Restoration Aquaculture

Luke Gardner
California Sea Grant Aquaculture Specialist
Moss Landing Marine Labs

What is Restoration Aquaculture?

- Called by lots of different names
  - Regenerative
  - Restorative
  - Conservation
  - Etc…
- Two main definitions
  - **TNC** - the cultivation of seaweed or shellfish, that generate positive ecological and social impact
  - **Froehlich *et al* 2017**: the use of human cultivation of an aquatic organism for the planned management and protection of a natural resource.

Sea Grant California

What is Restoration Aquaculture?

- My own definition: aquaculture that results in a net positive impact, directly or indirectly on the environment

Sea Grant
California

History

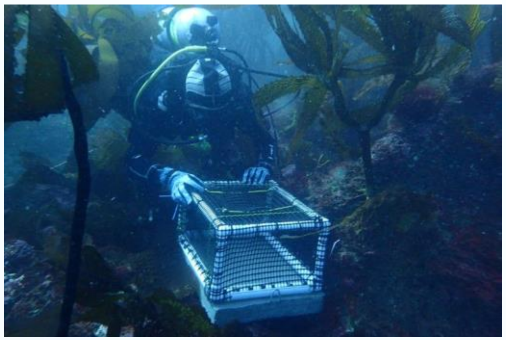
- 1800’s hatchery technologies first became common for recreational restocking efforts
- Aquaculture arrived in North America via hatcheries in 1800’s

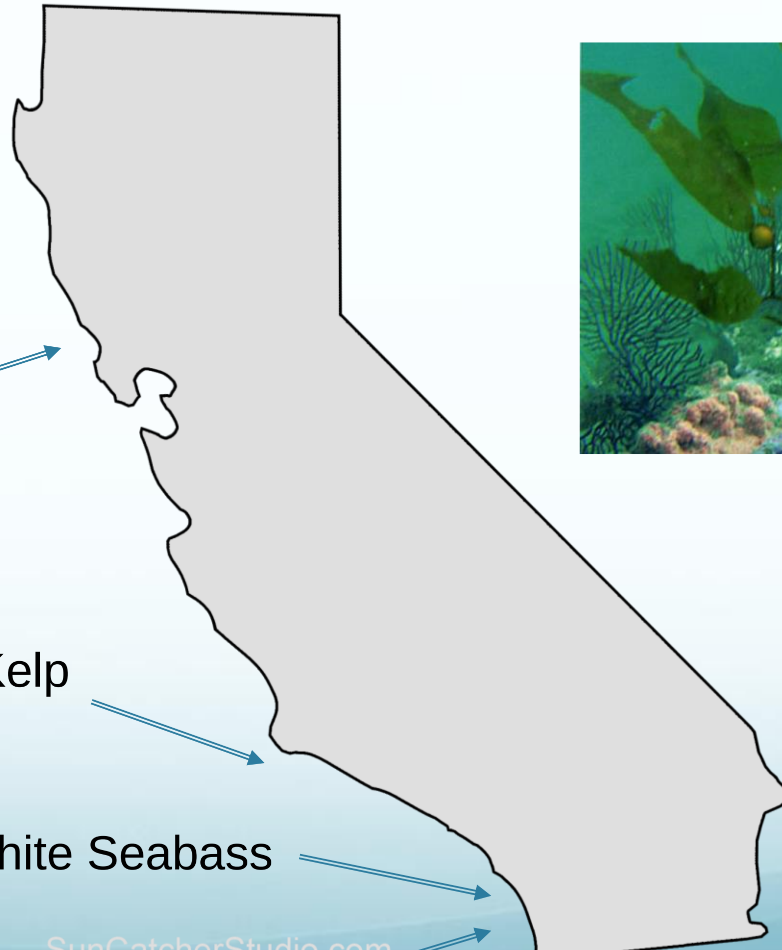
FIGURE 29. Interior of railroad fish distribution car. Hoses supplied air to the cans containing fish. Bunk beds provided sleeping accommodations for crew members.

FIGURE 23. Opening day at a well-stocked southern California pond.

Modern History

- In past years marine restoration aquaculture has focused on increasing populations of an organisms





Abalone

Abalone and Kelp

White Seabass

Abalone

Sea Grant California

How is it Restorative?

- Broadly, restoration aquaculture can be separated into species repopulation and/or providing ecosystem services
- Repopulation is used when species number is locally extinct or too low to repopulate by itself
- Ecosystem services can include water buffering, water filtration, habitat generation and societal benfits

Sea Grant California

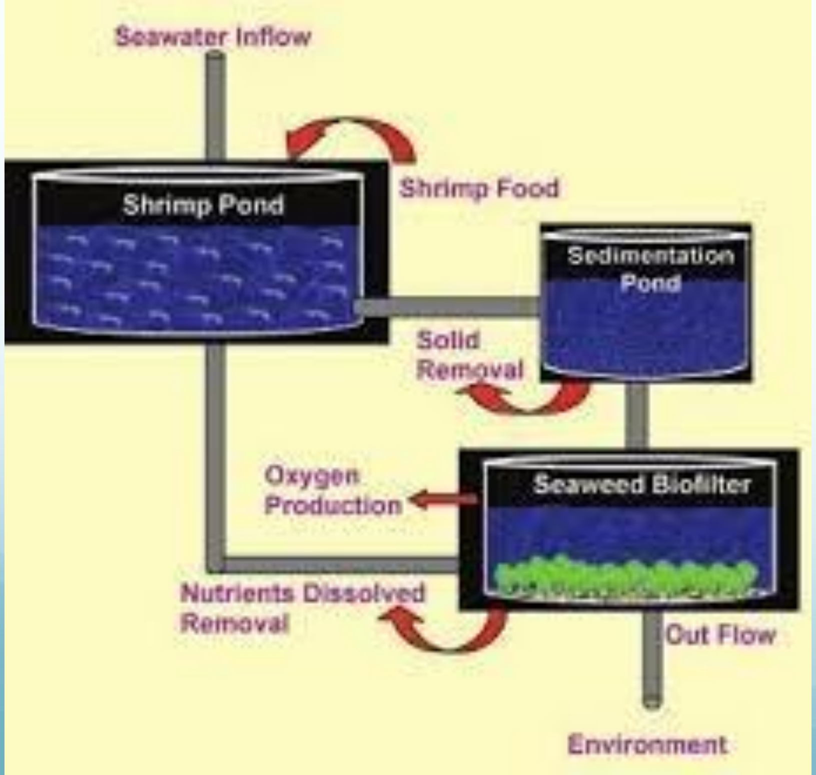
How is it Restorative?

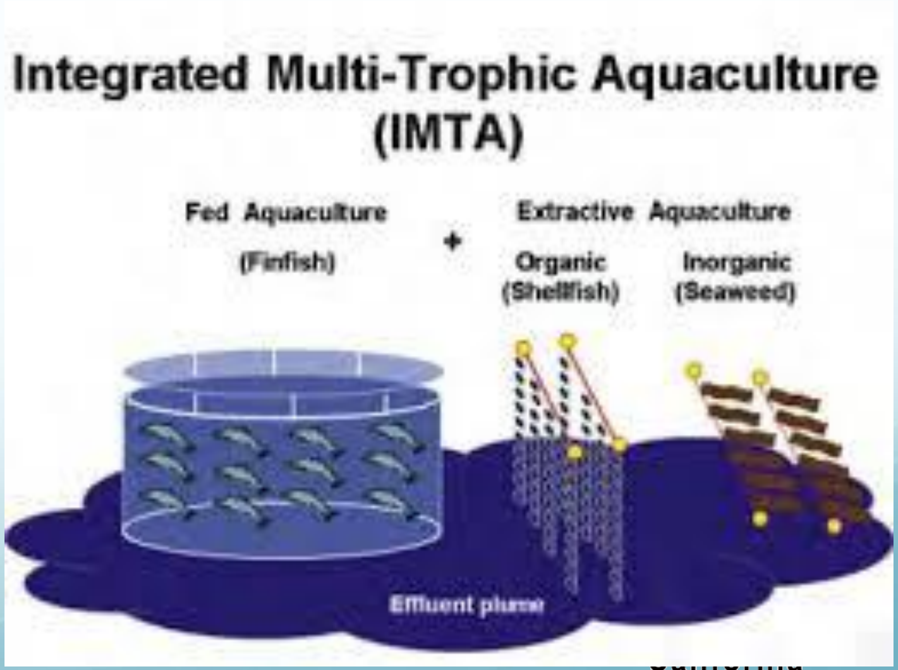
- Seaweed aquaculture ecosystem services
  - Bioremediation
  - Buffer OA via carbon sequestration
  - Habitat forming
- Bivalve aquaculture ecosystem services
  - Water filtration
  - Carbon sequestration
  - Habitat forming
  - Shoreline protection

Sea Grant California

Seaweed Bioremediation

- pollution from aquaculture and other industrial activities can be cleaned up with aquaculture
  - Biofiltration and/or IMTA (integrated multi-trophic aquaculture)





Seaweed Bioremediation

- Seaweed nutrient extractive capabilities
  - N, P and CO^2 taken up by seaweed for growth
  - Most recent estimates of seaweed harvest 30 million MT

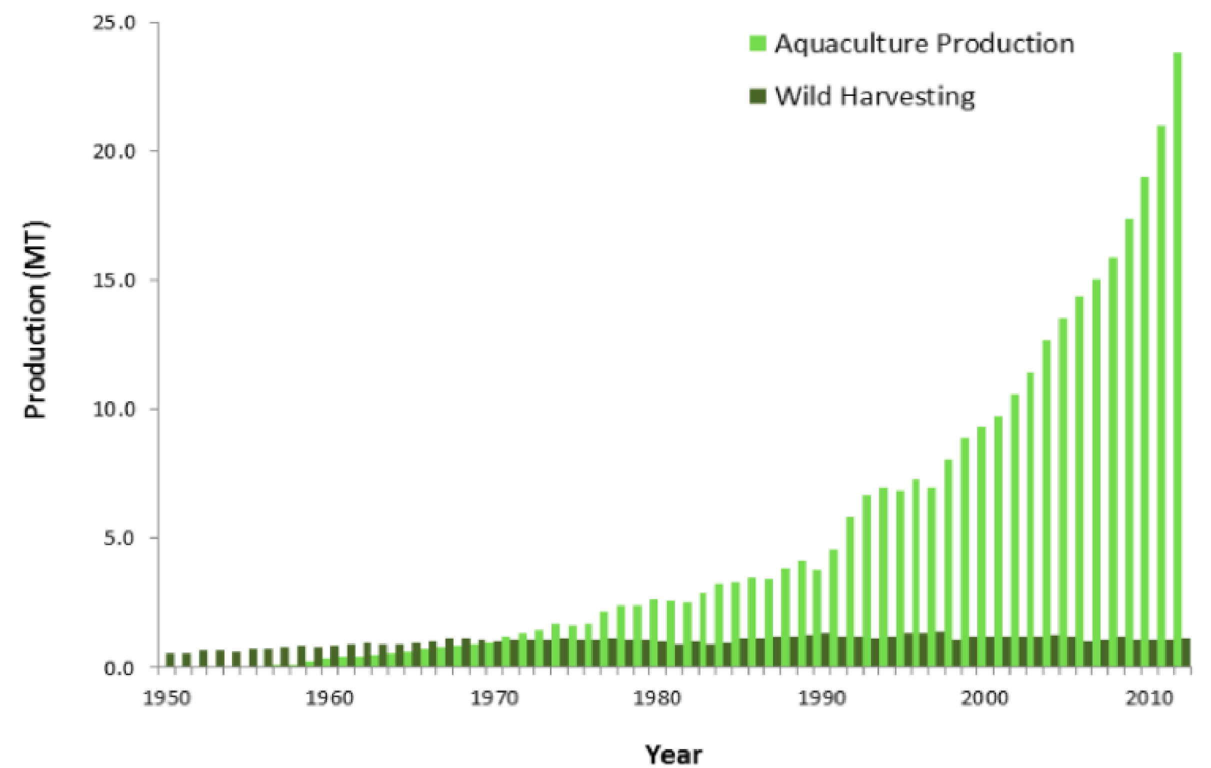


Figure 1. **Global seaweed aquaculture production (1950-2014). FAO (2015)**

Sea Grant
California

Seaweed Bioremediation

- 124 million MT of fertilizer used annually (2014)
  - 15-30% end up in coastal waters
- Nitrogen content of commercial seaweeds –
  - Pyropia / Porphyra 5.5%
  - Gracilaria 3.0%
  - Kappaphycus / Eukeuma 1.7%
  - kelp 2.0%
  - Sargassum 4.1%
- Total nitrogen removal by these five major aquaculture groups is approximately 65,000 tons of nitrogen per year

Sea Grant California

Seaweed Bioremediation

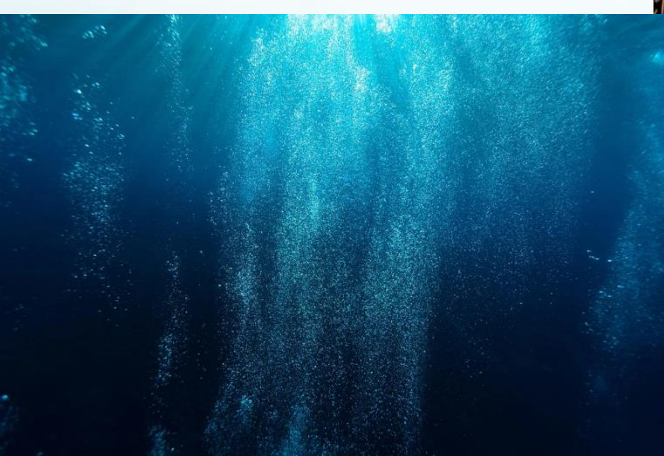
- Bjerregaard et al. (2016) estimates seaweed aquaculture could extract up to 30% of nitrogen and 61% of phosphorus if expanded

TABLE 1. Extrapolated ecosystem services from 500 million tons (dry weight) of seaweeds.

Ocean area required	500,000 km²	Based on average annual yield of 1,000 dry tons/km² undert current best practice. Equals 0.03% of the ocean surface area.
Protein for people and animals	50,000,000 tons	Assumes average protein content of 10% dry weight. Estimated value $28 billion. Could completely replace fishmeal in animal feeds.
Algal oil for people and animals	15,000,000 tons	Assumes average lipid content of 3% dry weight. Estimated value $23 billion. Could completely replace fish oil in animal feeds.
Nitrogen removal	10,000,000 tons	Assumes nitrogen content 2% of dry weight. Equals 18% of the nitrogen added to oceans through fertilizer.
Phosphorous removal	1,000,000 tons	Assumes phosphorous content 0.2% of dry weight. Represents 61% of the phosphorous input as fertilizer.
Carbon assimilation	135,000,000 tons	Assumes carbon content 27% of dry weight. Equals 6% of the carbon added annually to oceans from greenhouse gas emissions.
Bioenergy potential	1,250,000,000 MWH	Assumes 50% carbohydrate content, converted to energy. Equals 1% of annual global energy use.
Land sparing	1,000,000 km²	Assumes 5 tons/ha average farm yield. Equals 6% of global cropland.
Freshwater sparing	500 km³	Assumes agricultural use averages 1 m³ water/kg biomass. Equals 14% of annual global freshwater withdrawals.

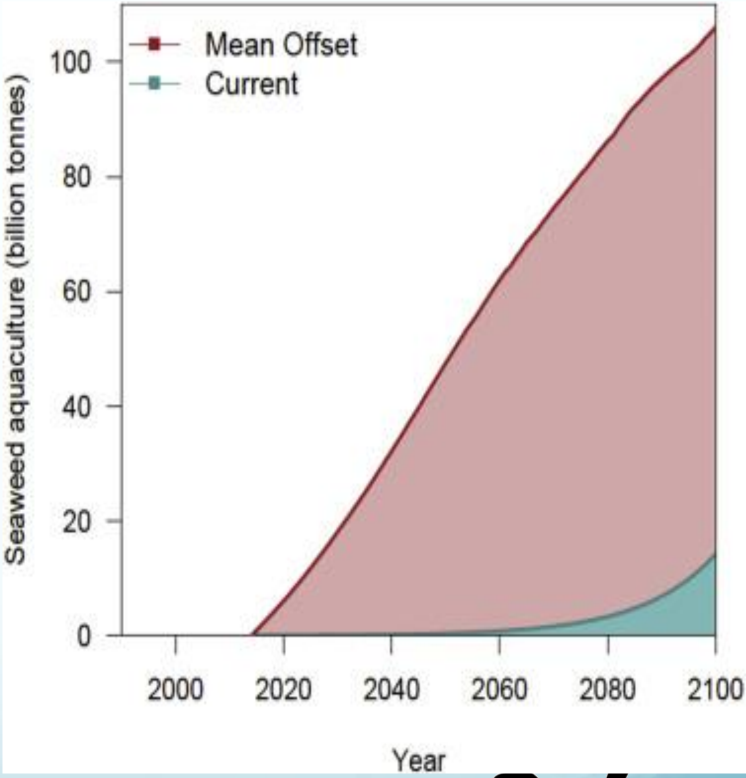
Seaweed Aquaculture Mitigation of Climate Change

- Seaweed aquaculture could be used as carbon offset
  - requires sequestration (sinking in the ocean or using as a soil amendment)



Seaweed Aquaculture Mitigation of Climate Change

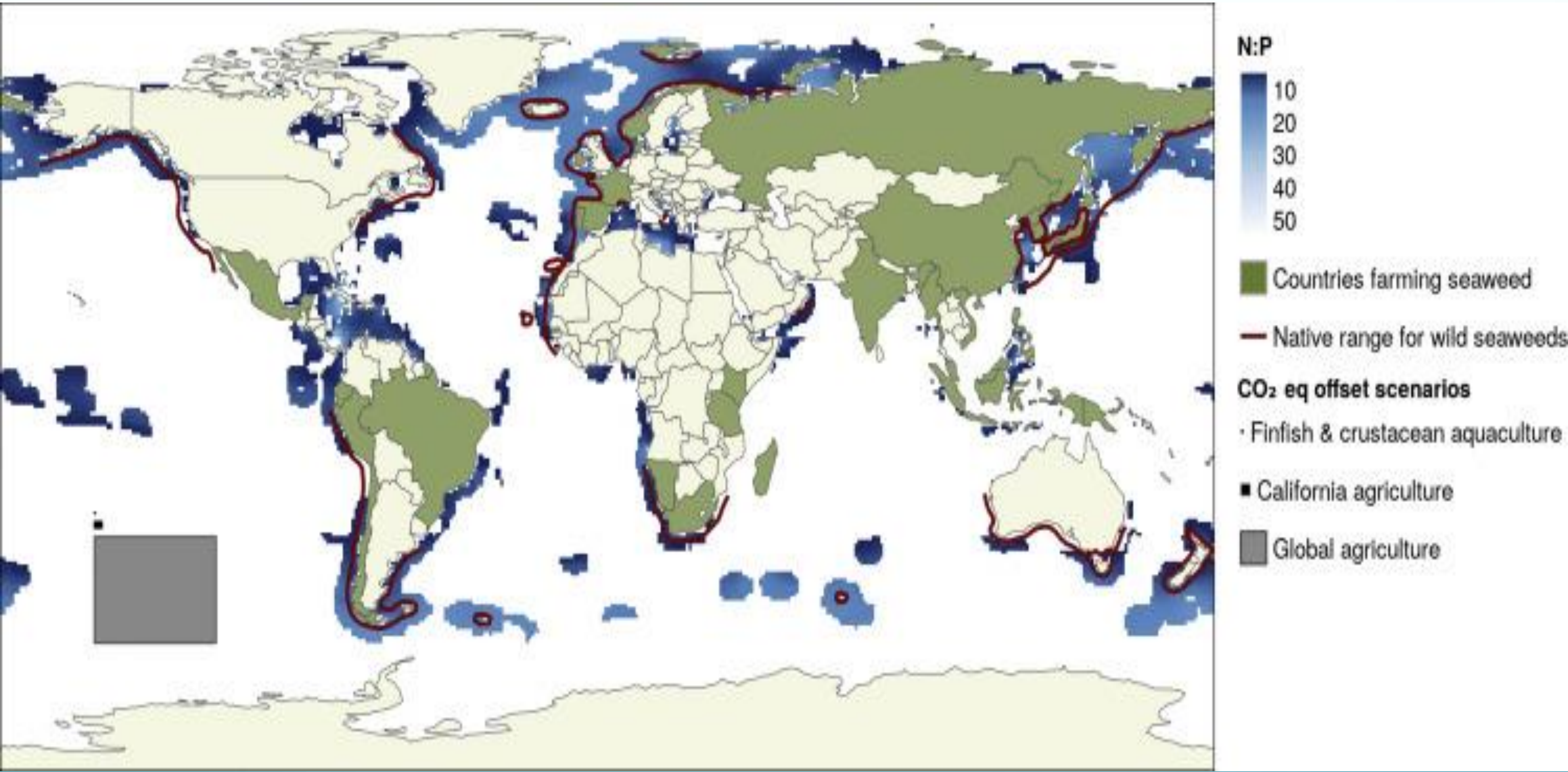
- Froehlich et al 2019 look at the feasibility of seaweed farming for carbon offsetting
  - 48 million km^2 of the oceans are suitable for seaweed aquaculture (SA)
  - Offsetting the aquaculture sector requires 14%–25% of current farmed seaweeds
  - Production scale and cost are too limiting to sequester global agricultural CO_2eq
  - SA could help buffer eutrophic, hypoxic, or acidic waters in at least 77 countries



Sea Grant California

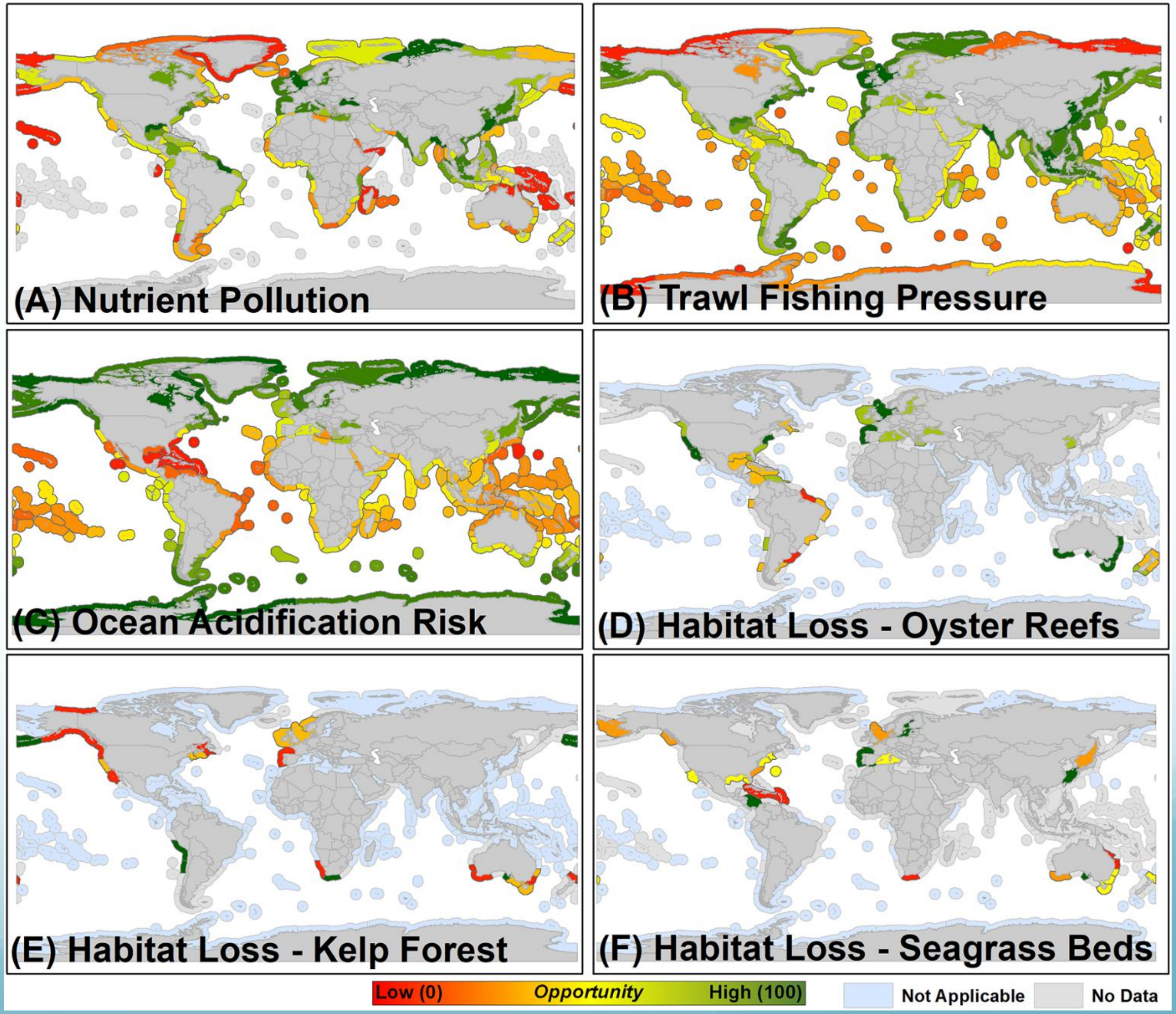
Seaweed Aquaculture Mitigation of Climate Change

- World map showing seaweed aquaculture suitable sites



Bivalve Restoration

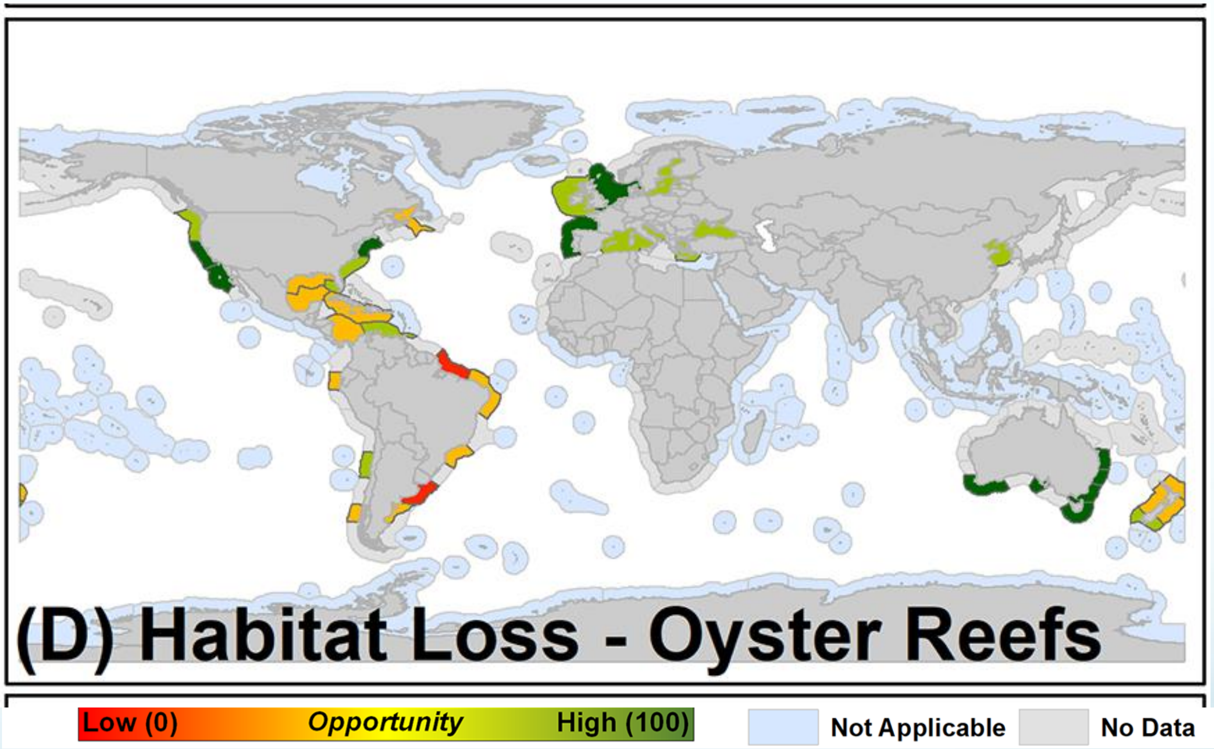
- A global spatial analysis reveals where marine aquaculture can benefit nature and people
- 85% of oyster reefs have disappeared globally



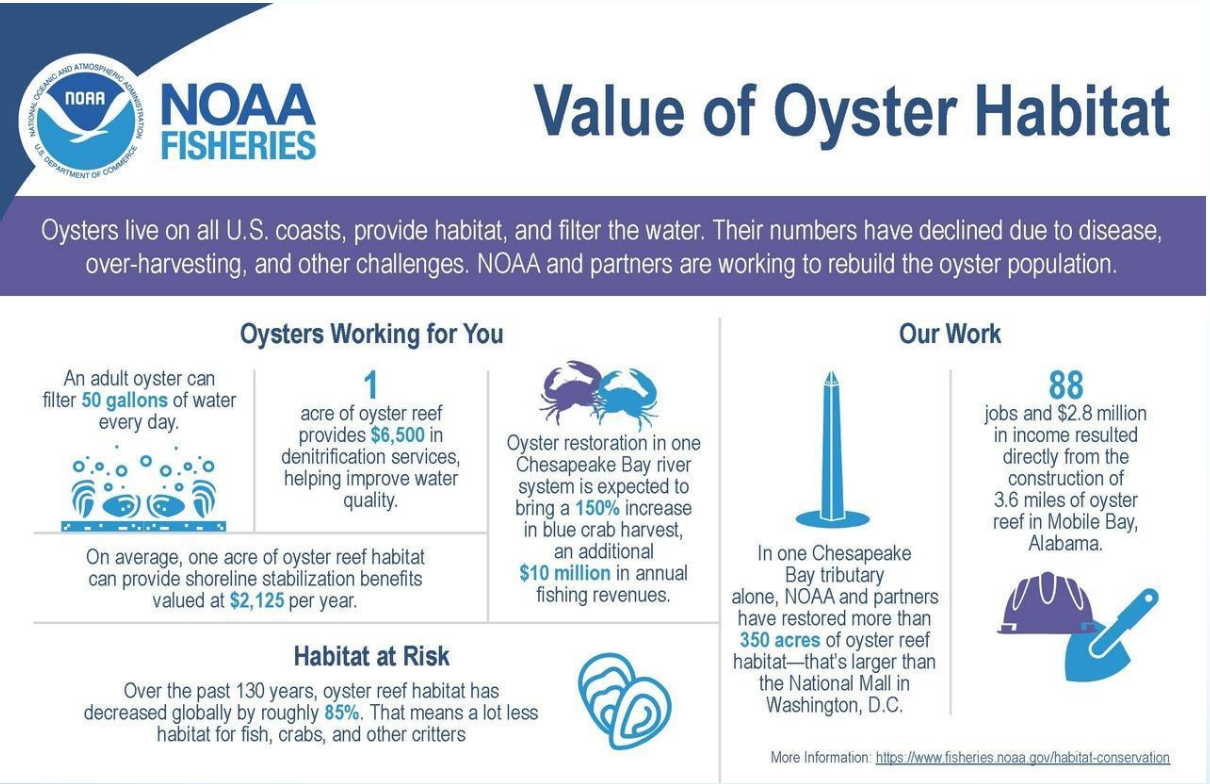
Theuerkauf et al 2019

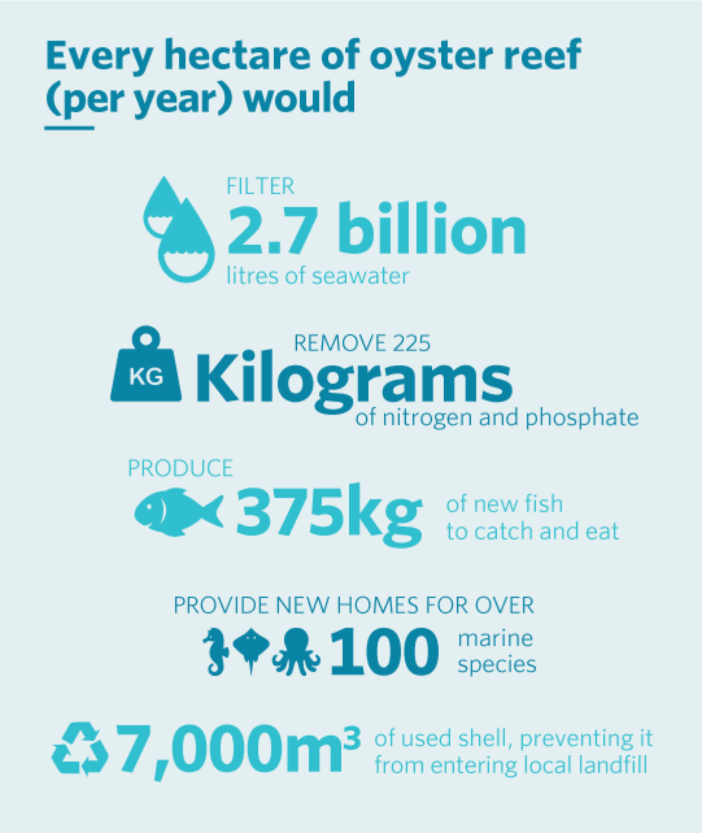
Bivalve Restoration

- A global spatial analysis reveals where marine aquaculture can benefit nature and people
- 85% of oyster reefs have disappeared globally



Bivalve Restoration





Bivalve Restoration

- 1 oyster can filter 50 gallons of water a day

Sea Grant California

Economics of Restoration Aquaculture

- Costs to restore oyster reefs and kelp beds - $80,000 to $1,600,000 per hectare
- Varied success - 38.0%– 64.8% survival two years post-restoration
- Some opportunities to align business interests with restoration

Sea Grant California

Restorative Aquaculture Locally

- Current activities are largely research and based out of MLML with associated partners
  - Purple urchin ranching
  - Reducing livestock methane emissions via seaweed
  - White abalone repopulation
  - Olympia oyster repopulation
  - Bull kelp repopulation

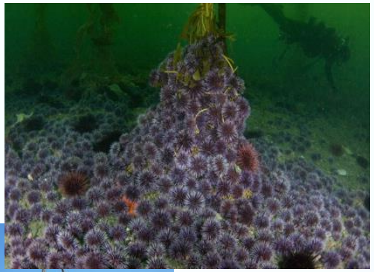
Sea Grant California

Restorative Aquaculture Locally

- **Purple urchin ranching**
- Purple urchins are eating all the kelp forests in California (93% decline)
- Kelp forests are important ecosystem habitat
- Kelp absence threatens ecosystem diversity and fishery production.
- Urchin barrens can persist for a long time

Restorative Aquaculture Locally

- **Purple urchin ranching**
  - MLML testing aquaculture potential to enhance roe of urchins for sale
  - Economic analysis of urchin ranching just funded
  - Aquaculture incentives removal of urchins to restore kelp forests







Restorative Aquaculture Locally

- **Reducing methane from livestock with seaweed**
  - Cattle have a gas problem
  - Livestock is the largest single contributor to methane emissions in California
  - California passed a 2016 law requiring 40% of methane emissions by 2030
  - Methane is 25X more potent than CO^2 in the atmosphere

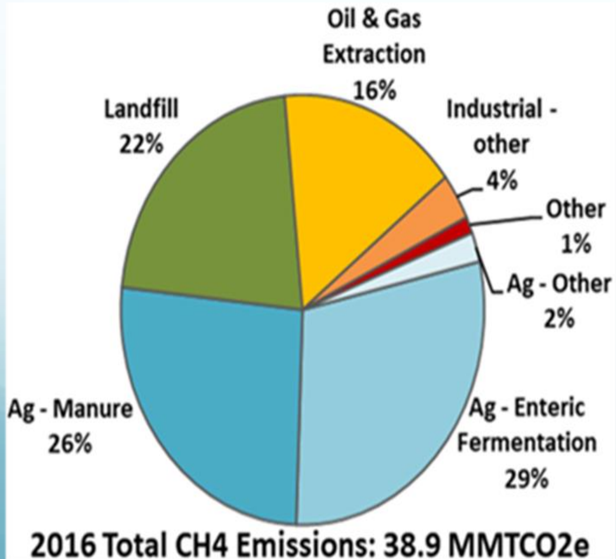
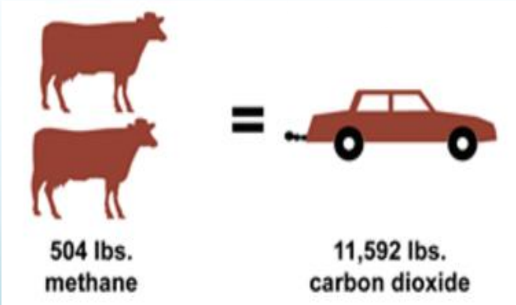
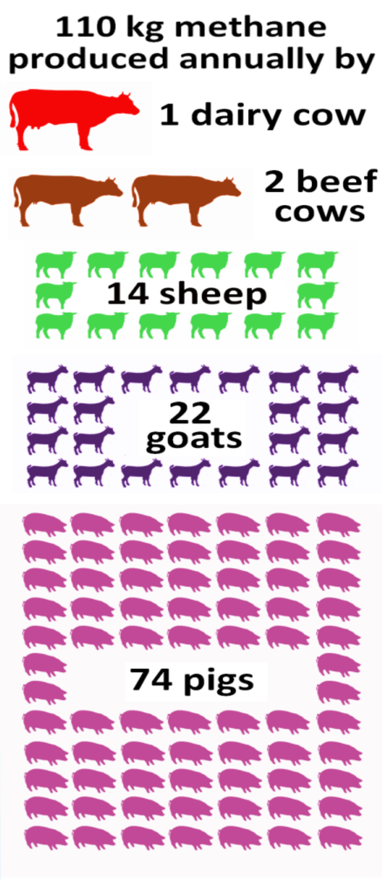


Figure 1. Pie chart depicting sources contributing to

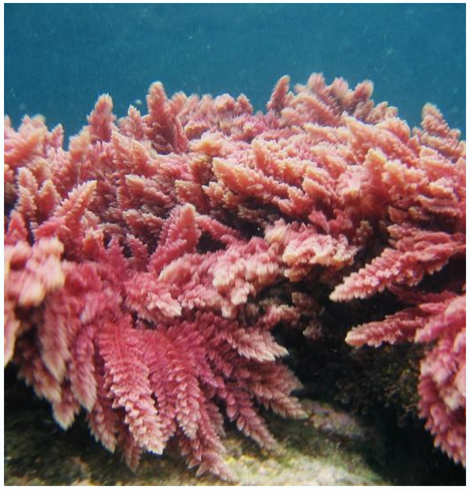




Sea Grant California

Restorative Aquaculture Locally

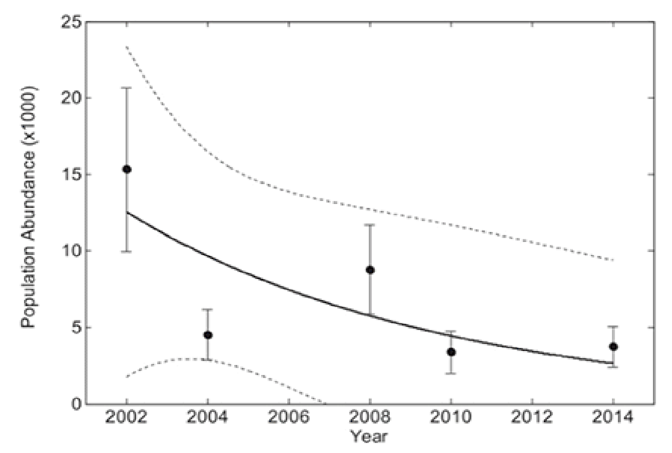
- **Reducing methane from livestock with seaweed**
  - Feeding some seaweeds to cows reduces methane
  - 99% methane reduction at 2% inclusion level (*in vitro*)
  - Lots of seaweed would be needed and the species identified isn't farmed yet.
  - MLML is researching native CA species for potential methane reducing properties as well as farming potential

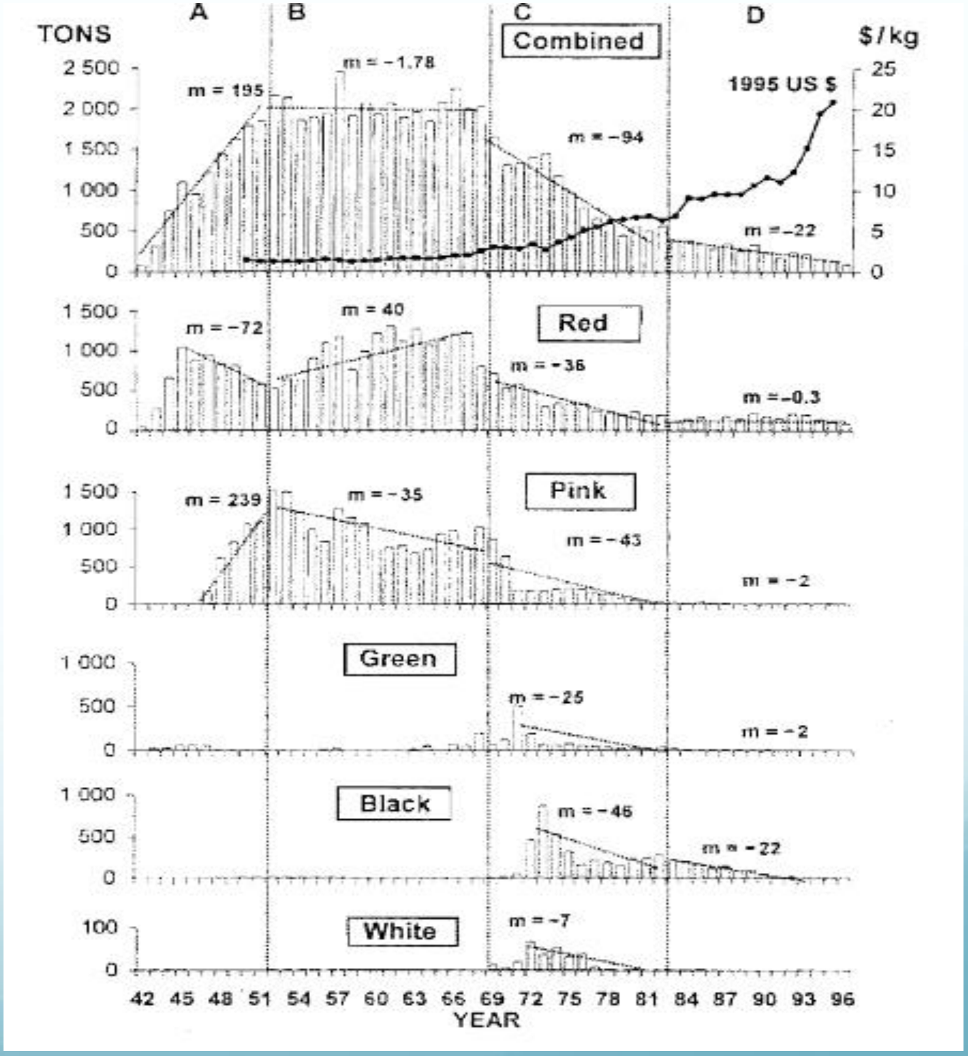


Sea Grant California

Restorative Aquaculture Locally

- **White abalone restoration**
  - First marine invertebrate to be declared endangered
  - Overfishing primarily considered responsible for their decline
  - Bodega Marine Lab along with CDFW, SWFSC and many others working to restore them via aquaculture





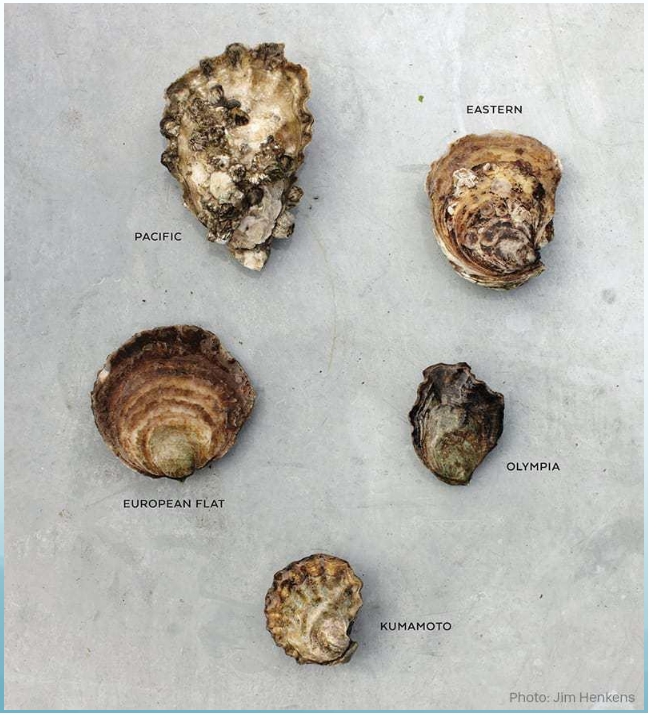
Restorative Aquaculture Locally

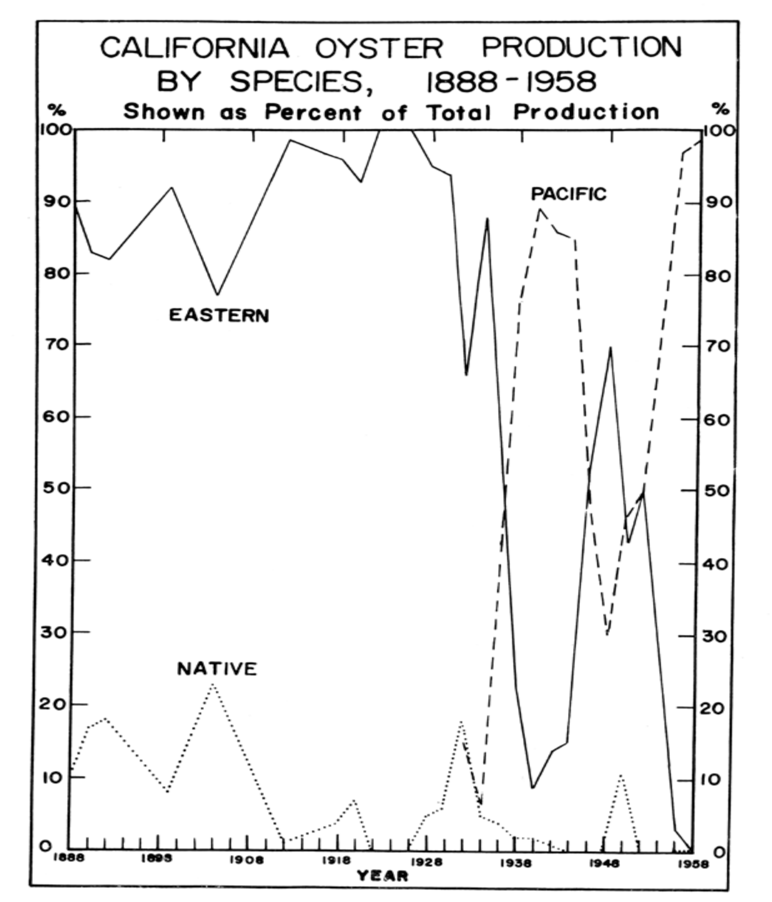
- **White abalone restoration**
  - MLML has been involved in rearing white abalone since 2019
  - 2021 out-planted 900 juveniles to the wild
  - More than 3000 juveniles at MLML

California

Restorative Aquaculture Locally

- **Olympia Oyster restoration**
  - Oyster aquaculture began in California as the native fishery collapsed in the late 1800s.
  - Many estuaries have very small remnant populations





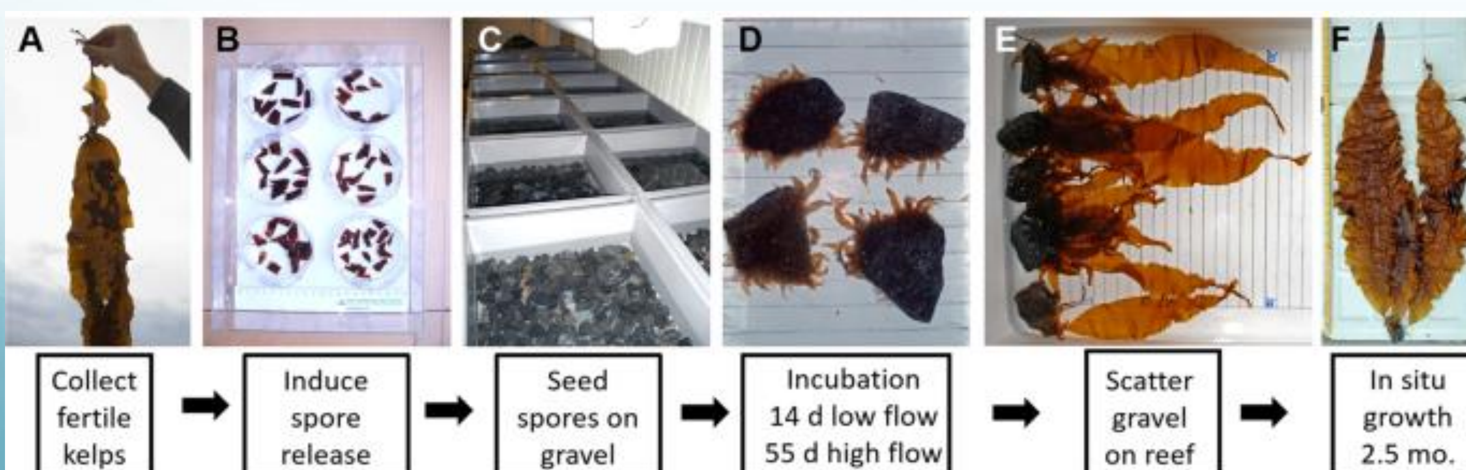
Restorative Aquaculture Locally

- **Olympia Oyster restoration**
  - MLML with Elkhorn Slough NERR cultured 3000 individuals as a pilot in late 2018
  - More coming this summer and for the next few years thanks to CDFW and OPC support

a Grant
alifornia

Restorative Aquaculture Locally

- **Bull Kelp restoration**
  - MLML testing hatchery techniques to produce bull kelp for out-planting to barrens
  - Green gravel technique being explored for distribution



Sea Grant California

Looking forward

- Doing restoration aquaculture on larger scales
  - Finding funding mechanisms
  - Assessing effects of restoration aquaculture
- More potential restoration efforts in the future
  - Sunflower sea star aquaculture (Marine Pollution Studies Laboratory/CDFW)
  - Black abalone repopulation (UCSC)
- Determine a regulatory pathway for restorative aquaculture

Sea Grant California