01/17/24

FLORIDA SEA GRANT'S 2024 SYMPOSIUM: SPOTLIGHTING UF'S ROLE

# Session IV
# Sustainable Aquaculture

**Dr. Laura Tiu**

FSG Extension Agent & County Extension Director

UF/IFAS Walton County Extension

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**FLORIDA KEYS WATER WATCH**

# Sponge Restoration Aquaculture

**Shelly Krueger**
Florida Sea Grant Extension Agent
UF/IFAS Monroe County, Key West, FL

#FSGsymp24
@FloridaSeaGrant

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## Project Overview

- Year 1: Document spawning seasons and reproductive biology in Loggerhead and Sheepswool sponges using histology and light microscopy
- Year 2: Determine onset of propagule reproduction by age-class following aquaculture propagation for 6 sponge species
- Create the first Florida Keys nearshore sponge identification field guide for 31 species

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FWC researcher Elliott Hart placing sponges into sponge nursery, Marathon, Florida (Jennifer Stein)

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Vase sponge propagules inside FWC-permitted nursery, Marathon, FL (Jennifer Stein)

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Vase sponge propagule 2-years later (Shelly Krueger)

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Vase sponge propagules 4-years later (Dr. Mark Butler)

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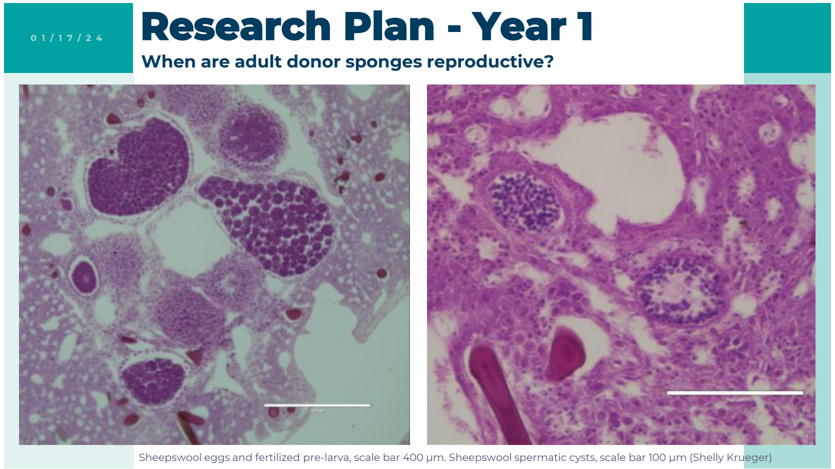

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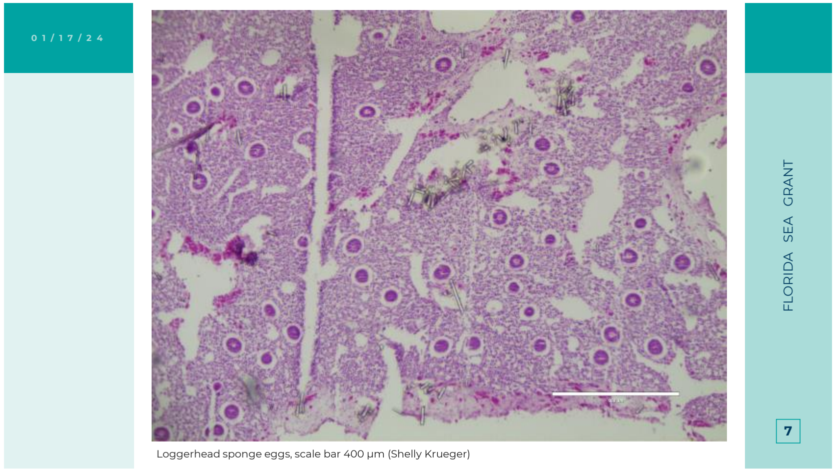
## Research Plan - Year 1

**When are adult donor sponges reproductive?**

Sheepswool eggs and fertilized pre-larva, scale bar 400 µm. Sheepswool spermatic cysts, scale bar 100 µm (Shelly Krueger)



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Loggerhead sponge eggs, scale bar 400 µm (Shelly Krueger)

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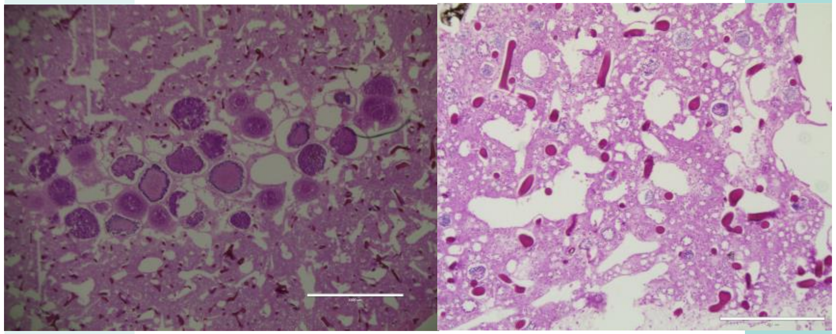
## Research Plan – Year 2

**Are the sponge propagules reproducing? YES!!**



Yellow sponge eggs and larva, scale bar 1,000 µm. Yellow sponge spermatic cysts, scale bar 400 µm (Shelly Krueger)

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## Florida Keys Nearshore Sponge ID Guide

Sample photo page for
Sheepswool Sponge
*Hippospongia lachne*

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## Sponge Restoration Aquaculture

- Summer 2023 Marine Heatwave: Sponge Die-Off in Lower Keys
- Sponge restoration aquaculture can help alleviate long-term ecological damage caused by sponge die-offs
- Sponge restoration aquaculture may help restore water quality, biodiversity, and support essential fish habitat for spiny lobster, stone crab, and bonefish
- Sponge propagules are reproductively viable and can contribute to sponge recruitment

References: Herrnkind & Butler 1993; Herrnkind et al. 1997; Wall et al. 2012; Butler et al. 2016; Butler et al. 2021

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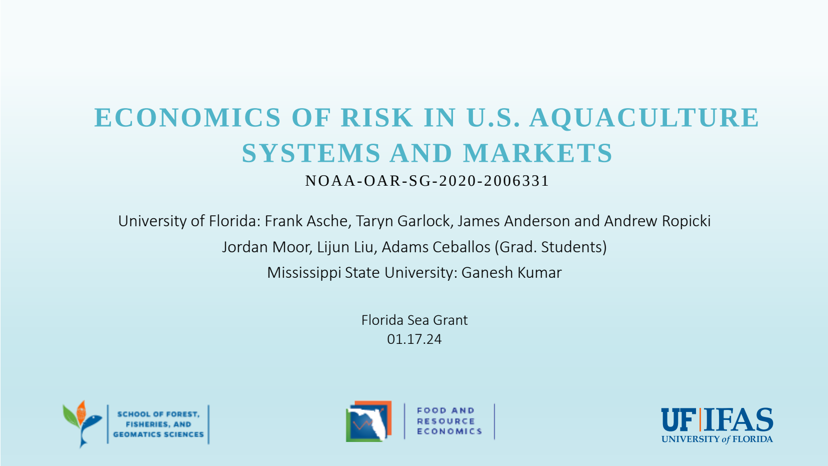
## Acknowledgements

- US EPA Region 4 Water Division, South Florida Program
- Project Team: Drs. Josh Patterson, Shirley Pomponi, Cristina Diaz Doug Gregory, Mimi & Simon Stafford
- Florida Fish and Wildlife Conservation Commission
- FAU Harbor Branch Oceanographic Institute
- University of California Santa Cruz
- Simi Sponge Company



# ECONOMICS OF RISK IN U.S. AQUACULTURE SYSTEMS AND MARKETS

NOAA-OAR-SG-2020-2006331

University of Florida: Frank Asche, Taryn Garlock, James Anderson and Andrew Ropicki
Jordan Moor, Lijun Liu, Adams Ceballos (Grad. Students)
Mississippi State University: Ganesh Kumar

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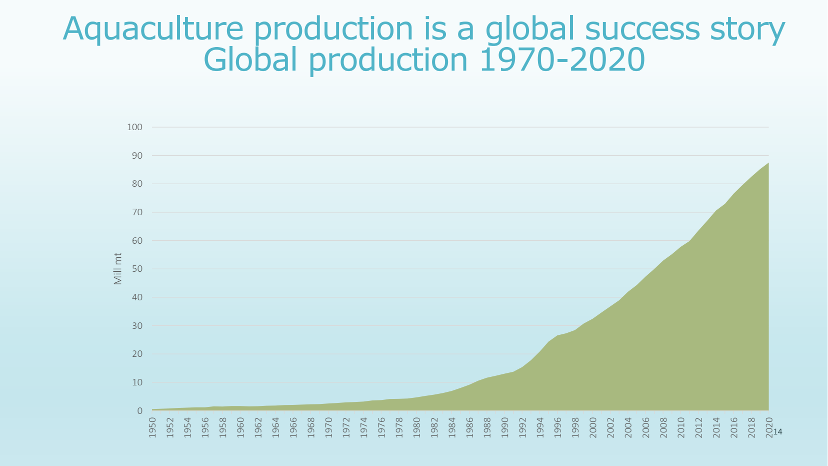
SCHOOL OF FOREST, FISHERIES, AND GEOMATICS SCIENCES
FOOD AND RESOURCE ECONOMICS
UF IFAS UNIVERSITY of FLORIDA



## Aquaculture production is a global success story
## Global production 1970-2020

14

## The U.S. is only to a limited extent taking part in this revolution as a producer:

U.S. aquaculture production

## But new technology and market opportunities are changing U.S. aquaculture and facilitate increased production

Homegrown Shrimp USA, Indiantown FL

2/9/2024

## Extensive oyster aquaculture has had strong growth as the half-shelf market was created

## Highly intensive land-based aquaculture reduces environmental interactions to virtually zero

Homegrown Shrimp USA, Indiantown, FL

## Atlantic Sapphire in building the world's largest salmon farm in Homestead, Fla.

Aquaculture is a complex industry with considerable risk.

- Economic factors – input and output prices, consumer acceptance, international trade and supply chain uncertainty.
- Regulatory factors - constrain production practices, slow and inconsistent permitting
- Biological and biophysical factors - growth rates, *disease/mortality*, system control and failure (temp, water quality)
- External shocks - hurricanes and algae blooms, economic crisis, war

And many of these factor can vary beyond the farmer's control.

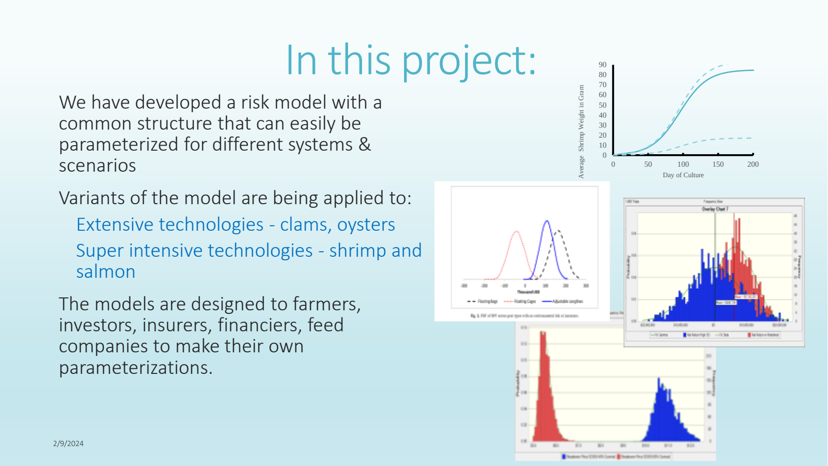
Given the failure rate of aquaculture enterprises it suggests risks are often under-estimated or not managed well

# Sustainable Aquaculture
By Asche

GOAL: To provide greater understanding about economic risk associated with aquaculture operations so that can inform producers, investors, bankers, and decision-makers on risk mitigation strategies and facilitate means to attract greater investment in sustainable U.S. aquaculture firms.

OBJECTIVE: Develop flexible economic models to quantify the expected risks and returns associated with production and health management practices and market uncertainties under various scenarios of firm-level integration.

2/9/2024



## In this project:

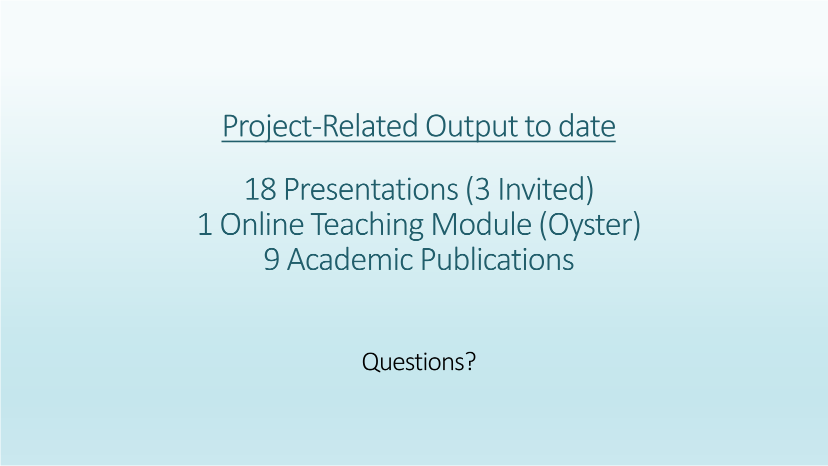
We have developed a risk model with a common structure that can easily be parameterized for different systems & scenarios

Variants of the model are being applied to:

- Extensive technologies - clams, oysters
- Super intensive technologies - shrimp and salmon

The models are designed to farmers, investors, insurers, financiers, feed companies to make their own parameterizations.

2/9/2024



## Project-Related Output to date

18 Presentations (3 Invited)
1 Online Teaching Module (Oyster)
9 Academic Publications

Questions?

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# Genomic Breeding through Transcriptome Analysis for Hard Clam Aquaculture

**Huiping Yang**
Associate Professor

Fisheries and Aquatic Sciences
School of Forest, Fisheries, and Geomatics Sciences
UF/IFAS

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# Project Summary

**Goal:**
Develop a high coverage annotated transcriptome alignment for farming northern quahogs M. mercenaria and local southern quahogs *M. campechiensis* for the establishment of genomic tools with an initial emphasis on heat tolerance to sustain the clam aquaculture industry.

**Objectives:**
1) Evaluate the effects of heat shock on physiology responses and survival of the *M. Mercenaria.*
2) Develop a high-coverage annotated transcriptome alignment for *M. mercenaria* and *M. campechiensis* to characterize heat shock gene expression profiles between these two clam species and between the clams susceptible to heat-related mortality and survival.
3) Establish families of M. mercenaria for further evaluation and breeding targeting on heat tolerance. .

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# Major Takeaways

**Objective 1.**
1) **Mortality with Heat Shock.** 24°C (control), 27°C, 31°C, and 34°C
   Acute: increased in 1 day and lasted for 7 days. 100% Mortality at 34 °C, no mortality in others
   Chronic: increased the T at 3°C/day. 34°C: mortality at day 4 (1/30), day 7 (7/30), and day 10 (100%).
2) **Body condition index (CI).** A total of 19 equations exist for bivalves.
   CI equations for Mm using non-lethal measurements of body sizes, body masses, and body volumes were generated. *Aquaculture Research, 2021, 52(1), 23-36*.
2) **Immunological assays of hemocytes.** Cell type, viability, lysosome, ROS, and phagocytosis
   A.Non-lethal hemocyte collection method was developed
   B. Osmolality: same as that of culture seawater; pH: (7.2) was different (8.4).
   C. Granulocytes, the dominant cell type (70 ± 16%), agranulocyte (14 ± 4%), and blast-like cell (16 ± 4%) *Fish & Shellfish Immunology, 2021, 118, 261-269)*

ORIGINAL ARTICLE

Review of molluscan bivalve condition index calculations and application in Northern Quahogs *Mercenaria mercenaria*

Yangqing Zeng | Huiping Yang

Fish and Shellfish Immunology

Immunological assays of hemocytes in the Northern Quahog *Mercenaria mercenaria*

Yangqing Zeng, Yuanzi Huo, Huiping Yang

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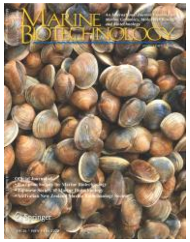
# Major Takeaways

**Objective 2.** **Develop a high-coverage annotated transcriptome**

**Chronic heat stress over 4 weeks from 24 to 34 °C with 2.5°C/week (96% survival), and transcriptome analysis of gill in response to heat shock indicated:**
1) **Upregulated genes: in chaperone-mediated protein folding and regulation of cell death pathways**
2) **Downregulated genes: involved mRNA processing and splicing pathways**
3) **Compared to M. mercenaria, *M. campechiensis* appeared to be more sensitive to prolonged heat stress as indicated by upregulating significantly more genes in coping with oxidative stress and protein degradation pathways, while downregulating some inhibitors of apoptosis.**



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# Major Takeaways

**Objective 3. Establish families of M. mercenaria for further evaluation and breeding**

**Experiment:**

**n =1050, heat shock treatment**

**Survivors were used to produce the F1 offspring (based on phenotype)**

**Hatchery seed:** Heat-shock offspring, and control.
**Land-based nursery:** Seed reaching 4.0-mm, ready for field evaluation
**Field nursery (Sep 2022 - March 2023):**
Growth: No difference between heat-shock and control ($P \geq 0.253$, shell metrics and body weight).
Survival: Heat-shock line was higher than the control line (82.9% vs. 74.0%, $P = 0.017$).
**Grow-out (March 2023 – Nov 2023, through summer heat and three hurricanes)**

**Summary of the total data on November 1, 2023 (from March 22, 2023)**

| | | Survival | Length (mm) | Width (mm) | Height (mm) | Mass (g) |
|---|---|---|---|---|---|---|
| Control | Mean | 51.3 | 43.70 | 36.52 | 22.44 | 22.90 |
| | SD | 5.4 | 3.88 | 3.17 | 2.15 | 6.04 |
| HeatShock | Mean | 43.0 | 45.13 | 37.27 | 23.88 | 25.96 |
| | SD | 15.1 | 4.16 | 3.68 | 4.10 | 7.26 |
| Comparison P value | | 0.419 | 0.000 | 0.004 | 0.000 | 0.000 |

01/17/24

# Acknowledgements

National Sea Grant.
Partners: **Dr. James Austin; Ms. Leslie Sturmer**
Project team
PhD student: Yangqing Zeng
Postdoc: Jingwei Song
Research Scientist: Jayme Yee
Undergraduate Students.

**Leverage Funds**
**1) East Coast Hard Clam Selective Breeding Collaborative**
**National Sea Grant. NY Sea Grant, NJ, VA, and CT**
**UF: Genomic selection in response to heat shock**

**2) Hard clam breeding**
**Gulf Marine Fisheries Commission**

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## ABIOTIC AND BIOTIC FACTORS INFLUENCING HARD CLAM SEED PRODUCTION

Shirley Baker, Professor
University of Florida, Gainesville

## PROJECT OVERVIEW

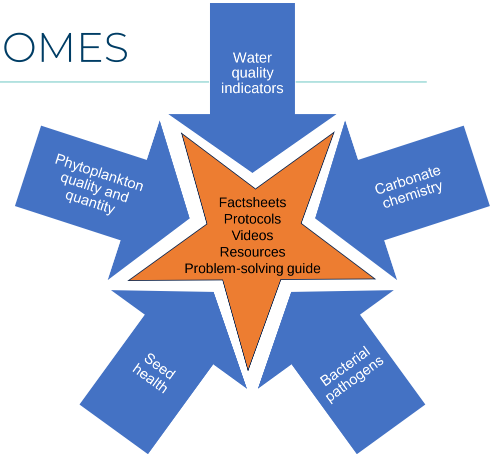
- **Relevance** – Decline in clam production related to difficulties in providing a consistent seed supply
- **Stakeholders** – FL hatchery and nursery operators
- **Objectives** – To better address seed production challenges
  - Monitor water quality indicators, bacterial pathogens, phytoplankton, and seed health

## RESEARCH PLAN

- **Disciplines involved**
  - **Shellfish biology** – Shirley Baker
  - **Shellfish aquaculture extension** – Leslie Sturmer, Angela Collins, Natalie Anderson
  - **Phytoplankton ecology** – Ed Phlips
  - **Aquatic animal health** – Ruth Francis-Floyd
  - **Pathology** – Susan Laramore
  - **Shellfish industry** – Florida seed producers

- **Scope of Work**
  - Hatchery/nursery facility selection
  - Facility monitoring and assessment
  - Training and educational materials

## OUTCOMES



Water quality indicators

Phytoplankton quality and quantity

Carbonate chemistry

Factsheets
Protocols
Videos
Resources
Problem-solving guide

Seed health

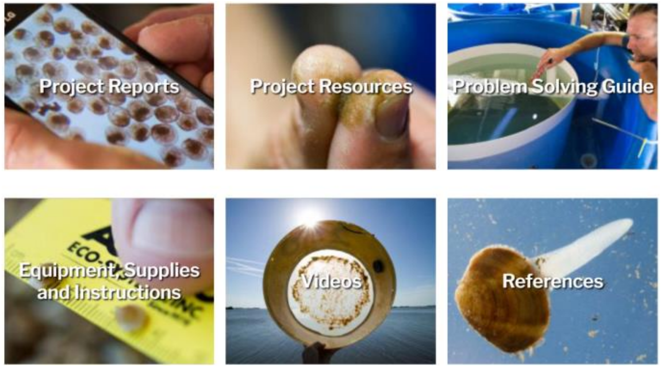
Bacterial pathogens

# Sustainable Aquaculture
By Baker

## OUTCOMES

Website: https://shellfish.ifas.ufl.edu/clam-seed-project-2020-22/

**Factors Influencing Florida Hard Clam Seed Production**



## IMPACTS

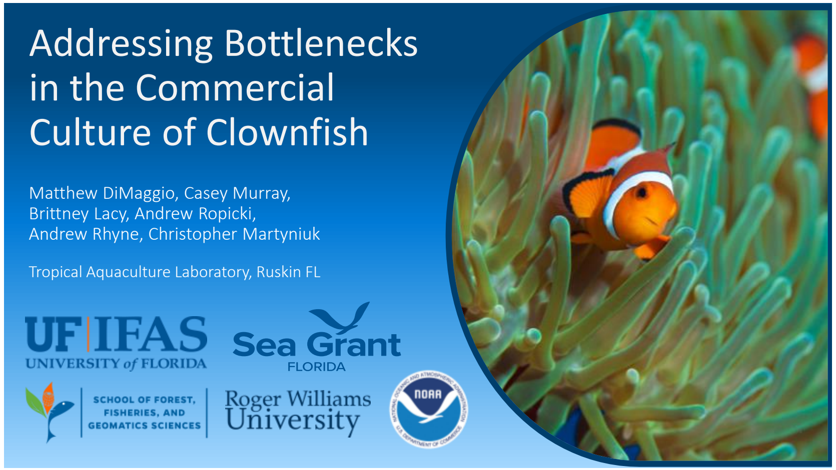
- **Industry workshops**
  - Economic benefits of $3,871
- **Equipment and services provided**
  - Investment of $8,000 in each of 9 seed suppliers
- **Online Resource Guide**
  - Reference point for assessing trends and evaluating interventions
  - Sustainability of 12 nurseries & hatcheries

## ADDITIONAL OUTCOMES

- **Workshop surveys**
  - Satisfied with usefulness/relevance of workshop topics
  - Indicated behavior change intent
  - Provided seed producers with information, protocols, tools, and resources to implement monitoring
- **Student training**
  - Bonnie Getter, MS, Florida Atlantic University
  - Emma Gaines, BS, University of Florida

## ACKNOWLEDGEMENTS

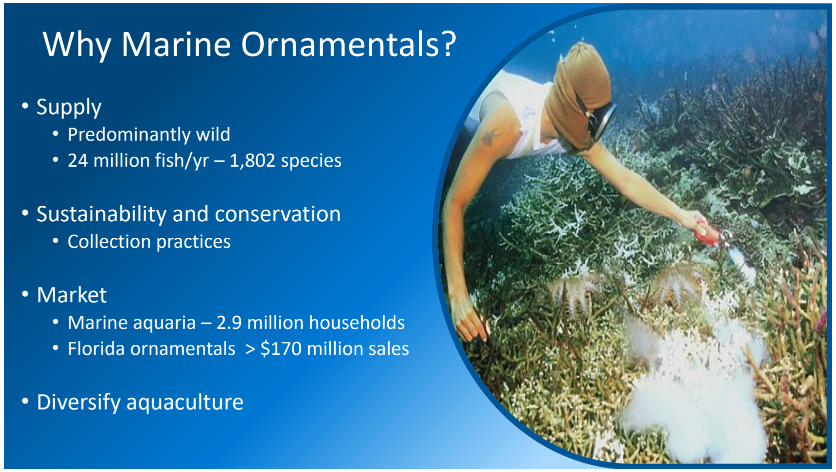
**Participating Florida Seed Producers**



## Addressing Bottlenecks in the Commercial Culture of Clownfish

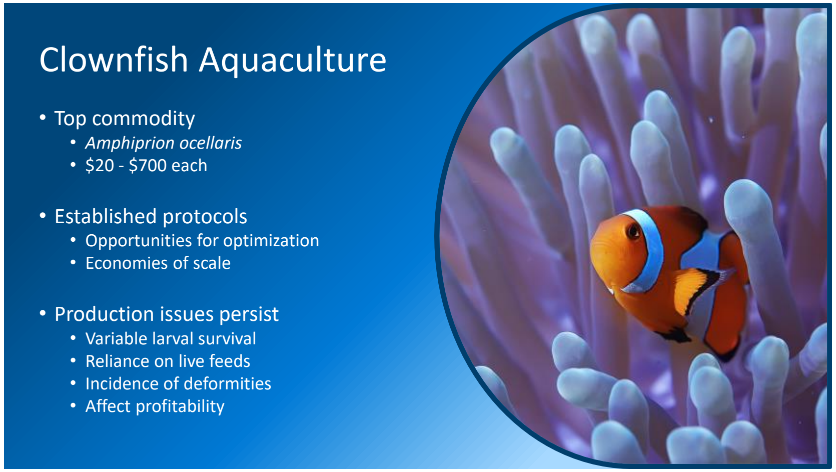
Matthew DiMaggio, Casey Murray,
Brittney Lacy, Andrew Ropicki,
Andrew Rhyne, Christopher Martyniuk

Tropical Aquaculture Laboratory, Ruskin FL



## Why Marine Ornamentals?

- Supply
  - Predominantly wild
  - 24 million fish/yr – 1,802 species
- Sustainability and conservation
  - Collection practices
- Market
  - Marine aquaria – 2.9 million households
  - Florida ornamentals > $170 million sales
- Diversify aquaculture

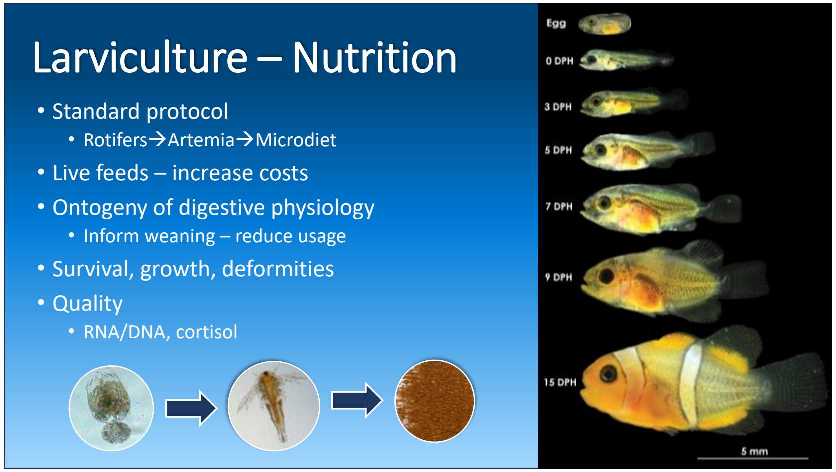


## Clownfish Aquaculture

- Top commodity
  - *Amphiprion ocellaris*
  - $20 - $700 each
- Established protocols
  - Opportunities for optimization
  - Economies of scale
- Production issues persist
  - Variable larval survival
  - Reliance on live feeds
  - Incidence of deformities
  - Affect profitability

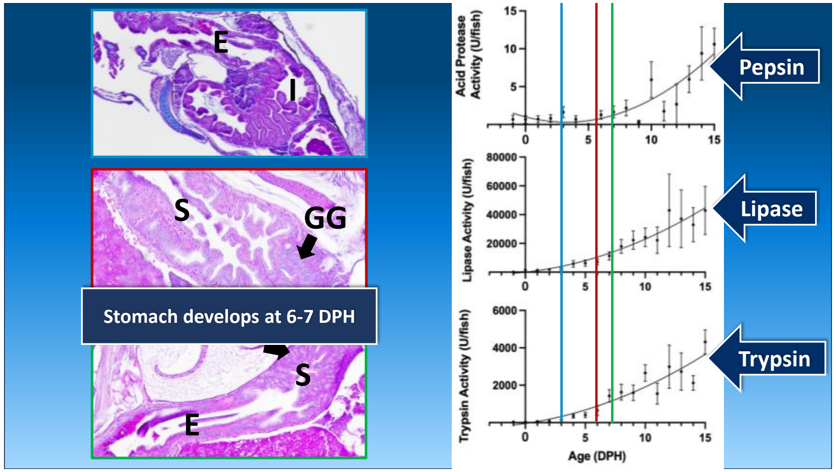
## Project Overview

- Optimize culture protocols
  - Egg handling, larval rearing, juvenile growout
- Reduce/eliminate live feeds in larviculture
- Characterize physical deformities
  - Identify causes and mitigation strategies
- Economics of revised culture protocols
- Survey clownfish wholesalers / retailers
  - Perceptions, purchasing preferences, opportunities for cultured products
- Outreach - industry stakeholders
  - Workshops, webinars, and publications

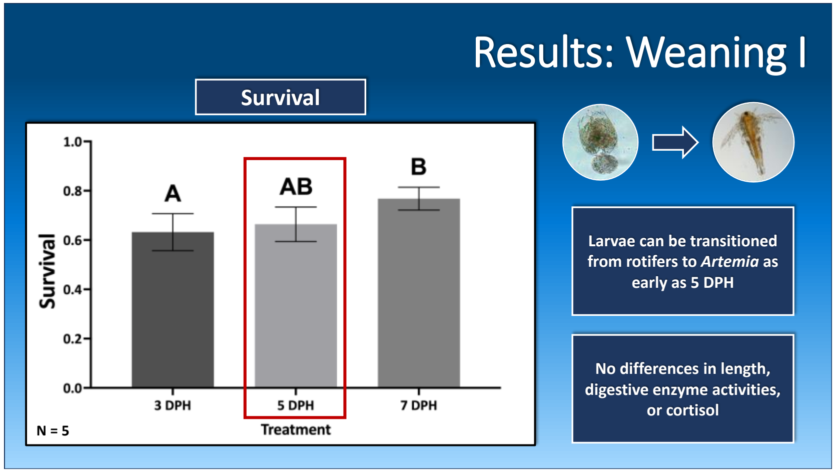


## Larviculture – Nutrition

- Standard protocol
  - Rotifers→Artemia→Microdiet
- Live feeds – increase costs
- Ontogeny of digestive physiology
  - Inform weaning – reduce usage
- Survival, growth, deformities
- Quality
  - RNA/DNA, cortisol



Stomach develops at 6-7 DPH

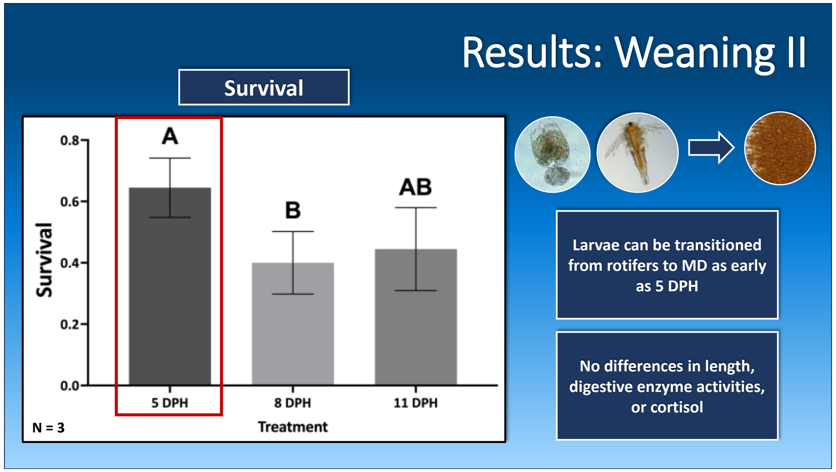


## Results: Weaning I

**Survival**

Larvae can be transitioned from rotifers to *Artemia* as early as 5 DPH

No differences in length, digestive enzyme activities, or cortisol

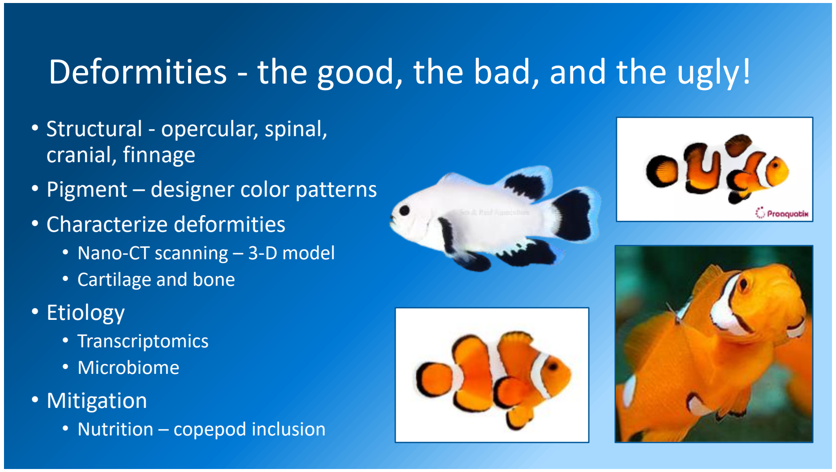


## Results: Weaning II

**Survival**

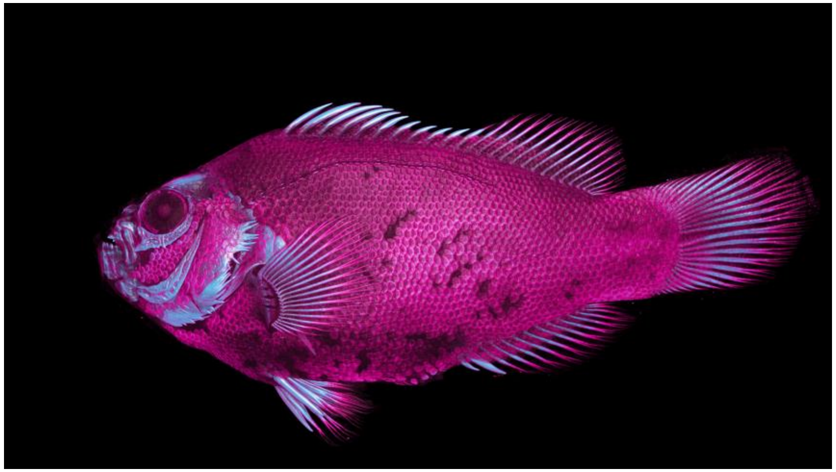
Larvae can be transitioned from rotifers to MD as early as 5 DPH

No differences in length, digestive enzyme activities, or cortisol



## Deformities - the good, the bad, and the ugly!

- Structural - opercular, spinal, cranial, finnage
- Pigment – designer color patterns
- Characterize deformities
  - Nano-CT scanning – 3-D model
  - Cartilage and bone
- Etiology
  - Transcriptomics
  - Microbiome
- Mitigation
  - Nutrition – copepod inclusion



## Outcomes and Impacts

Clownfish can be transitioned from rotifers directly to microdiet

Microdiet introduction can occur at 5 DPH, 1-2 days prior to stomach functionality

These results suggest that *Artemia* can be removed completely from clownfish culture

## Future Directions (2022 – 25)

- Optimize culture protocols
  - Egg handling, larval rearing (density, algae, enrichments), juvenile grow out
- Characterize physical deformities
  - Continue scanning and describe various phenotypes
- Survey clownfish wholesalers / retailers
  - Validating survey instrument
  - Lists of retailers and wholesalers
- Outreach - industry stakeholders
  - Publications, surveys
- Personnel
  - Dr. Casey Murray, Ms. Brittney Lacy

ELSEVIER

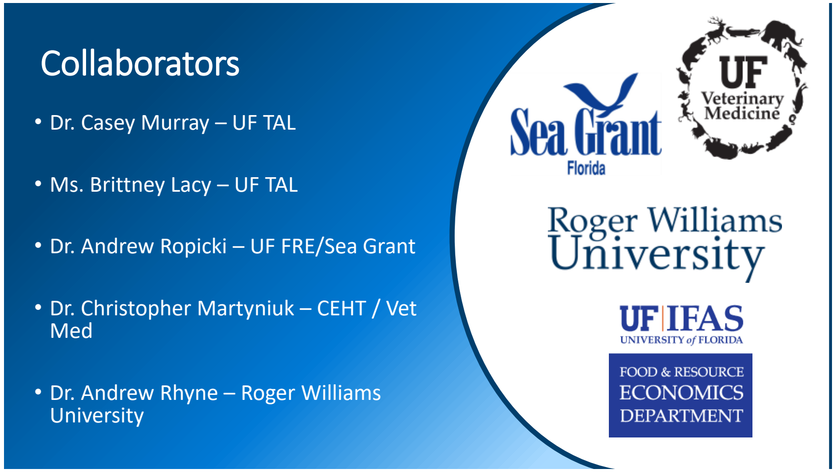
Aquaculture

Volume 563, Part 1, 30 January 2023, 738897

Short communication

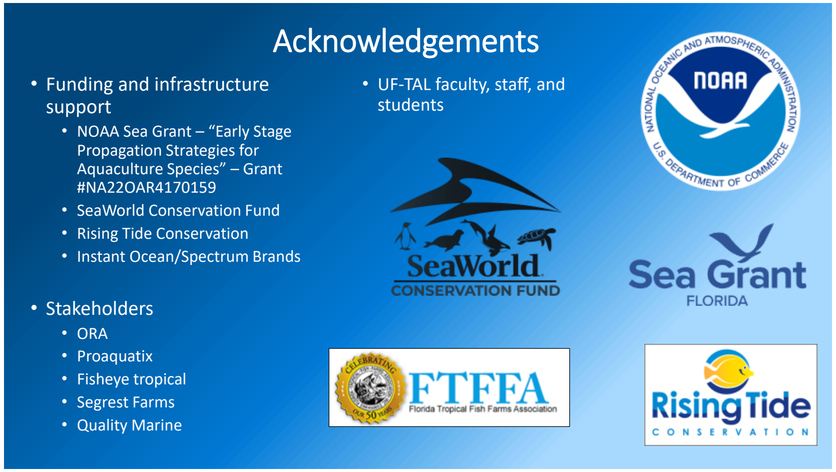
Characterizing the gastrointestinal development and digestive enzyme ontogeny of larval *Amphiprion ocellaris*

Casey A. Murray, Olivia I. Markham, Sarah W. Hutchins,



## Collaborators

- Dr. Casey Murray – UF TAL
- Ms. Brittney Lacy – UF TAL
- Dr. Andrew Ropicki – UF FRE/Sea Grant
- Dr. Christopher Martyniuk – CEHT / Vet Med
- Dr. Andrew Rhyne – Roger Williams University



## Acknowledgements

- Funding and infrastructure support
  - NOAA Sea Grant – "Early Stage Propagation Strategies for Aquaculture Species" – Grant #NA22OAR4170159
  - SeaWorld Conservation Fund
  - Rising Tide Conservation
  - Instant Ocean/Spectrum Brands
- Stakeholders
  - ORA
  - Proaquatix
  - Fisheye tropical
  - Segrest Farms
  - Quality Marine
- UF-TAL faculty, staff, and students

## Questions?

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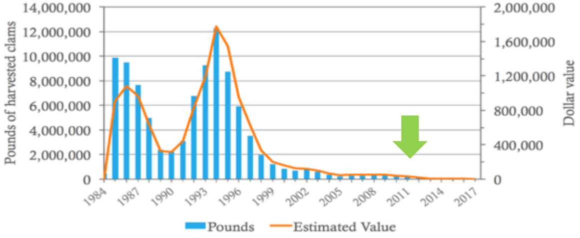
# Clam Restoration and Research in the Indian River Lagoon

Todd Z. Osborne
Associate Professor
Whitney Laboratory for Marine Biosciences – St. Augustine FL
Soil, Water and Ecosystem Sciences Department UF/IFAS

# PROJECT OVERVIEW

- Significant ecological and economic impacts of HABs
- >$9 Billion economic impact
- Loss of ecosystem function / characteristic flora & fauna

# PROJECT OVERVIEW



Pounds and estimated value of harvested clams (Brevard, Indian River and Volusia counties combined)

Source: FWC 2019

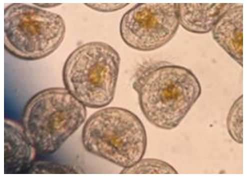
# Sustainable Aquaculture
By Osborne

Sea Grant FLORIDA

## RESEARCH PLAN

Objectives:

- Utilize commercial aquaculture techniques to spawn, rear and repatriate native hard clams (*Mercenaria mercenaria*)
- Leverage short-tern natural selection for robust broodstock
- Provide Industry with alternative market for shellfish products
- Conduct fate tracking & assessment
- Engage public in all aspects of the project



SUPER IRL CLAM

## FINDINGS & IMPACTS

**Stakeholder Outcomes**:

- 27 Mil clams out-planted to date across 14 sites
- Engaging three commercial growers
- Formation of 2 NGO's and 1 private company
- Clam Industry "buy back" to alleviate demand shortfalls due to Covid-19

**Science Outcomes:**

- 2021 Most Innovative Restoration Project – Marine Resource Council
- 2 manuscripts in review, > 20 presentations
- Development of novel techniques (r-strategy via drone)
- Refocus efforts to stormwater

## FINDINGS & IMPACTS

Photo: Malcom Denmark- Florida Today

**Public Outreach**:

- >935,000 views on social media
- Blair Wiggins Outdoors – Discovery Channel- est. 12 mil viewers
- 345 volunteers
- 2 documentaries (Emerald Sanctuary, Rivers are Life)

## NEXT STEPS

- Expanding efforts with statewide partners (research & application)
- Clam & seagrass co-restoration study
- K-12 engagement
- Drone dispersal
- Encourage aquaculture industry to take lead

## ACKNOWLEDGEMENTS

- IRL NEP, FWC, SJRWMD, FSG, Nature Conservancy, Cedar Key Aquaculture Association, Space Coast Office of Tourism, Coastal Conservation Association
- Leonardo Ibarra-Castro, Leslie Sturmer, Angela Collins, Jose Nunez, Lorae Simpson, John Rueben, Taryn Chaya & Conor MacDonnell

Thank You!

# Cellular Aquaculture for Sustainable Seafood Production

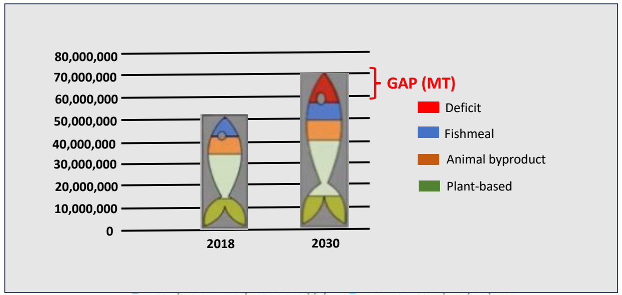
**Razieh (Rah-zee-eh) Farzad**

Assistant Professor and Seafood Safety Extension Specialist

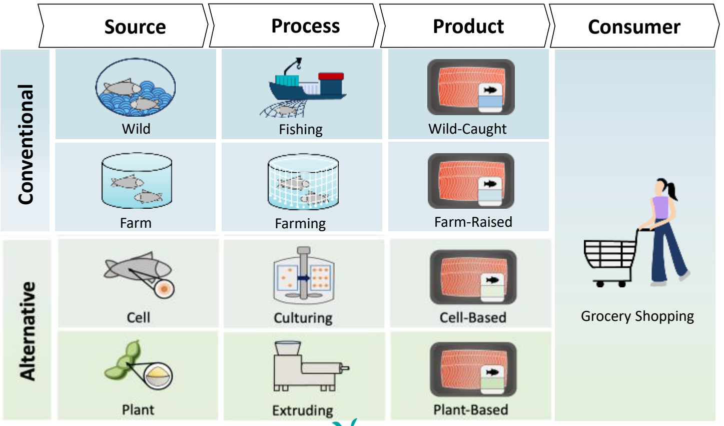
Food Science & Human Nutrition Department and Florida Sea Grant, Gainesville, FL

## RESEARCH GOAL

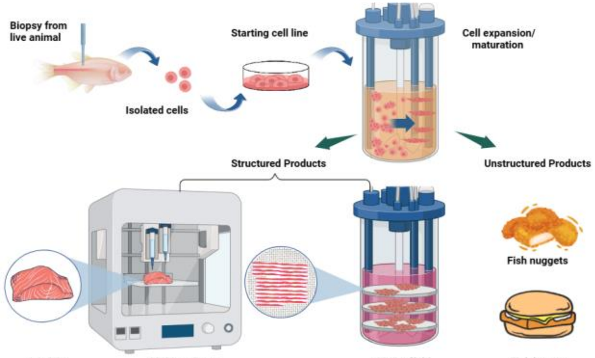
Support the sustainable seafood production by optimizing aquaculture nutrition practices.

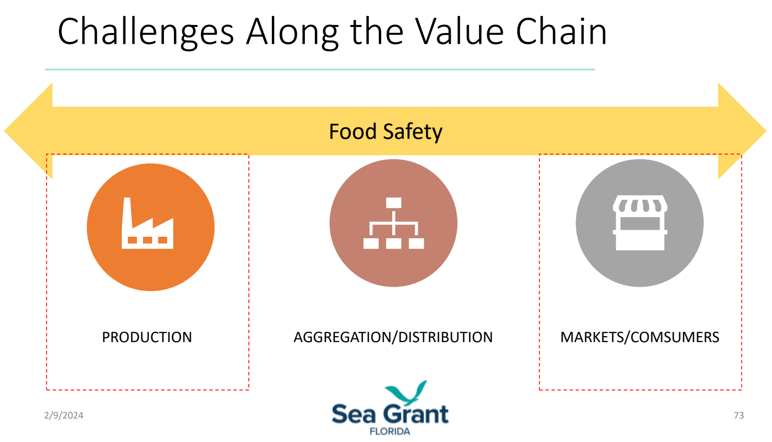


Sources: Nature Communication 2021, UN FAO, 2021, World Bank 2022 &https://www.youtube.com/watch?v=KEPrgnjDdlY



| | Source | Process | Product | Consumer |
|---|---|---|---|---|
| Conventional | Wild | Fishing | Wild-Caught | Grocery Shopping |
| | Farm | Farming | Farm-Raised | |
| Alternative | Cell | Culturing | Cell-Based | |
| | Plant | Extruding | Plant-Based | |





## Challenges Along the Value Chain

Food Safety

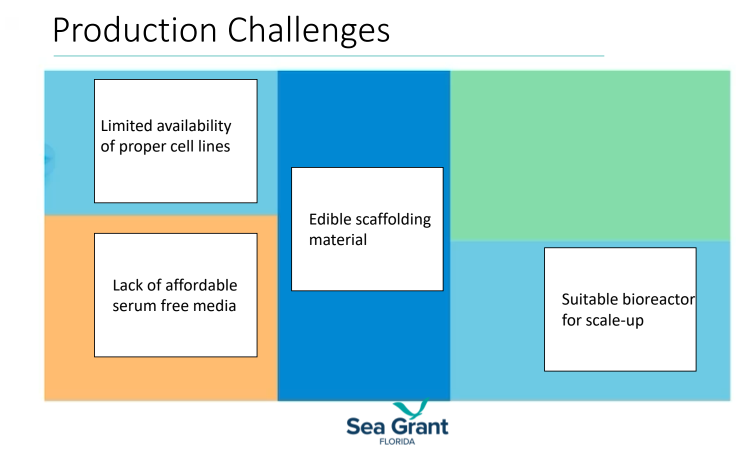
PRODUCTION

AGGREGATION/DISTRIBUTION

MARKETS/COMSUMERS

2/9/2024

73



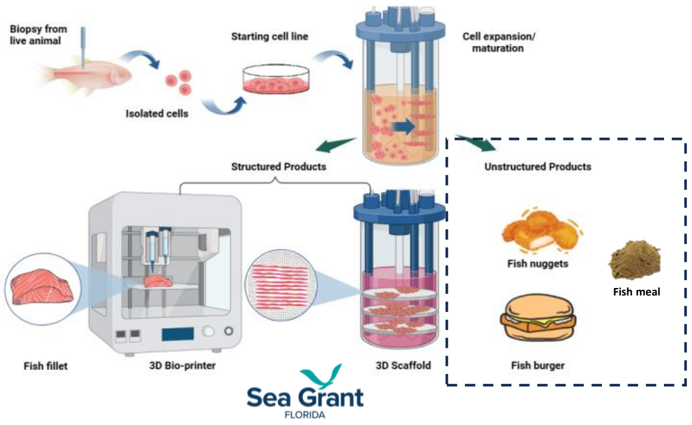
## Production Challenges

Limited availability of proper cell lines

Edible scaffolding material

Lack of affordable serum free media

Suitable bioreactor for scale-up



## RESEARCH AIM & OBJECTIVES

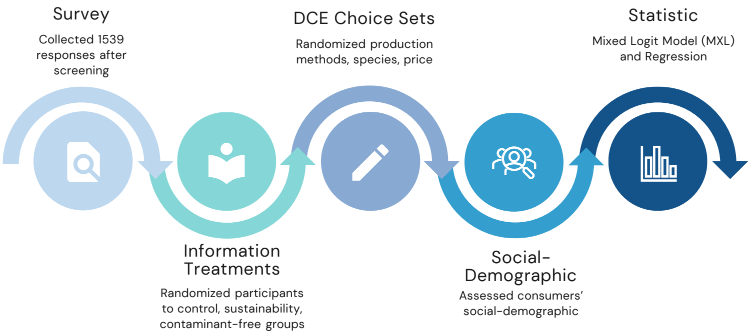
Our aim is to leverage cellular agriculture technology to create cell-based aquafeed ingredients and seafood alternatives.

Objectives:

1.Assessing stakeholders' perception; consumers, extension educators, producers and processor of seafood and aquafeed
2.Developing cell lines for producing cell-based fish meal ; myoblast(muscle cell), and adipocytes(fat cell)
3.Conducting nutritional trials to evaluate the impact of cell-based fish meal on fish or shellfish production and health
4.Analyzing the environmental impact of cellular aquaculture through Life Cycle Analysis.

# Sustainable Aquaculture
By Farzad

Objective one; Consumers' Perception and Willingness to pay



**Survey**
Collected 1539 responses after screening

**Information Treatments**
Randomized participants to control, sustainability, contaminant-free groups

**DCE Choice Sets**
Randomized production methods, species, price

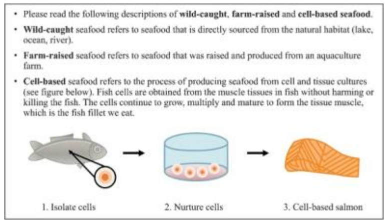
**Social-Demographic**
Assessed consumers' social-demographic

**Statistic**
Mixed Logit Model (MXL) and Regression

Food Quality and Preference

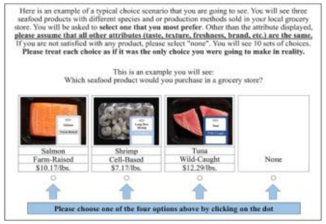
Cell-Based Seafood Marketability: What Influences United States Consumers' Preferences and Willingness-To-Pay?

Objective one; Consumers' Perception and Willingness to pay



- Please read the following descriptions of **wild-caught**, **farm-raised** and **cell-based seafood**.
- **Wild-caught** seafood refers to seafood that is directly sourced from the natural habitat (lake, ocean, river).
- **Farm-raised** seafood refers to seafood that was raised and produced from an aquaculture farm.
- **Cell-based** seafood refers to the process of producing seafood from cell and tissue cultures (see figure below). Fish cells are obtained from the muscle tissues in fish without harming or killing the fish. The cells continue to grow, multiply and mature to form the tissue muscle, which is the fish fillet we eat.

1. Isolate cells → 2. Nurture cells → 3. Cell-based salmon



Here is an example of a typical choice scenario that you are going to see. You will see three seafood products with different species and or production methods sold in your local grocery store. You will be asked to **select one that you most prefer**. Other than the attribute displayed, **please assume that all other attributes (taste, texture, freshness, brand, etc.) are the same.** If you are not satisfied with any product, please select "none". You will see 10 sets of choices. **Please treat each choice as if it was the only choice you were going to make in reality.**

This is an example you will see:
Which seafood product would you purchase in a grocery store?

| | | | |
|---|---|---|---|
| Salmon | Shrimp | Tuna | |
| Farm-Raised | Cell-Based | Wild-Caught | None |
| $10.17/lbs. | $7.17/lbs. | $12.29/lbs. | |
| ○ | ○ | ○ | ○ |

**Please choose one of the four options above by clicking on the dot**

Objective one

- Consumers' preferences for seafood species varied with changes in production methods.
- Wild-caught seafood was most favored, followed by cell-based and farm-raised.
- Positive information increased consumers' willingness-to-pay for cell-based seafood.
- Contaminant-free qualities aids cell-based seafood marketing.

Consumers' Attitude for Cell-Based Seafood: Motivations, Barriers, and Effective Marketing Strategies in the US Market & Extension Educators Perceptions of Alternative Seafood Products.

Objective Two

## Cell Line Development: Optimized Nile Tilapia Primary Muscle Cell Isolation Protocol

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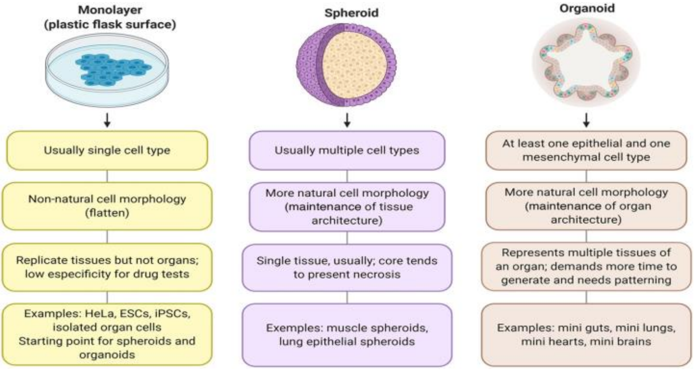
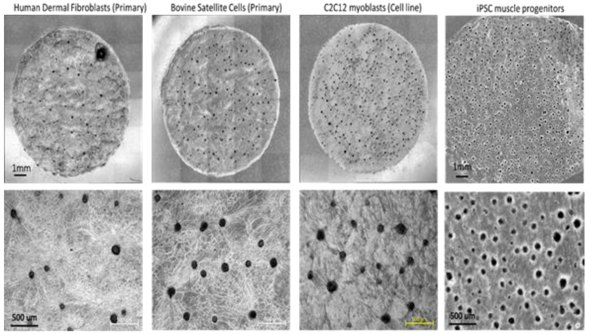


| Monolayer (plastic flask surface) | Spheroid | Organoid |
|---|---|---|
| Usually single cell type | Usually multiple cell types | At least one epithelial and one mesenchymal cell type |
| Non-natural cell morphology (flatten) | More natural cell morphology (maintenance of tissue architecture) | More natural cell morphology (maintenance of organ architecture) |
| Replicate tissues but not organs; low especificity for drug tests | Single tissue, usually; core tends to present necrosis | Represents multiple tissues of an organ; demands more time to generate and needs patterning |
| Examples: HeLa, ESCs, iPSCs, isolated organ cells<br>Starting point for spheroids and organoids | Exemples: muscle spheroids, lung epithelial spheroids | Examples: mini guts, mini lungs, mini hearts, mini brains |

# Sustainable Aquaculture
By Farzad

Objective Two



The ability of the Cholesterol Liquid Crystal (CLC) to form spheroids from various cell lines after 15 hours of culture

## IMPACTS

## NEXT STEPS

- Aquaculture farmers and feed producers survey and focus groups
- Cell-based fishmeal production using the Nile Tilapia muscle cell line
- Life Cycle Analysis
- AI-enabled technique for cell-based aquafeed/seafood quality control method

## ACKNOWLEDGMENT

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