

# Shellfish Culture Opportunities for Hawai'i



U.S. DEPARTMENT OF AGRICULTURE

# Contents

- Why grow shellfish?
- Basic oyster biology and life history
- Hatchery production
- Spat collection
- Nursery systems
- Growout
- Sanitation & food safety
- Harvest
- Value-added products

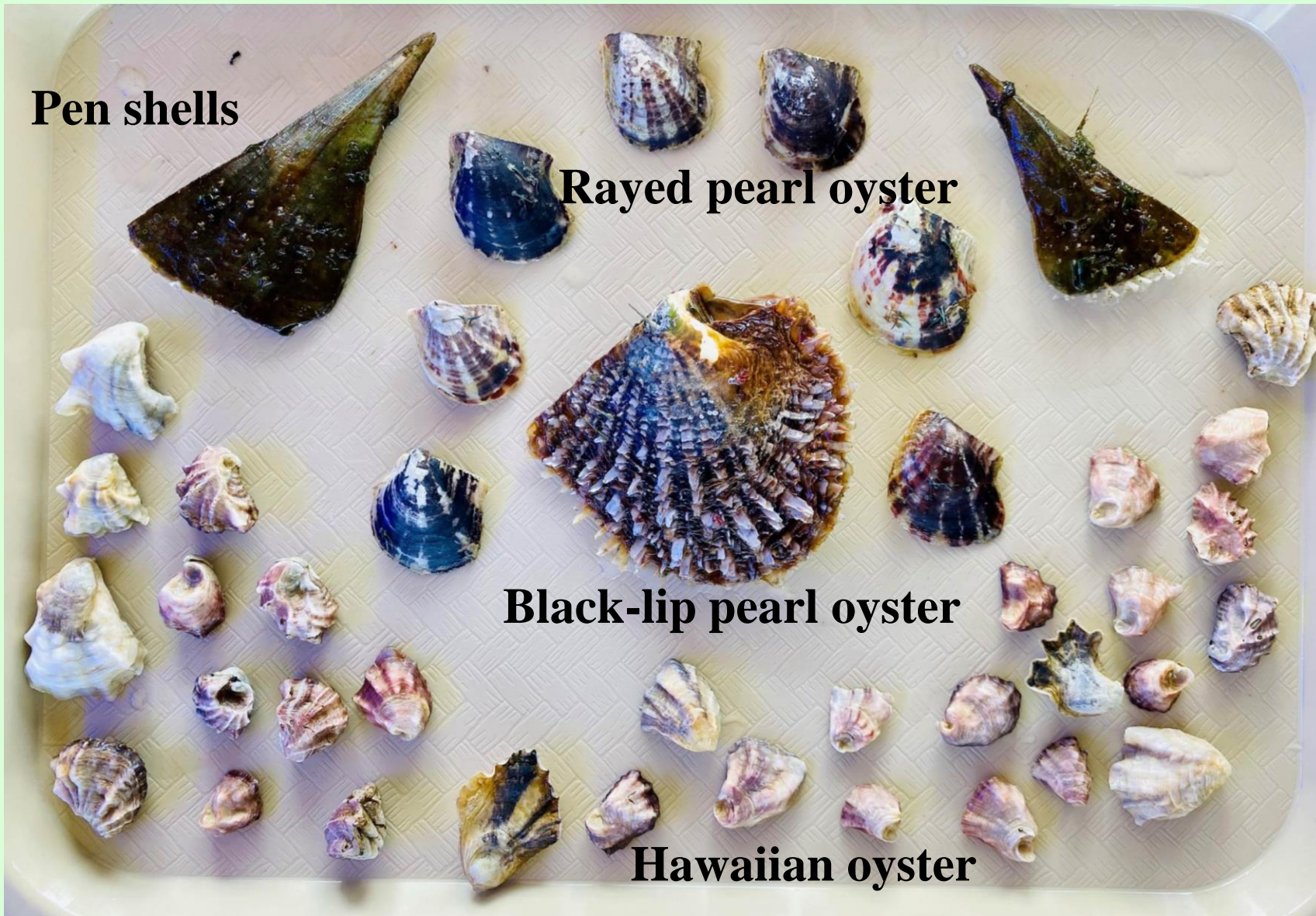


# The need for shellfish culture in Hawai‘i

- 60-80% of food is imported
  - ~400,000 pieces of oysters imported monthly
- Cultural traditions & education
- Unexploited opportunities/new species
- Sustainable form of aquaculture
  - Low on the food chain
- Environmental improvement
  - Water quality
  - Fish habitats
  - Native species restoration
  - Shoreline stabilization



# Some Hawai'i bivalve species (216 known)



**Pen shells**

**Rayed pearl oyster**

**Black-lip pearl oyster**

**Hawaiian oyster**

# Taxonomy

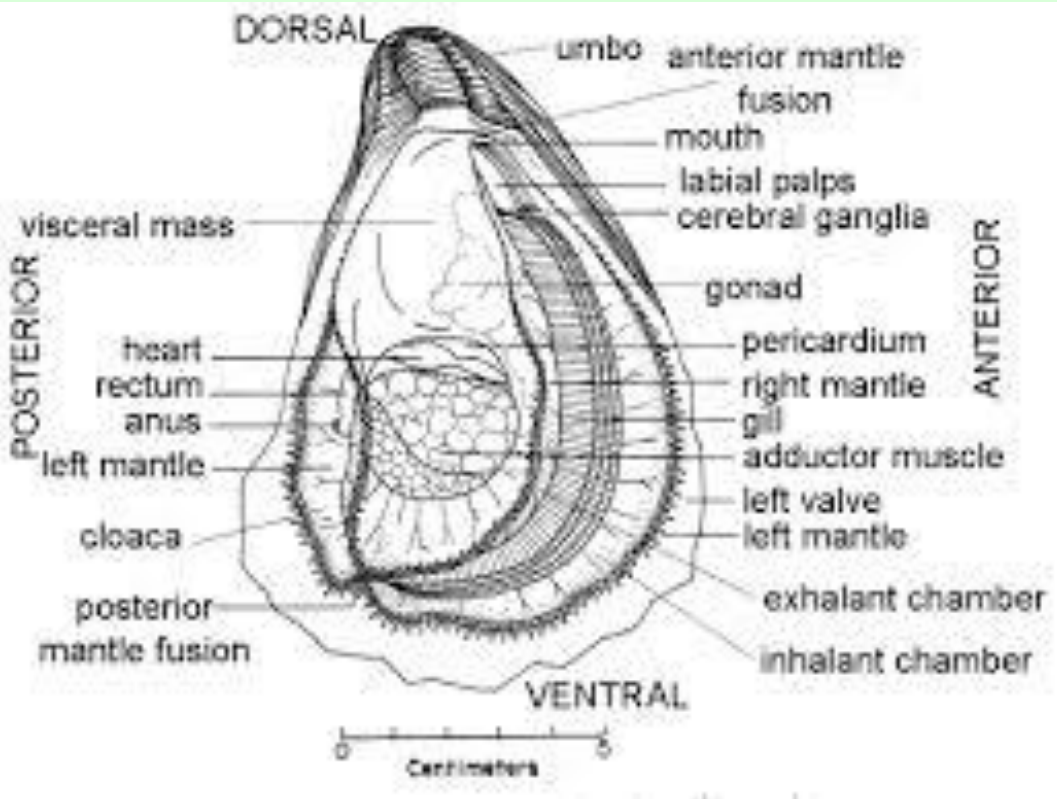
- **Kingdon:** Animalia
- **Phylum:** Mollusca
- **Class:** Bivalvia
- **Subclass:** Pteriomorpha
- **Order:** Ostreoida
- **Family:** Ostreidae
- **Genera:** *Crassostrea (Magallana)*, *Ostrea*, *Saccostrea*, *Dendrostrea*
- **Species:** >200
  - *Oysters may be difficult to identify by morphological characteristics.* Genetic identification by DNA fingerprinting is possible, but actual number of species is disputed.



# Two major groups of oysters

- Cupped oysters (*Crassostrea* and *Saccostrea*)
- Flat oysters (*Ostrea* and *Dendroostrea*)

# General Oyster Morphology



Landers University

Maryland Sea Grant

# Major culture species

## Crassostrea

- *C. virginica* (American/Eastern)
- *C. gigas* (Pacific/Japanese)
- *C. ariakensis* (Suminoe)
- *C. sikamea* (Kumamoto)
- *C. rivularis* (Jinjiang oyster)
- *C. rhizophorae* (Mangrove)
- *C. corteziensis* (Pleasure)
- *C. iridescens* (Rock)

## Origin and Distribution

Eastern N. America  
Pacific Asia Coast, now widely distributed  
Pacific Asia Coast, now widely distributed  
Pacific Asia Coast, now widely distributed  
Pacific Asia Coast, now widely distributed  
Tropical East Coast of N. and S. America  
Tropical West Coast of N. and S. America  
Mexico, Central America

## Ostrea

- *O. edulis* (European flat oyster) Europe, also culture on E. and W. U.S. Coasts
- *O. lurida* (Olympic oyster) Pacific Coast of U.S. and Canada
- *O. equestris* (Crested oyster) Northwest Atlantic
- *O. stentina* (Provence oyster) Hawai'i, New Zealand Japan

## Saccostrea

- *S. glomerata* (synonymous with *S. commercialis*) Indo-Pacific, including Australia/N.Z.
- *S. cucullata* Indo-Pacific, worldwide

## Dendroostrea

- *D. sandvicensis* (Hawaiian oyster) Hawai'i

# Oyster species and their sizes



***Crassostrea gigas***  
**(Pacific Oyster) 16"**



***Ostrea edulis***  
**(Flat oyster) 4"**



***Crassostrea virginica***  
**(Eastern oyster) 6"**



***Crassostrea sikamea***  
**(Kumamoto) 2-3"**



***Saccostrea glomerata***  
**(Sydney rock oyster) 4"**



***Dendroostrea sandvicensis***  
**(Hawaiian oyster) 2-3"**

# Many species of bivalves are ecologically important

- Form reefs in temperate areas-provide habitat for other species
- They are the ecological equivalent of corals in tropical areas
- Improve water quality
- Reduce sedimentation
- Important part of the food chain



# Suspension-feeder (filter feeders)

- Most bivalves ingest phytoplankton (microalgae)
- Some species are selective-they can sort out particles and reject the non-edible particles as pseudo-feces
- Oyster hatchery production and culture depend on the availability of microalgae
- This feeding habit lends itself to clarifying water



# Biological Parameters

## Pacific Oyster *Crassostrea gigas*

- **Depth:** 1.5 to 3.0 meters
- **Temp:** -1.8 to 35 °C (28-95 F)
- **Salinity:** 8.0 -35.0 ppt
- **DO:** 2.9 to 10.6 mg/L  
(can live without oxygen for extended periods)
- **pH:** 6.0 to 9.2
- **Filter Feeders** – pumps bring in food and take out waste  
bacteria, protozoa, detritus, and a wide variety of diatoms





Largest  
living oyster  
14''

# Oyster Aquaculture Production



Chelsea Farms, WA



Willapa Bay, WA 1911

# West Loch-Pearl Harbor

Eastern oysters introduced in 1880's to start farming

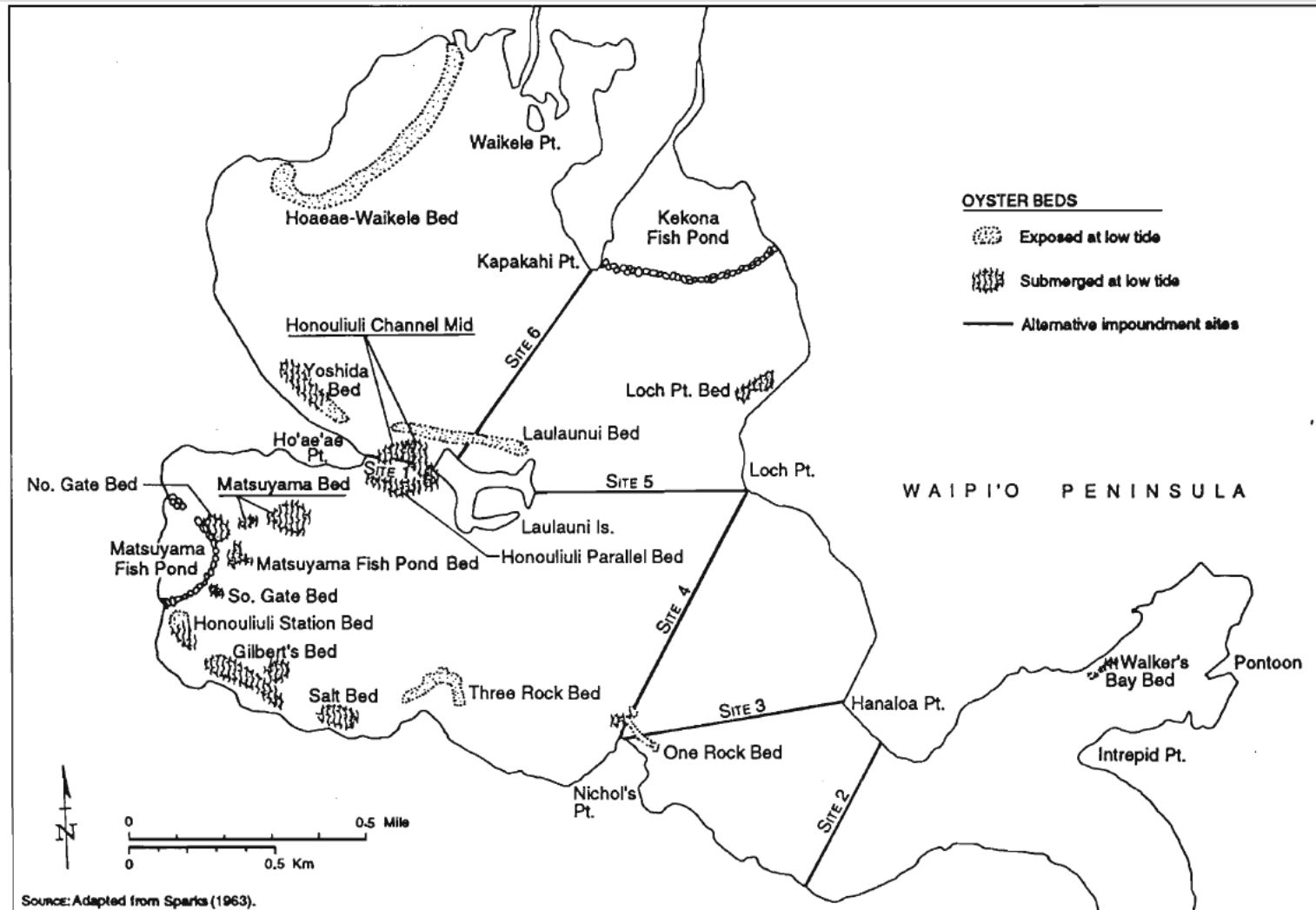
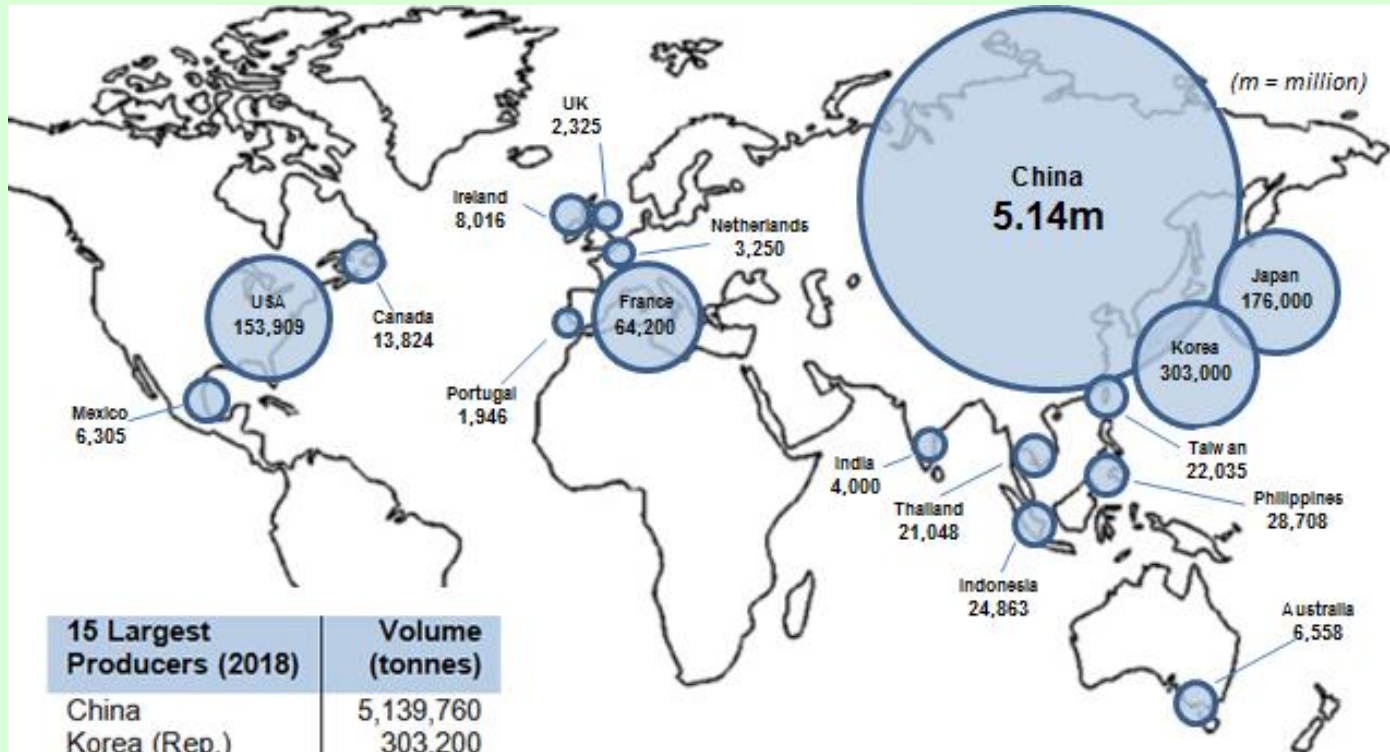
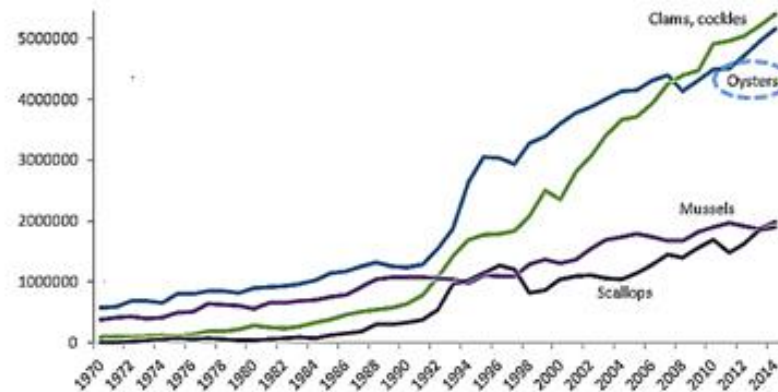


Figure 11. Oyster beds in West Loch, Pearl Harbor, O'ahu, Hawai'i

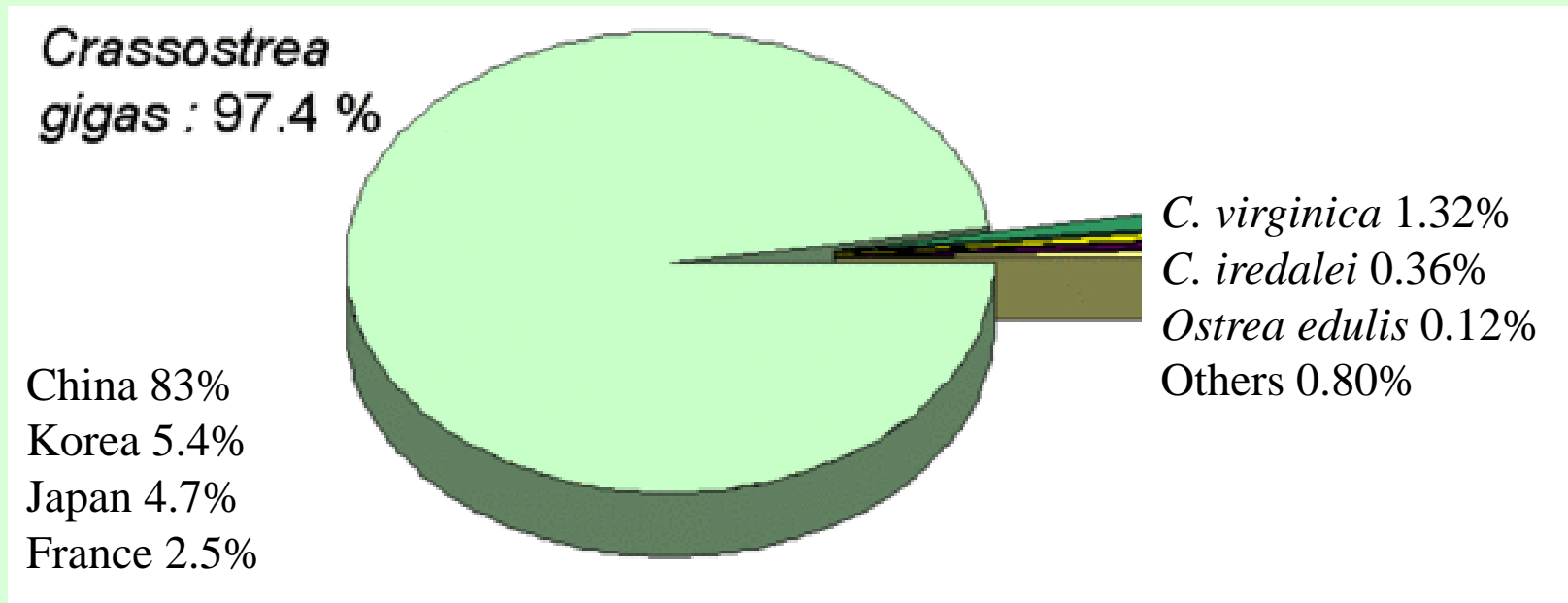
# Global production



15 Largest Producers (2018)	Volume (tonnes)
China	5,139,760
Korea (Rep.)	303,200
Japan	176,000
<b>USA</b>	<b>153,909</b>
France	84,910
Philippines	28,708
Indonesia	24,863
Taiwan	22,035
Thailand	21,048
Canada	14,614
Ireland	10,369
Australia	6,558
Mexico	6,305
India	4,000
UK	2,325



# Global production by species



IFREMER 2005

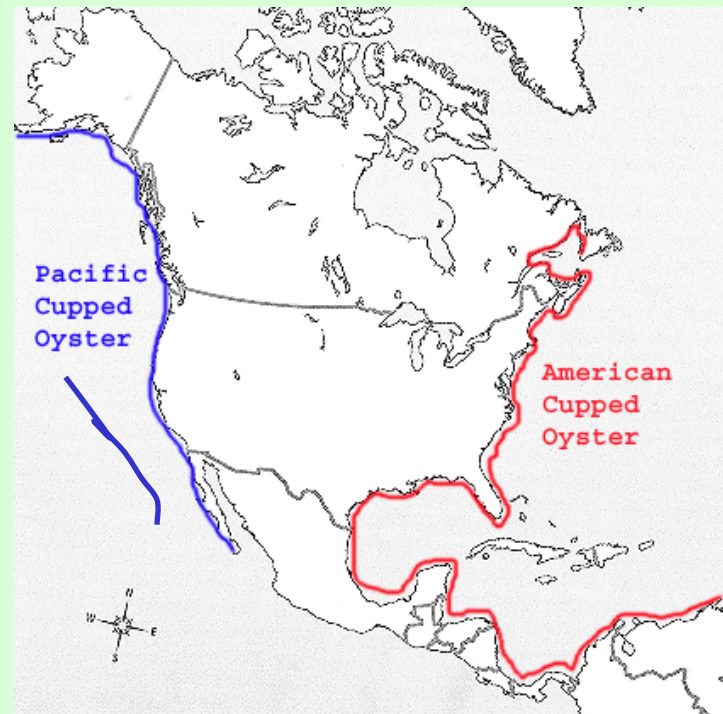
# U.S. Aquaculture production, 2018

Species	2018		
	Thousand pounds	Metric tons	Thousand dollars
<b>Freshwater:</b>			
Catfish	350,343	158,915	341,915
Striped bass	8,688	3,941	32,800
Tilapia	14,436	6,548	37,986
Trout	49,316	22,370	95,856
Crawfish	160,235	72,682	210,595
<b>Total Freshwater</b>	<b>583,018</b>	<b>264,455</b>	<b>719,152</b>
<b>Marine:</b>			
Salmon	36,355	16,491	66,536
Clams	10,778	4,889	122,119
Mussels	862	391	9,883
Oysters (meat)	44,729	20,289	219,234
Shrimp	4,486	2,035	12,556
<b>Total Marine</b>	<b>97,210</b>	<b>44,094</b>	<b>430,328</b>
Miscellaneous	-	-	374,749
<b>Totals</b>	<b>680,229</b>	<b>308,550</b>	<b>1,524,229</b>

# U.S. Aquaculture production, 2018

## By species

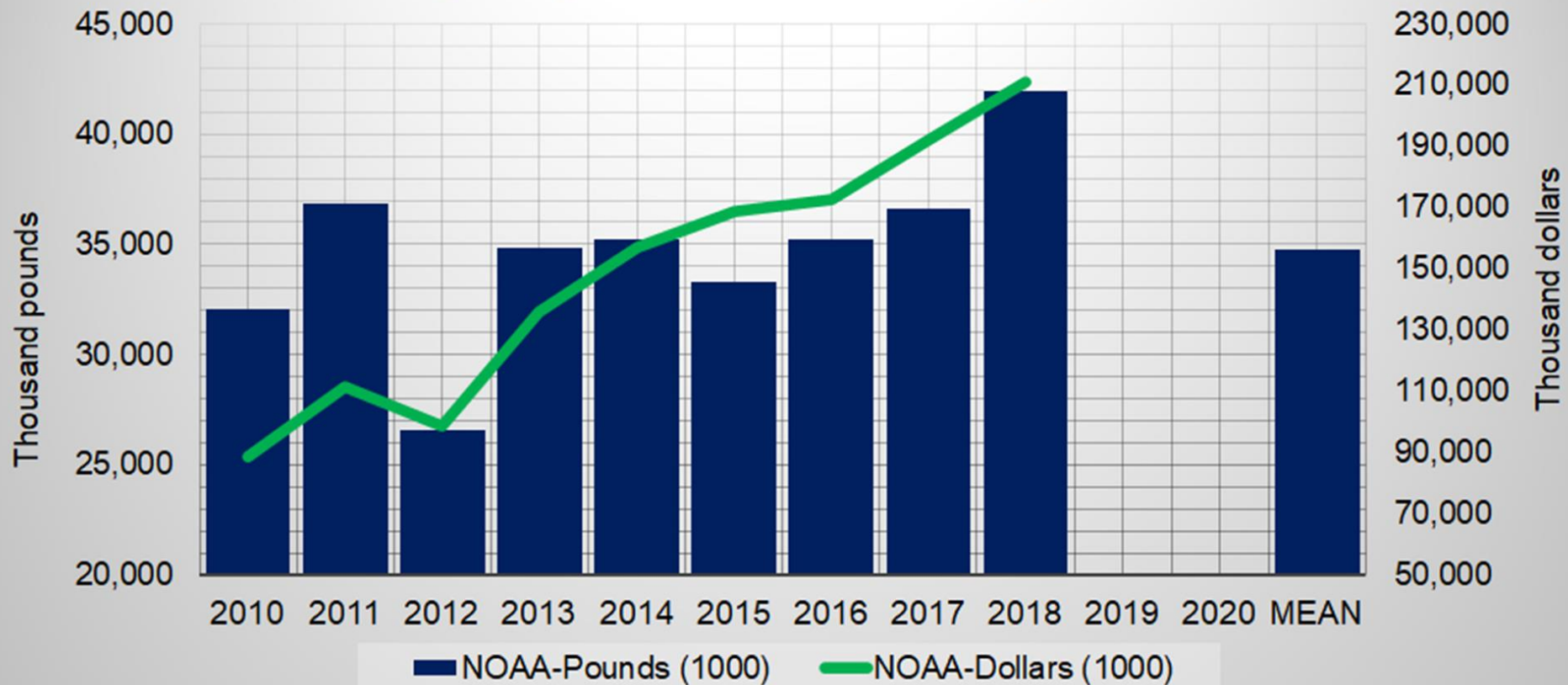
Species	#farms	#sold (1,000's)	Live weight (1,000)	Total sales (\$1,000's)	Average price/lb (\$)
Eastern	528	406,972	76,548	134,385	1.70
Pacific	145	168,237	52,463	89,467	1.58
Other	44	124,189	38,897	61,086	?



2017 Census of Agriculture USDA, National  
Agricultural Statistics Service

# U.S. oyster prices

## U.S. oyster production and farm-gate values



# Current status of bivalve culture in Hawai‘i



4 shellfish hatcheries on Hawai‘i Island  
-These hatcheries provide ~50-80% of the shellfish seed used on the West Coast

3 commercial farms (2 more in process)

6 Hawaiian fishponds groups with experience

7 restorative aquaculture sites

Pacific Oysters (*Crassostrea gigas*) are the main commercial species

Hawaiian Oysters (*Dendostrea sandvicensis*) mostly for restorative aquaculture but have commercial potential



# Oyster species for Hawai‘i



***Crassostrea gigas***  
**(Pacific Oyster) 16"**



***Ostrea edulis***  
**(Flat oyster) 4"**



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***Dendroostrea sandvicensis***  
**(Hawaiian oyster) 2-3"**

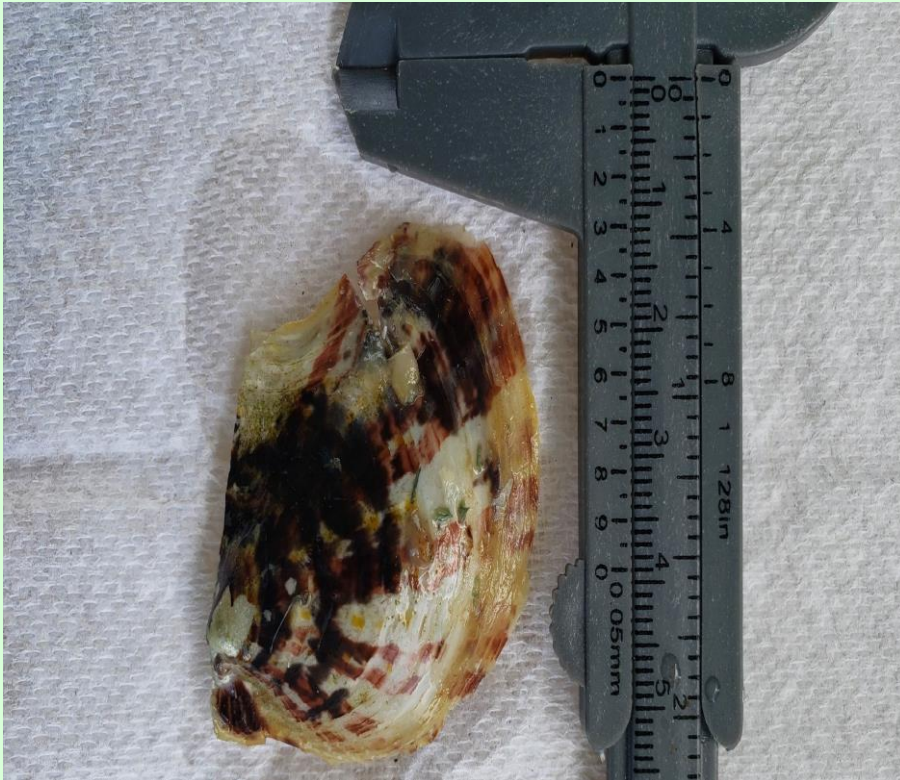
# Native oysters

## *Dendostrea sandvicensis*

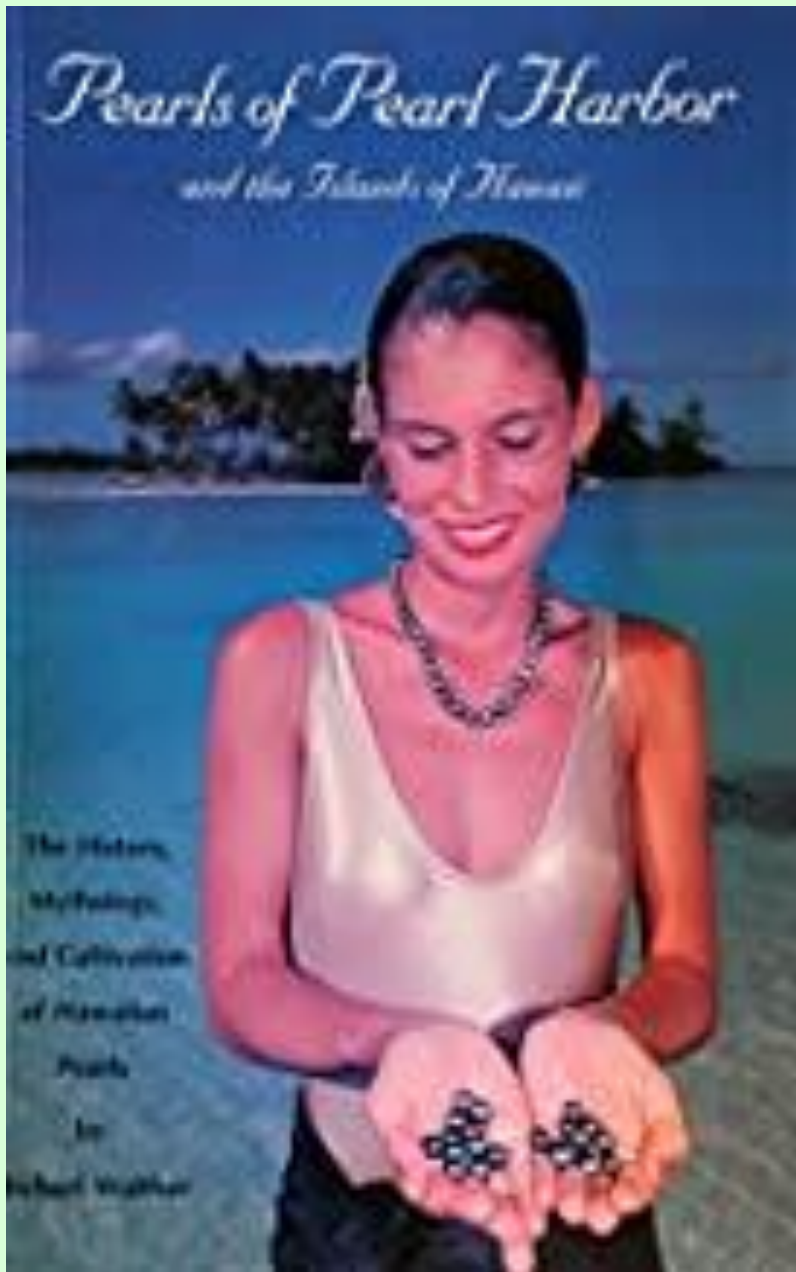


# Other culture species

**Black-lip pearl oyster**  
(*Pinctada margaritifera*)



**Rayed pearl oyster**  
(*Pinctada radiata*)



**Mourning apparel,  
Society Islands, Bishop Museum**

# Pen Shells



**Pen shells** (*Atrina* spp.,  
*Streptopinna* spp., *Pinna* spp.)

**Callo de Hacha**  
México



Hawaiian Clam- *Tellina palatum*



# Why These Native Species?

- Many native bivalves are now extremely rare
  - If efforts are not made to assist populations, they may disappear
- Native species more suited to oligotrophic waters
- Bivalve diversity provides new opportunities for aquafarmers and restorative aquaculture
- Filtration and assimilation rates vary by species
- These are larger species, with higher filtration capacity



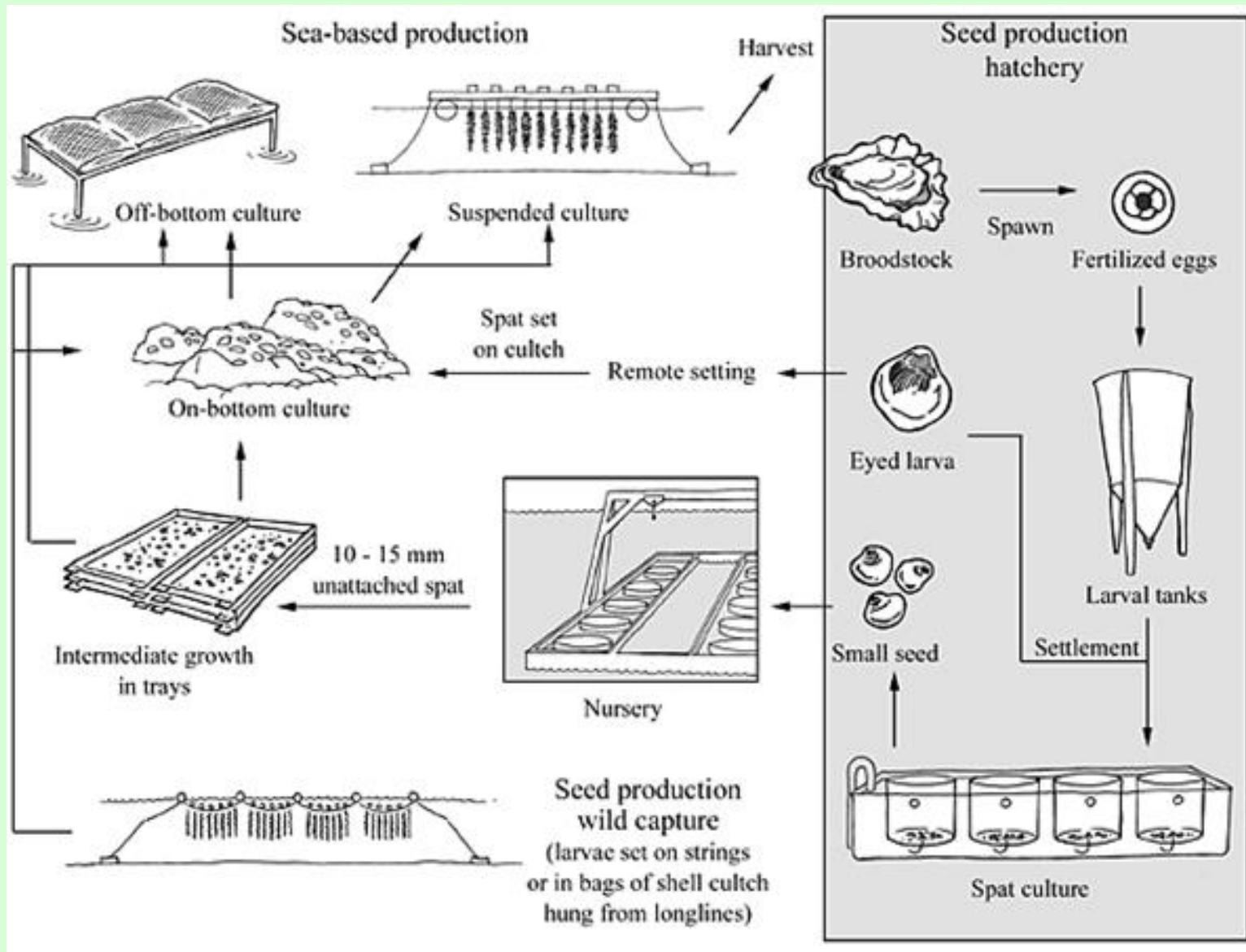


# **Aquaculture Methods**

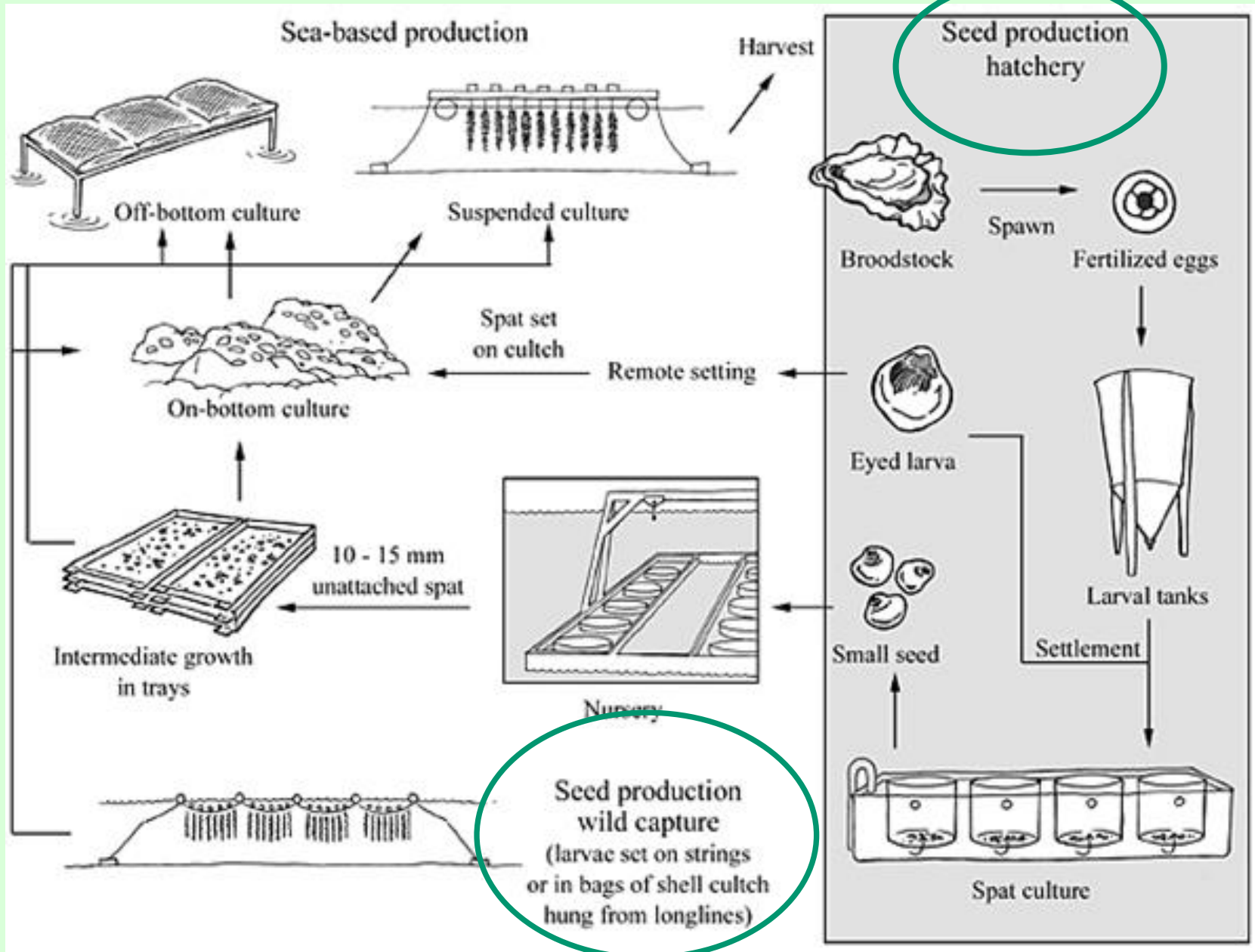
## **Part I**

### **Obtaining “seed” for the farm**

# Oyster production systems



# Hatchery production of seed



# Spat collection

- Many shellfish industries start with spat collection (cheaper, easier in some ways)
- May require studies to determine setting seasons, best locations
- Avoids the expense of building and operating a hatchery
- Materials are put in the water, larval bivalves set on these materials
- Must understand seasonality of settlement
- May collect many species
- Limited experience in Hawai'i

# Seed Stock

## Wild vs. Hatchery

- Must know the reproductive cycle of the target population
- Sample wild adults for gonad development
- Sample area environmental factors for egg release predictions
- Accurate spatfall forecasting is crucial for successful collection
- Bottom material spread to collect wild seed
- Collection techniques – from dredging to floating bags and ropes
- Wild seed is planted in prepared “seed beds”
- Labor intensive
- Less expensive than purchasing
- Broodstock management
- Rearing of larvae and juveniles
- Algal production for food
- Need a clean enclosed facility
- Expensive
- More complicated process
- Could be a second marketable crop
- Tanks instead of intertidal zones
- Prepare and provide a clean stable environment
- Harvesting is easier
- More quality control



**Fig. 27.11** Terminal branches of red mangroves used for spat collection.



**Fig. 27.8** Lime-coated tiles used as spat collectors. (From *Fish Farming International*, 7(4).)

# Spat collection

Seed can be collected from the wild on shells and artificial substrates ( cultch ) placed near spawning grounds.





**Coupelle**



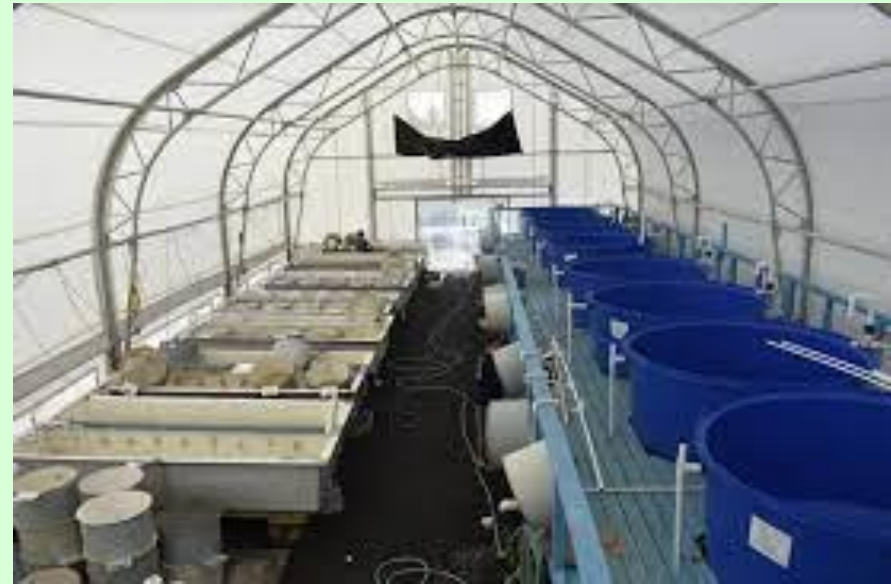
**Pearl oyster spat collectors**



# Hatchery Production

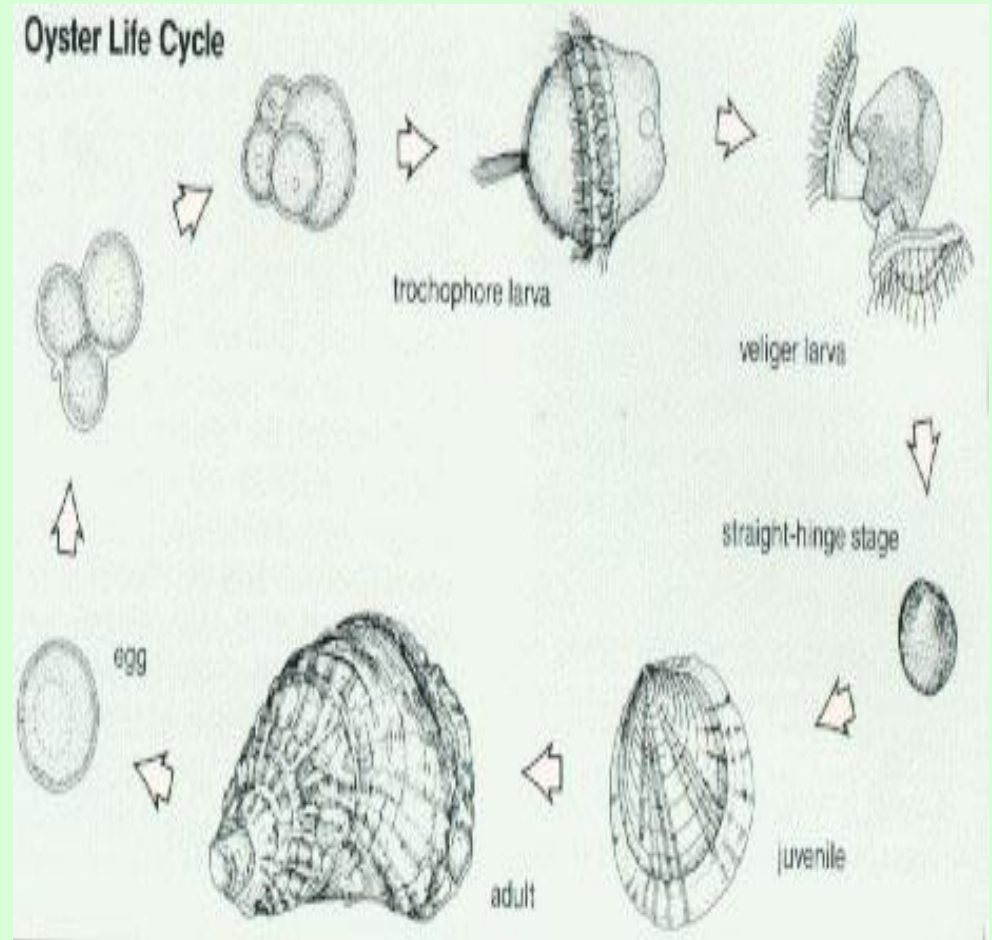
- Needed for large industries, but even small farms depend on hatcheries
- There are 4 in Hawai‘i
- Most operate all year
- Makes selective breeding & triploid production possible

**UH Hilo hatchery**



# Life Cycle

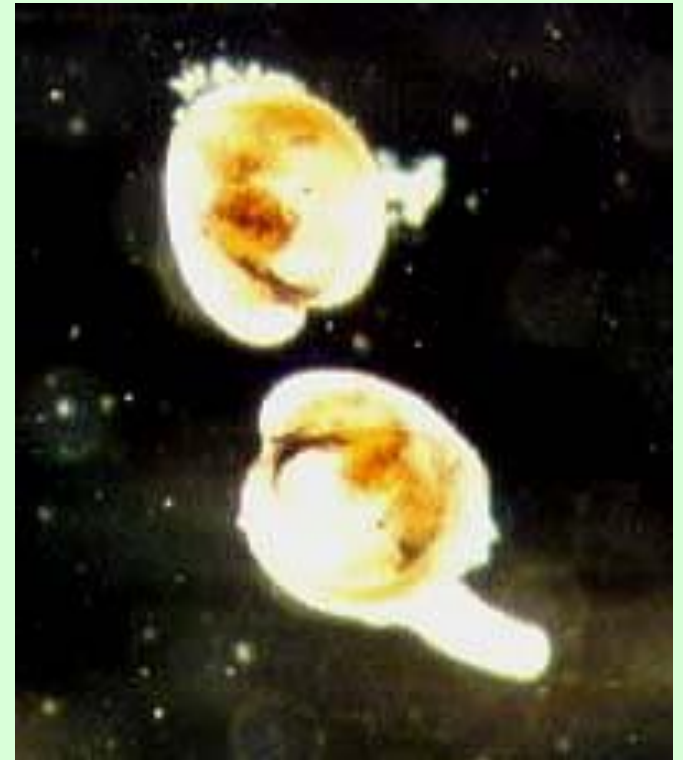
- External release and fertilization of egg – 50 to 200 million
- Fertilized egg – zygote
- Embryo undergoes mitosis
- 3 Larval Stages
  - Trochophore - 24 hrs – ciliated for mobility – microscopic – 70 microns
  - Veliger - 2-4 weeks – swims and feeds with ciliated lobe - velum
  - Pediveliger – prominent foot - settles and metamorphose into juvenile
- Juvenile (Spat) development – on substrate – byssal threads
  - Velum is absorbed
  - Gills and feeding mechanism develop
  - Mature in 2 + years
- Adult can live 10 to 100 years



Lucas, J.S. & Southgate P.C. (2003) Aquaculture Farming Aquatics Animals and Plants. Blackwell Publishing.  
score.dnr.sc.gov/ktmlpro10/images/uploads/oysterlifecycle.jpg

# Hatchery Production

- **Adults are induced to spawn.**
- **Larvae are reared for ~3 weeks**
- **Large volumes of several species of microalgae are required**



# Adults-broodstock

- **Large adults used**
- **Most oyster broodstock used in HI sourced from WA**
- **“Seed” goes back to West Coast**

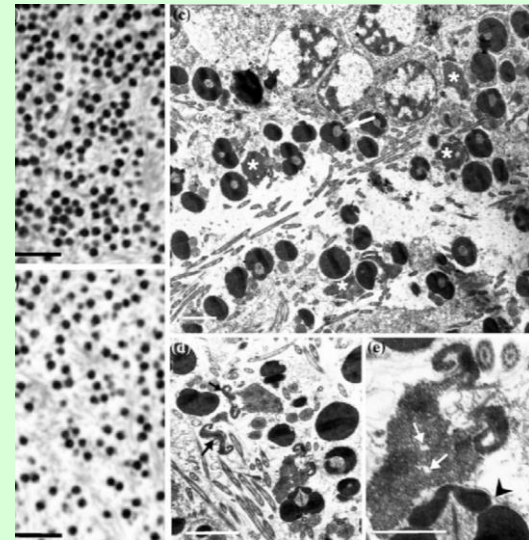
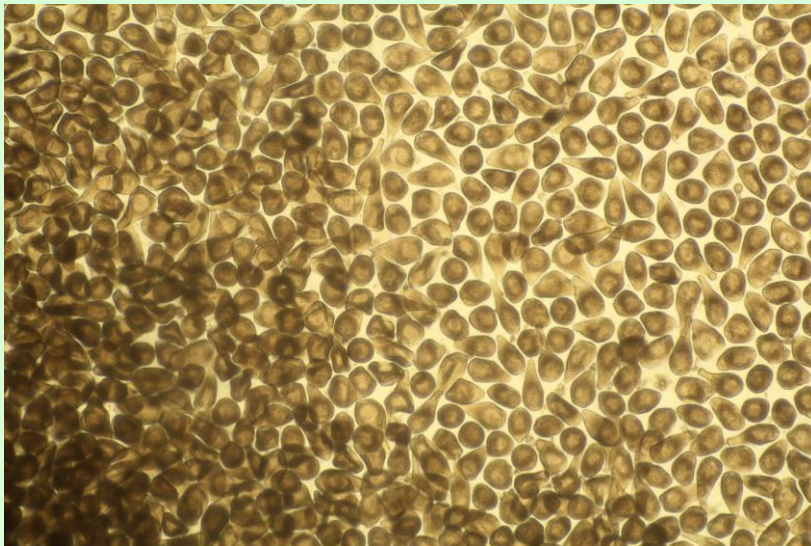


# Broodstock conditioning

Natural seasonal conditions are imitated

1. cold period-promotes glycogen accumulation
2. slow warming (spring)-formation of eggs and sperm

Heavy feeding with microalgae is required



# Spawning

- Gametes are liberated into the water column during mass spawning events
- Fertilized in the water column
- Summer breeders - higher temps – 20-30<sup>0</sup>C (68-86<sup>0</sup>F)
- Salinity – 20-25 ppt
- Planktonic larvae – free swimming for 3 weeks



# Inducing spawning

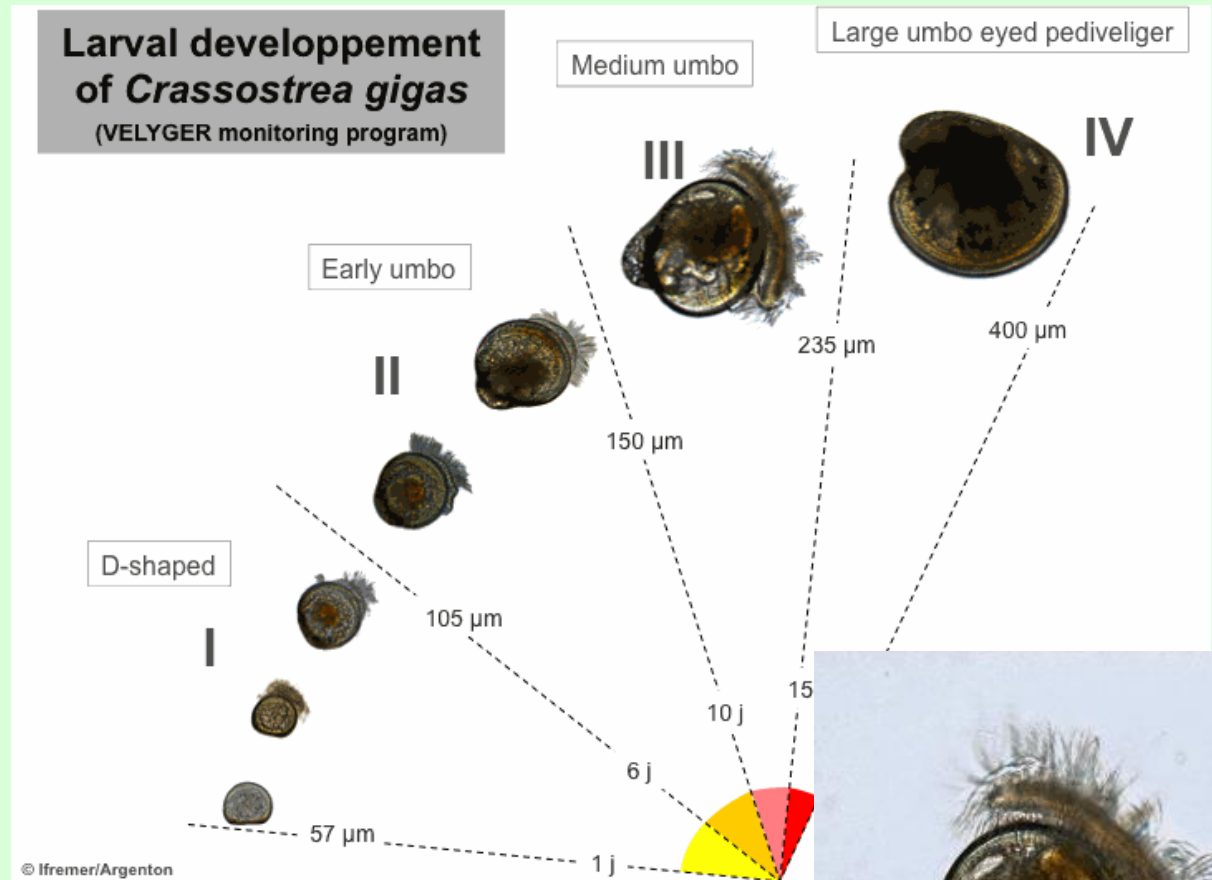
**If the broodstock is adequately conditioned, spawning is induced by:**

- **Changes in water temperature**
- **Introducing sperm**
- **Adding microalgae**



# Larval stages (~3 weeks)

- Planktonic Larvae – free swimming for 3 weeks
- Foot and eye spot develop when metamorphosis is near
- Crawling behavior-looking for place to settle



# Larval rearing

- After fertilization, embryos are stocked into large tanks
- Tanks are drained every other day, cleaned, and the status of the larvae assessed
- Large quantities of microalgae are added every day
- Larval period is about 3 weeks



# Metamorphosis & Setting

- Metamorphosis occurs at the end of the larval stages when the oyster is ready to transform itself into a settled or attached adult oyster
- Energetically costly, mortality can be high
- The manner in which setting is conducted depends on the growout methods (e.g. bottom culture vs. suspended culture)

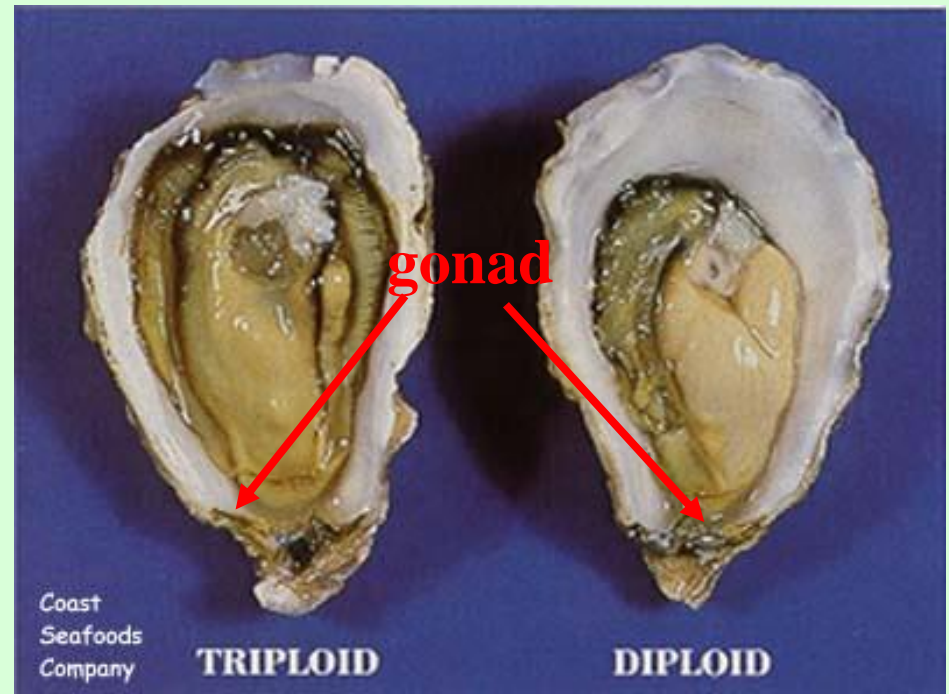


Pediveliger  
(last larval stage)

After metamorphosis  
(spat)

# Triploid Oysters (3N)

- Triploid oysters are preferred in Hawai'i to diploid oysters because they generally do not produce gametes, or produce very few
- Lack of gamete production means that triploid oysters have higher levels of glycogen stores during the summer months
- Use less energy for reproduction and allocate more to growth



# Production of triploids

- Fertilized eggs are subjected to high pressure or chemicals, affects the assortment of chromosomes so each animals ends up with three sets of chromosomes
- Can also do a tetraploid (4N) x diploid (2N) cross
- Both methods have their pros and cons
- They are not GMO

# Setting

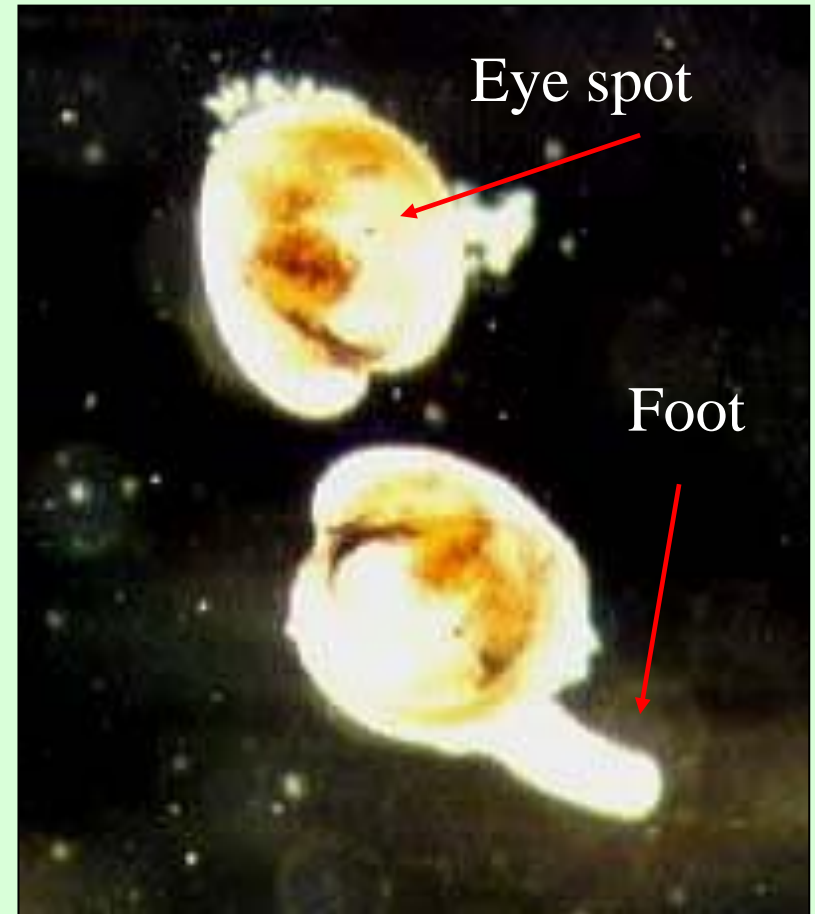
**1. Cultch (substrate)  
or microcultch**

**2. Cultchless**

**Use epinephrine to keep  
them from cementing to  
shell**

**Remote setting**

- **Setting tanks with  
shells**



***Setting tanks*** -usually with bags of shell as cultch

***Downwellers***-produces single oyster or set on microcultch

Pediveligers are shipped to the setting location



# Remote setting

- Eyed-larvae is collected from hatchery, shipped to farm sites
- Placed in tanks or raceways with artificial substrate or mesh bags of crushed shells to settle
- Fed algae in the water column
- Constant flow of seawater at constant temperatures
- Growout in mesh bags, trays, nets or bottom substrate
- Cleaned and thinned regularly
- 2-4 years for maturity



**Spat on crushed shell are single set and spat on whole shells are multiple or cultch set.**



# Nursery

Spat can be placed in protected intertidal zones to grow and harden for several months.

Exposing the oysters to the air protects them from predators.



# FLUPSY (Floating Upwelling Systems)

- FLUPSY are deployed in harbors, calm water
- Large-scale nursery systems



**Hog Island Oyster Co.  
Californai**



**Solar-powered FLUPSY at He'eia**

# *Dendostrea sandvicensis*

## Hawaiian Oyster

- Small flat oyster found in Hawai‘i and Pacific Rim areas
- Larval brooder



# Reproduction of flat oysters larval brooders



**Hawaiian oysters in a  
broodstock container**

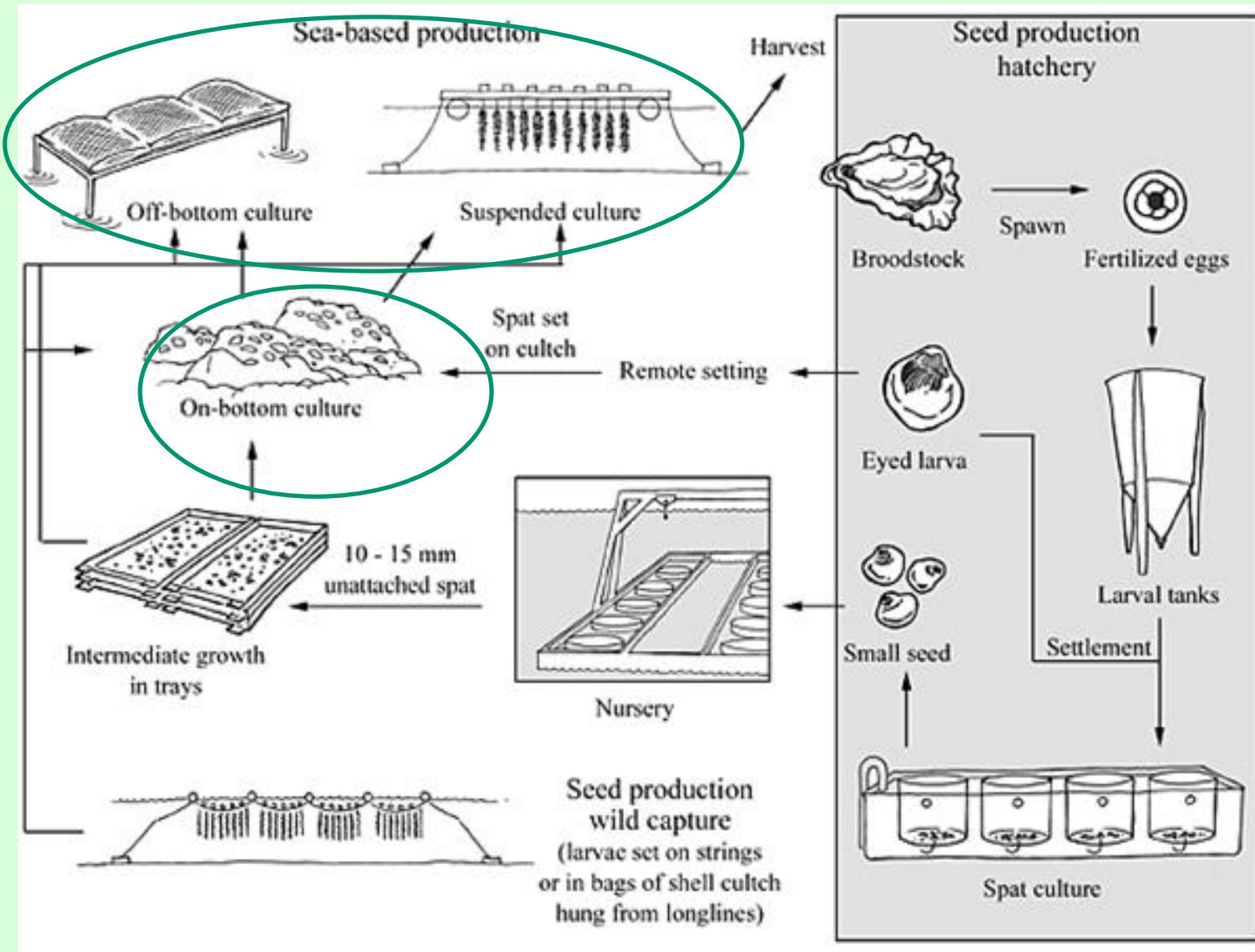


**Larvae in the pallial cavity of a  
female European Flat Oyster**

# Grow out



# Oyster production systems



# Forms of Culture

**Extensive:**

- \*Minimum level of control
- \*Minimal maintenance
- \*Exposed to natural environment
- \*Production level tends to be variable

**Intensive:**

- \*Medium or high level of control
- \*Medium or high maintenance
- \*Protected from natural environment
- \*Production level more reliable

# Grow out

## Cultched oysters

**Shells with spat are moved from spawning or nursery grounds to growout areas. Shells are transplanted directly on to the bottom. Little care is given to the oysters. Culture is extensive.**





## Extensive culture- On bottom

- Wild larvae
- Cultch materials
- Harvest is similar to fishing



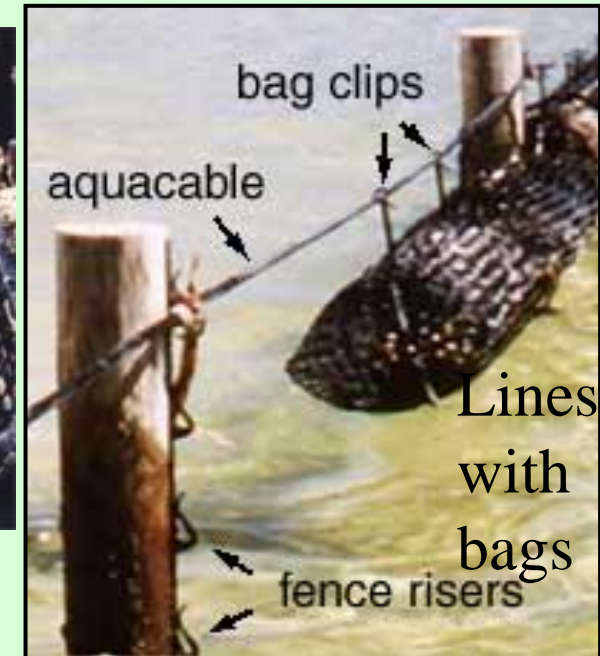
# Harvest – on bottom culture

Reef oysters are harvested from the bottom with tongs and dredges. Oysters are ready for harvest in 1 to 5 years depending on water temperatures.

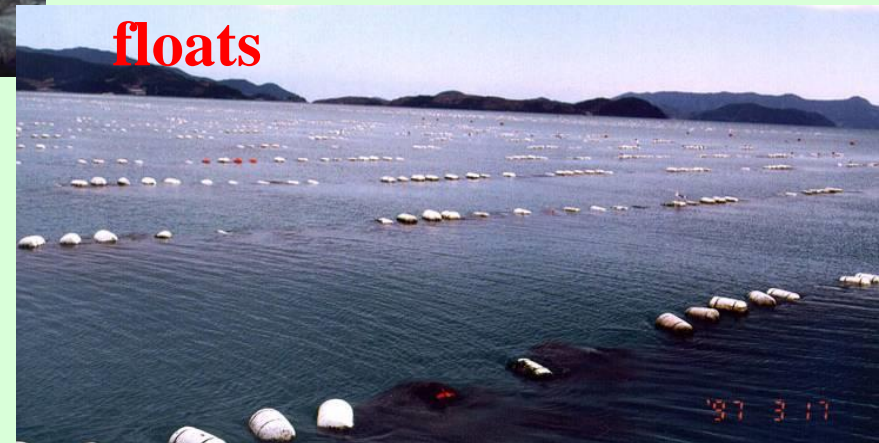


# Intensive Growout

Cultchless or single  
oysters are grown in:



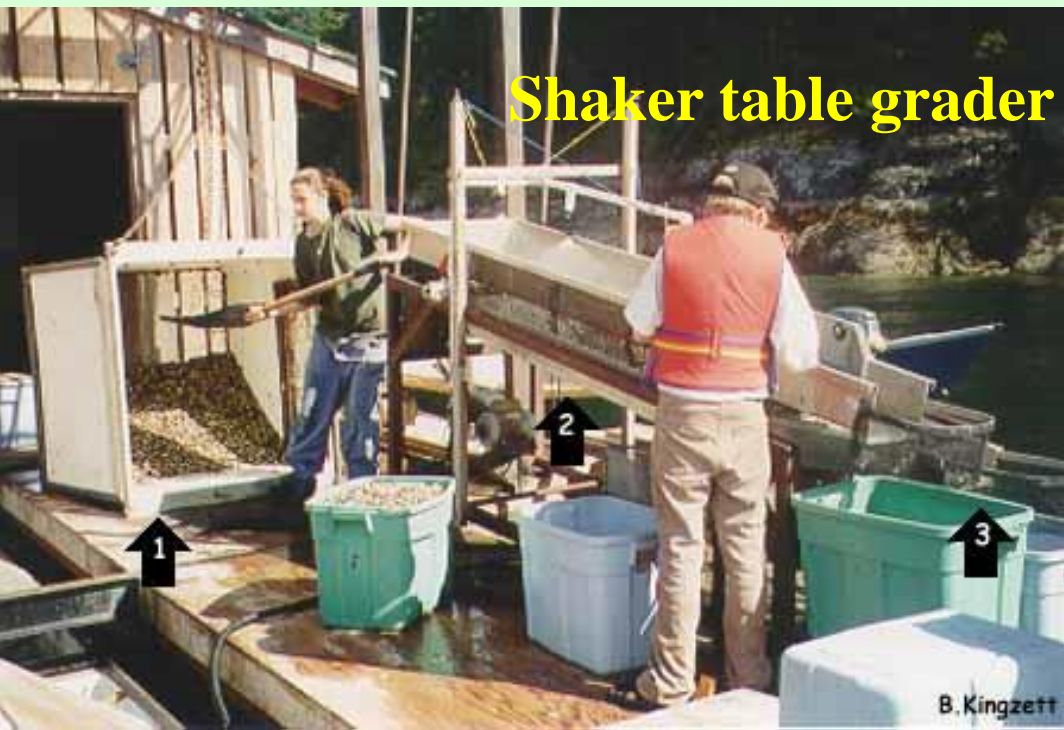
**Growout** –Trays and bags are suspended off the bottom by ropes tied to rafts and floats or on stationary platforms. Culture is extensive.



Oyster density and sizes, predators and fouling are controlled.

# Oyster culture in Sinaloa, México





**Oysters are graded several times to assure uniform growth and size at harvest.**



**Predators are controlled by exposing the oysters to air, keeping the oyster off the bottom and manual cleaning**



**starfish**



**Puffer fish**



**crabs**



**oyster drill**

# *Polydora* spp.

(mud worms, blister worms)



These worms burrow into the shells, disfiguring them

Detritus in the tunnels has a foul smell

Heavy infestations can make oysters inedible

Frequent cleaning and drying helps

**Fouling organisms are removed by drying, pressure spraying, manual cleaning and dipping in a toxic solution.**



**Fouling organisms compete for space and food with oysters and restrict water flow through enclosures**

**Harvest – on bottom culture**

**Large areas are harvested by dredges**



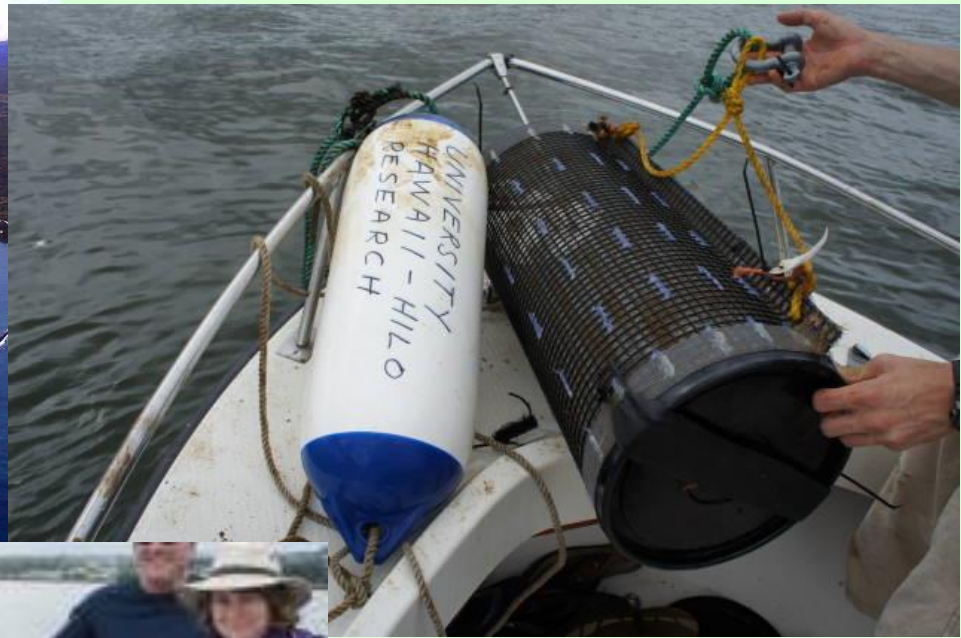
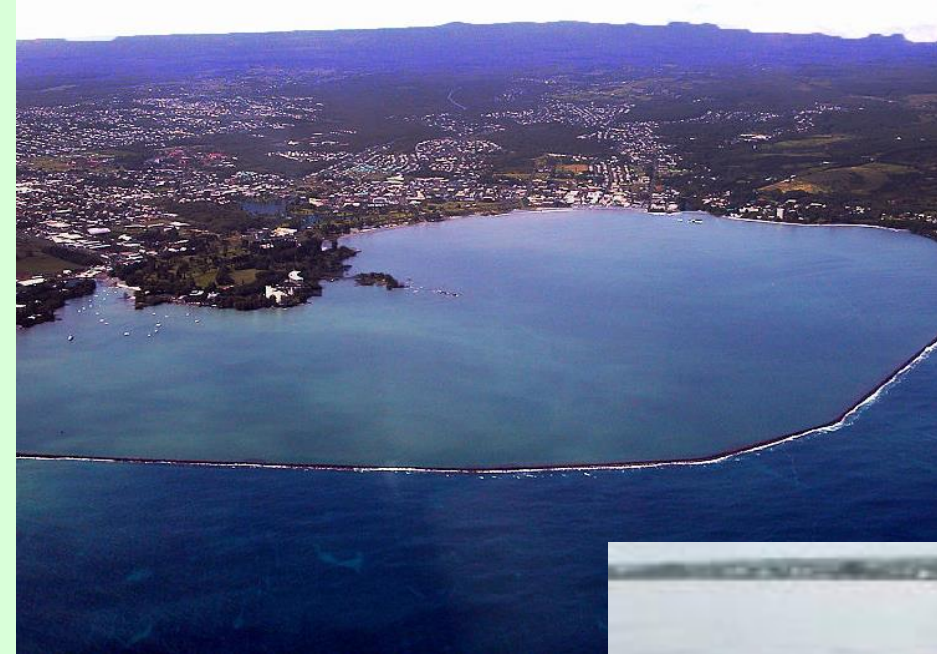
# Harvest

Oysters cultured in bags, trays and on ropes are harvested mechanically because of their weight.



# Oysters in Hilo Bay-started 2013

First trials with oysters for water quality improvement in HI



# **Part II**

## **Shellfish sanitation**

### **Post-harvest considerations**

# Shellfish sanitation

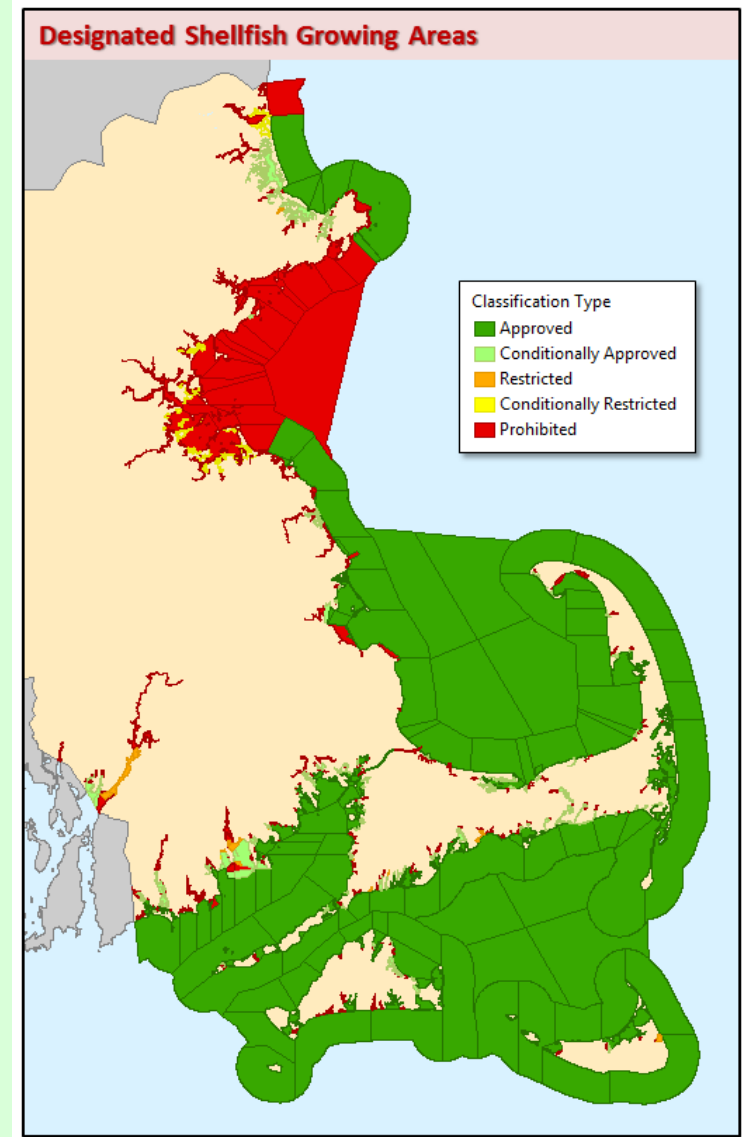
- **Risks due to:**
- **Bacteria (*E. coli* as indicator, salmonella)**
- **Viruses (Hepatitis A)**
- **Toxins**
- **Heavy metals**
- **Decomposition after harvest**

# Sanitation

- **Applies when the whole meat is eaten.**
- **Safety of molluscs is assured by:**
  - **Assuring adequate water quality in grow out areas**
  - **Relocation (relaying) to other areas for natural depuration**
  - **Depuration in land-based systems**
- **New high pressure methods**

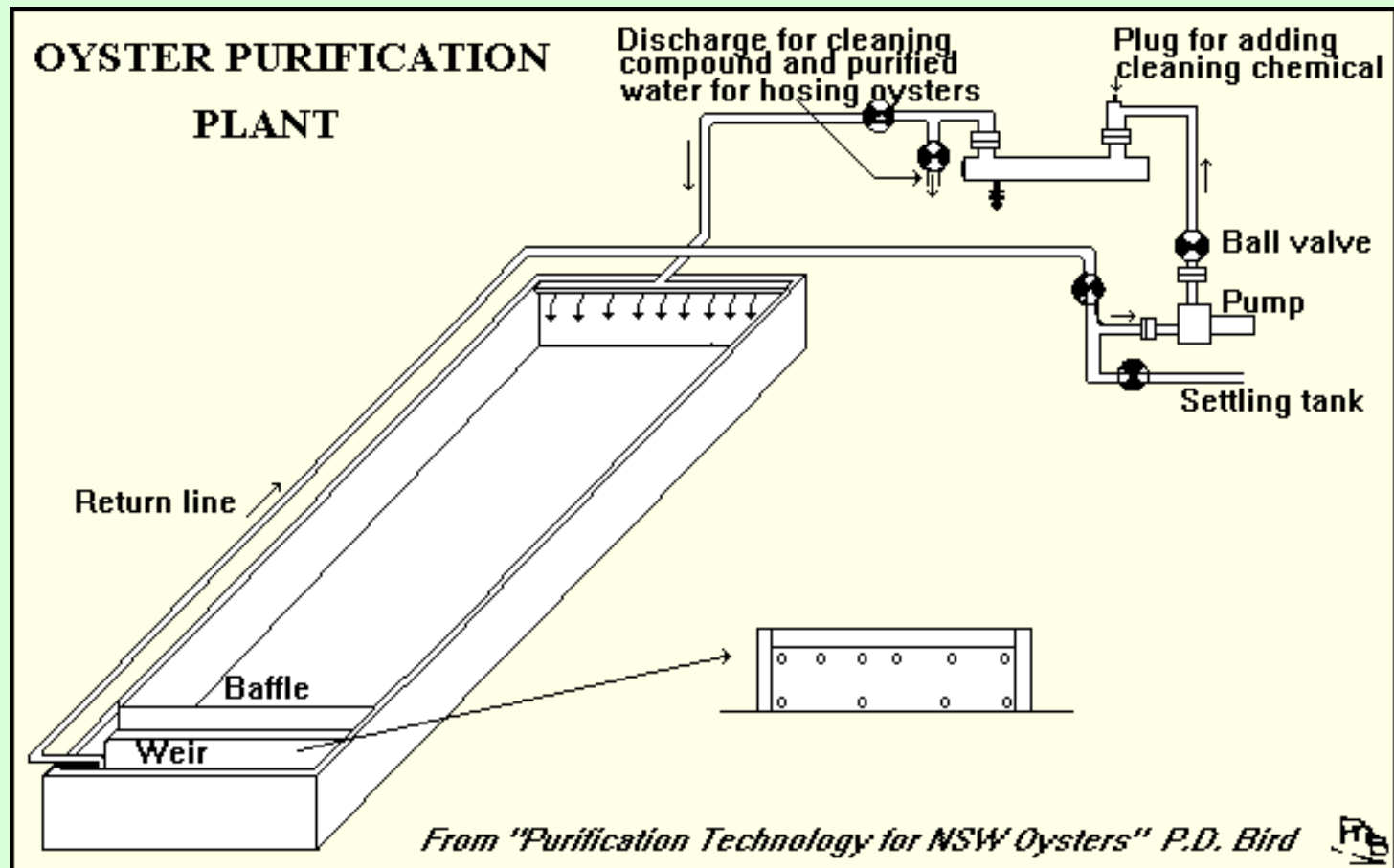
# Shellfish growing area classification in Hawai‘i

- Hawai‘i’s shellfish sanitation plan is limited
- Lacks “conditional” category for growing areas
  - Approved (always open)
  - Restricted (depuration)
  - Prohibited (no culture)
- Classifying a growing area takes 15 months



# Depuration

Oysters may be contaminated by bacteria and viruses harmful to the consumer of raw oysters. Oysters can be purged by moving them to clean water in the ocean or on land.



# Depuration in Hawai'i



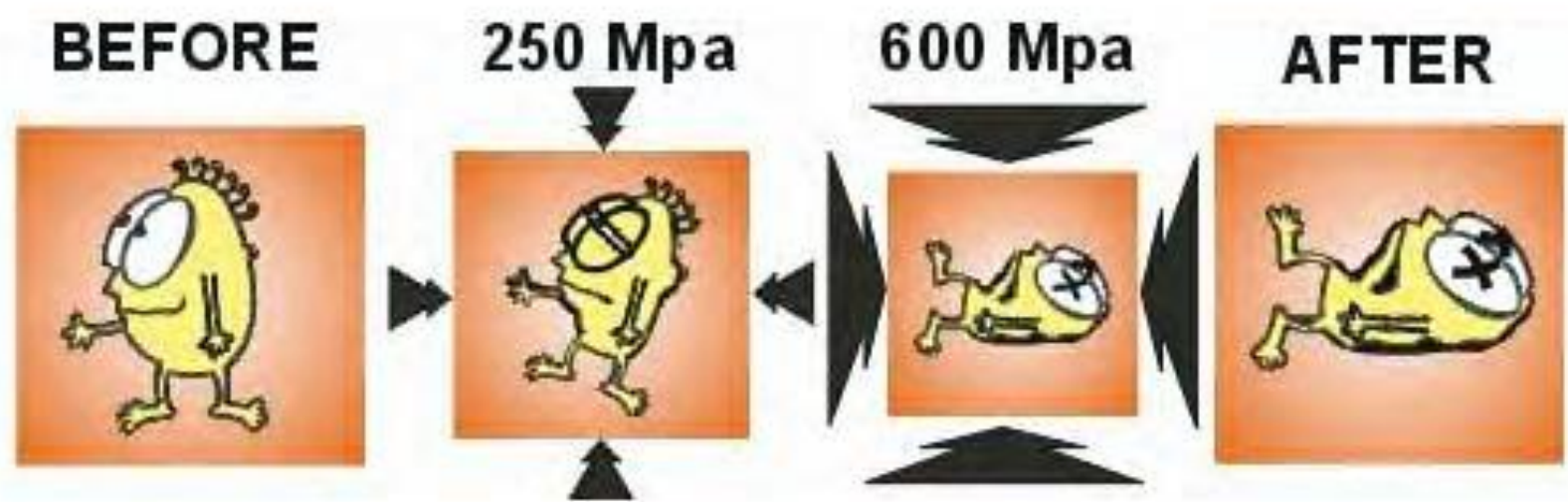
**Depuration tank at Kualoa Ranch  
Artificial seawater is used**



Hydrostatic “cold” pressure)



## *Fresher Under Pressure Guided Tour*







**live**



**shucked**



**Oysters are sold live, fresh and frozen on the half shell and shucked, canned and smoked.**

**Fresh on half shell**



**Frozen on half shell**



**canned**



# THE END



# Acknowledgements

- Our 100's of students!
- **USDA Farmers and Ranchers Development Program**
- Waiwai Ola Waterkeepers Hawaiian Islands
- University of Hawaii Sea Grant College Program
- National Sea Grant Program
- DAR, HDOA, DOH
- NOAA
- Western Sustainable Agriculture and Extension (WSARE)
- Center for Tropical and Subtropical Aquaculture
- PIPES internship program
- Hilo Fish Company
- Goosepoint Oyster Co. & Hawaiian Shellfish



*High School Students  
Keawanui, Moloka'i*