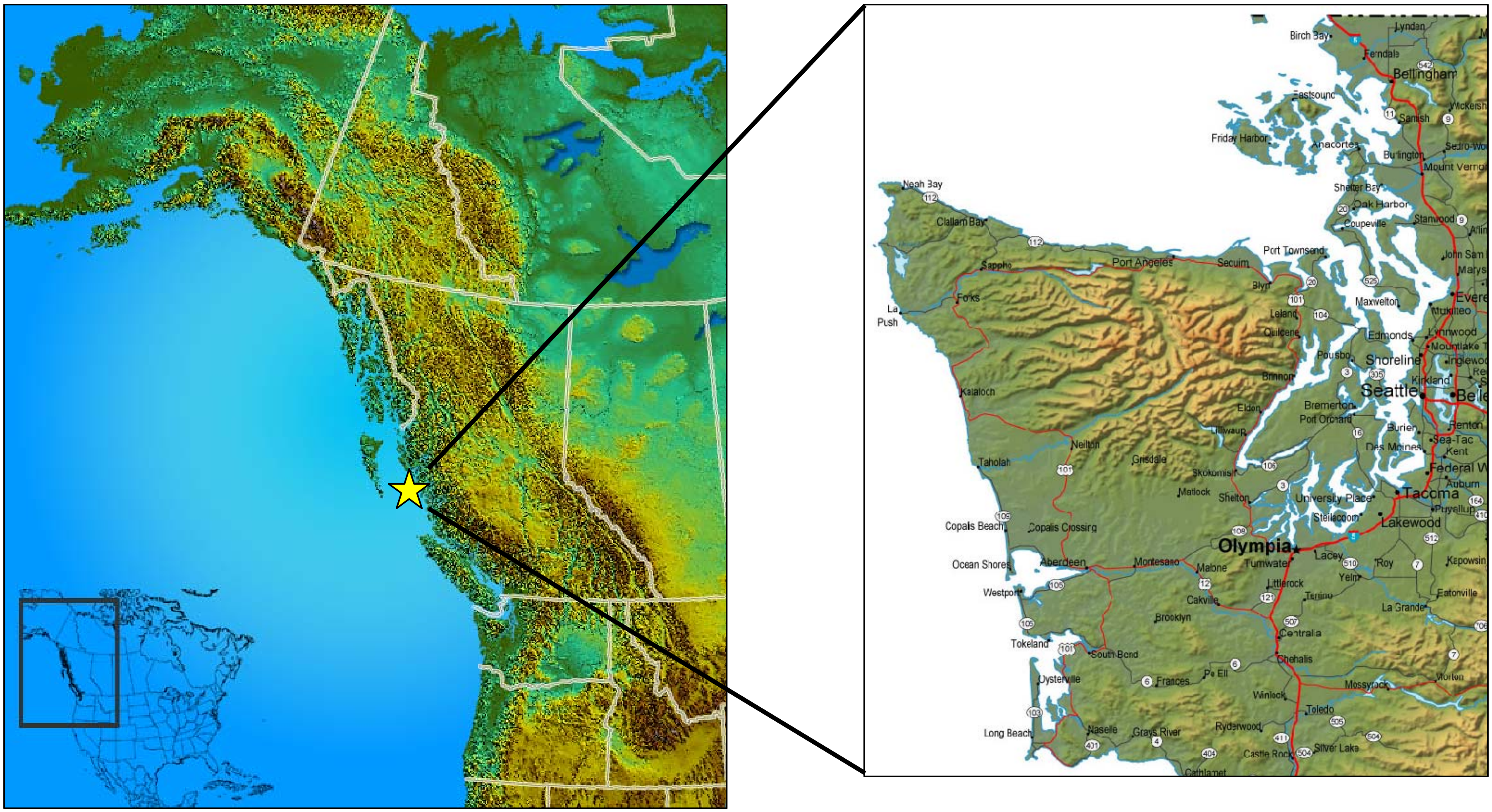


Represents shellfish growers in Oregon, Washington, Alaska, California, and Hawaii

Over 100 member companies growing Pacific and Kumomoto oysters, Manila and Geoduck Clams, and mussels

Oysters	94 million lbs/yr
Manila clams	8.5 million lbs/yr.

Pacific Coast Shellfish Growers Association (PCSGA)

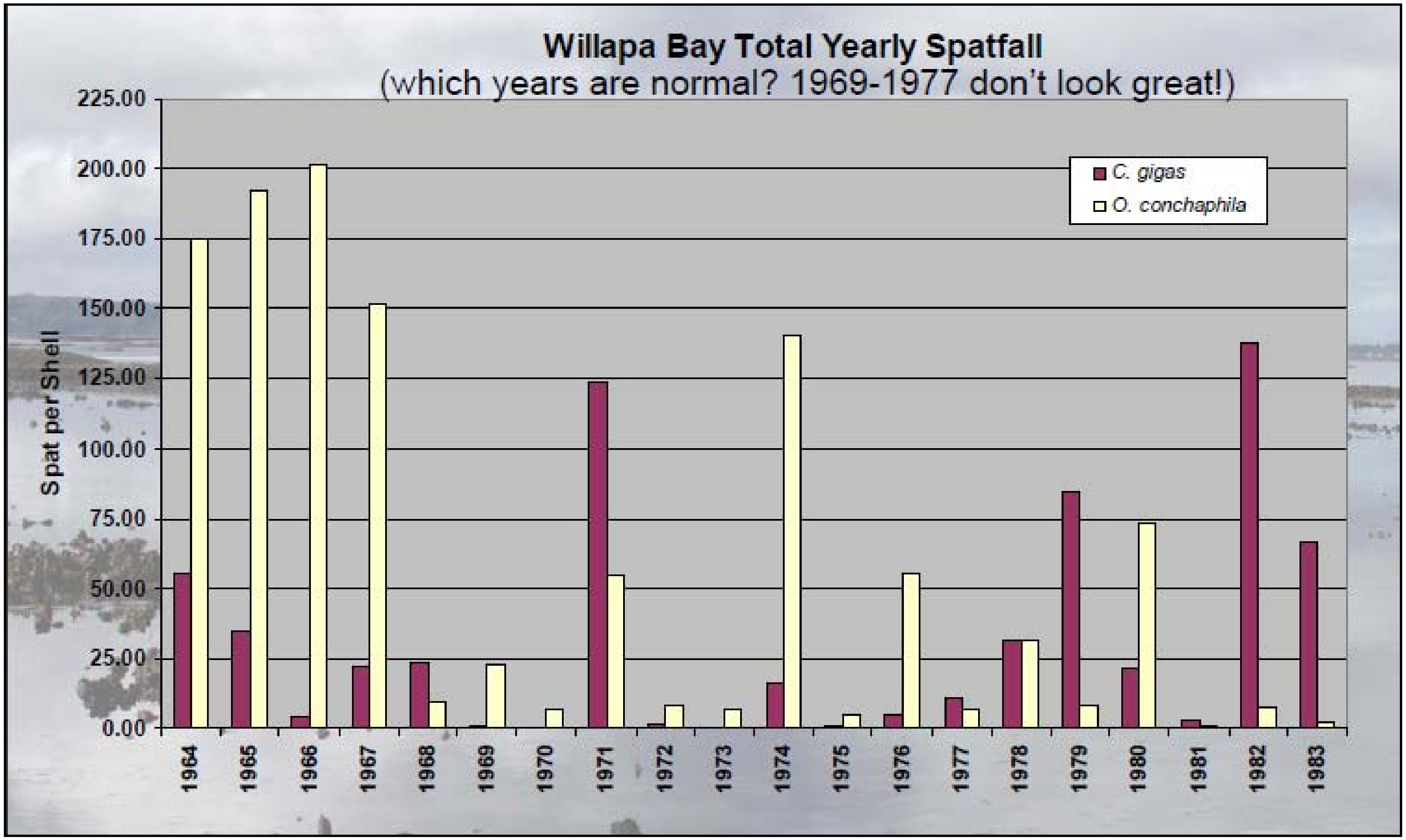


Oyster Farming in Willapa Bay

Adapting to a changing ocean

Farmers like Brian Sheldon, whose family has relied on natural recruitment for three generations, are now being forced to look for new sources of seed

Willapa Bay Natural Recruitment



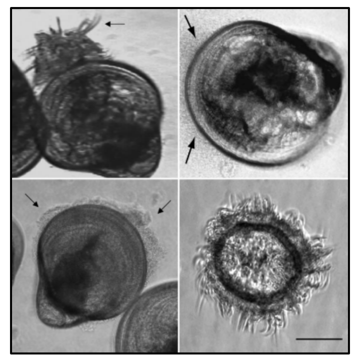
Commercial Hatchery Production

- Three major commercial hatcheries in the Pacific NW
  - Two are located in close proximity in Hood Canal, WA
  - Whiskey Creek Shellfish Hatchery in Netarts Bay, OR

- Whiskey Creek Shellfish Hatchery
  - 30 year history of consistent production
  - Produces 75-80% of all oyster larvae sold to independent growers in the Pacific NW
  - Experienced losses in 2007-2008 that reduced production to 25% of normal levels

Understanding the causes of larval mortality at Whiskey Creek

- Initial efforts focused on the marine bacterium *vibrio tubiashii* as the sole source of mortality in the hatchery



$>10^6$ cfu/ml in seawater samples from Netarts Bay

Estes, et al 2004

- In 2008, shifted focus to understanding the effects of low pH, upwelled seawater on larval survival and growth

Arrows show the wind speed and direction

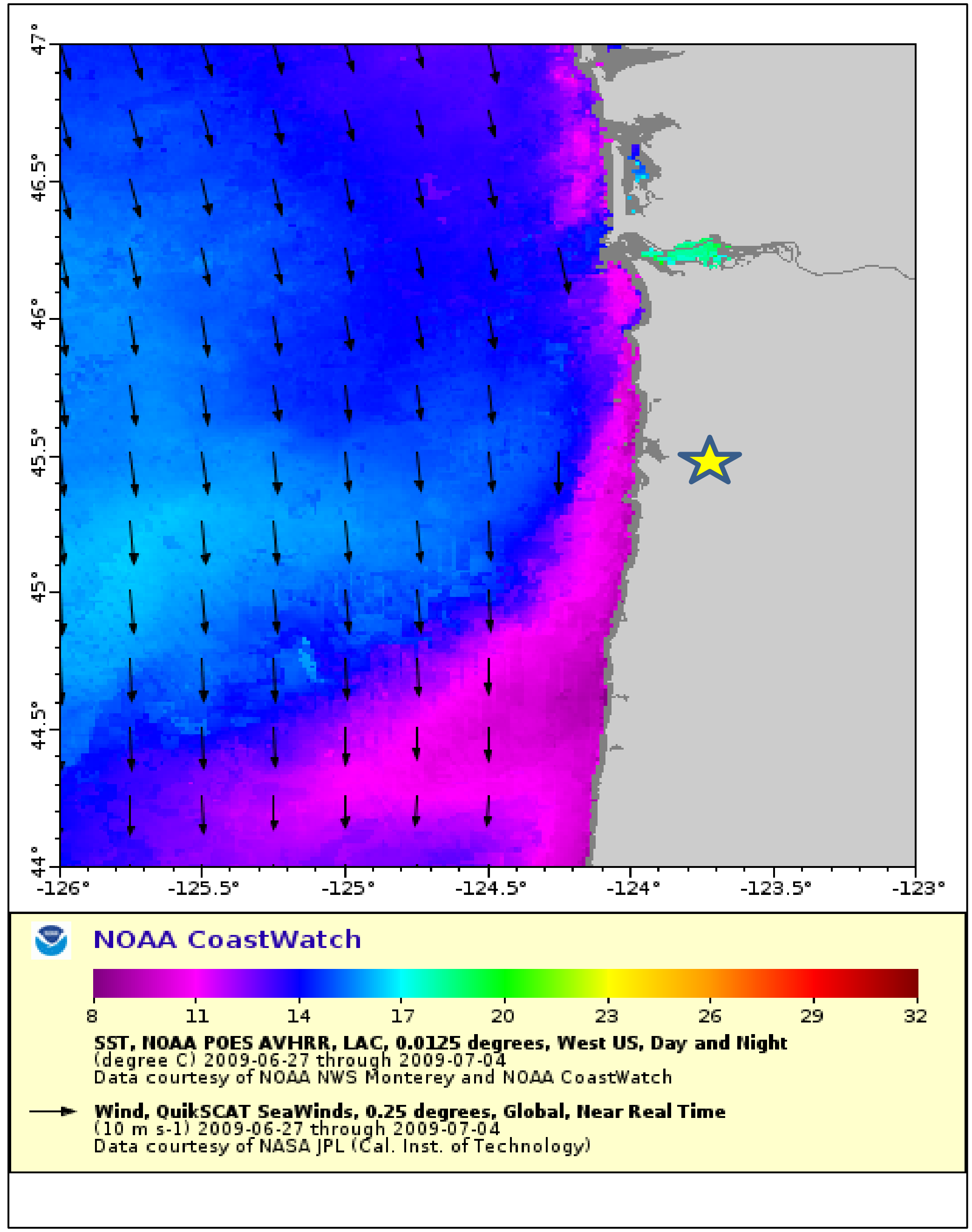
the longer the arrow, the stronger the wind

Winds from the North produce Upwelling of cold seawater

Colors show the Sea Surface Temperature (SST)

Blue ~ 14 deg C

Purple ~ 10 deg C (upwelled seawater)



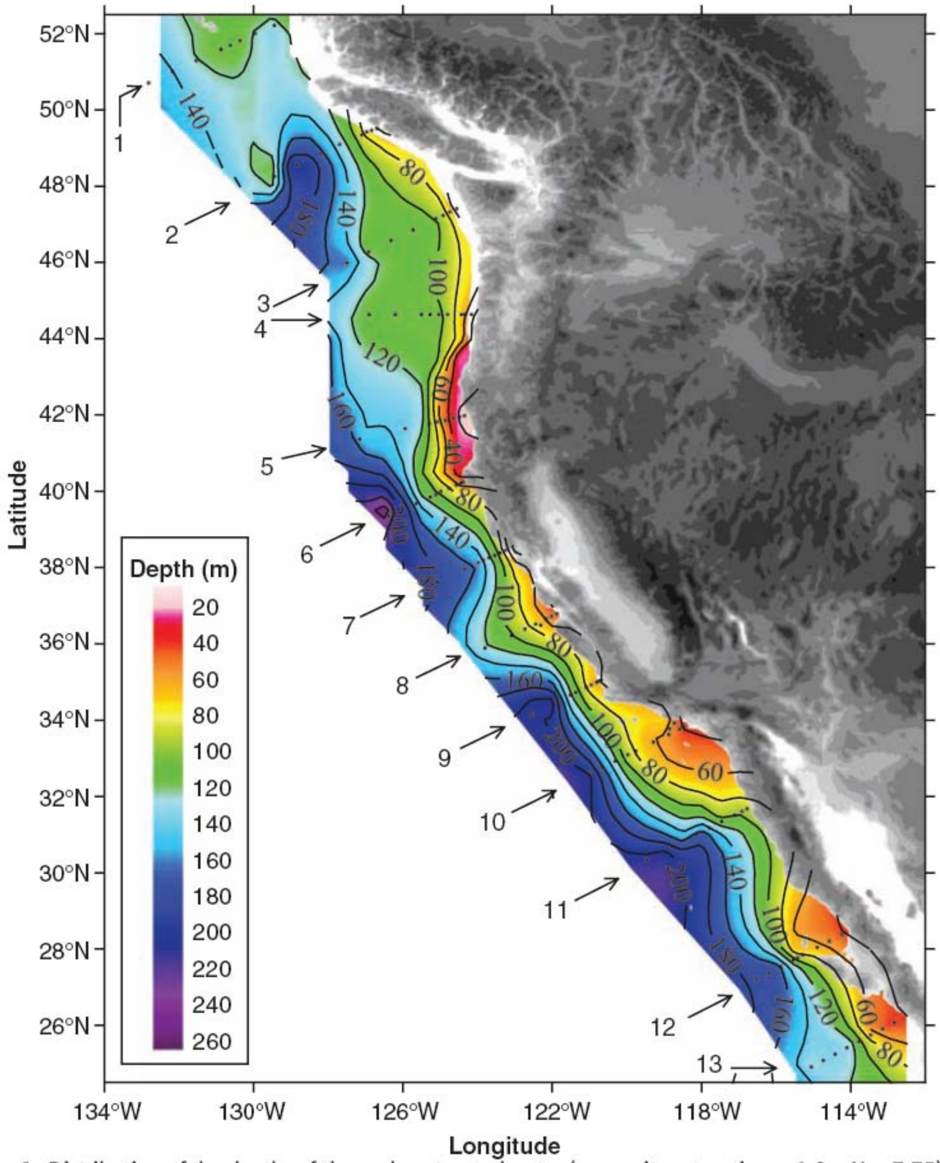


Fig. 1. Distribution of the depths of the undersaturated water (aragonite saturation < 1.0; pH < 7.75) on the continental shelf of western North America from Queen Charlotte Sound, Canada, to San Gregorio Baja California Sur, Mexico. On transect line 5, the corrosive water reaches all the way to the surface in the inshore waters near the coast. The black dots represent station locations.

As noted, the North Pacific aragonite saturation horizons are among the shallowest in the global ocean (3). The uptake of anthropogenic CO2 has caused these horizons to shoal by 50 to
100 m since preindustrial times so that they are within the density layers that are **currently being upwelled along the west coast of North America.**

These results indicate that the upwelling process **caused the entire water column shoreward of the 50-m bottom contour to become undersaturated with respect to aragonite**, a condition that was not predicted to occur in open ocean surface waters until 2050 (5).

Feely et al 2008

Saturation State- the 'Magic Number' for dissolving shell

$$\Omega = [Ca^{2+}][CO_3^{2-}] / K_{sp}$$

$\Omega > 1$ animals can make shell

$\Omega >> 1$ easier to make shell (Langdon & Atkinson, 2005)

$\Omega < 1$ shell dissolves

Adult oyster shell	-	calcite	small K_{sp}	**harder to dissolve**
Larval oyster shell	-	aragonite	bigger K_{sp}	**easier to dissolve**
Young oyster larvae	-	ACC	really big K_{sp}	**<u>really</u> easy to dissolve**

(Carriker & Palmer, 1979 Weiss et al 2002)

Defining the problem

- Scenario 1 - Direct Effects of Upwelling

  - Slow growth and mass mortality of small larvae after 10-12 days
  - Initial survival and swimming behavior of small larvae is often quite normal
  - Elevated pCO2 concentrations (and lower pH)
  - NO *vibrio* blooms in the bay
  - NO major mortality events with larger larvae

  Upwelling -> Death of small larvae

- Scenario 2 - Indirect Effects of Upwelling

  - Mortality of larvae of all sizes in the hatchery
  - Extremely high pCO2 concentrations (values >2500 uatm observed)
  - Persistent Upwelling leads to Hypoxia
  - Decaying organic matter supports bacteria blooms

  Upwelling -> Algae Blooms -> Dieoff -> Decay -> Low O2 -> Death

Tracking the Performance of Small Larvae in the Hatchery

<u>GROWTH</u>- days required to reach 120 um

when larvae reach 120 microns and begin forming an umbone, they are 'out of the woods'

hatchery maintains detailed growth records

-larvae are measured at each water change

<u>SURVIVAL</u>- tanks of DH → tanks of +100 screen

coarse indicator of survival from DH past 120 microns

Normal- 4 tanks DH produces 6 tanks +100 larvae

Bad Water- 4 tanks DH yields 1 tank of +100 larvae

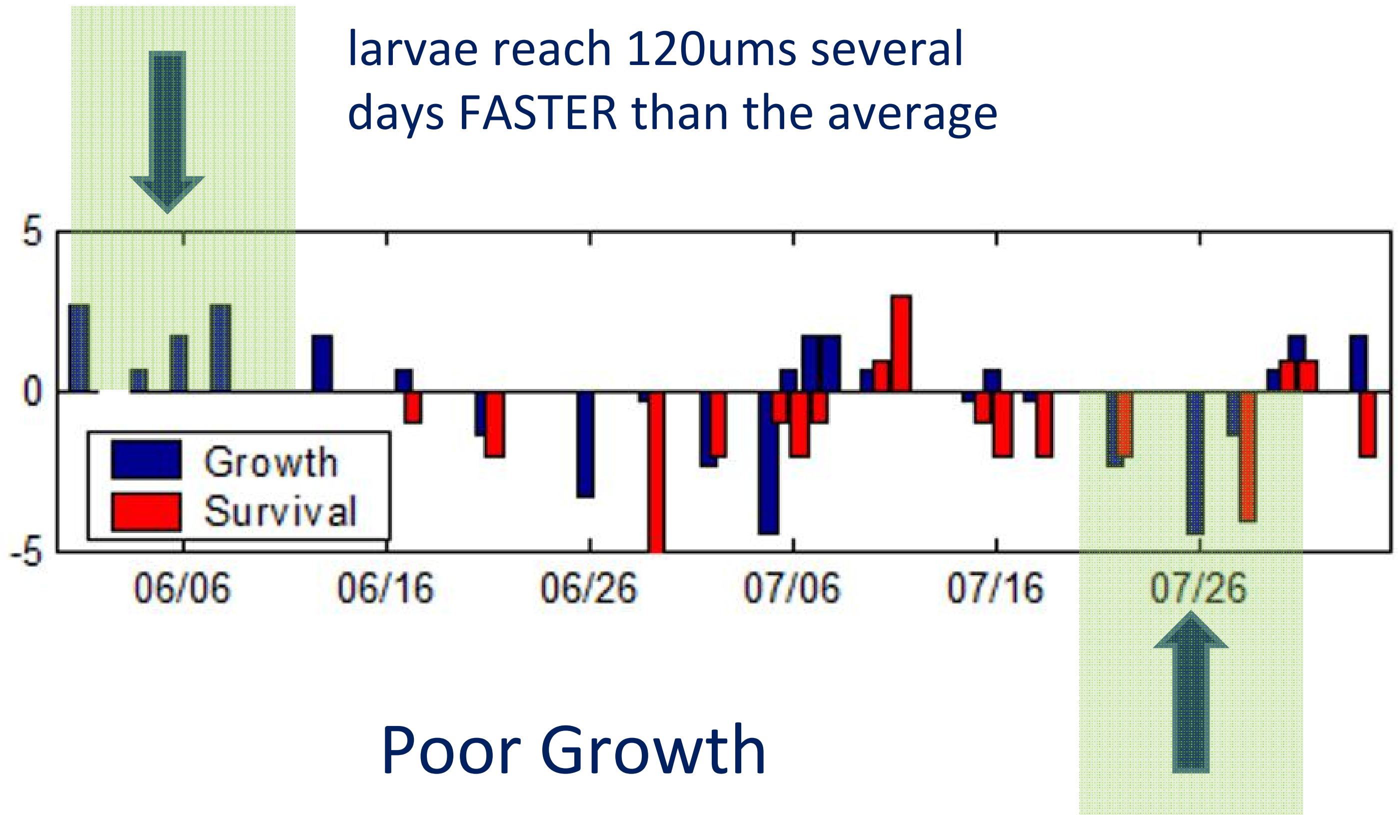
Variation in # of days required reach 120um

Good Growth

larvae reach 120ums several
days FASTER than the average

Days ahead
of the average

Days slower
than the average



Poor Growth

Average days to 120um = 10 days

larvae reach 120ums several
days SLOWER than the average

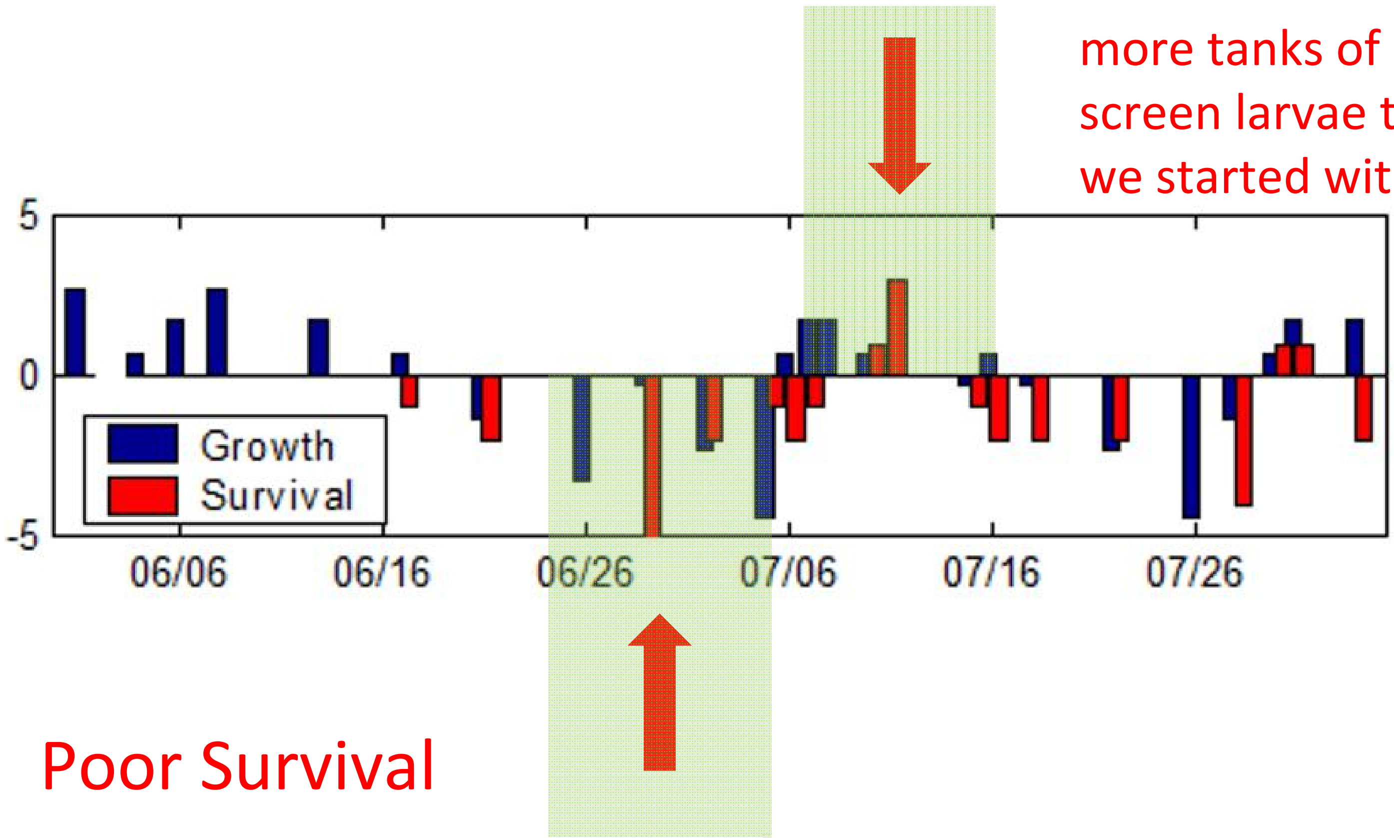
Variation in # tanks from DH to +100 screen

Good Survival

more tanks of +100 screen larvae than we started with

Gaining tanks

Losing tanks



Poor Survival

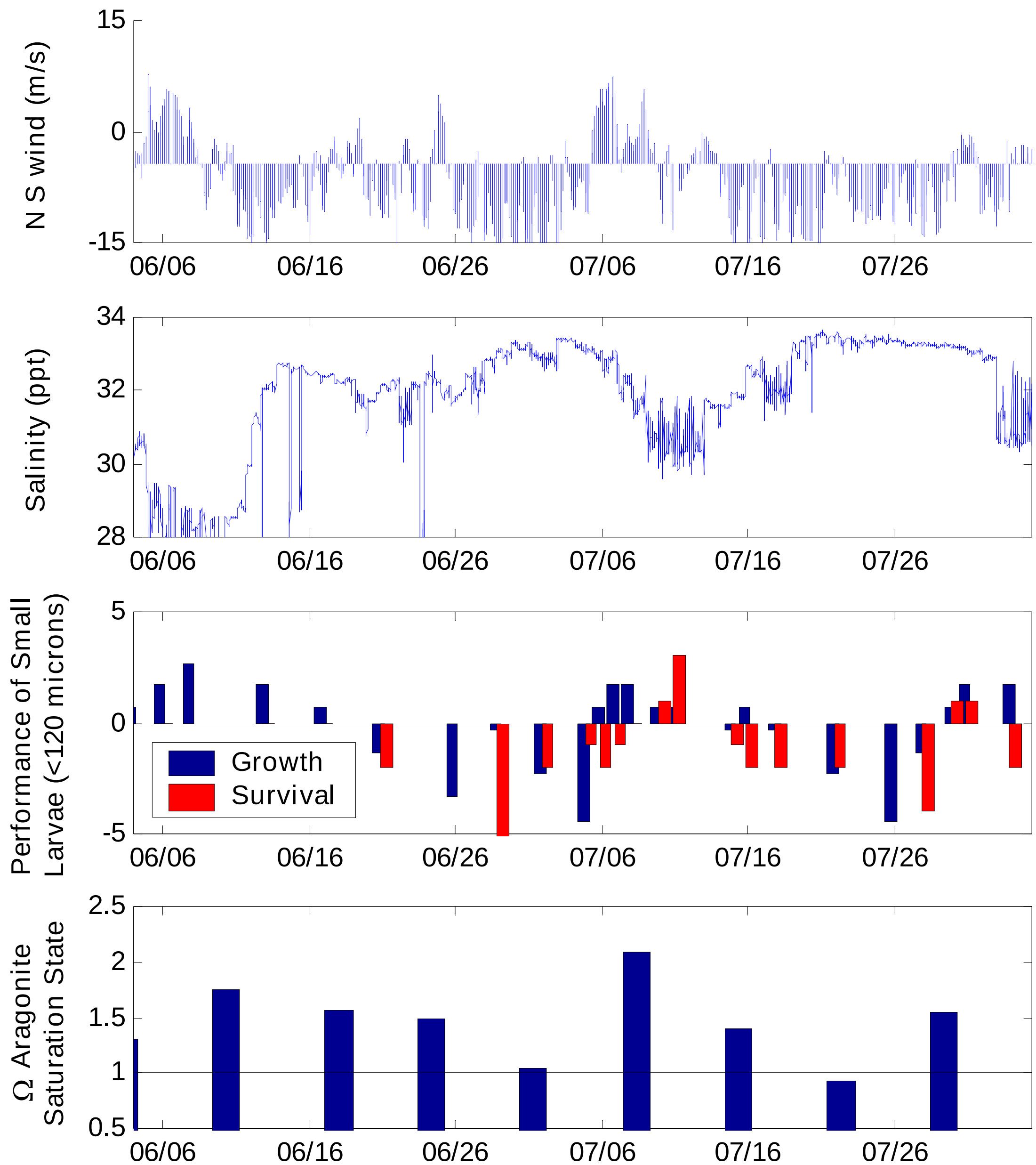
less tanks of +100 screen larvae than we started with

N/S Winds

Salinity

Performance of Small Larvae

Ω – Aragonite Saturation State

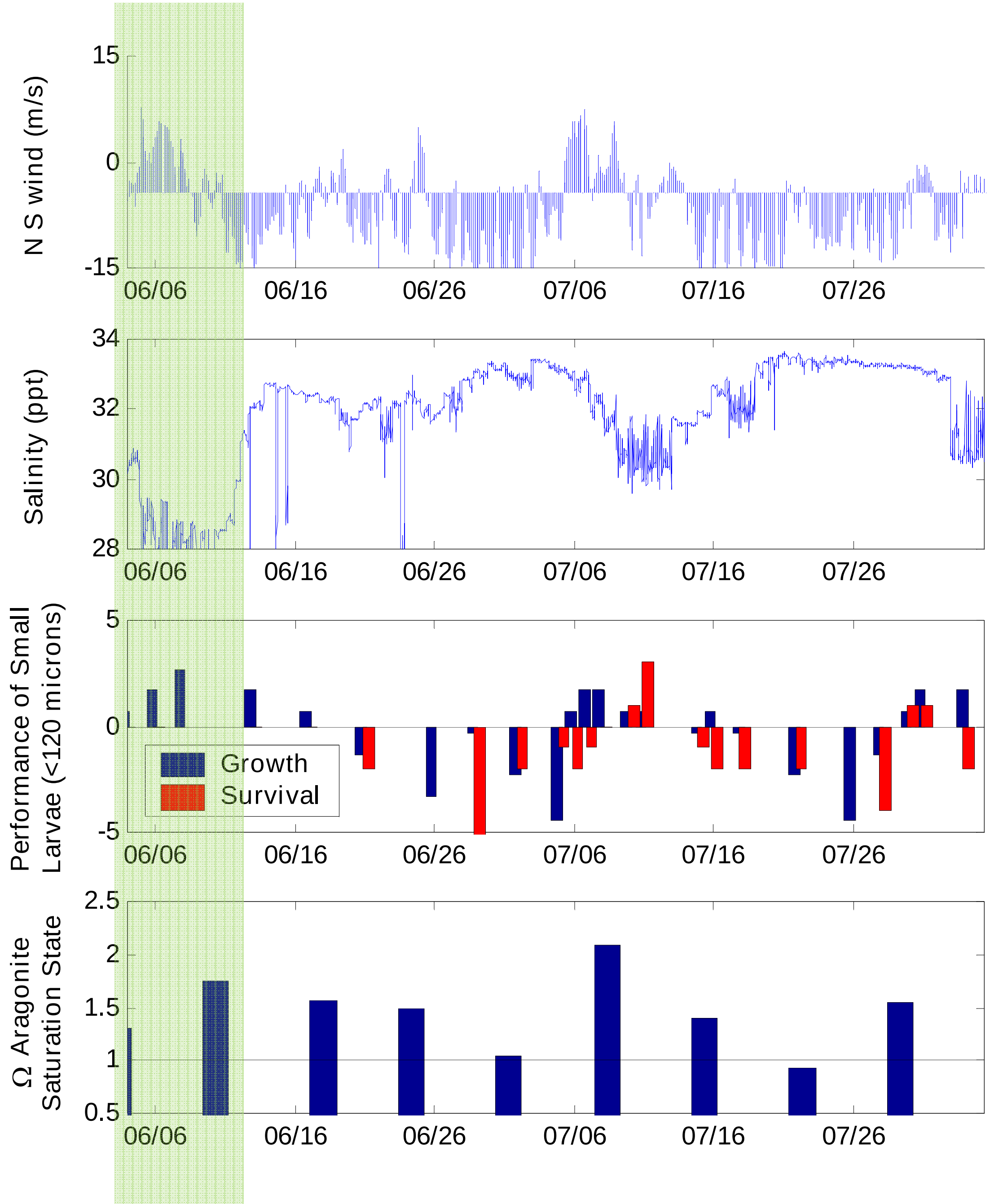


Winds from the South

Lower Salinity 28-30 ppt

Fast Growth of Small Larvae

$\Omega > 1.7$

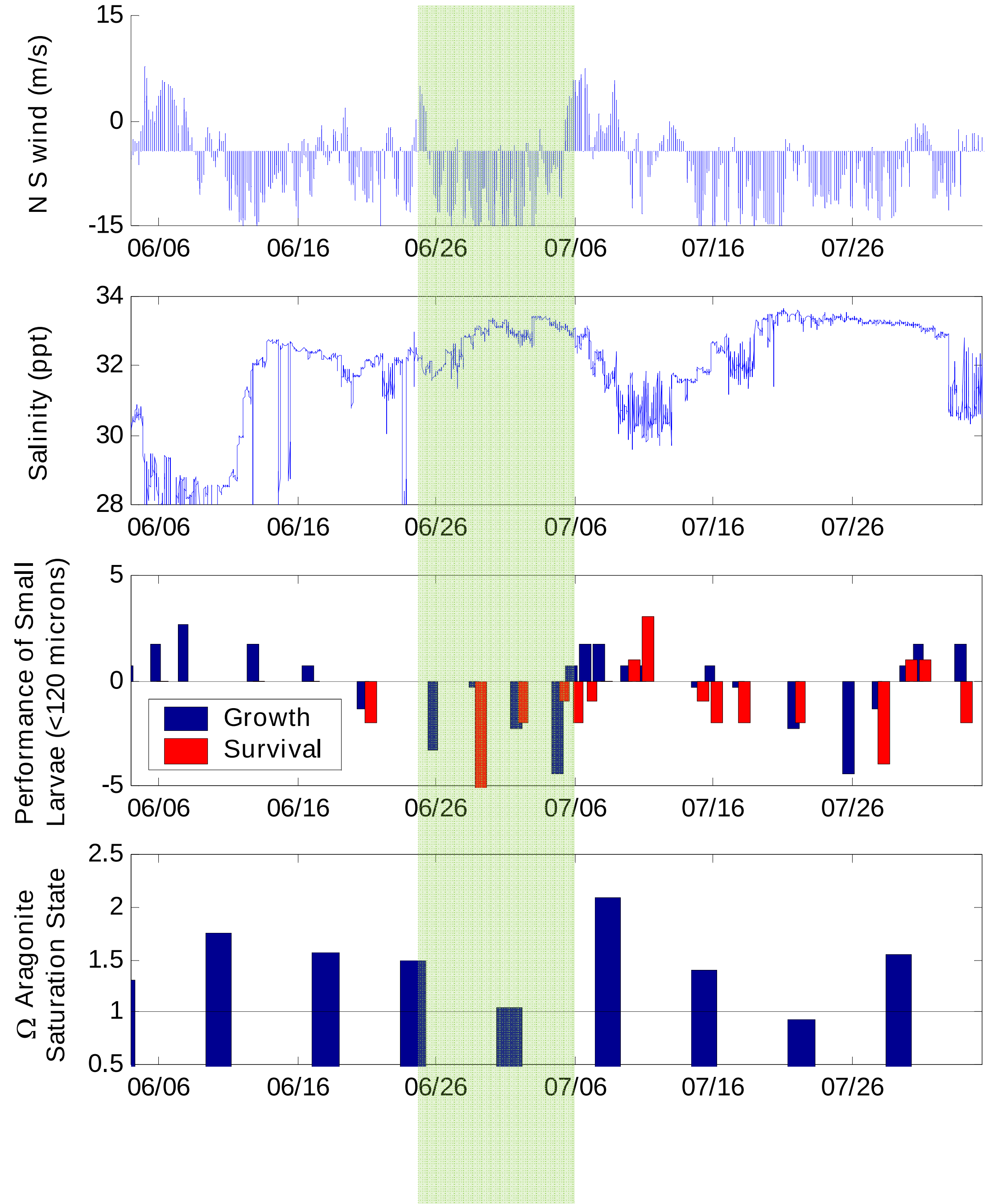


Winds from the North

High Salinity >33 ppt

Poor Growth and Survival of Small Larvae

Ω < 1 in AM Shell dissolves

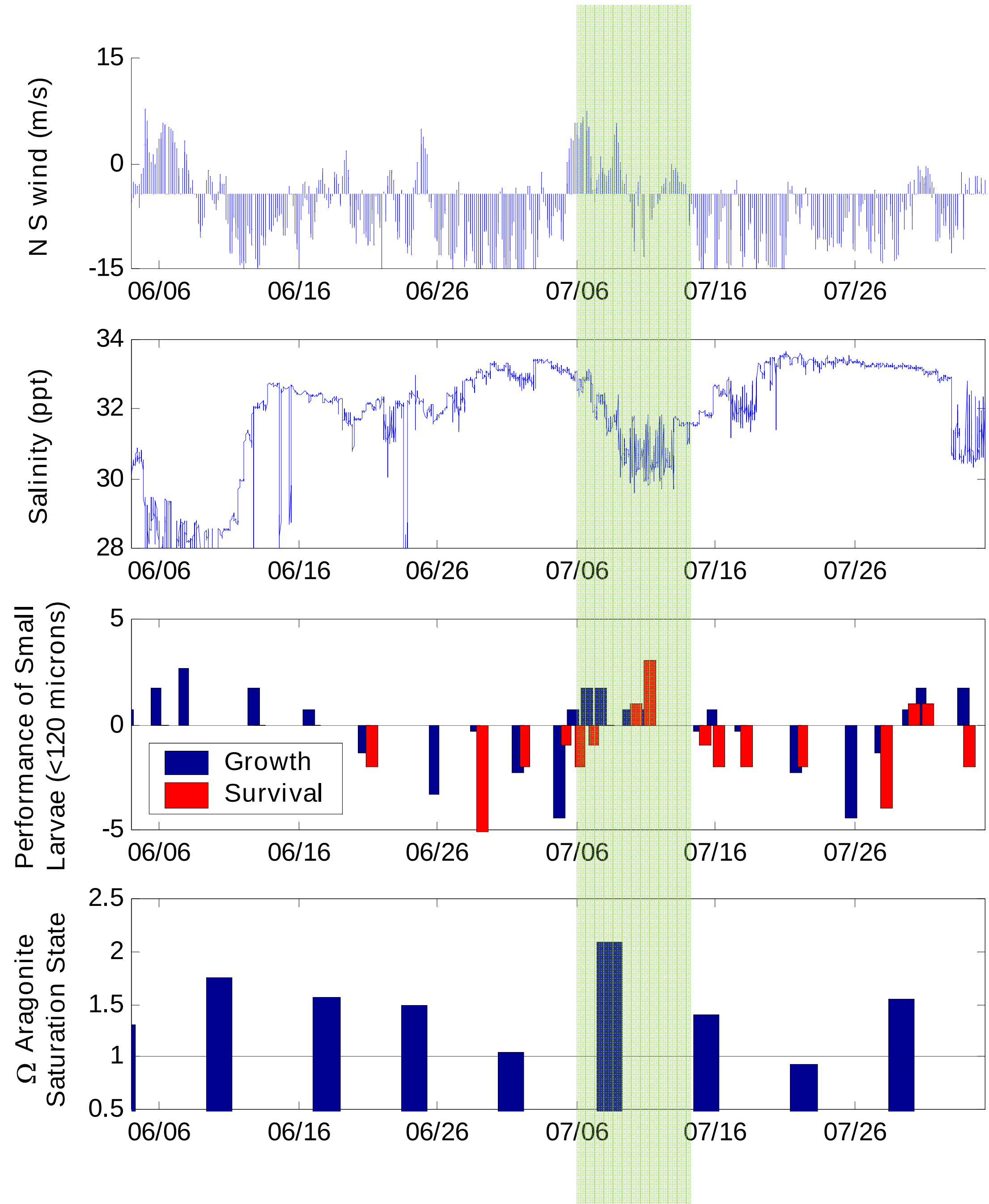


Winds from the South

Lower Salinity
30-31 ppt

Fast Growth and Good Survival of Small Larvae

Ω > 2
Easy to form shell

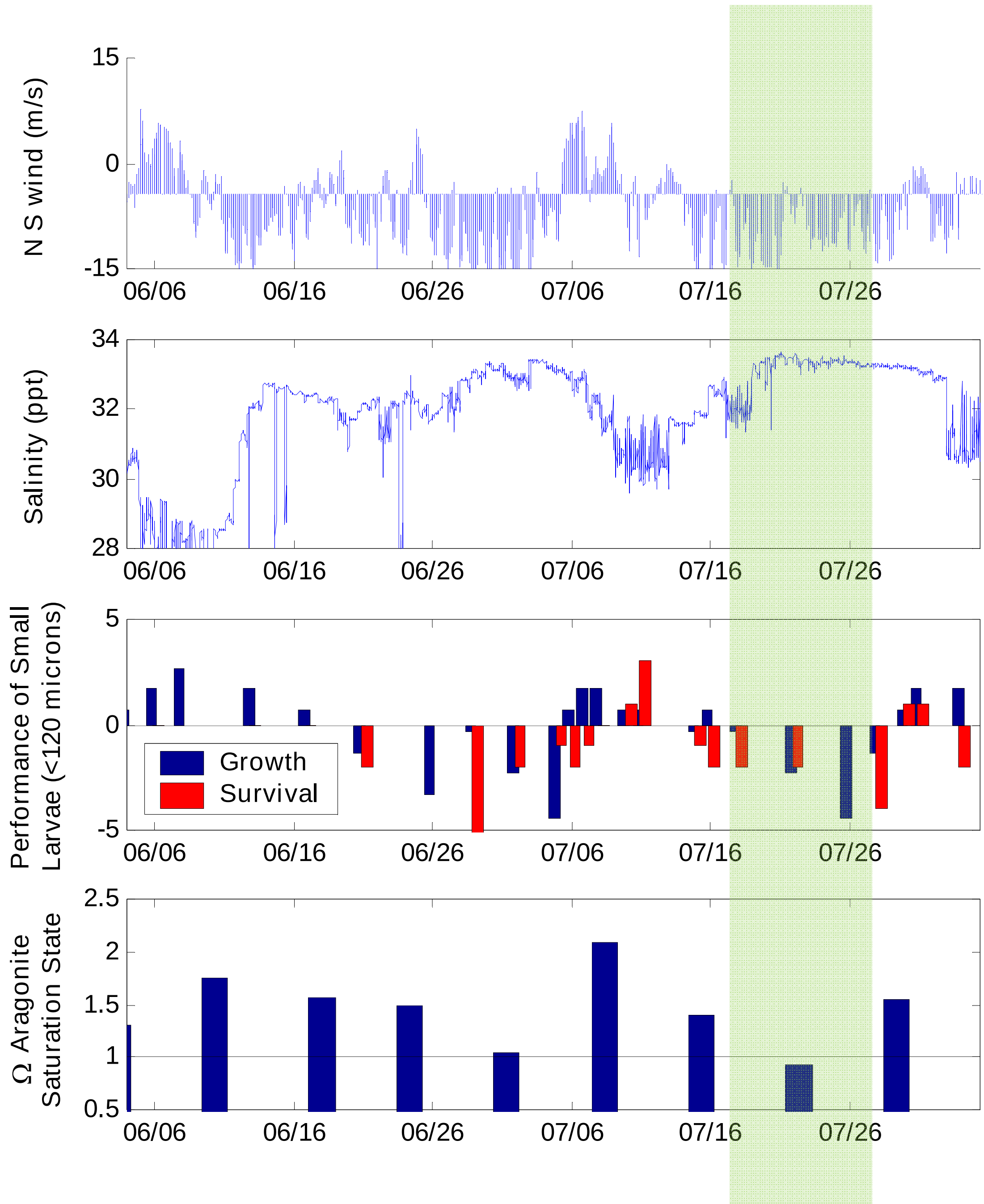


Winds from the South

High Salinity >33.5 ppt

Slow Growth and Poor Survival of Small Larvae

$\Omega < 1$
Shell dissolves

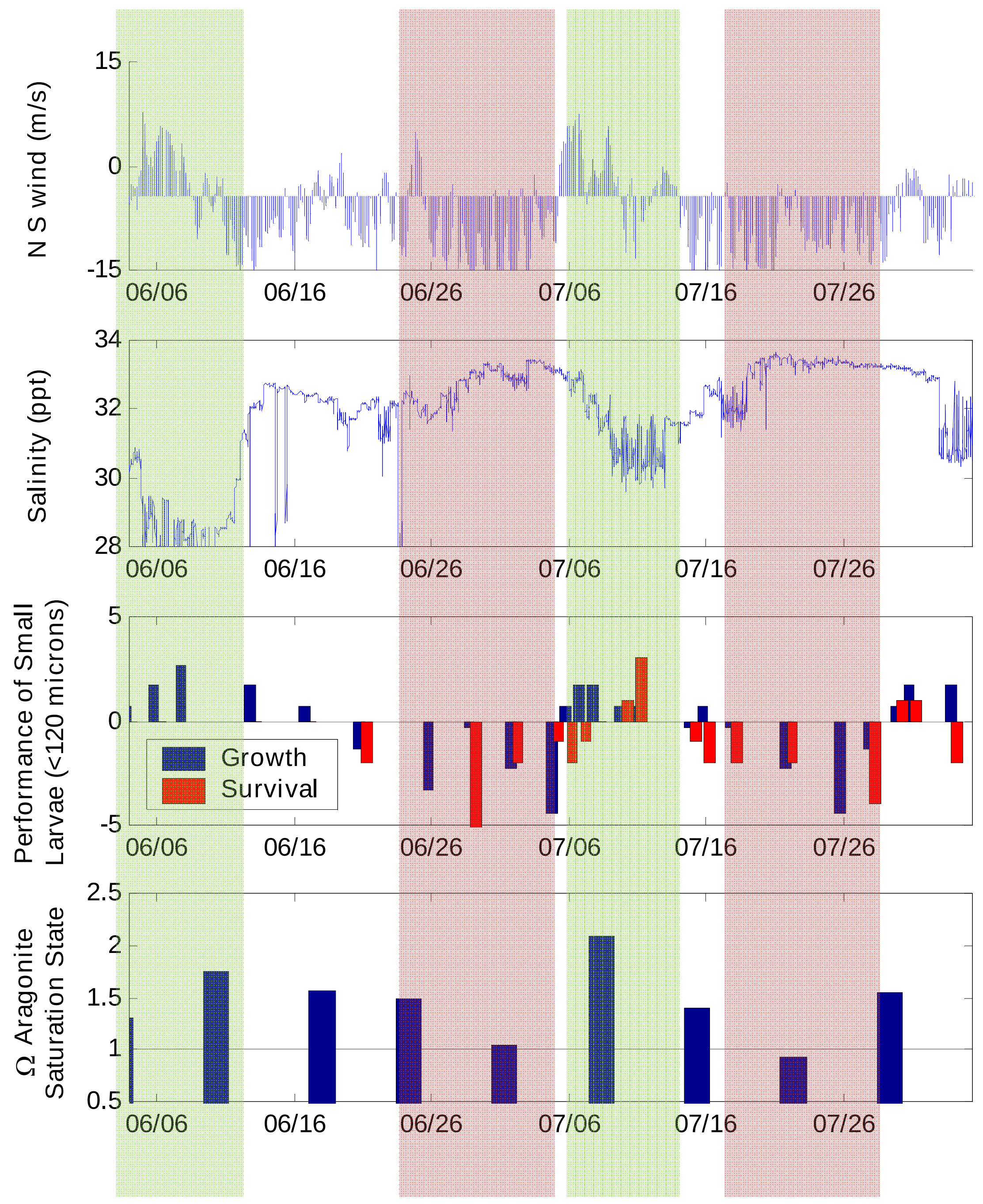


South winds produce downwelling

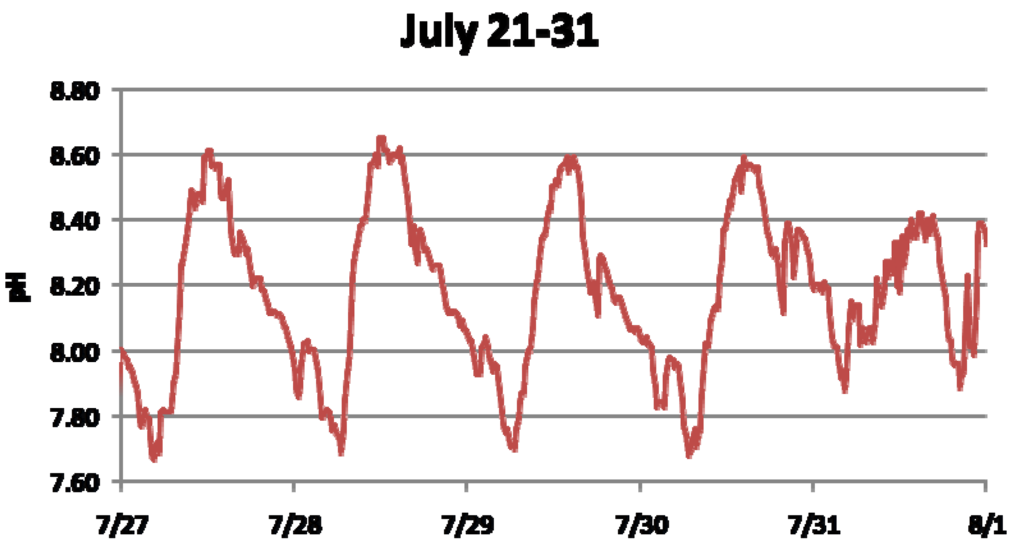
Lower salinity
Ω>>1 (easy to form shell)
Fast growth and good survival of small larvae

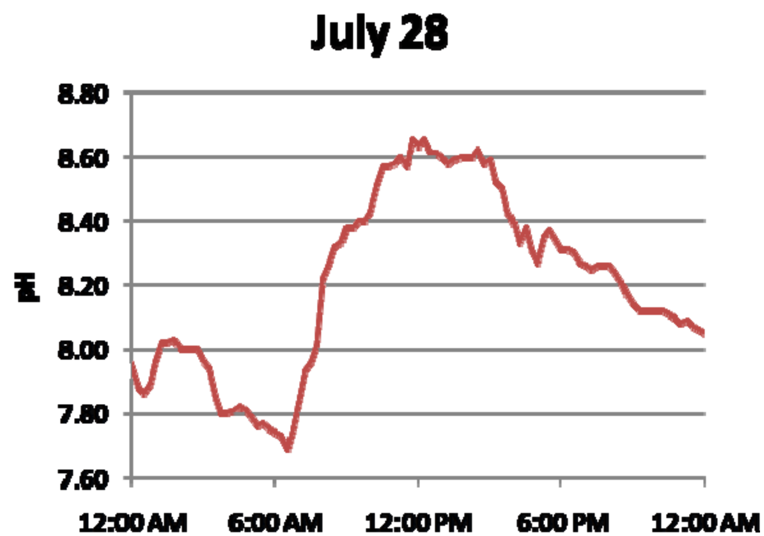
North winds produce upwelling

Higher salinity
Ω <= 1 (difficult or impossible to build shell)
Poor growth and mass mortality of small larvae



Daily Variability in pH and Ω





Daily minimum pH – **7.65**

6:00-7:00 AM

Daily maximum pH – **8.6**

1:00-3:00 PM

Average AM Ω = 1.14

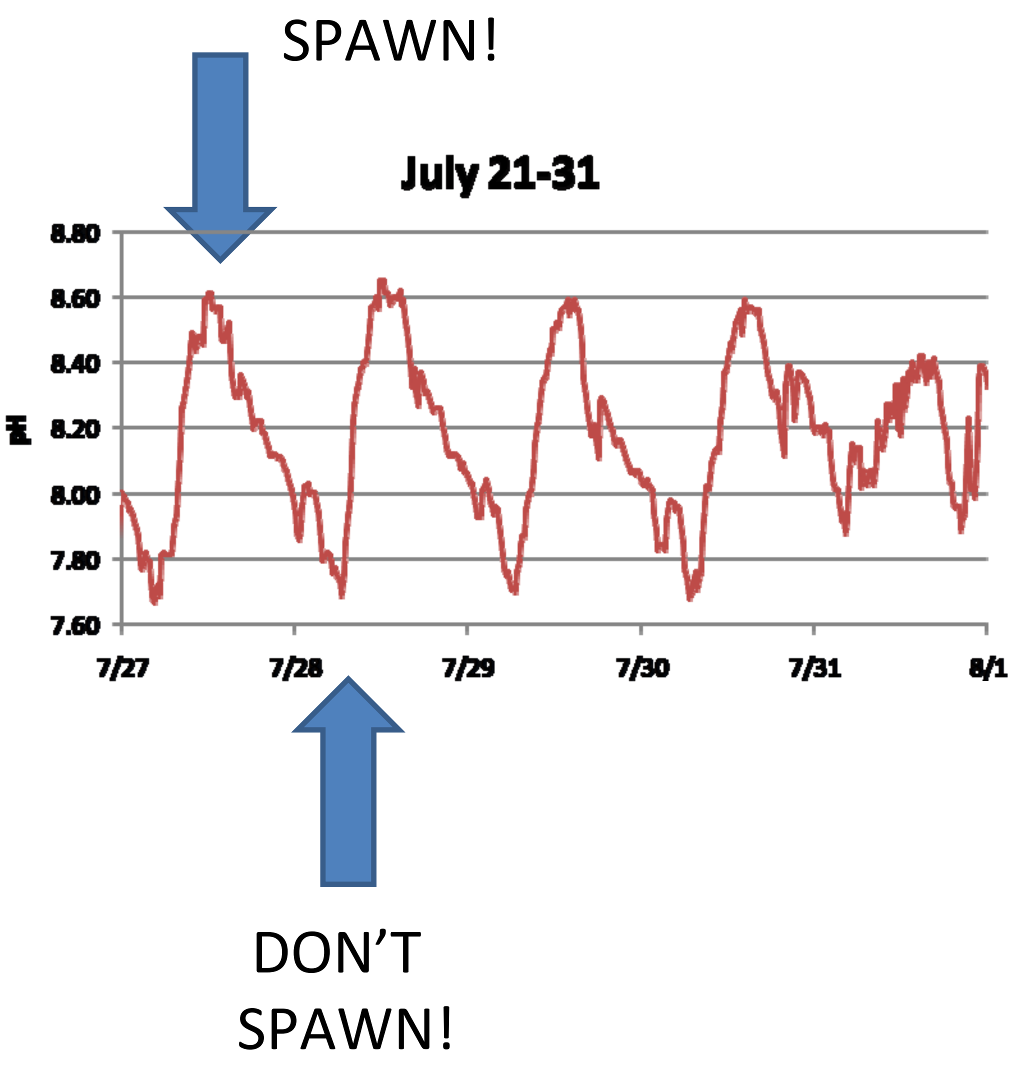
Average PM Ω = 1.60

*for all paired samples May-Sept 2009

Managing around the problem

- **Put small larvae into tanks filled in the afternoon or overnight**
  - Works if the suns out

- 24 hour notice- Upwelling takes a day or two to start up, so when winds from the North, fill tanks late in the day and spawn like crazy



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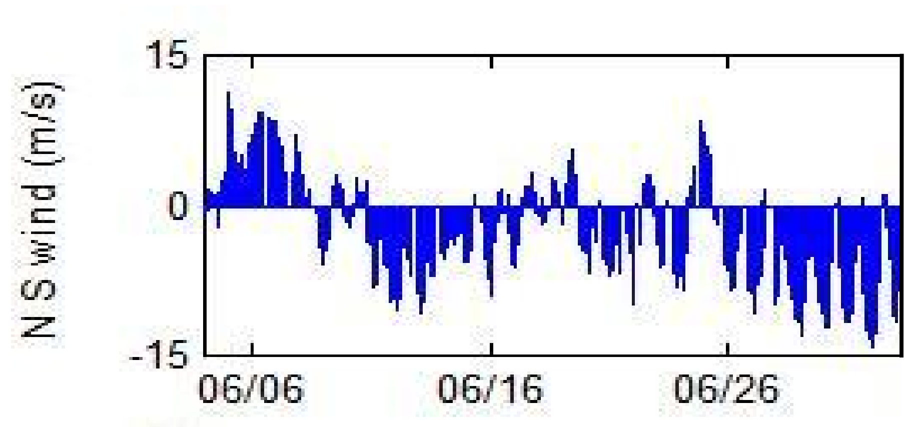


SPAWN LOTS!

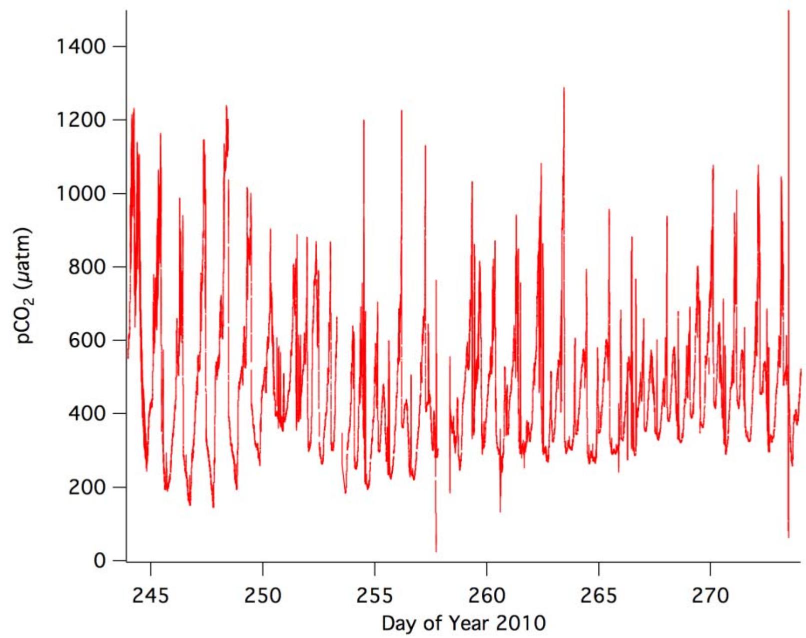
DON'T SPAWN!

Continuous pCO2 data – the ‘Burkilator’

Burke Hales, Jesse Vance – OSU COAS

- Installed in April 2010
- Provides real-time pCO2 measurements of incoming seawater
- Threshold for normal early development of small larvae:

  ≤ 300 uatm at 14° C



Egg Development – delayed mortality

	Treated Seawater (buffered and degassed)	Control (untreated)
	pCO2= 349uatm @ 25°C, pH=8.25, tCO2=2580.97	pCO2=759uatm @25°C pH=7.80, tCO2=2159.54
Initial Survival–	76.7%	65.8%
Survival at Day 10-	66.0%	**0%**

*Seawater conditions were manipulated for egg development ONLY
After the first water change (t=48hrs), all larvae in the experiment were stored in untreated seawater, and both groups saw identical water conditions until day 10
The Control larvae in this experiment were irreparably damaged during egg development, but mortality was not observed until day 10
Data shown are average values from two replicate 6000 gallon tanks per treatment

Prolonged effects of seawater treatment on small larvae

	Treated Seawater (buffered and degassed)	Control (untreated)
	pCO_2= 350-370uatm @ 25°C	pCO_2=650-900uatm @25°C
Initial Survival–	64.2%	71.5%
Survival at Day 12-	58.2%	**27.2%**
Size class at Day 12- (% of larvae ≥ +100um screen)	41.0%	31.9%

*Treatment of seawater continued throughout the 12 day experiment
Data shown are average values from three replicate 6000 gallon tanks per treatment

PCSGA monitoring program

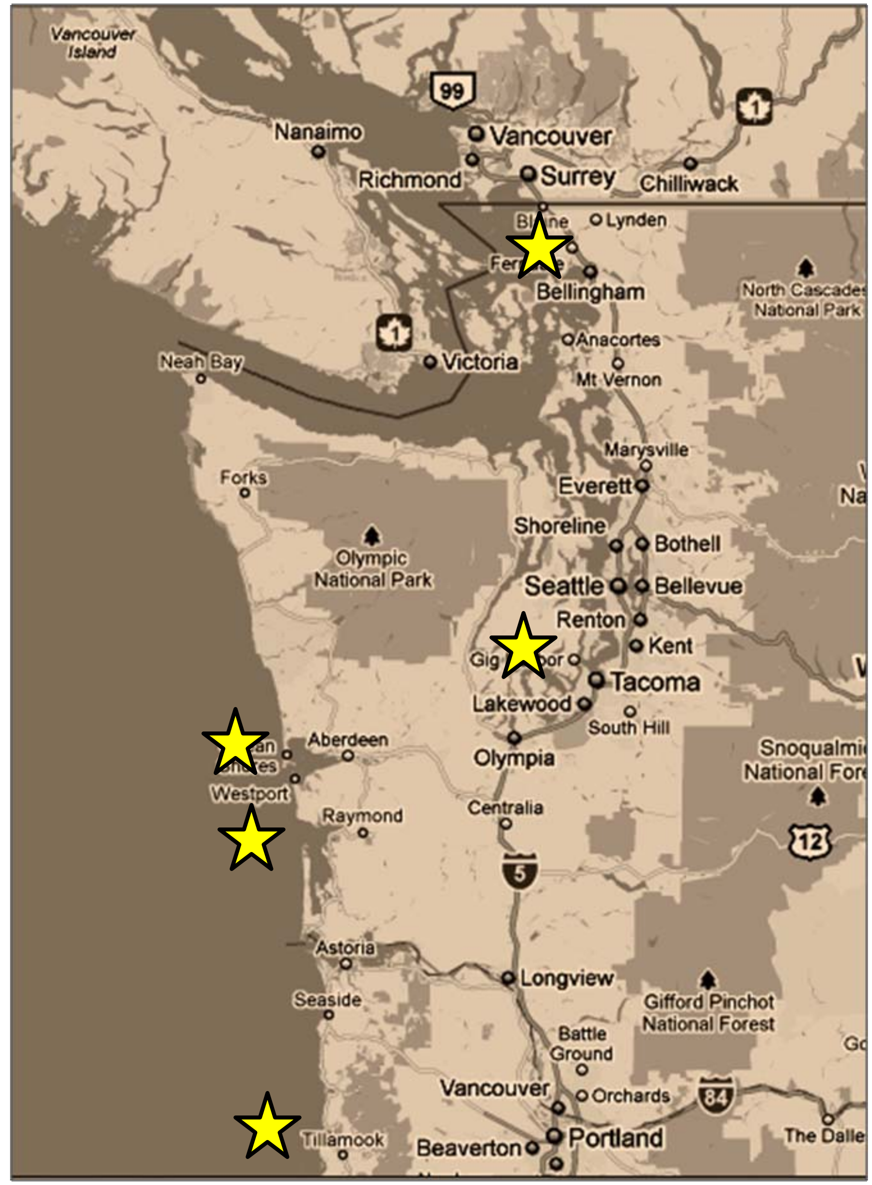
- Experiments and equipment upgrades in commercial hatcheries

- Network of monitoring stations in commercially important bays
  - Continuous pCO2 data
  - Continuous monitoring of pH, temp., salinity, DO, etc.
  - Dicrete samples – weekly AM/PM samples for DO, carbonate chemistry, nutrients, and bacteria levels
  - Larval performance data

- Funds supplied by NOAA through Sen. Maria Cantwell last only until October 2011

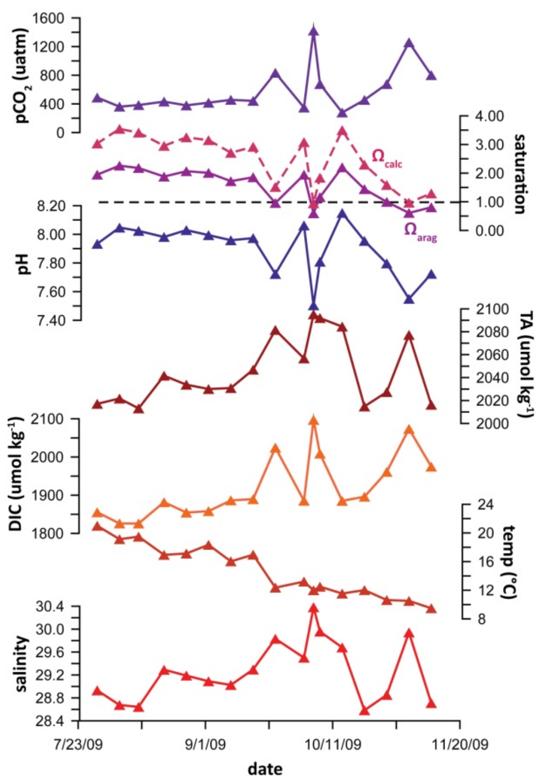
2011 Monitoring Stations

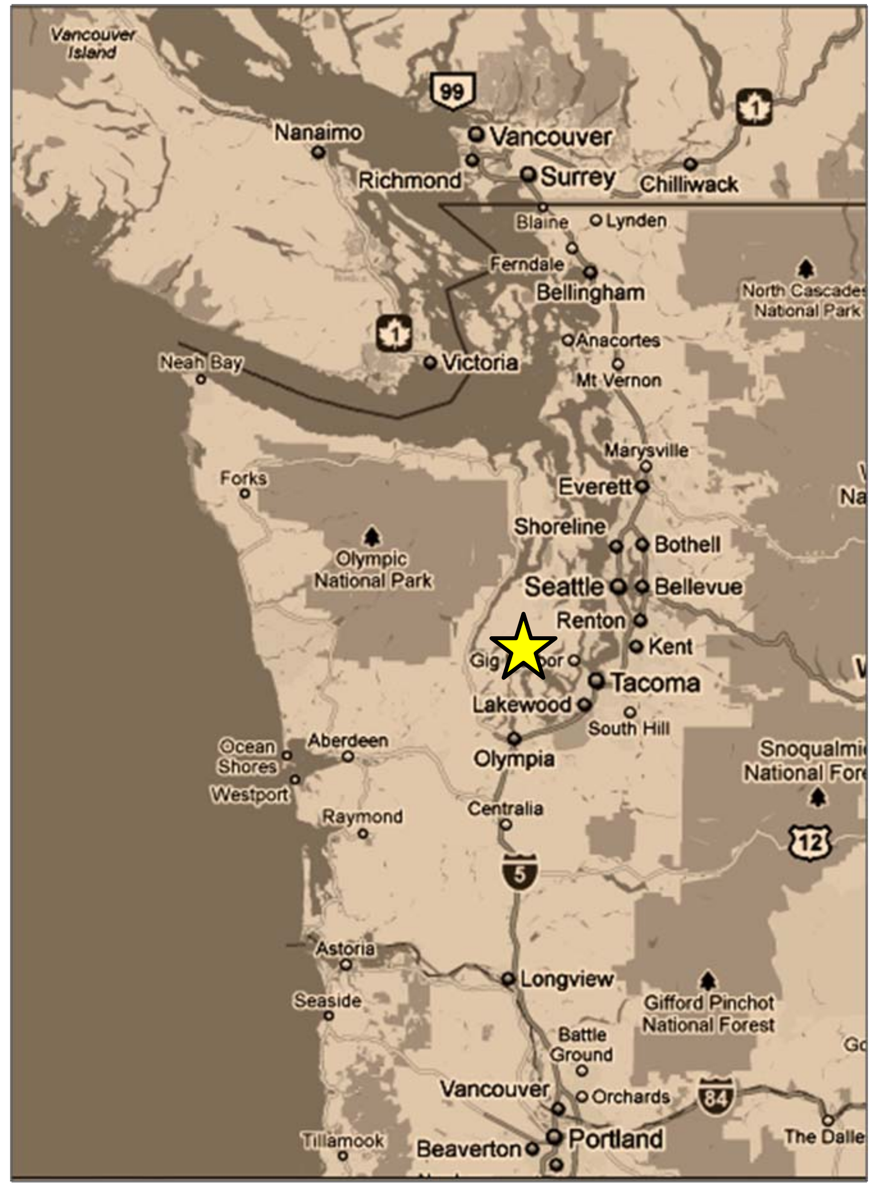
- ☆ Bellingham, WA- Lummi Hatchery
- ☆ Dabob Bay, WA- Taylor Shellfish Hatchery
- ☆ Gray's Harbor, WA- setting stations
- ☆ Willapa Bay, WA-
  Tokeland, Bay Center, and
  Nahcotta monitoring stations
- ☆ Netarts Bay, OR-
  Whiskey Creek Shellfish Hatchery



Dabob Bay, WA- Taylor Shellfish Hatchery

NOAA, UW, PCSGA, PSRF partnership
Newton, Feely, Sabine,etc.





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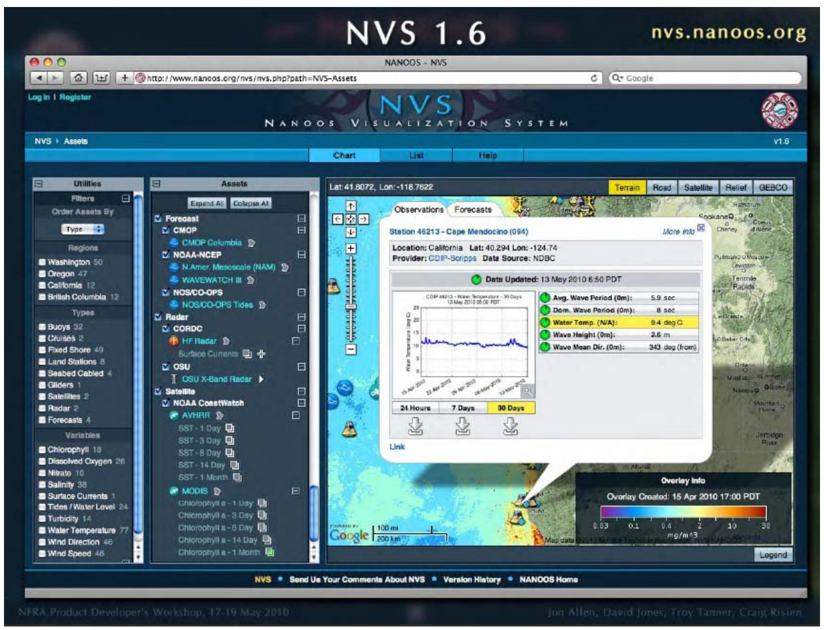
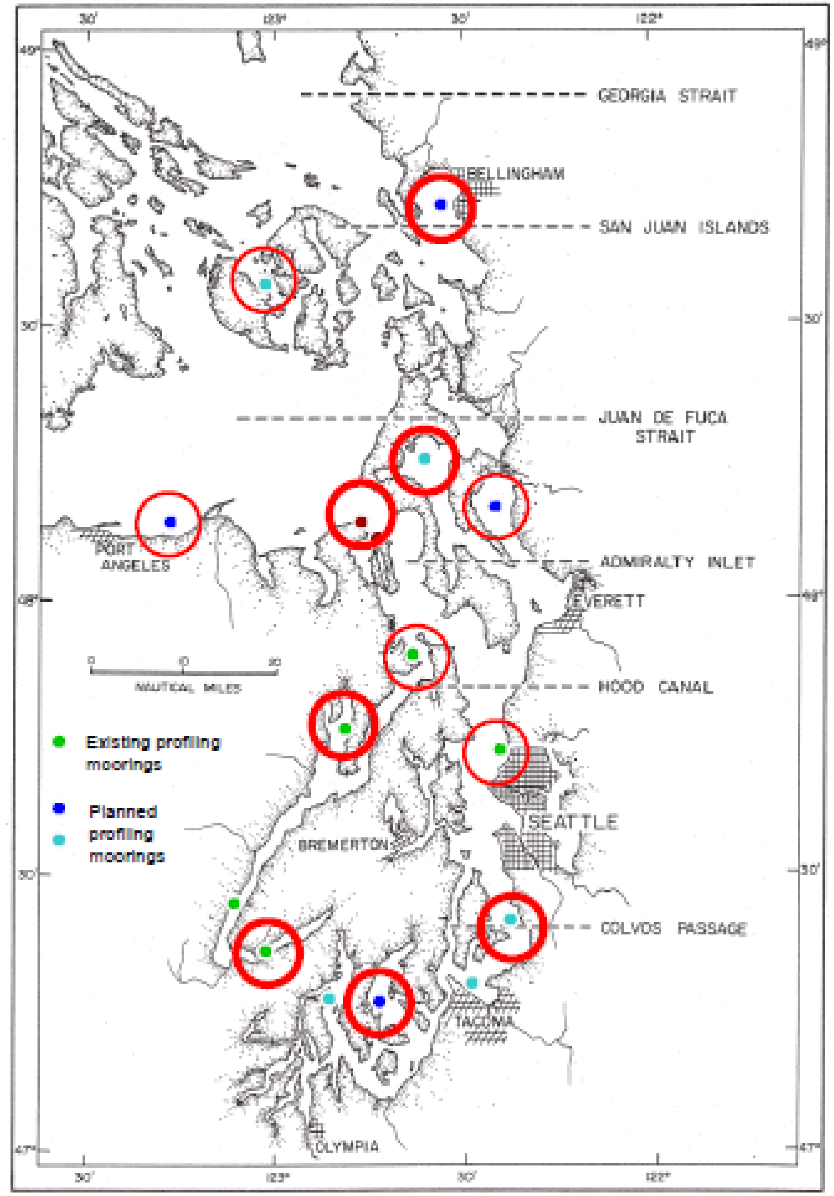
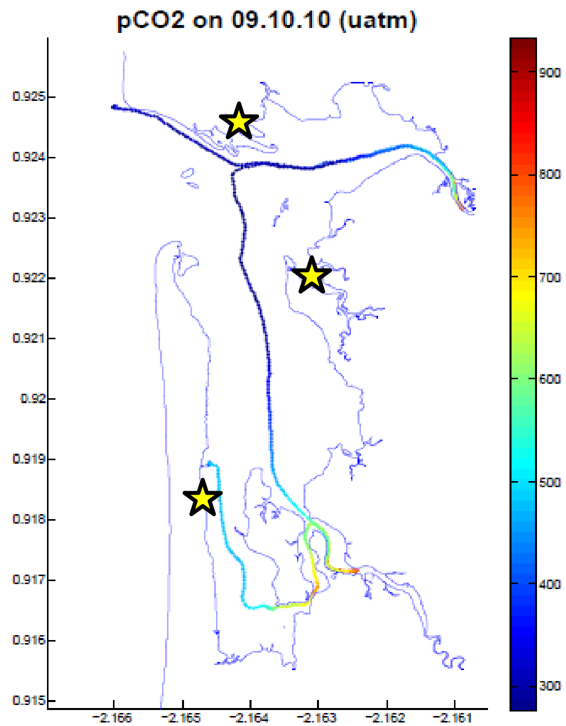


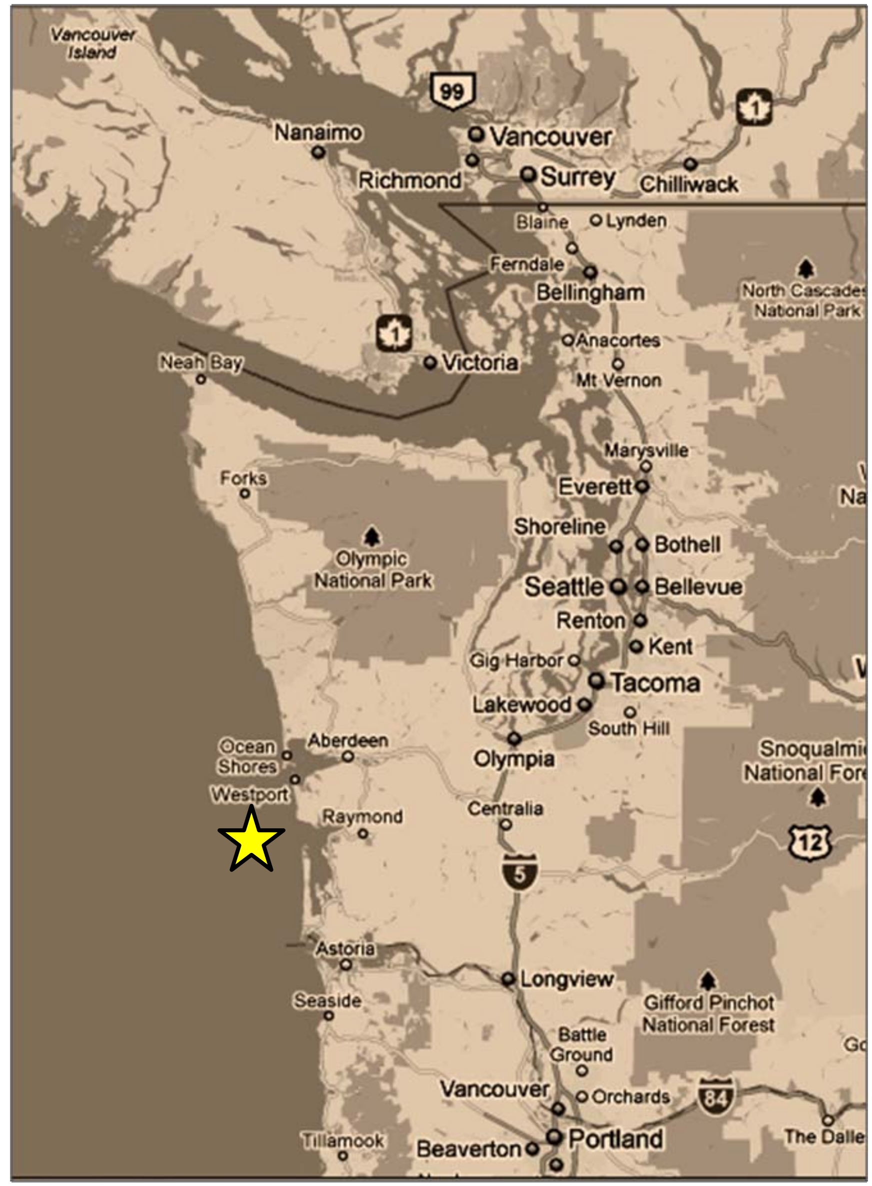


Willapa Bay, WA-

Tokeland, Bay Center, and
Nahcotta monitoring stations

UW,PSI,WDFW,WRF partnership
Trimble,Suhrbier,Kaufman, etc.





Thanks to:

- NOAA and Senator Maria Cantwell's office
- Chris Langdon and the Molluscan Broodstock Program
- Burke Hales, Jesse Vance, George Walbusser, and Joe Jennings (COAS)
- Richard Feely, Chris Sabine, and Jan Newton (UW,NOAA)
- Alan Trimble (UW), Andy Suhrbier (PSI), and Bruce Kaufman (WDFW)
- Ralph Elston (Aquatechnics), Claudia Hase (OSU), Carolyn Friedman, Steven Roberts, and Brent Vadopalas (UW)

Science, Service, Stewardship

Addressing Ocean Acidification through Research and Policy at the NOAA Aquaculture Program

December 2, 2010
Ocean Acidification Task Force

Dr. Michael Rubino
Manager, NOAA Aquaculture Program

NOAA FISHERIES SERVICE

Today's Talk

- Overview of US marine aquaculture
- Overview of NOAA's Program
- Ocean Acidification Research

NOAA's Definition of Aquaculture

Aquaculture is …

the propagation and rearing of aquatic organisms in controlled or selected aquatic environments for any commercial, recreational, or public purpose.

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Major U.S. Commercial Marine Farmed Species

Shellfish (Oysters, Clams & Mussels), Salmon & Marine Shrimp

Stock Enhancement & Restoration Aquaculture Supporting…

Commercial Fisheries – Salmon, oysters, king crab

Recreational Fisheries – Pacific rockfishes, Gulf redfish, California white seabass

Habitat – Oysters, grasses

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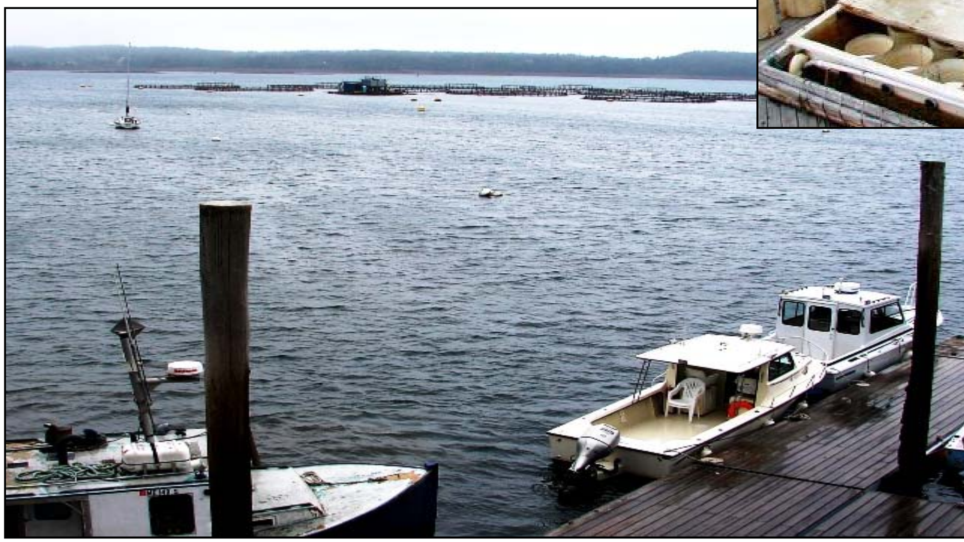
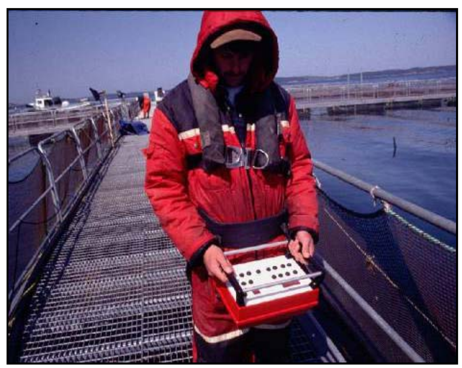
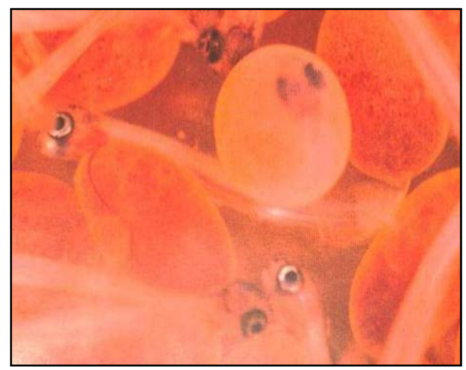
Maine







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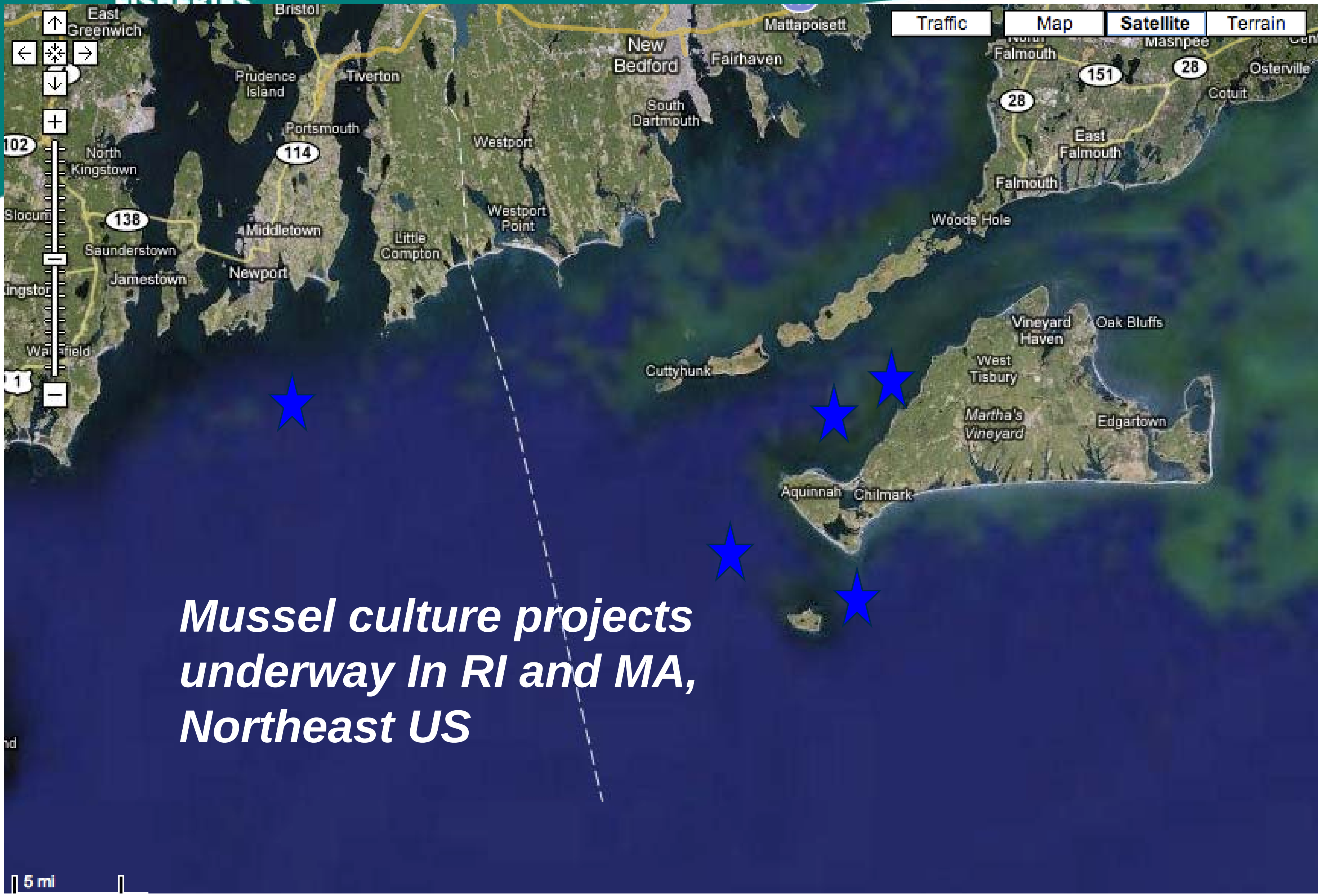
New Hampshire

New England



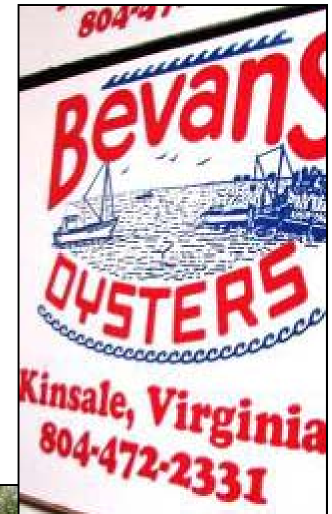
Mussel culture projects underway In RI and MA, Northeast US

Rhode Island, Massachusetts

Maryland

Virginia


Cherrystone
AQUA·FARMS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North Carolina

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Florida

Louisiana

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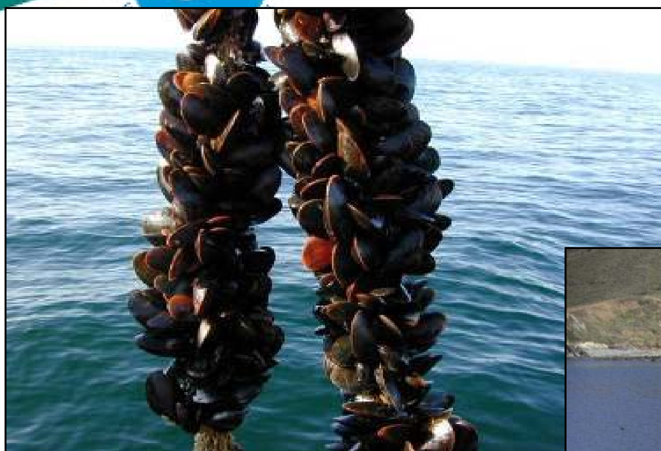
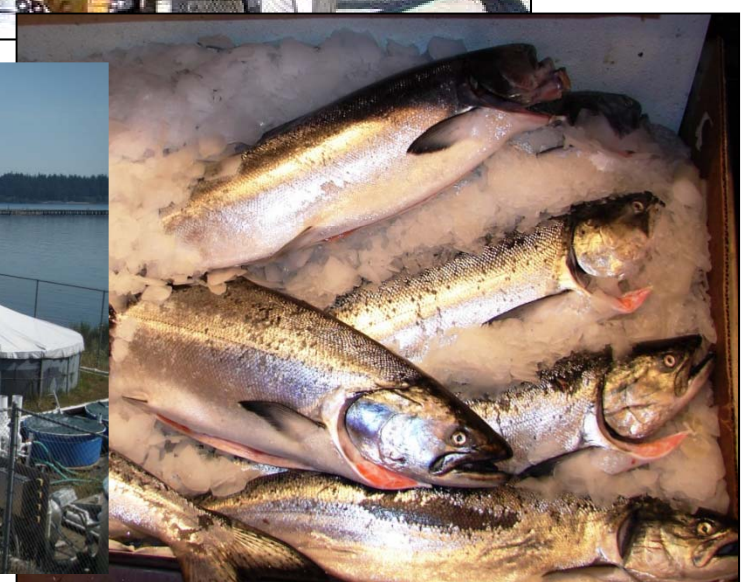
California



Washington State



Alaska

Hawaii

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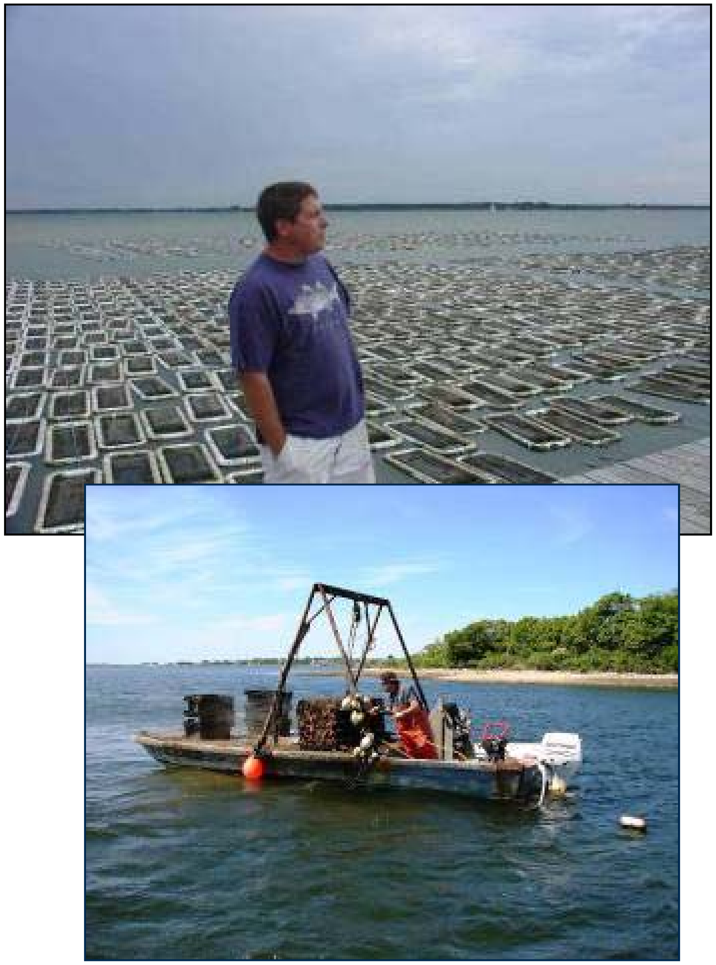
Common Features of Commercial U.S. Marine Aquaculture



- Owner/operators: U.S. fishermen, seafood businesses
- Local, regional approaches and support
- Working waterfronts
- Range of technologies
- Synergies with commercial and recreational fishing
- Innovative, sustainable

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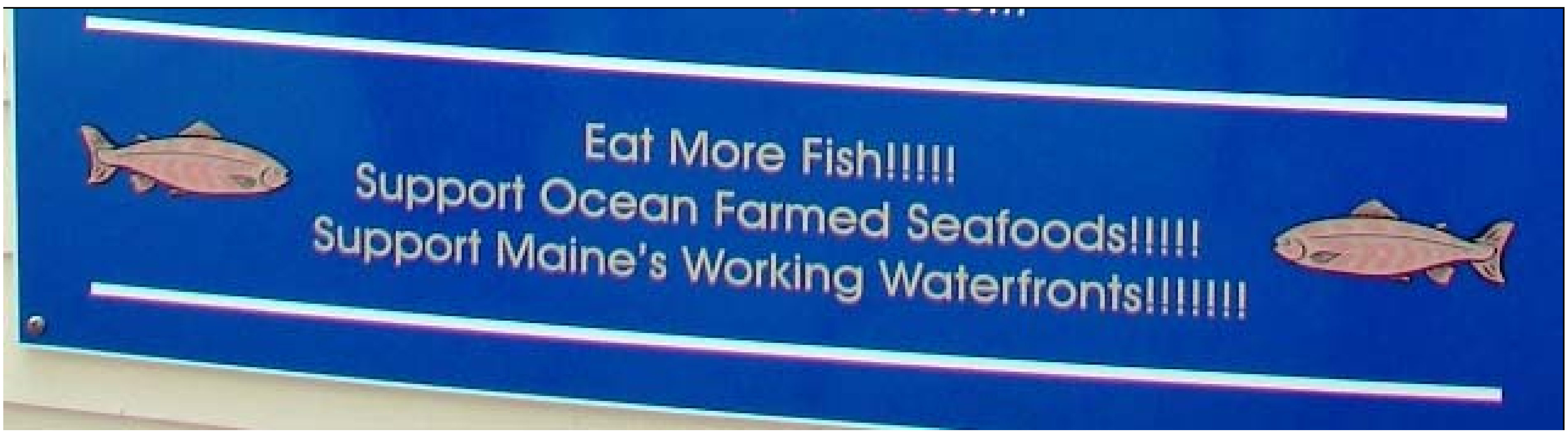

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NOAA's Aquaculture Program

- Regulation, Policy
- Science, Innovation
- Outreach and Education
- International

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Call for New NOAA Aquaculture Policy

"We will develop a national policy that focuses on the protection of ocean resources and marine ecosystems, addresses the fisheries management issues posed by aquaculture, and allows U.S. aquaculture to proceed in a sustainable way"

~ *Dr. Jane Lubchenco, September 3, 2009*

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The New Policy will …

- ✓ Address **all forms** of marine aquaculture – on land, coastal, open ocean, production, enhancement, and restoration.
- ✓ Enable sustainable aquaculture.
- ✓ Protect ocean resources and marine ecosystems.
- ✓ Address fisheries management issues posed by aquaculture.

- ✓ Address environmental, regulatory, and public outreach aspects of aquaculture.
- ✓ Include principles for permitting aquaculture in federal waters.
- ✓ Include ample opportunity for public comment preceding the development of a draft policy and once the draft is released.

Major Themes from Listening Sessions

- Advance science knowledge (incl. ocean acidification)
- More aquaculture produced under U.S. laws rather than importing most of our seafood
- More closely align interests of fishing and aquaculture to support working waterfronts
- Develop and refine innovative/sustainable forms of aquaculture
- Develop alternative feeds
- Expand shellfish farming and restoration
- Mixed views on aquaculture in federal waters

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Pacific Northwest Oyster Emergency

- Failure of larval oyster recruitments in recent years
- Hatchery failure threatens $100M industry
- Ocean acidification a potential factor in failures
- Larval oyster may be "canary in coal mine" for nearshore acidification
- NOAA administered emergency funds ($500K) to Pacific Coast Shellfish Growers Association for equipment and monitoring of water quality at oyster hatcheries in OR & WA

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Northwest Fisheries Science Center – Ocean Acidification Research

- Experimental equipment to test effect of acidified conditions on shellfish
- Field monitoring
- Advising shellfish industry and academic partners on research and monitoring efforts to assess seawater chemistry and interactions with microbial pathogens (*vibrios*).

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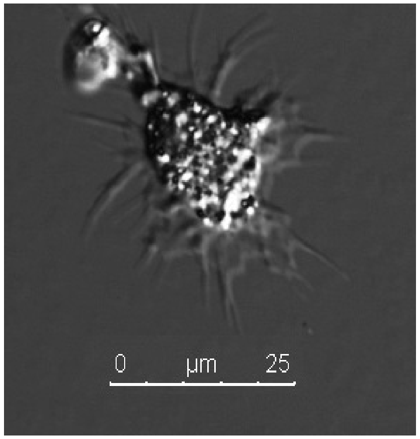
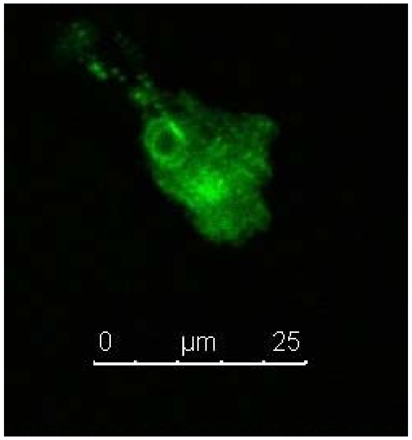
NE Fisheries Science Center – Ocean Acidification Research

- Competition between different phytoplankton under ocean acidification scenarios – how does acidification affect the food web?
- What shellfish species show the most susceptibility to changing pH? (evaluating hemocyte recovery rate after *in vitro* acidification)
- On what species and to what degree does acidification impact finfish & shellfish larvae?





pH and calcium in hemocytes can be quantified using fluorescent probes

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For More Information

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Silver Spring MD 20910

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Chris Botnick, Outreach Specialist

Email: NOAA.Aquaculture@noaa.gov

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Questions?