Future-proofing aquaculture in a changing climate

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UCDAVIS DEPARTMENT of ANIMAL SCIENCE

Outline

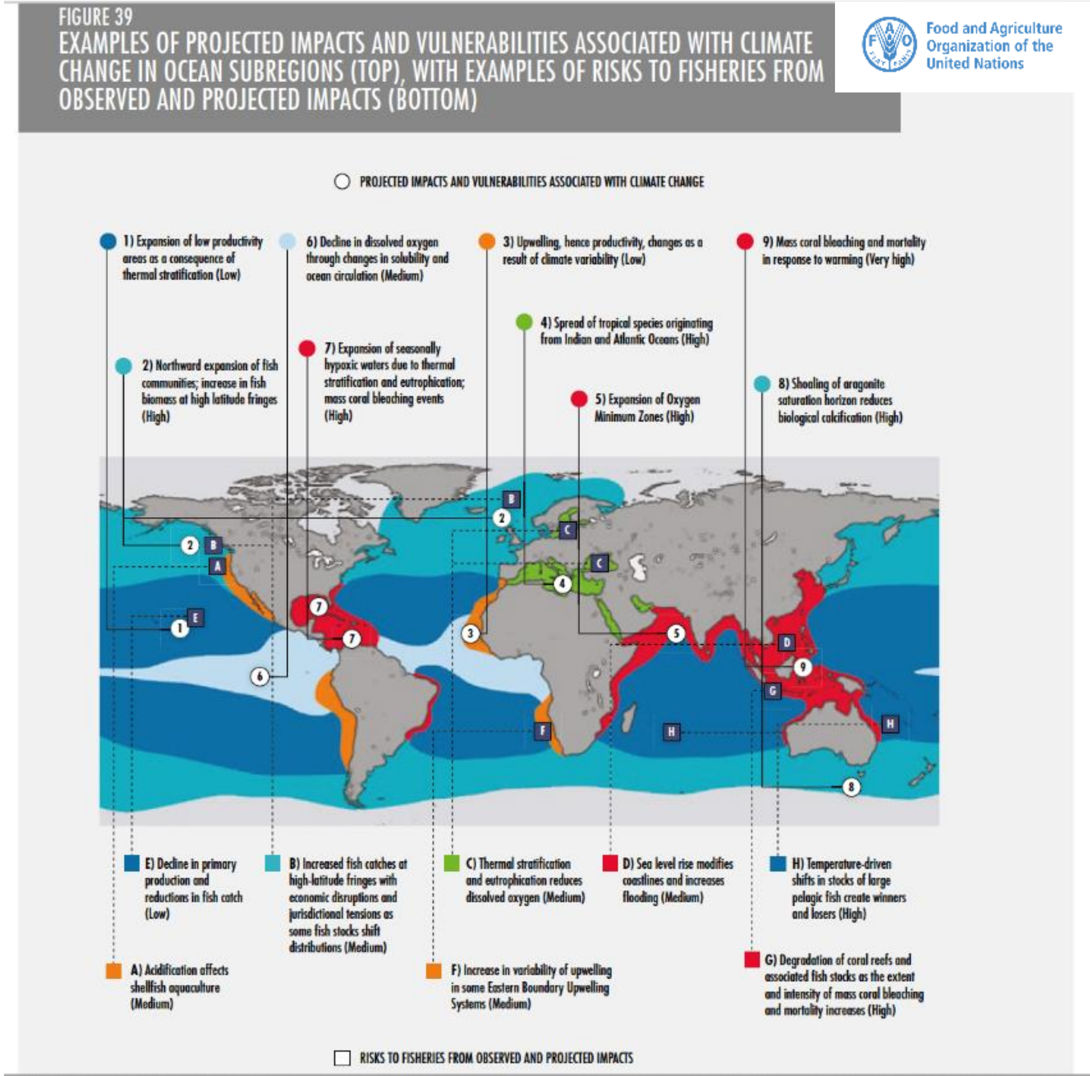
- Challenges and Opportunities facing Aquaculture
- Managing Stress in Sustainable Aquaculture
  - White Sturgeon
  - Pacific Oysters
  - Red Abalone
- The Future of Food from the Sea

Aquatic systems are changing at unprecedented rates

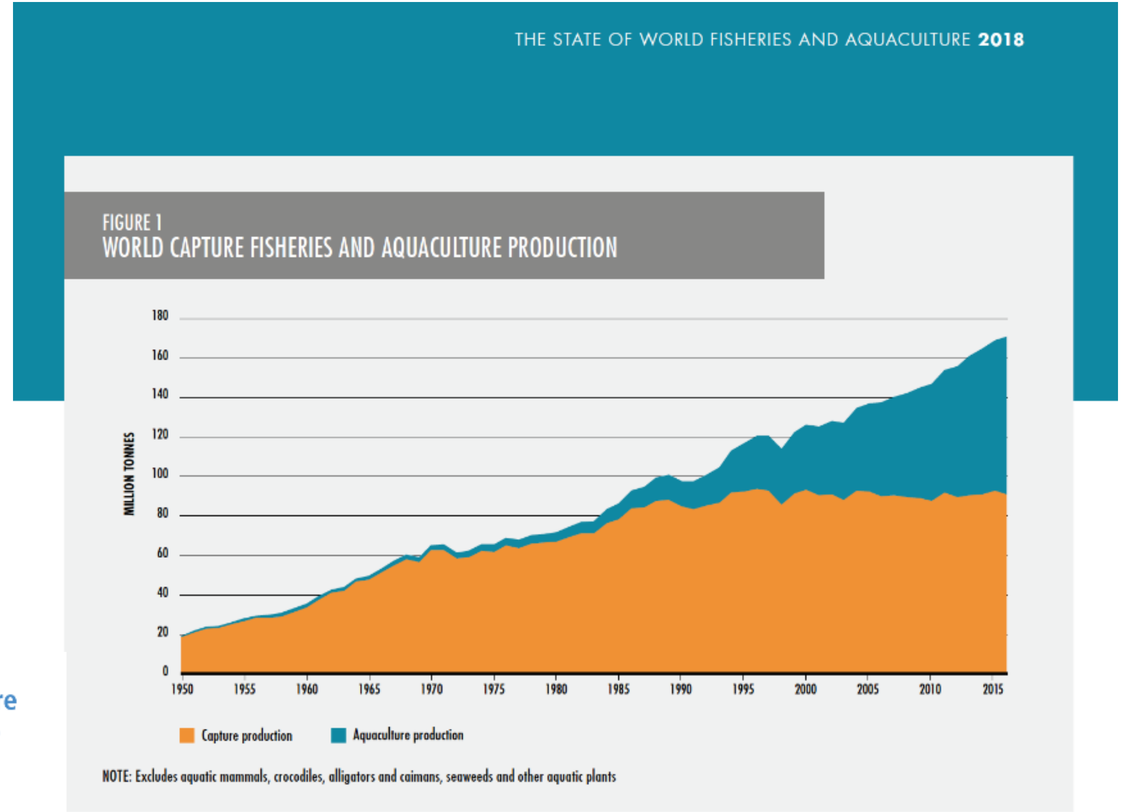
Environmental Challenges

- Warmer temperatures
- More acidic oceans
- Lower oxygen levels
- Invasive Species
- Drought & Competition for water
- Sea level rise

Many factors are changing together



All while reliance on aquaculture protein production increases



Food and Agriculture Organization of the United Nations

State of world aquaculture

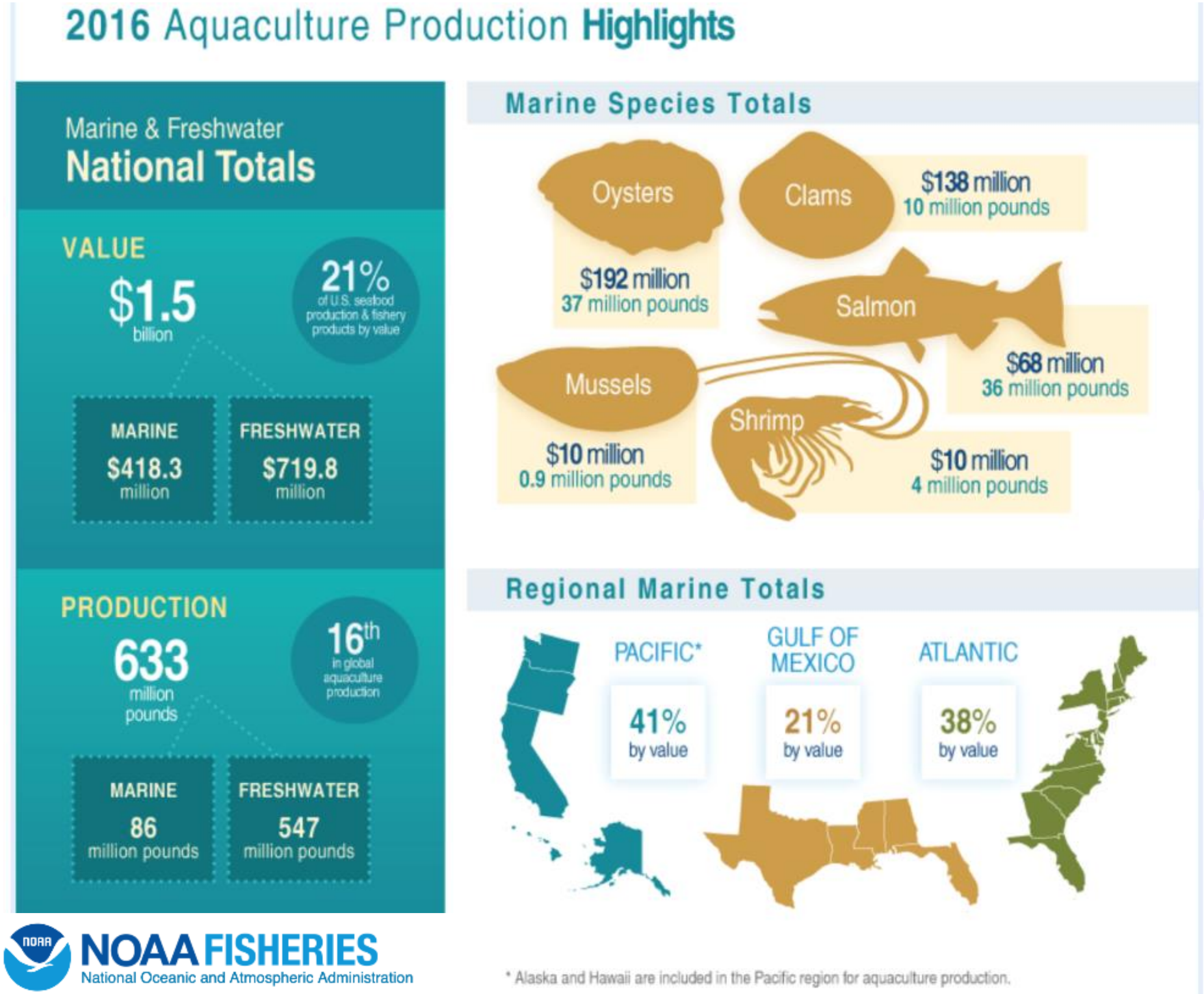
Aquaculture continues to be the fastest growing animal food-producing sector

- Global aquaculture production ~110M tonnes (2016)
  - USD $243 Billon
- 9.5kg per capita consumption of aquaculture products
- Set to overtake capture fisheries for food fish
  - Currently provides 46.8% of food fish (25.7% increase from 2000)
- The United States produced $1.5 billion worth of aquaculture seafood in 2016. The top U.S. marine aquaculture species were oysters ($192 million), clams ($138 million), and Atlantic salmon ($68 million)

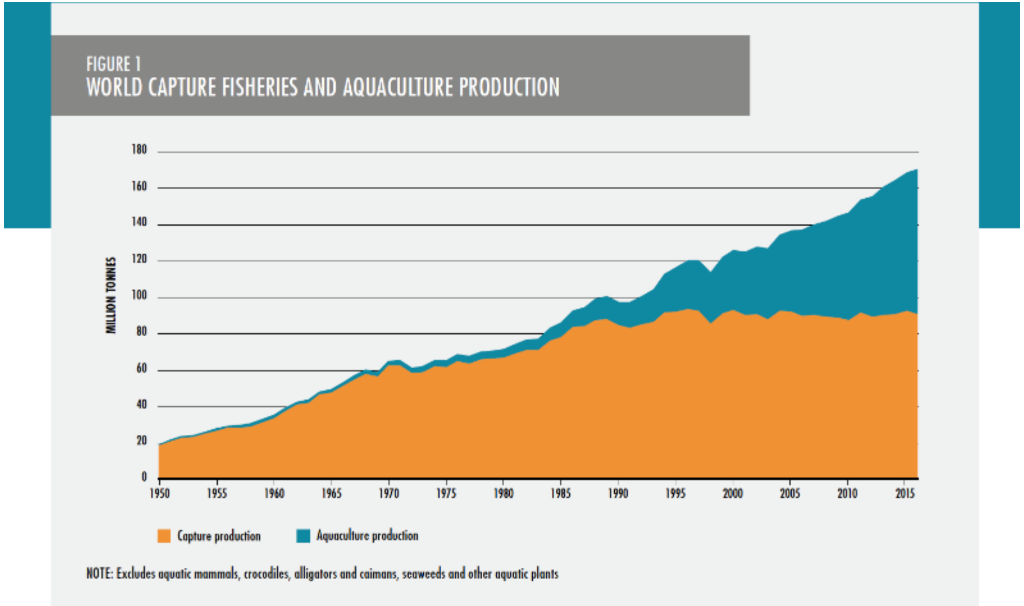
Food and Agriculture Organization of the United Nations

NOAA FISHERIES National Oceanic and Atmospheric Administration

State of US aquaculture



Challenges (& Opportunities) facing Aquaculture

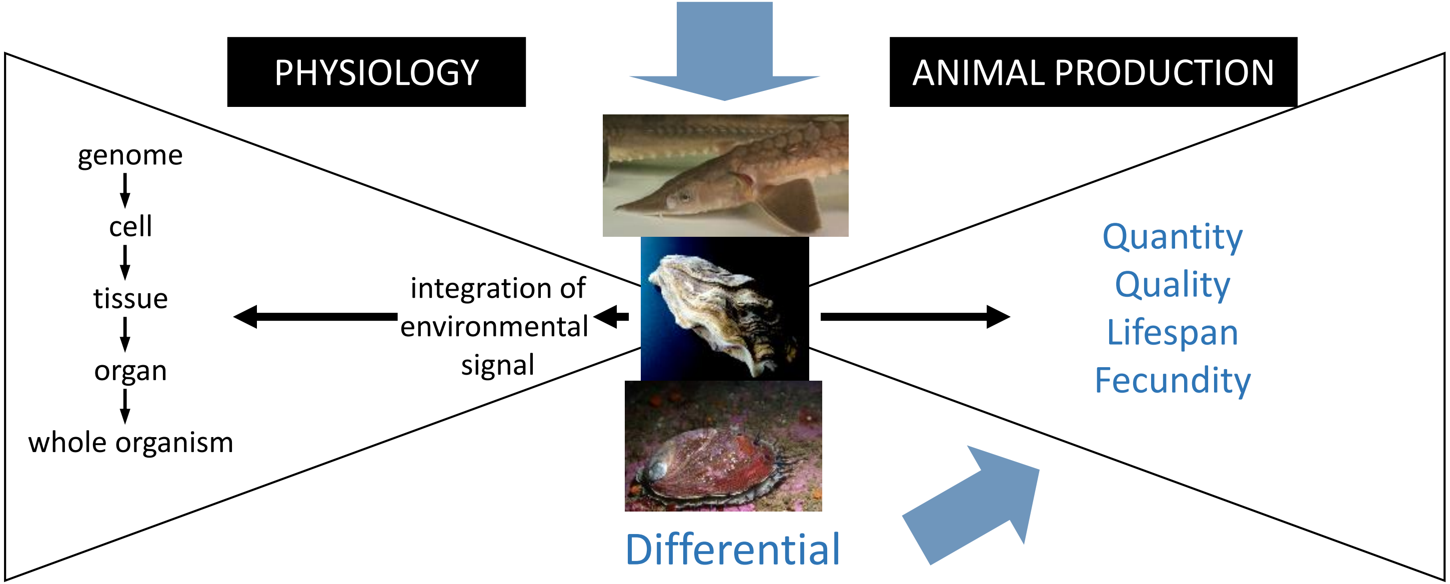


- About half of the seafood imports come from aquaculture
- Aquaculture is the fastest growing sector in global food production, predicted to increase by 33% over the next decade.

- We are intensifying existing aquaculture to meet increased demand, in a time when environmental conditions are also changing
- Potential for stress & disease increases with intensification and warming

The State of the World Fisheries & Aquaculture - FAO 2018

Managing Stress in Sustainable Aquaculture



Differential
Physiological Performance
e.g. growth, reproduction, stress tolerance

Polyploidy in white sturgeon (*Acipenser transmontanus*)

- Produced for caviar and meet in California
- Industry developed through collaboration with Emeritus Prof. Serge Dorshov at UC Davis
- White sturgeon are 8N (8 copies of their genome)
- Can undergo spontaneous autopolyploidy
  - 8N → 12N
  - 12N fish are fertile
    - Can produce 10N offspring
- Preliminary evidence that 12N sturgeon have a female biased sex ratio & produce larger eggs
  - potential benefit to caviar industry
- Triploid salmonids perform poorly in sub-optimal conditions
  - Is lower stress tolerance a cost of polyploidy in sturgeon?

Sterling Caviar

WRAC Western Regional Aquaculture Center

Physiological performance of sturgeon of different ploidies

- White sturgeon are able to acclimate to 4^{o}C increases in temperature
- Ploidy does not impact the capacity to respond to an acute (low water) or chronic (warm temperature) stress
- Ploidy may affect the metabolic capacity to acclimate to warming in 10N stugeon
    - Suggests lower aerobic capacity in 10N sturgeon
    - Does this result in lower energy available for growth and egg production?
    - Implications for both aquaculture and stocking programs

Stress tolerance of shellfish to future ocean conditions

- Documented losses in oysters, mussels & scallops on Pacific coast of North America
- 80% reduction in oyster seed output between 2005-2009
- Lead to collaborations between universities & industry to uncover causes of declines

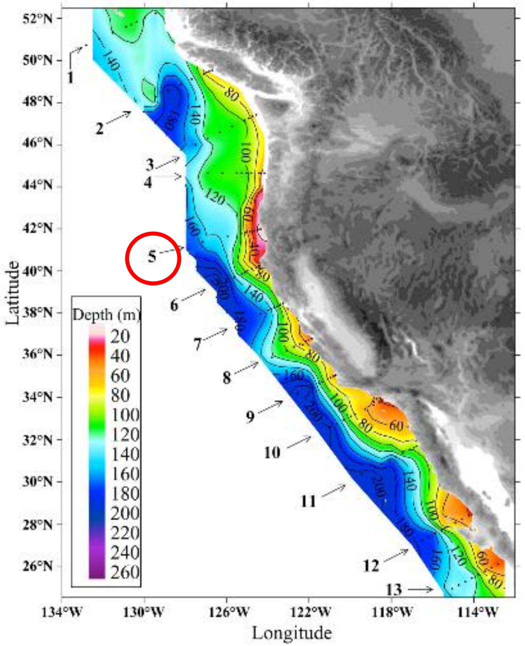
TABLE 1. US West Coast shellfish production estimates for 2009 (the most recent data available) compiled by the Pacific Coast Shellfish Growers Association (PCSGA). Shellfish sales are divided by species and by state, and when available, total sales are shown both by live weight and economic value.

		Oysters Current*	Clams Current*	Mussels Current*	Geoduck Current*	All Shellfish Larvae and Seed	Total Current
Washington	Pounds	61,000,000	9,520,000	2,750,000	1,650,000		74,920,000
	Sales	$57,750,000	$19,550,000	$3,162,500	$20,100,00	$7,000,000	$107,562,500
California	Pounds	9,270,995	741,463	315,000			10,327,458
	Sales	$12,361,326	$830,000	$945,000		$2,300,000	$16,436,326
Oregon	Pounds	2,379,988					2,379,988
	Sales	$2,253,135				$750,000	$3,003,135
Alaska	Pounds	206,709	7,839	1,988			216,536
	Sales	$441,781	$24,841	$6,610		$126,000	$599,232
Total	**Pounds**	**72,857,692**	**10,269,302**	**3,066,988**	**1,650,000**		**87,843,982**
	Sales	**$72,806,242**	**$20,404,841**	**$4,114,110**	**$20,100,000**		**$117,425,193**

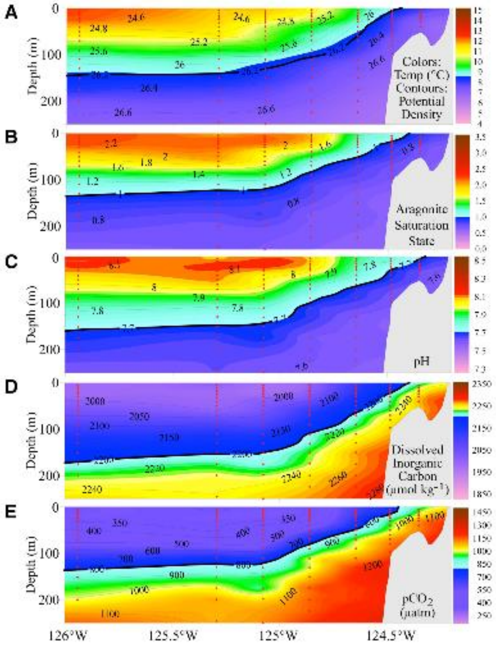
*All pounds converted to live weight/in the shell

Barton et al 2015 - Oceanography

Shoaling of corrosive waters affecting shellfish production



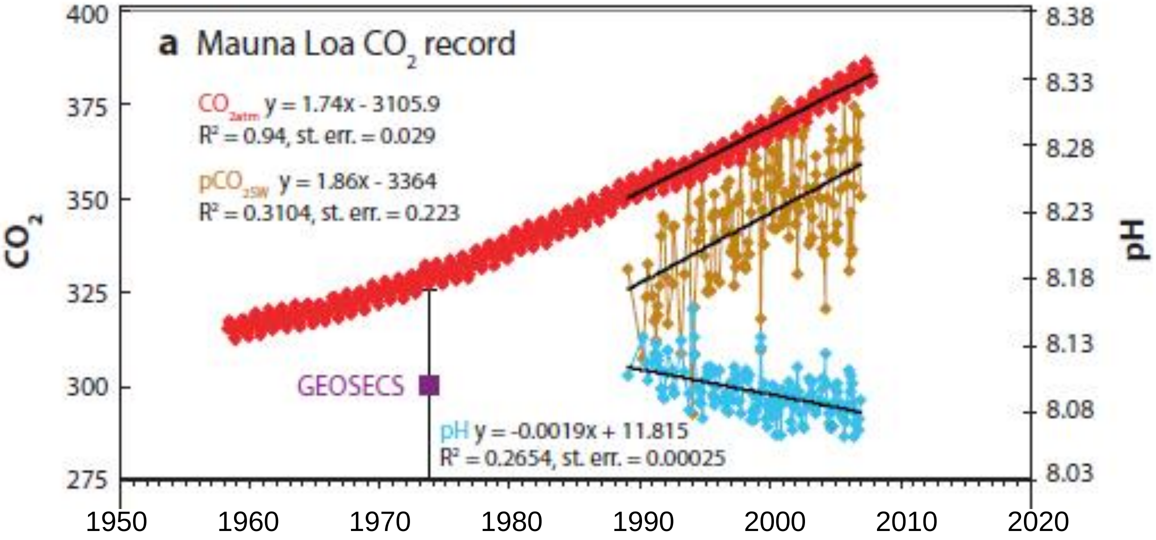
Transcect line 5 - Pt. George CA



Shoaling of corrosive waters

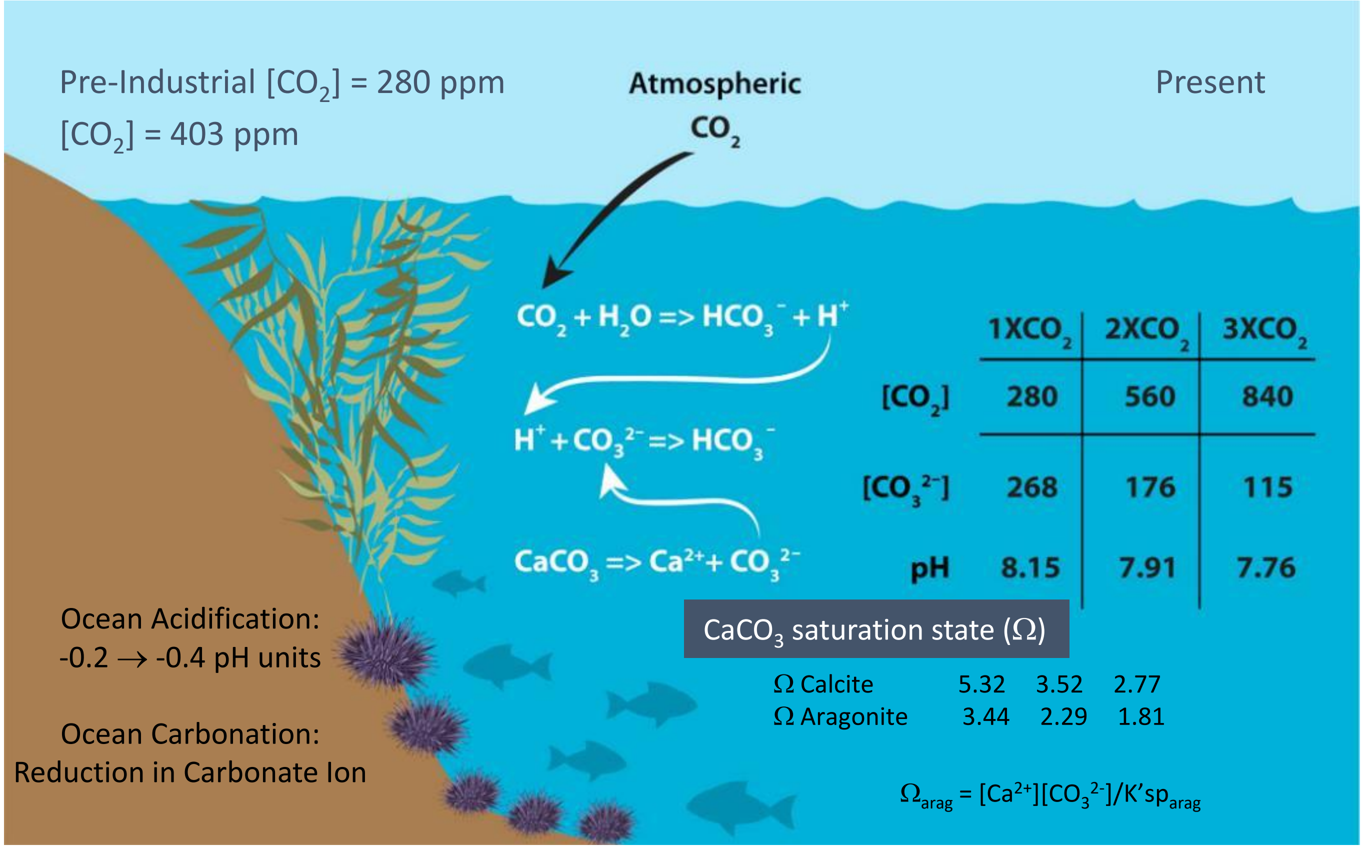
Feely et al (2008) Science

Ocean Acidification:
The “Other” CO_2 Problem is intensifying the issue



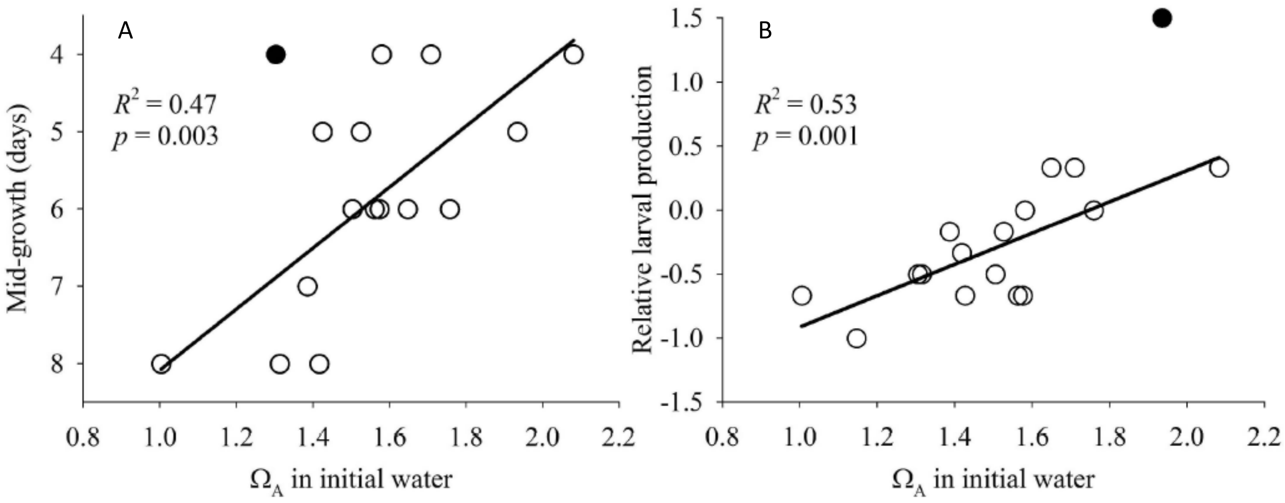
Dr. Pieter Tans, NOAA/ESRL

The ocean is a sink for atmospheric CO_2



Impacts of corrosive water on Pacific oyster production

Whiskey Creek Hatchery, WA



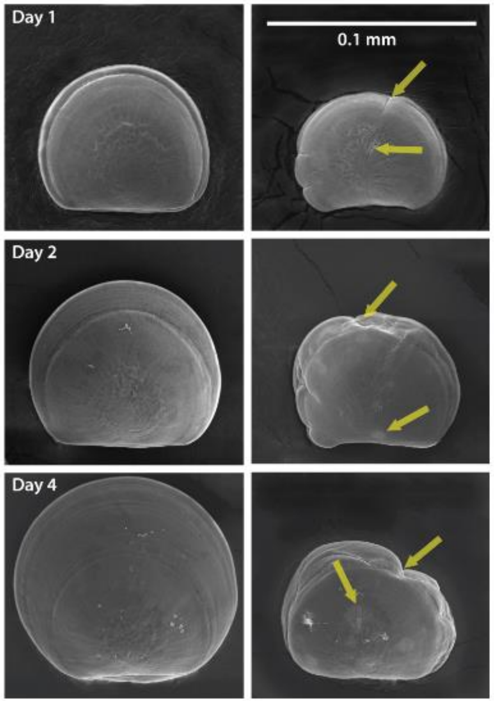


FIGURE 4. Pacific oyster larvae from the same spawn, raised by the Taylor Shellfish Hatchery in

403 uatm pCO_2 1420 uatm pCO_2

As aragonite saturation decreased:

- Larvae took longer to reach a particular size (A)
- Larval production decreased (B)

Barton et al. 2012 Limnol Oceanogr.

Barton et al 2015 - Oceanography

Impacts to Shellfish

Impacts of Ocean Acidification on California Living Marine Resources

Ocean acidification is already impacting important species and ecosystems in California. Visualizing these impacts can aid state resource managers in understanding what's at stake as oceans acidify.

Benthic Invertebrates

SPECIES COMMON NAME	RESPONSE TO OCEAN ACIDIFICATION: Calcification	Growth	Reproduction	Survival	Behavior	ECOSYSTEM ROLE	ECONOMIC IMPORTANCE
California Mussel	↓	↓	U	↓	U	■	R
Dungeness Crab	U	NE	M	↓	U	▲ ●	C, R
Ochre Sea Star	↓	↓	U	U	U	▲	
Olympia Oyster	↓	↓	U	↓	U	■	C, R
Pacific Oyster	↓	↓	U	↓	U		C
Purple Sea Urchin	M	↓	M	M	U	■ ●	C, R
Red Sea Urchin	U	↓	↓	↓	U	■ ●	C, R
Red Abalone	U	↓	↓	M	U	●	R

KEY

- ↑ Increase
- ↓ Decrease
- M Mixed Results (Increased, Decreased, No Effect)
- NE No Effect
- U Unknown (Not Studied)
- I Impacted

- ▲ Predator
- ■ Engineer
- ● Food Web Link

- C Commerical
- R Recreational

Resident California species whose responses to ocean acidification have not been studied:

California Spiny Lobster*
Pacific/Ocean Pink Shrimp*
California Spot Prawn
Brown/Pacific/California Rock Crab
Red Rock Crab
Warty Sea Cucumber
Giant Red Sea Cucumber
Giant Keyhole Limpet
Purple Hinged Rock Scallop*
Pacific Geoduck*
Lingcod
California Sheephead
Chinook Salmon
Steelhead (Coastal Rainbow Trout)
Coho Salmon*
California Halibut
Pacific Jack Mackerel
Pacific Herring
Night Smelt
Shiner Surfperch
California Grunion*

*Indicates work in progress.

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Impacts to Commercial Shellfish Production

Impacts of Ocean Acidification on California Living Marine Resources

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Mussel	↓	↓	U	↓	U	■	R
Dungeness Crab	U	NE	M	↓	U	▲ ●	C, R
Ochre Sea Star	↓	↓	U	U	U	▲	
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Pacific Oyster	↓	↓	U	↓	U		C
Purple Sea Urchin	M	↓	M	M	U	■ ●	C, R
Red Sea Urchin	U	↓	↓	↓	U	■ ●	C, R
Red Abalone	U	↓	↓	M	U	●	R

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California Shellfish Aquaculture:
$25 Million annual industry

1. Oysters
2. Abalone
3. Mussels

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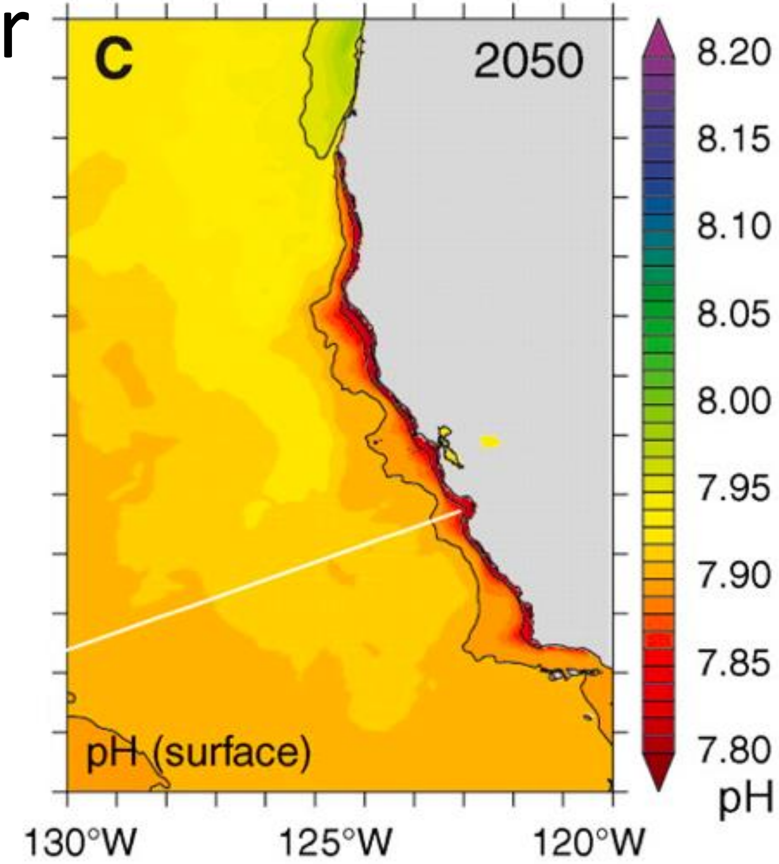
Shoaling of corrosive waters will continue to be a factor for shellfish production



(Gruber et al. 2012)

Developing Resilience to Ocean Acidification in California Shellfish Aquaculture

UCDAVIS BODEGA MARINE LABORATORY

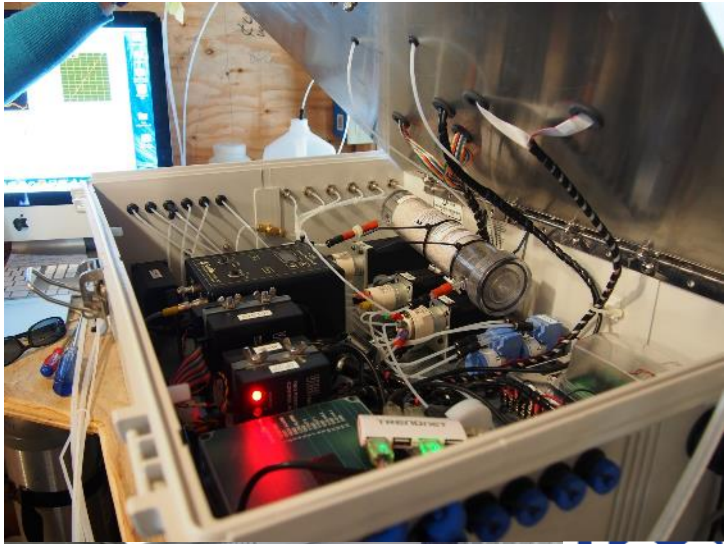
HOG ISLAND OYSTER CO.

THE CULTURED ABALONE FARM

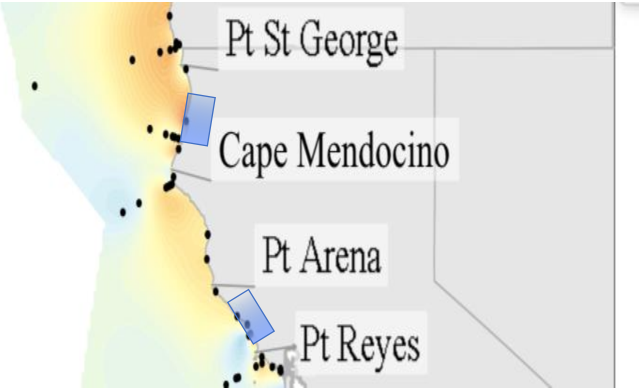
UCDAVIS Coastal and Marine Sciences Institute Bodega Marine Laboratory

Research lead by Dan Swezey, Tessa Hill, Brian Gaylord & Eric Sanford

Adaptation: Monitoring at Industry Facilities



- "Burke-o-lator" developed by Burke Hales, Oregon State University
- Monitors ocean seawater chemistry in real time
- Used to determine when to pull water into facilities

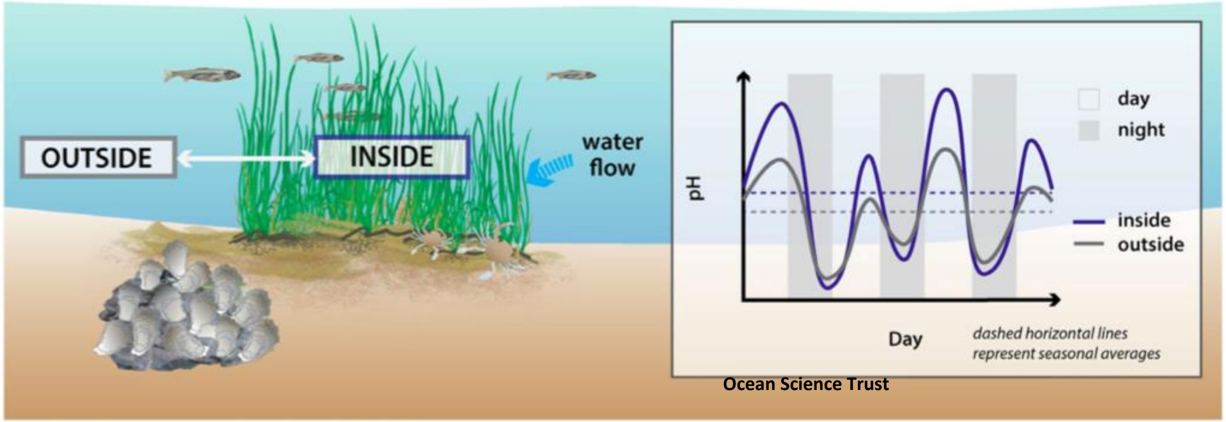


Modified from Feely et al. 2016

Adaptation: Research into Local Mitigation

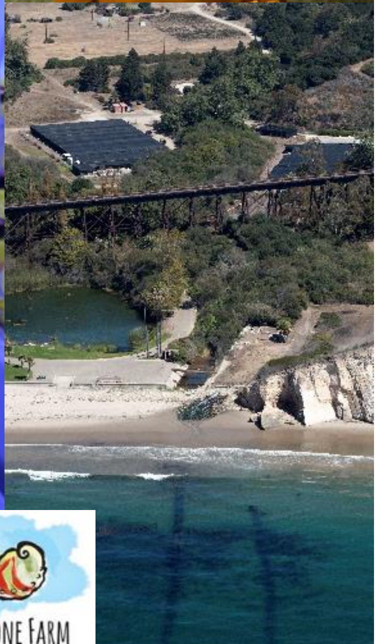
- Seagrass restoration and propagation to reduce fluxes in seawater chemistry

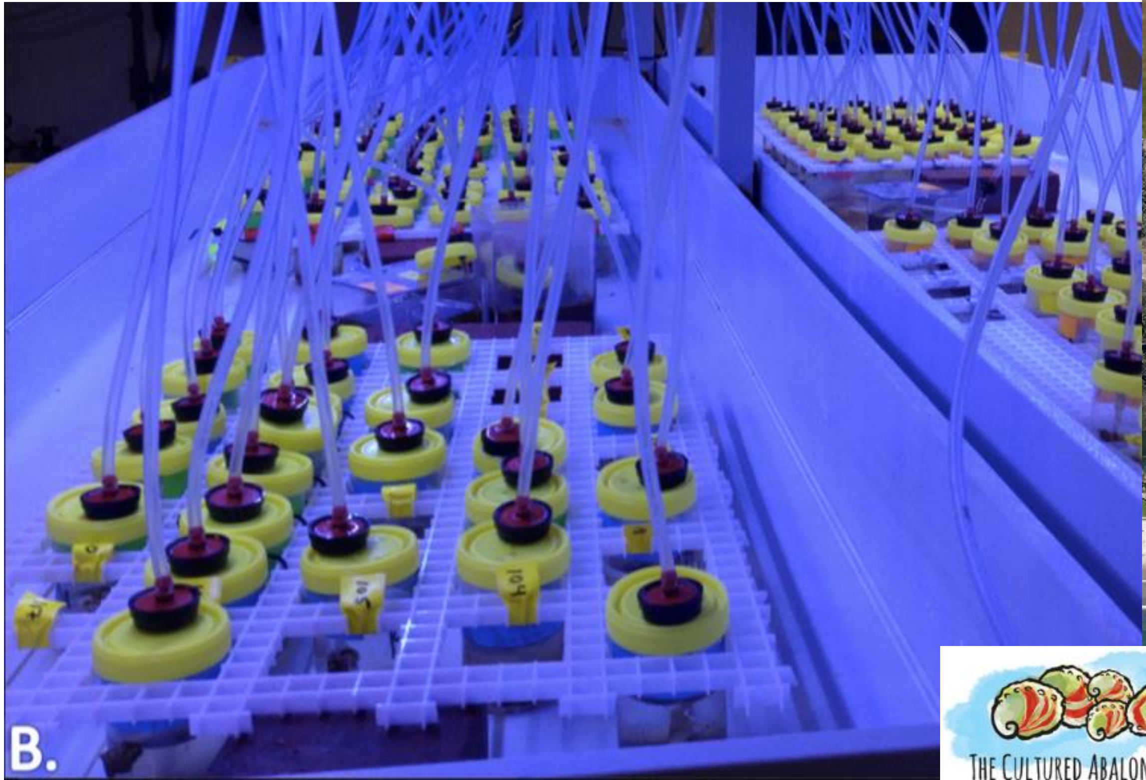
Tessa Hill, UC Davis Bodega Marine Lab
Terry Sawyer, Hog Island Oyster Co.



Red Abalone Aquaculture at Risk

Daniel Swezey, Cultured Abalone & UC Davis
Bodega Marine Lab

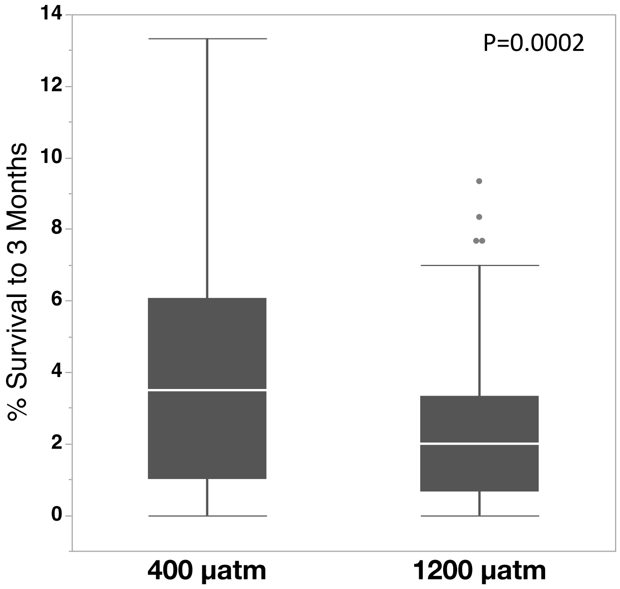


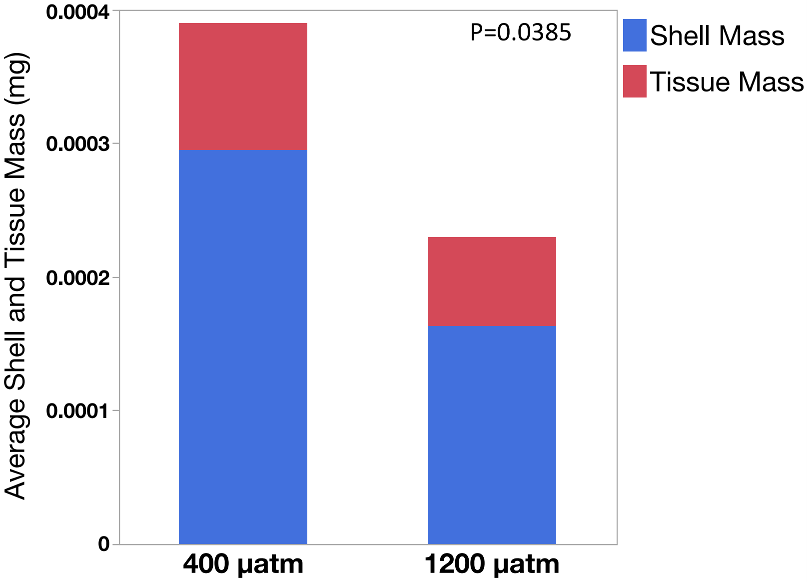


THE CULTURED ABALONE FARM

Red Abalone Aquaculture at Risk

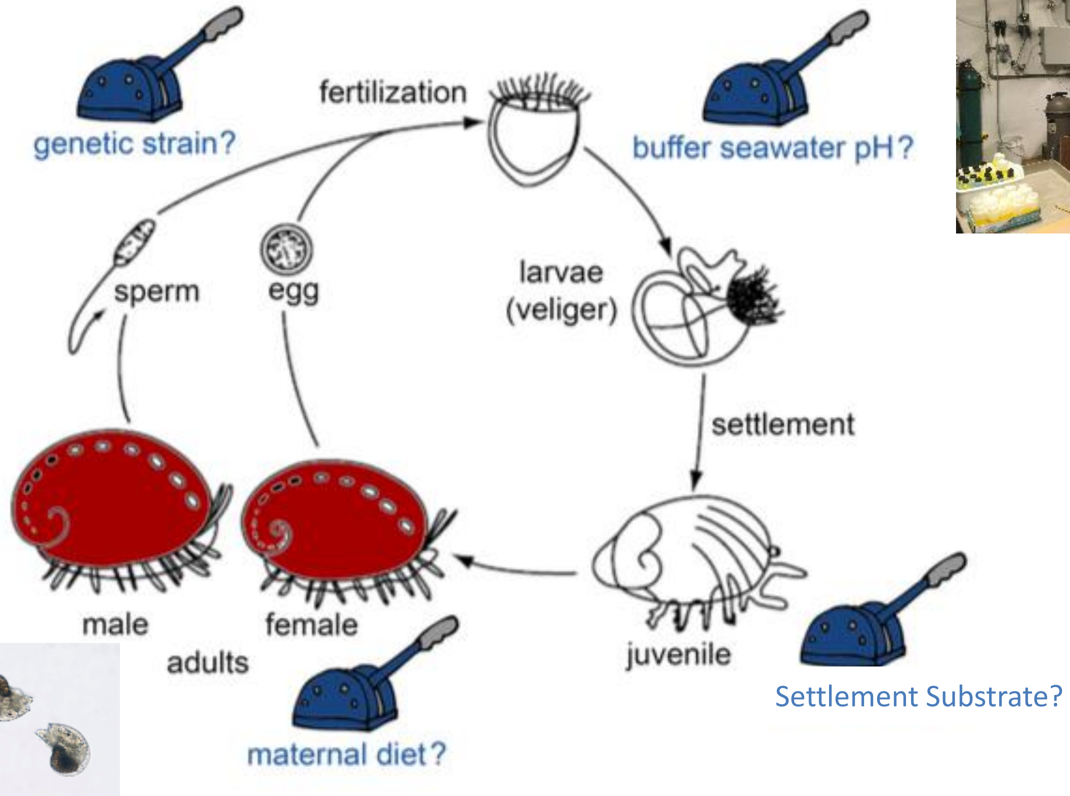
THE CULTURED ABALONE FARM

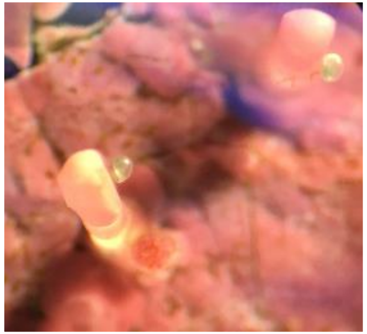




Swezey et al unpublished data

Adaptation: Assessing Mitigation Options at Key Abalone Life Cycle Phases





Modified from California Department of Fish and Wildlife

Strain differences in stress response

Increased metabolic rate

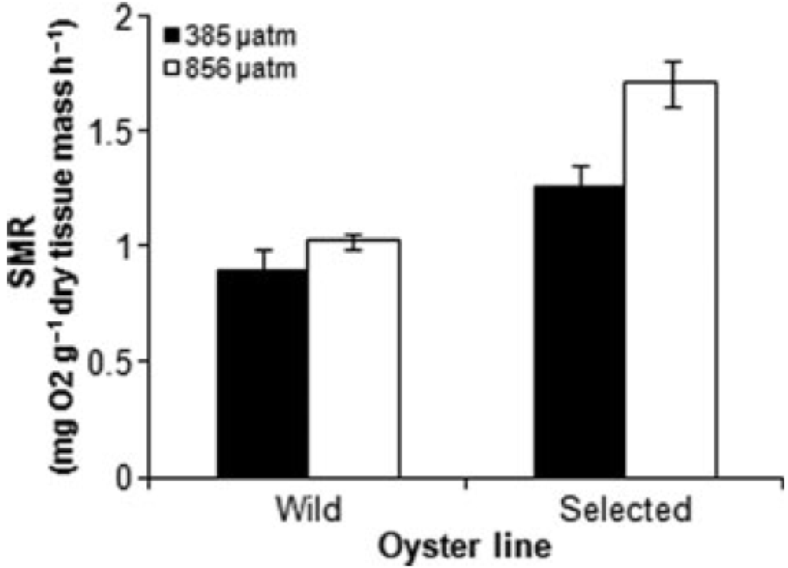
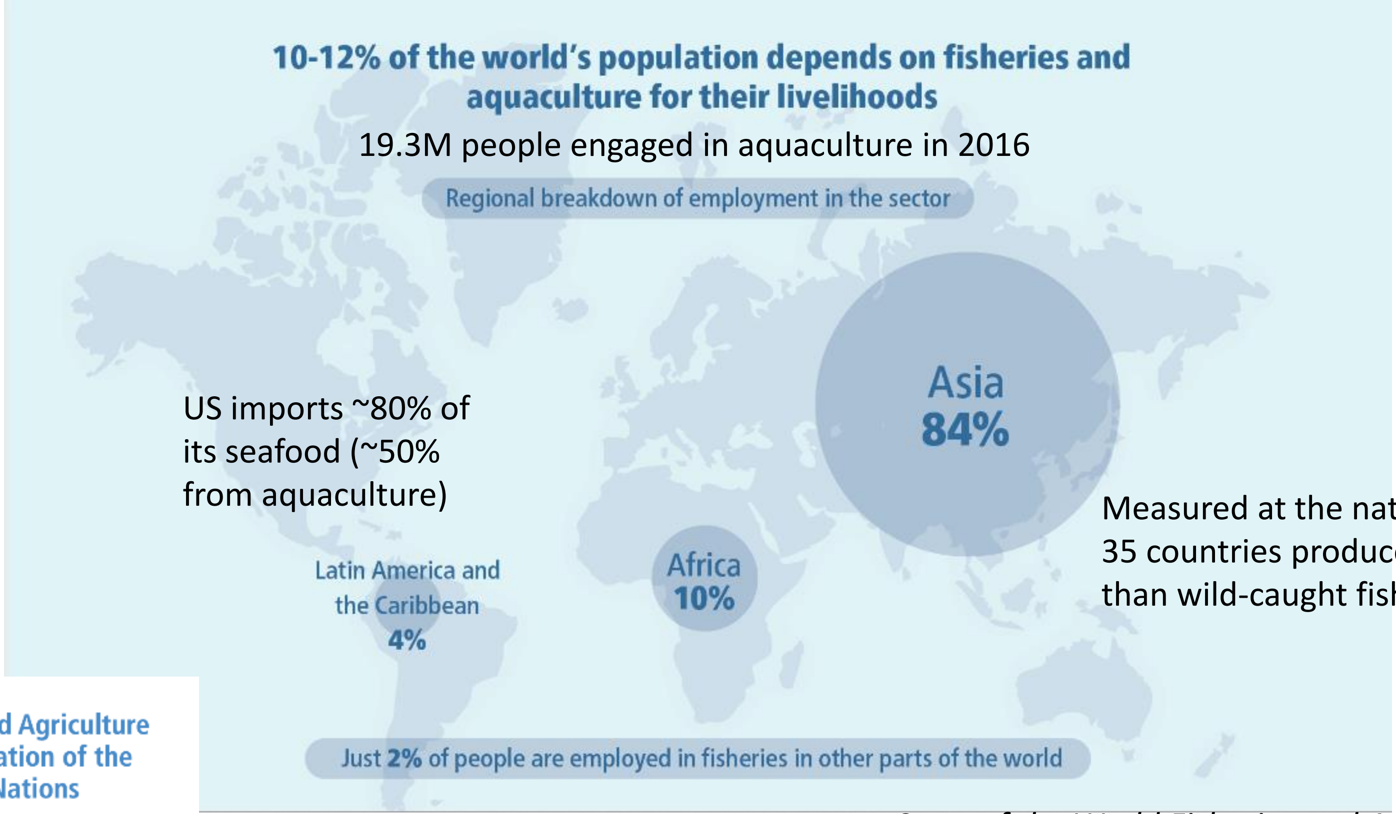


Fig. 4 Standard metabolic rate of wild and selectively bred adults of the Sydney rock oyster, *Saccostrea glomerata*, exposed to ambient (380 µatm) and elevated (856 µatm) P_{CO_2} for 5 weeks; 24 °C; salinity 34.6; n = 3; bars = SEM.

Parker et al. (2011) GCB

Sustainable Aquaculture: Why we should not forget to look out to sea



19.3M people engaged in aquaculture in 2016

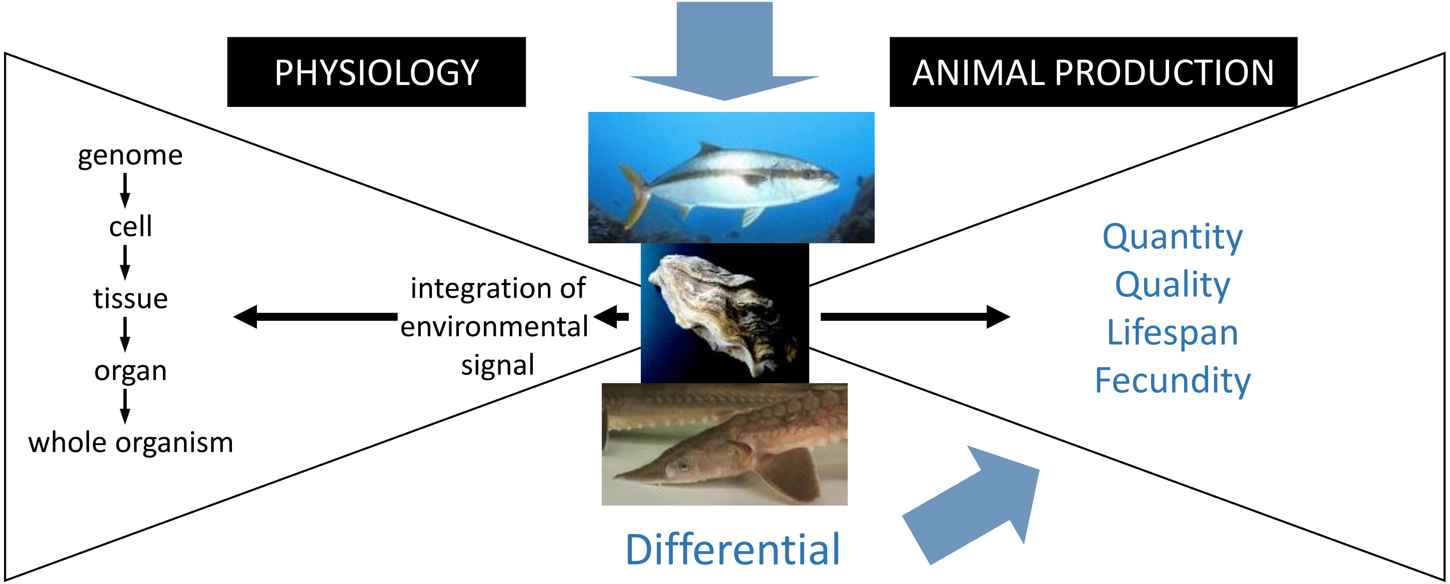
US imports ~80% of its seafood (~50% from aquaculture)

Measured at the national level, 35 countries produced more farmed than wild-caught fish in 2014

Food and Agriculture Organization of the United Nations

State of the World Fisheries and Aquaculture 2014

New Opportunities and Synergisms through Collaborations

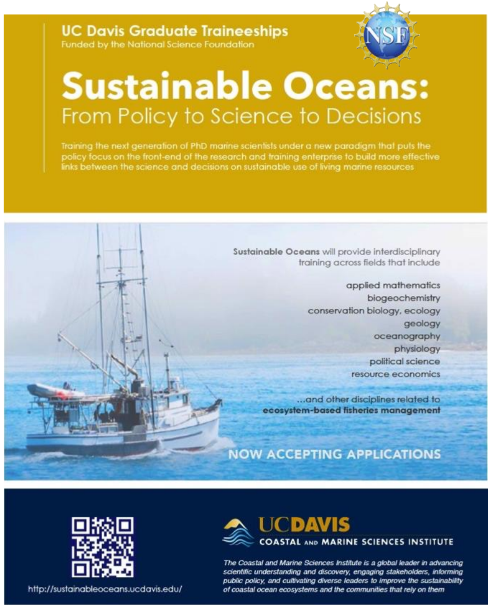


Differential Physiological Performance

e.g. growth, reproduction, stress tolerance

Sustainable Aquaculture: Building Capacity at UC Davis

Graduate Group in Marine Sciences



Thank-you

Collaborators

Andrea Schreier (UC Davis)
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Fred Conte (UCD)
Molly Webb (Bozeman Fish Tech. Ctr)
Shawn Young (Kootenai Tribe of Idaho)
Nate Jensen (KTOI)

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Aviva Fiske
Mandy Frazier

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Sterling Caviar

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