OOA IV

Open Ocean Aquaculture IV

From Research To Commercial Reality

ST. ANDREWS, NEW BRUNSWICK

Open Ocean Aquaculture IV

Symposium Program and Abstracts

June 17 – 20, 2001 St. Andrews, New Brunswick

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Fisheries and Oceans Canada Pêches et Océans Canada

I would like to welcome the delegates to the Open Ocean Aquaculture IV Symposium to St. Andrews.

St. Andrews has a long history in marine research, dating back to 1899-1900 when Canada's first marine biological station, a small portable laboratory, was operated at St. Andrews. A permanent laboratory, the St. Andrews Biological Station, has been operating at its current location since 1908.

Almost since the beginning, aquaculture has been a focus of research at the Biological Station. Various species have been studied over the years, including oysters, trout, lobsters, and more recently haddock, halibut, and sea urchins, but it was research on salmon aquaculture which has to date led to the biggest commercial success. In the late 1970s, the Biological Station was involved, with the Province of New Brunswick, and a private company, in the establishment of Canada's first successful salmon farm, at Deer Island in southwestern New Brunswick.

That farm had its first harvest – 6 tonnes – in 1979. Since then, the southwestern New Brunswick salmon farming industry has grown considerably. Preliminary estimates indicate that production in 2000 was in the order of 25-30 tonnes. It is estimated that about one in four jobs in southwestern New Brunswick are now directly or indirectly related to salmon farming.

There are now about 90 salmon farms in southwestern New Brunswick. Most of the best nearshore sites are already occupied by salmon farms. Proposals for new farms in the remaining suitable nearshore sites are being hotly contested by other users including traditional fisheries, boating, ecotourism, and coastal landowners.

Open ocean aquaculture technology may allow expansion of the industry, without creating further conflicts in nearshore areas. There will, however, be considerable challenges, including finding the appropriate technology to withstand the more severe conditions offshore. Other issues, such as fisheries, environmental concerns, and navigation, will still be concerns in offshore areas and will have to be addressed.

So you can see that this is a topic which could be extremely important to the industry in this part of the world. The fact that participants have come to this conference from so many different countries points to the worldwide interest in offshore aquaculture.

I look forward to attending the sessions and I wish you a successful symposium.

Thomas W. Sephton
Director
St. Andrews Biological Station
Fisheries and Oceans Canada

Steering Committee for the Open Ocean Aquaculture IV Symposium June 17 – 20, 2001

Barry Costa-Pierce	OOA IV Organizing Committee Mississippi-Alabama Sea Grant Consortium, USA
Christopher Bridger	OOA IV Organizing Committee University of Southern Mississippi, USA
Tim Reid	OOA IV Organizing Committee Mississippi-Alabama Sea Grant Consortium, USA

Nigel Allen	Marine Institute of Memorial University of Newfoundland, Canada
Chris Bartlett	Maine Sea Grant, USA
Ron Becker	Louisiana Sea Grant, USA
Blythe Chang	Fisheries and Oceans Canada
Rick DeVoe	South Carolina Sea Grant Consortium, USA
Sharon Ford	Fisheries and Oceans Canada
Clifford Goudey	MIT Sea Grant, USA
Charles Helsley	University of Hawaii, USA
Richard Langan	University of New Hampshire, USA
Jay Parsons	Fisheries and Oceans Canada
Bill Rickards	Virginia Sea Grant, USA
Robert Stickney	Texas Sea Grant, USA

OOA IV: From Research to Commercial Reality

OVERVIEW

To provide the ever-expanding global population with safe, consistent and high quality seafood, aquaculture development will face many new challenges in the next millennium. There is no doubt that with current population increases and shifts in human consumption towards seafood, wild fisheries will not be able to meet consumer demands. Current population shifts towards coastal areas will increase user conflicts and human-induced sources of pollution limiting coastal aquaculture production. As a result, open ocean aquaculture may be the only viable option for future seafood production to meet desired consumer demand.

OBJECTIVE

In reflection of the OOA IV's theme, "From Research to Commercial Reality," the Organizing Committee has targeted the world's top researchers, aquaculture experts, and government and commercial-sector representatives to discuss ongoing and future developments in open ocean aquaculture to ensure its sustainable future. Their presentations are part of the "evolution of the blue revolution" of open ocean aquaculture. OOA IV is a pivotal event that will help overcome the common hurdles that will be encountered along the way.

STRUCTURE OF THE SYMPOSIUM

Presentations will be organized in four non-overlapping theme sessions as described below. These broad sessions outline the major thematic issues to developing open ocean aquaculture throughout the world. Each session will begin with one or more invited keynote speakers. Presenters are asked to hold their presentations to 15 minutes (12 minutes for their presentation; 3 minutes for general discussion).

Marine Policy and Social/Economics: Issues associated with marine policy and regulatory challenges to offshore aquaculture development and the social and economic benefits/impacts;

Ocean Engineering: Developments relating to cage designs, shellfish grow-out platforms, feeding systems, mooring options and other logistical issues;

Ocean Environmental: Results from monitoring open ocean aquaculture's environmental impacts; and,

Candidate Species and Logistics/Operations: Overviews of advancements in the culture of candidate marine species, and the continued research and mitigation of the logistics of operating an open ocean aquaculture enterprise.

PROCEEDINGS PUBLICATION

Presenters have been invited to submit a manuscript to be published in a symposium proceedings. To give all presenters the proper exposure their papers deserve, the OOA IV Steering Committee is exploring the final form of this product.

General Information

OOA IV Registration Desk
The Registration Desk will be open during the following times:

Sunday, June 17	1:00 pm to 9:00 pm
Monday, June 18	7:00 am to 4:00 pm
Tuesday, June 19	7:00 am to Noon

Messages
If you are a guest staying at the Algonquin, persons trying to reach you may contact the hotel's front desk at 506-529-8823 and leave a message for you. If you are not a guest, persons trying to reach you should call the Algonquin front desk and ask them to relay a message to the OOA IV Registration Desk. Our registration staff will make every effort to pass along that message to you.

Lost and Found
Valuables found in any of the session or break rooms can be turned in, and reclaimed, at the OOA IV Registration Desk.

Storage of Items
Temporary storage of all items (briefcases, slides, coats, purses, luggage, computers, etc.) must be done through the hotel's Bell Captain located near the front door.

Algonquin Check In/Check Out Times

Check In:	4:00 pm
Check Out:	Noon

Electric Power

120 volts

Tax
15% HST

Algonquin Dining and Entertainment
Passamaquoddy Veranda (200 seats)
The Library (50 seats)
Dockside Pub (60 seats)
Library Veranda (40 seats)
Clubhouse Restaurant (60 seats)

On-Property Recreation
Outdoor Heated Swimming Pool
Health Spa
Katy's Cove Beach
Shuffleboard
Bicycling
2 Tennis Courts
18-Hole Golf Course

Symposium Events

Welcoming Reception | **Lazy Croft Garden** | **7:00 pm - 10:00 pm**

Be sure not to miss the first event of OOA IV. Mingle with the other delegates as you sample a "Taste of New Brunswick." The reception will feature several culinary choices native to the local area including Atlantic Mussels Sauteed in Moosehead Red Pale Ale, Baked Cajun Citrus Honey Salmon, Roast Baron of Canadian Beef, and New Brunswick Mapel & Ginger Glazed Ham — and the list of desserts is even longer! Brian Maxwell from Kingston, New Brunswick will provide a background of maritime and folk music.

Monday Luncheon Speaker | **Shaughnessy Room** | **12:00 pm - 1:30 pm**

Roland Cormier, Assistant Deputy Minister of New Brunswick's Fisheries, Aquaculture, and Policy division will speak about aquaculture in the province, which is worth more than $100 million annually. Though Atlantic Salmon is the dominant species raised on the province's aquaculture farms, trout, oysters and mussels are also grown and harvested.

Monday Night Mixer | **Roof Garden** | **6:30pm - 8:00 pm**

After a full day of listening to presentations it's time to unwind — whether it's stopping by for an appetizer before heading out for dinner on the town, or meeting another delegate to continue a discussion over a drink. The Roof Garden will let you get some fresh air while overlooking the scenic Passamaquoddy Bay and enjoy hot hors d'oeuvres, chocolate fondue, and other munchies. Be sure to remember your two free drink tickets!

Tuesday Luncheon Speaker | **Shaughnessy Room** | **11:30 am - 1:00 pm**

Donal Maguire, of Ireland, will present, "A Review of Established Offshore Cage Technology in Irish Salmon Farming." Mr. Maguire will discuss the evolution of Irish salmon farming since 1984 to present, detailing the very important role that offshore aquaculture is playing in Irish farming, their production goals, and how the state and industry are working together to realize these ambitious goals.

St. Andrews Biological Station Tour | **Meet in Main Lobby** | **9:00 am - 11:00 am**

Join the tour to see history as well as cutting edge research. The St. Andrews Biological Station (SABS) was built in 1908 as Atlantic Canada's first permanent marine laboratory. The station is now a modern facility equipped with seawater and freshwater operations, laboratories, computer facilities, a library, and a wharf for research vessels. SABS, operated by Fisheries and Oceans Canada, has established a national and international reputation for research on aquaculture, stock assessments and biology of commercially harvested finfish and invertebrates.

Industry Boat Tour | **Meet in Main Lobby** | **1:00 pm - 5:00 pm**

Spend the afternoon on the M/V Quoddy Link for a special tour of the area's cage aquaculture sites. The well-experienced crew as well as Fisheries and Oceans Canada locals will educate everyone on the history and development of the coastal aquaculture operations in the Bay of Fundy. Further details of the tour will be announced at OOA IV.

OOA IV Keynote Speakers' Biographies

Yves Bastien

Mr. Yves Bastien was appointed Commissioner for Aquaculture Development in December 1998. Mr. Bastien, who holds a B.Sc. in Biological Sciences from the University of Montreal, has extensive experience in aquaculture, project management, and wildlife and aquatic resource management. He worked at the Misistère de l'Aquaculture, des Pêcheiries et de l'Alimnetation du Québec (MAPAQ) as an aquaculture development officer, an extension services coordinator for Fisheries and Aquaculture, and a mariculture coordinator/specialist. Prior to his appointment as Commissioner, Mr. Bastien served as Executive Director of the Societé de développement de l'industrie maricol (SODIM) in the Gaspé Penninsula and Magdalen Islands, managing a one-million dollar mariculture investment fund. He has sat on various boards of directors, including the Aquaculture Association of Canada (AAC), the Canadian Aquaculture Industry Alliance, and the World Aquaculture Society. He served as President of the AAC in 1992-93 and 1998 and has participated in study missions on salmon farming in Scandinavia and scallop farming in Japan.

The Commissioner is the champion for the aquaculture industry within the federal domain. His mandate is to bring together all appropriate federal government resources, lead required regulatory reforms, and work with the provinces to develop a vibrant, environmentally sustainable aquaculture industry. He is responsible for overseeing the implementation of the Federal Aquaculture Development Strategy (FADS) launched in 1995.

Clifford Goudey

Mr. Cliff Goudey is the Director of MIT Sea Grant's Center for Fisheries Engineering Research and is active in the field of open ocean aquaculture. His research interests include the engineering of systems for offshore fish production as well as the design and optimization of mobile systems operated as fleets. His current research thrusts include mooring systems, automated feeder systems, and the remote monitoring and control of cage systems. He also leads a land-based initiative developing systems and species hatchery and grow-out in an urban aquaculture setting. Working in the field that overlaps fisheries and aquaculture, Mr. Goudey lead the successful permitting process for the first and largest aquaculture site in U.S. federal waters – SeaStead – the Sea Scallop Enhancement Site, south of Martha's Vineyard. He has Masters degrees from MIT in Naval Architecture and in Mechanical Engineering. Mr. Goudey has worked for the MIT Sea Grant College Program since 1980.

Charles Helsley

Dr. Helsley is the former Director of the Sea Grant College Program at the University of Hawaii and former Director of the Hawaii Institute of Geophysics. He is a geologist by training and became interested in Open Ocean Aquaculture in 1996. He organized the "Open Ocean Aquaculture '97" Conference, the second in this series of international conferences.

Dr. Helsley is an avid proponent of open ocean aquaculture and was the Principle Investigator of the Sea Grant sponsored open ocean aquaculture demonstration project in Hawaii. This project has now successfully produced two crops of fish in a totally submerged cage two miles off the coast of Oahu. He is a member of the US-Japan Natural Resources Aquaculture Panel and the author of several papers dealing with open ocean aquaculture in Hawaii as well as over 100 scientific papers in geology, geophysics, and related subjects. In 1999 he retired from the University of Hawaii, but still retains an Emeritus position with the university while he continues to assist in the development of an offshore aquaculture industry in Hawaii.

I. Chiu Liao

Dr. Liao led the establishment and directed the aquaculture research programs of Tungkang Marine Laboratory (TML), Taiwan Fisheries Research Institute (TFRI). Among the major breakthroughs at TML was the artificial propagation of grass prawn (*Penaeus monodon*), grey mullet (*Mugil cephalus*), and milkfish (*Chanos chanos*). Commercial culture of these species was achieved with successful transfer of developed technologies to aquaculturalists. As the current TFRI Director General, Dr. Liao supervises the research programs of the headquarters and eight branches of the Institute. Priority research areas at present include sea cage aquaculture, super-intensive recirculating aquaculture, stock enhancement and sea ranching, and species diversification. Research in these areas is being actively pursued in collaboration with the aquaculture industry. In November 1999, Dr. Liao was chair of the organizing committee of the First International Symposium on Cage Aquaculture in Asia, which was jointly organized by the Asian Fisheries Society and the World Aquaculture Society – Southeast Asian Chapter. As one of the founding members and current president of the Asian Fisheries Society, Dr. Liao trains young leaders for aquaculture development, directs international collaborative ventures, and facilitates implementation of strategies for sustainable aquaculture development in the region.

James McVey

Dr. James McVey is responsible for managing aquaculture research in the National Sea Grant College Program. He serves on the Executive Committee of the Joint Sub-Committee on Aquaculture and the NOAA/DOC Aquaculture Steering Committee, and he serves on the Build Sustainable Fisheries budget committee that is responsible for including aquaculture as a prime component of the NOAA fisheries plan. He is also the Chair for NOAA on two international panels with China and Japan dealing with aquaculture. He has contributed time and resources to the first three Open Ocean Aquaculture conferences and written several papers on the subject.

Harald Rosenthal

Dr. Rosenthal has worked in aquaculture systems research and environmental interactions in aquaculture for more than 30 years, and with projects spread out in more than 20 countries. He has over 300 scientific publications. Dr. Rosenthal is on the Editorial Boards of seven scientific journals and Editor-in-Chief of the Journal of Applied Ichthyology. He possesses specific expertise in environmental assessment of cage farms in nearshore and offshore situations as well as behavioral studies of fish in tanks and cages under changing environmental conditions. Dr. Rosenthal has Honorary Degrees from Heriot-Watt University (UK) and the University of New Brunswick (Canada), and is a member of the Royal Swedish Academy of Science. He has a Ph.D. and a Habilitation from the University of Hamburg.

OOA IV Agenda

Sunday, June 17, 2001

1300 - 2100 OOA IV Registration, Main Lobby

1900 - 2200 Welcome Reception with Local Entertainment, Lazy Croft Garden

Monday, June 18, 2001

0700 - 1600 OOA IV Registration, Foyer on Lower Level

0700 - 0800 Breakfast Buffet, Shaughnessy Room

0800 Welcome and Introductions (all sessions in New Brunswick Room)
Thomas Sephton
Barry Costa-Pierce
Christopher Bridger

0830 Symposium Keynote Address
Charles Helsley, Professor Emeritus, University of Hawaii, USA

Marine Policy and Social/Economics

Session Chair
Sharon Ford
Director-Programs, Office of Sustainable Aquaculture, Canada

0900 Canadian Keynote Address
Yves Bastien
Commissioner for Aquaculture Development

0930 U. S. Keynote Address
James McVey
Aquaculture Program Director, National Sea Grant College Program

1000 Discussion

1015 Break, St. Andrews Room

1045 Proposed Policy Framework for Offshore Aquaculture in the United States
Biliana Cicin-Sain*, Susan M. Bunsick, Rick DeVoe, Tim Eichenberg, John Ewart, Harlyn Halvorson, Robert W. Knecht and Robert Rheault

1100 Governing Offshore Aquaculture: A Conceptual Framework
Susan M. Bunsick

1115 Legal Hurdles to Offshore Aquaculture Leasing
Kristen M. Fletcher* and Erinn Neyrey*

1130 Administrative and Public Policies for Sustainable Offshore Cage Culture in Puerto Rican Waters
Dallas E. Alston*, Ricardo Cortés-Maldonado, Alexis Cabarcas, Herbert Quintero and Jorge Capella

1145 The Use of Mathematical Models by the Regulator to Support the Setting of Licenses of Marine Discharges from the Cage Fish Farm Industry
Peter Singleton

1200 Lunch, Shaughnessy Room
Invited Luncheon Speaker:
Roland Cormier, Assistant Deputy Minister,
Fisheries, Aquaculture, and Policy
New Brunswick, Canada

1330 A Comparison of Access Systems for Natural Resources: Drawing Lessons for Ocean Aquaculture in the U.S. Exclusive Economic Zone
P. Hoagland*, Kenneth M. Riaf, H.L. Kite-Powell and Katherine Cox

1345 Knowledge, Relevance and Attitudes Towards Open Ocean Aquaculture in Northern New England: A Comparison of Data from Five Sample Surveys
R.A. Robertson

1400 Northern New England Commercial Fishermen and Open Ocean Aquaculture: An Analysis of How Commercial Fishermen Perceive the Government, Fishing and Their Way of Life
R.B. Nichols*, R.A. Robertson and Bruce E. Lindsay

1415 Conflict for Space Between Aquaculture and Fishing – The New Zealand Experience
Susan Jane Grey* and Michael Sean Sullivan

1430 A Model of the Socially Optimal Scale of Ocean Aquaculture
D. Jin, P. Hoagland* and H.L. Kite-Powell

1445 Economic Models for Open Ocean Grow-out of Sea Scallops (*Placopecten magellanicus*) and Blue Mussels (*Mytilus edulis*)
H.L. Kite-Powell*, P. Hoagland and D. Jin

1500 Economic Potential of Offshore Aquaculture in the Gulf of Mexico
Benedict C. Posadas*, Christopher J. Bridger and Barry A. Costa-Pierce

1515 A Bioeconomic Model of Open Ocean Grow-out Operations for Finfish
H.L. Kite-Powell*, P. Hoagland, K. Murray and D. Jin

1530 Break, St. Andrews Room

Ocean Environmental

Session Chair
David Wildish
Senior Researcher, Fisheries and Oceans Canada

1600 Session Keynote Address
Harald Rosenthal
Professor, Institute for Marine Sciences, University of Kiel, Germany

1630 Environmental Impact of an Open Ocean Aquaculture Cage on the Benthic Invertebrate Community Off Oahu, Hawaii, USA
D.R. Bybee

1645 An Ecological Engineering Approach to Open Ocean Aquaculture
John Benemann and Daniel Herman*

1700 A New Approach to Sustainable Mariculture: Stimulating "Natural" Biofilters to Capture Fish Farm Wastes
D.L. Angel*, Spanier, N. Eden, T. Katz, A. Yurman and S. Breitstein

1715 The Evolution of Sustainable Offshore Aquaculture Ecosystems
Barry A. Costa-Pierce* and Christopher J. Bridger

1730 Measurements of the Physical Environment: What Have We Learned and What Do We Need?
Frank L. Bub*, John Lund and Melissa Brodeur

1745 Environmental Monitoring in the Vicinity of an Open Ocean Aquaculture Site in the Southwestern Gulf of Maine: Some Preliminary Results
Ray Grizzle, Larry Ward*, Richard Langan, Gwynne Schnaittacher and Jennifer Dijkstra

1830 - 2000 Monday Night Mixer, Roof Garden

Tuesday, June 19, 2001

0700 - 1200 OOA IV Registration, Foyer on Lower Level

0700 - 0800 Breakfast Buffet, Shaughnessy Room

Ocean Engineering

Session Chair
Robert Stickney
Director, Texas Sea Grant College Program, USA

0800 Session Keynote Address
Clifford Goudey
Director, Center for Fisheries Engineering Research,
MIT Sea Grant College Program, USA

0830 General Analysis of Longline Constructions Used for Cultivation of Blue Mussels *Mytilis edulis*
A. Fredheim* and E. Lien

0845 Development of Longtube Mussel Systems for Cultivation of Blue Mussels (*Mytilis edulis*)
E. Lien* and A. Fredheim

0900 Recent Advances in Open Ocean Aquaculture
L. Gace

0915 Vertical Positioning of Submersible Cages
L.Yu. Bugrov

0930 Break, St. Andrews Room (Special Poster Session)

1030 The Design, Installation, and Performance of a Single Point Mooring for an Offshore Cage
Clifford A. Goudey*, Tomer Boaz and Christopher J. Bridger

1045 Modeling of Net Structures Exposed to 3D Waves and Current
Pål F. Lader*, Arne Fredheim and Egil Lien

1100 Fluid Dynamic Drag Modeling of a Central Spar Fish Cage
D.W. Fredriksson*, M.J. Palczynski, M.R. Swift, J.D. Irish and B. Celikkol

1115 Finite Element Simulation to Predict the Dynamic Performance of Tension Leg Fish Cage
I. Tsukrov*, O. Eroshkin, D.W. Fredriksson and B. Celikkol

1130 Lunch, Shaughnessy Room
Invited Luncheon Speaker:
Donal Maguire, BIM
Dublin, Ireland

Candidate Species and Logistics/Operations

Session Chair
Richard Langan,
Co-Director, CICEET, University of New Hampshire, USA

1300 Session Keynote Address
I. Chiu Liao
Director General, Taiwan Fisheries Research Institute, Taiwan

1330 Advances in Submerged Longline Culture of Blue Mussels *Mytilis edulis* in the Open Ocean
R. Langan

1345 How the Semi-Intensive Rearing System Used in the Culture of Juvenile Atlantic Halibut (*Hippoglossus hippoglossus* L.) Could be Applied in Tropical Marine Aquaculture
José J. Casas

1400 Advances in Aquaculture Technology of Mutton Snapper (*Lutjanus analis*) and Greater Amberjack (*Seriola dumerli*), Two Candidate Species for Offshore Cage Aquaculture
Daniel D. Benetti*, Jorge F. Alarcón, Michael W. Feeley, Owen Stevens, Federico Rotman, Gill-Banner-Stevens, Tracy Hamilton, Loyal Eldridge and Brian O'Hanlon.

1415 Ionic and Hematological Changes in the Summer Flounder (*Paralichthys dentatus*) Associated with their Movement from a Recirculating System Hatchery to an Open Net Pen
James A. Sulikowski*, W. Huntting Howell, Jennifer M. Wanat, Glen A. Rice, Nathan Rennels, Carroll Jones and George Nardi

1430 Production of Atlantic Cod (*Gadus morhua*) for Open Ocean Aquaculture in New Hampshire
N.J. King*, G.C. Nardi and W.H. Howell

1445 Break, St. Andrews Room

1515 Offshore Mariculture in Texas: Past, Present, and Future
J.B. Kaiser

1530 Offshore Culture of the Pacific Threadfin *Polydactylus sexfilis* in Hawaii: Results of the Hawaii Offshore Aquaculture Research Project (HOARP) Phase II
Anthony C. Ostrowski*, Charles E. Helsley, Michael Chambers, Angelos Apeitos, Jackie Zimmerman, Randy Cates, Julie Bailey-Brock, PingSun Leung, Lotus E. Kam and David Bybee

1545 Status of Open Ocean Aquaculture in New Hampshire
M.D. Chambers*, W.H. Howell, R. Langan and B. Celikkol

1600 Offshore Aquaculture Development in the Gulf of Mexico and the Offshore Aquaculture Consortium (OAC)
Christopher J. Bridger*, Barry A. Costa-Pierce, Robert R. Stickney and C.A. Goudey

1615 Oceanographic and Meteorological Considerations for Open Ocean Aquaculture in the Puerto Rico-USVI Platform
Jorge Capella, Dallas E. Alston*, Alexis Cabarcas, Herbert Quintero, Ricardo Cortés-Maldonado

1630 Recent Progress and Constraints Towards Implementing an Offshore Cage Aquaculture Project in Puerto Rico, USA
Brian O'Hanlon*, Daniel D. Benetti, Owen Stevens, José Rivera and Joseph Ayvazian

1645 - 1700 Symposium Closing Remarks

Wednesday, June 20, 2001

0900 - 1100 Tour of St. Andrews Biological Station
Meet in Main Lobby

1300 - 1700 Aquaculture Industry Boat Tour
Meet in Main Lobby

OOA IV Poster Presentations

Measurements of the Physical Environment: What Have We Learned and What Do We Need?
Frank L. Bub*, John Lund and Melissa Brodeur

Salmon Aquaculture Industry in New Brunswick: Why Go Offshore?
B.D. Chang

Management Strategies for Fish Cultivation in Floating Cages in the Mediterranean Sea and Atlantic Ocean
Eucario Gasca-Leyva*, Carmelo J. León and Juan M. Hernández

Bioeconomic Analysis of the Impact of Location on Gilthead Seabream *Sparus aurata* Cultivation in Floating Cages
Eucario Gasca-Leyva*, Carmelo J. León , Juan M. Hernández and J.M.Vergara

Environmental Monitoring in the Vicinity of an Open Ocean Aquaculture Site in the **Southwestern Gulf of Maine: Some Preliminary Results**
Ray Grizzle, Larry Ward*, Richard Langan, Gwynne Schnaittacher and Jennifer Dijkstra

Aquaculture Development in India
R. Jayaraman

Habitat Value of Commercial Oyster Culture Gear in Tomales Bay, California
P.G. Olin

The Design, Construction and Testing of the University of New Hampshire Feed Buoy
G.A. Rice

Potential Species for Offshore Culture: Larval Rearing of the Red Hind Grouper *Epinephelus guttatus* Under Hatchery Conditions
Herbert Quintero-Fonseca*, Alexis Cabarcas-Núñez, Dallas E. Alston, and Edgardo Ojeda and Jorge Capella

OOA IV
Extended Abstracts

ADMINISTRATIVE AND PUBLIC POLICIES FOR SUSTAINABLE OFFSHORE CAGE CULTURE IN PUERTO RICAN WATERS

Alston, Dallas E.[1]*, Ricardo Cortés-Maldonado[2], Alexis Cabarcas[3], Herbert Quintero[4], Jorge Capella[5]

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Emails: d_alston@rumac.uprm.edu[1]; r_cortes@rumac.uprm.edu[2];
arlenegf@coqui.net[3];qfherbert@hotmail.com[4]; jcapella@rmocfis.uprm.edu[5]

As an island, Puerto Rico should benefit from its ideal location of being surrounded by the pristine oceanic waters of the Atlantic Ocean and the Caribbean Sea. However, from a production standpoint, Puerto Rico produces less than 5% of its seafood. Because the island is small and congested with 3.9 million inhabitants, the terrestrial environment has been heavily impacted. Large tracts of land are difficult to obtain for mariculture purposes, leaving room only for intensive mariculture operations. Terrestrial mariculture operations have to be managed carefully to minimize the impact on the environment.

Law Title III, Article 13, General Regulations for Aquaculture in oceanic waters has been considered by the Puerto Rican Legislature, but has not been approved. The proposed lead agency for submitting proposed projects would be the Department of Natural Resources and Environment. Required information would include bottom characteristics, hydrologic characteristics (velocity and direction of currents, temperature, dissolved oxygen content), proximity to significant habitats, and applicable data from previous studies. The operation could not be located within 1,500 feet from a submerged cable. Solids, trash, and sanitary and domestic wastes such as water from kitchens, oils, and grease could not be discharged in waters near the operations. This measure excludes organisms adhering to the project and the excrement from the cultured species. The incidental capture of fish, crustaceans, or mollusks could be used as food. Dumping of dead animals in public waters would not be allowed. All imported animals for aquaculture purposes would be inspected with the origin specified and inspected by Departmental agents. The cultured aquatic organisms are the property and responsibility of the aquaculturist. Exotic organisms would be examined by a taxonomist to assure only the desired species is present. The aquaculturist would maintain a register of the number and species cultured, size when sold, the quantity, and type of feed administered and medicines, chemicals or toxic substances applied within the facilities. The operation would be located one-mile distance from significant special habitats designated by the Secretary. Other regulations in the document refer to the lights required on boats (to avoid perturbing marine turtles), the control of predation, location near navigable channels, proper signs, and esthetic concerns (scenery). At least 5 meters would be left from a cage bottom to the ocean floor. The water quality impact would have to be minimized, including reducing the stocking density or increasing the depth from the cage bottom to the ocean floor. Cages could not be located within two miles of the high water mark of island coasts. Production would be limited to 110 tons/km^2 per year. The current velocity would be at least 5 cm/sec. All aquaculture operations would have to comply with a Pre-operational Environmental Inspection with detailed information concerning the bottom characteristics and the water column conditions. In addition, an Operational Monitoring Program should be established before starting the operation to include a hydrographic inspection, sediment chemistry, water quality, and benthic inventory. Deaths from wild fish must be filed each month. The Department must be notified immediately in cases of the death of any endangered species. Native species fished for aquaculture purposes must be approved.

The following issues need to be considered for conducting open ocean aquaculture operations off the coast of Puerto Rico:

- Delineation of the offshore areas subject to Commonwealth of Puerto Rico and Federal jurisdiction. Within the Commonwealth, jurisdiction logistics might be advantageous and should complement existing regulations;
- Determination of the stability of long-term tenure of offshore aquaculture sites. This will help to provide motivation for future operations:
    - This tenure should be integrated to include the site and what is contained in the facility (e.g., the fish) and the surrounding area (e.g., water quality).
    - Ascertain possibilities for obtaining licenses for leasing open ocean areas.
    - What sized area can be leased?
    - What are the durations of the lease?
    - Are there any lease laws that take into account common law among multiple users of surrounding waters?;
- Determination of Commonwealth and Federal regulations on the importation of protected fish species. To protect against illegal harvesting of protected species, determine if protected species has to be packaged and labeled properly to be sold within Puerto Rico;
- Evaluation of the laws needed to protect native stocks from impact of the culture of a particular species. This includes the possible change (dilution of) in the genetic pool of the native species;
- Assessment of the laws concerning the protection of the ecosystem, especially regulations protecting the ecosystem of the native population of fishery species;
- Determination of the liability of the University of Puerto Rico (or the Commonwealth of Puerto Rico, the issuer of the permits) in cases where damage to the environment is questionable;
- Determination of US Coast Guard regulations concerning navigation, especially concerning the placement of buoys and the regulated submerged depths of the submerged cages;
- Determination of esthetic perception of locating cages in tourist or scenic areas. With submerged cages, this impact should be minimized, but must be documented;
- Consideration of abandonment liability issues. These include safety, potential risk to the environment and the impact on mariculture operations;
- Determination of chemical substances that are forbidden, not recommended, or potentially cause environmental damage. Determine Federal (especially FDA) and local regulations for use of these chemicals, especially for treating parasites and diseases;
- Determination of water and air quality regulations concerning suspended solids, ammonia, biological oxygen demand, chemical oxygen demand, phosphorus, carbon dioxide, etc.;
- Ascertain new regulations concerning sewage treatment plants and their release of treated waters and compare to wastes from submerged cages;
- Determination of how local and federal laws regulating fisheries resources will affect the mariculture industry, particularly with reference to seasonal closures, zone closures, and catch limits;
- Determination of laws related to poaching or vandalism in offshore areas; and,
- Ascertain laws pertaining to the inhumane keeping of large numbers of animals in enclosures.

The University of Puerto Rico (UPR) should play a major role in helping government officials of the Commonwealth of Puerto Rico to understand the complicated issues involved in offshore mariculture development. UPR should also help the government to develop new legislation that will provide an excellent environment for the expansion of the industry while protecting native species and the marine environment, and consider the socioeconomic impact of the mariculture industry.

Keywords: Puerto Rico, laws, policy

Oral Presentation: Marine Policy and Social/Economics

A NEW APPROACH TO SUSTAINABLE MARICULTURE: STIMULATING "NATURAL" BIOFILTERS TO CAPTURE FISH FARM WASTES

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Intensive finfish mariculture generally focuses on species that require high protein diets. As a result, commercial net pen fish farms discharge large amounts of dissolved and solid wastes into the surrounding waters. One major nutrient released by caged fish is ammonia which is rapidly taken up by planktonic microorganisms and attached macrophytes, such that there may be a region adjacent to the fish farm characterized by elevated levels of chlorophyll or even noticeably greener than surrounding waters. Moreover, many of the available substrates (platforms, ropes, buoys, etc.) around farms are often covered by large communities of endemic macroalgae. In order to limit the discharge of nutrients to the surrounding waters, it is possible to capture and harvest farm effluents by means of the algae and invertebrates that develop around fish cages. This may be accomplished by deploying substrates near fish cages and allowing the naturally occurring "biofouling" community to serve as a biofilter for effluents.

We have demonstrated the effluent-removal potential of such a biofilter in an ongoing field study in the Gulf of Aqaba, Red Sea. In March 1999 two small (280 x 240 cm base and 240 cm height; surface area 115 m^2) pyramid-shaped plastic structures (Figure 1) were deployed on the seafloor (20 m depth); one adjacent to a commercial seabream fish farm (RC) and the second structure 500 m west of the fish farm (RN; control site). Both reefs became rapidly colonized by a wide variety of organisms with potential for removal of compounds released from the farms (Figure 2). Fish abundance and the number of species reached 518 - 1185 individuals per reef and 25 - 42 species per reef, respectively. Moreover, numerous benthic algae, small sessile invertebrates (bryozoa, tunicates, bivalves, polychaetes, sponges, anemones), and large motile macrofauna (crustaceans, sea urchins, gastropods) settled on reef surfaces. Depletion of chlorophyll *a* (chl *a*) was measured in the water traversing the artificial reefs in order to assess the biofiltration capacity of the associated fauna. Chlorophyll *a* was significantly reduced to a level 15 – 35% lower than ambient chl *a* concentrations. This reduction was greatest at intermediate current speeds (3 – 10 cm s^{-1}), but was not influenced by current direction. Reef structures served as a successful base for colonization by natural fauna and flora, thereby boosting the local benthic biodiversity, and also served as effective biofilters of phytoplankton.

These results are promising in terms of demonstrating the potential for biofiltration of fish farm effluents. We are currently focusing efforts (within the framework of the multi-national EU-funded research project, *BIOFAQs*) toward development of biofilters that are situated in the water column in order to process larger fluxes of dissolved nutrients released from fish cages. Moreover, we find that there is a need to design readily-harvestable biofilters so that the nutrients trapped within these may be removed from the marine environment and reduce local nutrient and particulate loads.

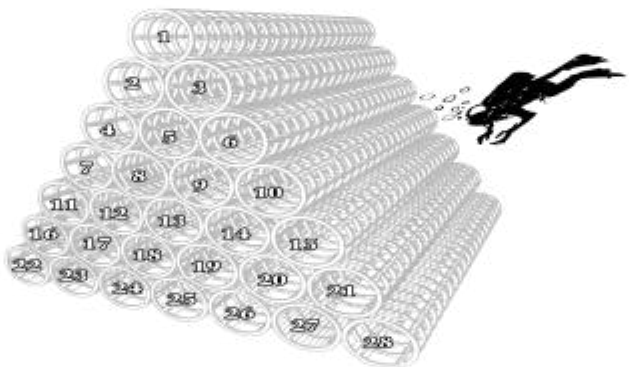

Figure 1. Sketch of the biofilter showing the elongated pyramid structure made of 40cm diameter plastic cylinders.

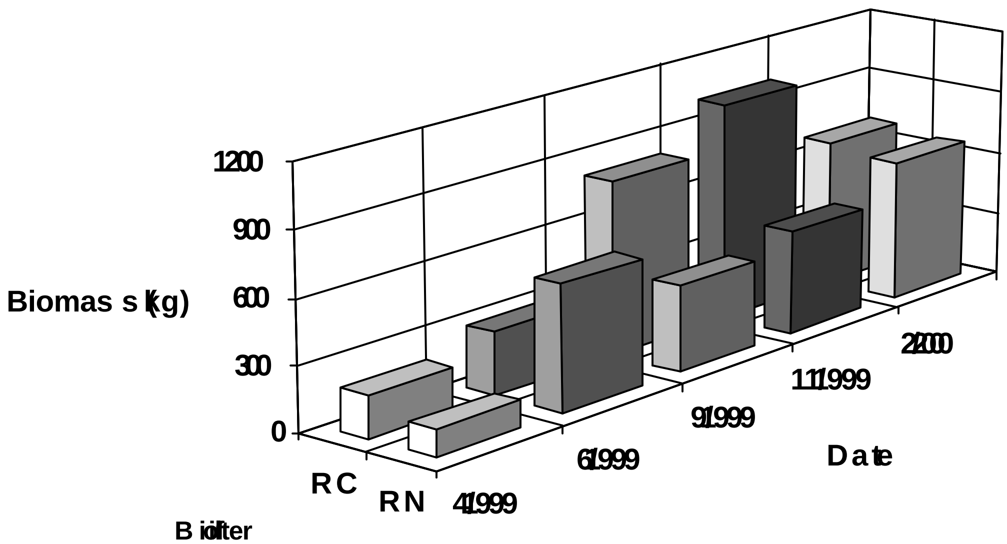

Figure 2. Summary of temporal changes in the biomass (kg) of attached organisms on the surfaces of the two biofilters, RC (below the fish farm) and RN (artificial reef 500m west of the farm).

Keywords: impacts, mitigation, biofilter

Oral Presentation: Ocean Environmental

AN ECOLOGICAL ENGINEERING APPROACH TO OPEN OCEAN AQUACULTURE

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The Joint Subcommittee on Aquaculture's National Aquaculture Development Plan (NADP) is in the final revision stage and is on track to be presented to the new administration in 2001 (specifically the Committee on Science of the President's Executive Office of Science & Technology). The National Marine Fisheries Service (NMFS) is also completing a "Code of Conduct for Responsible Aquaculture in the US Exclusive Economic Zone (EEZ)." With this document most of the legal basis for ownership, as well as guidance to U.S. regulators for projects in the EEZ, will be set. The completion of these two documents and associated developments signal a new era in approaching Open Ocean Aquaculture (OOA) projects. There will be new opportunities for industrial partnering and joint venture development in the near future. There is also an opportunity to approach offshore aquaculture research and development as an aspect of ecological engineering.

Large, multinational partners involved in ocean engineering and marine technology should be recruited for joint-venture research and development projects to bring some of their existing designs, engineering expertise, and prototypes to the OOA community. Part of this effort would be achieved through working with the corporate membership and contacts of associations like the NFI, NAA and GAA. Partners identified to date include oil & gas companies with related support industries; defense contractors developing Very Large Floating Structure (VLFS) technology & platforms; and ocean engineering companies laying submarine cable and developing affiliated technology for telecom corporations. Also of interest would be possible partnerships with marine technology corporations exploring "New Age" engineering endeavors involving wind &/or wave-energy generating stations; ocean thermal energy conversion (OTEC) systems & related deep ocean water upwelling systems; CO2 sequestration & mitigation; and ocean fertilization concepts.

Additionally, an "ecological engineering" approach to offshore aquaculture and its future possibilities is necessary. Although OOA will begin with growing and processing high value fish & seafood, offshore aquaculture has the capability to truly be the beginning of a "Blue Revolution." Future provision of dietary protein requirements to large areas of the developing world is not beyond the realm of possibility. If development is done correctly, the industry will be sustainable and ecologically friendly (engineered).

OOA is, and should be thought of as, "Big Science." The offshore aquaculture community needs to begin positioning itself as such, as well as communicating the concept that this is revolutionary stuff – possibly the next "Big Science" Biological Project after the Human Genome Project. This positioning and communication will provide the justification necessary for partnering with industrial giants and DoE/DoD contractors on their very large and costly R&D projects. In this manner offshore aquaculture will obtain the ocean engineering & marine technology developments and breakthroughs necessary to match the sophistication of current biological knowledge (i.e. species selection, nutritional/dietary requirements, net pen/cage design, etc.).

Keywords: EEZ, marine technology, offshore development

Oral Presentation: Ocean Environmental

ADVANCES IN AQUACULTURE TECHNOLOGY OF MUTTON SNAPPER (*Lutjanus analis*) AND GREATER AMBERJACK (*Seriola dumerili*), TWO CANDIDATE SPECIES FOR OFFSHORE CAGE AQUACULTURE.

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Recent progress in hatchery and grow-out technology of mutton snapper (*Lutjanus analis*) and greater amberjack (*Seriola dumerili*) at the Aquaculture Center of the Florida Keys (ACFK) are described. Advances in maturation, spawning, egg production, larval rearing, nursery, fingerling production and grow-out of these two prime candidates for offshore aquaculture are presented and discussed. In addition, aquaculture performance of mutton snapper raised in floating net cages was assessed by measuring growth, survival and feed conversion rates. Besides, a preliminary assessment of the environmental impact of the operation in the ecosystem was conducted. Captive mutton snapper brood stock were conditioned to spawn voluntarily in maturation tanks using environmental cues alone. Newly caught brood stock mutton snapper were also induced to spawn using hormone injections. Criteria for predicting final ovulation and spawning were developed and are described in this paper. Spawning events, which are preceded by males and females assuming a distinctive courtship behavior, are also described.

During the Spring of 2001, brood stock greater amberjack ranging in size from 10-20 kg were caught, transported to the ACFK hatchery, exposed to prophylactic treatment against ectoparasites and endoparasites and held in quarantine. Subsequently, fish were acclimated and stocked in maturation tanks for conditioned voluntary spawning. Greater than 13,000 fingerlings produced at ACFK were stocked in two circular high density extruded polyurethane (HDEP) floating net cages moored in a 7-acre saltwater lake in the Florida Keys. Cage dimensions were 10 m diameter x 7 m deep (600 m^3) and 7 m diameter x 7 m deep (300 m^3), and both fitted with 1/2" mesh size (stretched). Fish grew from an average weight of 12.25 g to over 300 g in nine months, indicating that the commercial size of 0. 5 kg (over 1 lb) can be achieved within a 1-year grow-out period (Figure 1). Estimated survival rate was over 70%. Stocking densities were 25 fish/m^3 (3.2 kg or 6.0 lb/m^3) and 5 fish/m^3 (0.72 kg or 1.4 lb/m^3). Fingerlings were fed a 2.5-5.0 mm marine grower (Moore-Clark) pellet containing 50% crude protein and 14% crude fat, and a 1/4" pellet (AquaXcel, Burris) containing 53% crude protein and 10% crude fat. Estimated feed conversion ratio (FCR) was 1.4, ranging from 0.79-3.4. Results confirm that *L. analis* has excellent potential for commercial aquaculture development in net cages in the U.S. and the Caribbean.

Water quality parameters (temperature, salinity, D.O., TAN, pH and S_2) were routinely measured at the surface, 3.3 m and 7.5 m depth. Current measurements, using a surface drifter, indicated a maximum wind and tide driven surface current of 5 cm/sec (0.1 knot). Water quality parameters measured upstream and downstream from the cage site did not show any evidence of negative environmental impact caused by the cage operation in the lake. The experimental grow-out trial was terminated when a cold front brought about an abrupt drop in air temperature (from 31 to 23 ^{o}C) and high winds to the area, causing the colder, dense upper layer of water in the lake to sink. Subsequently, the lake "turned over"- a phenomenon that brought anoxic water with high levels of ammonia and sulfur from the bottom to the surface - causing mass mortality in the lake, including fish stocked in the cages. This kind of problem is not anticipated to occur in the offshore environment, where D.O. concentration levels are always at or above saturation levels and other water quality parameters are excellent for marine fish aquaculture.

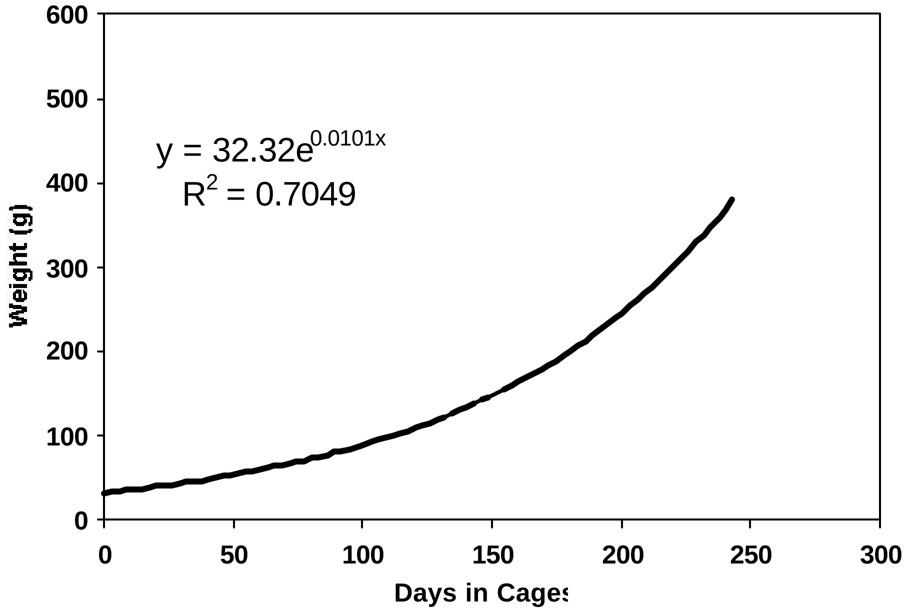

Figure 1. Growth rate of mutton snapper (*Lutjanus analis*) raised in floating net cages

Keywords: hatchery, grow-out, snapper, amberjack

Oral Presentation: Candidate Species and Logistics/Operations

OFFSHORE AQUACULTURE DEVELOPMENT IN THE GULF OF MEXICO AND THE OFFSHORE AQUACULTURE CONSORTIUM (OAC)

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The Gulf of Mexico Offshore Aquaculture Consortium (OAC) was formed in response to the Department of Commerce Aquaculture Policy signed by the Secretary of Commerce in 1999. The OAC was created as a collaborative, Gulf-wide, university-based interdisciplinary research program to address social, environmental and technological issues inherent to the development of offshore aquaculture in the Gulf of Mexico. The OAC has formed university/industry partnerships and has obtained broad public/commercial input needed to develop socially and environmentally acceptable offshore aquaculture for the Gulf of Mexico region.

The OAC organized a Gulf-wide Offshore Aquaculture Workshop at Texas Sea Grant in February 1999 to stimulate discussion from all stakeholders in the Gulf of Mexico region on sustainable development of offshore aquaculture. The OAC maintains a web site (http://www-org.usm.edu/~ooa/index.htm) to communicate findings rapidly and to provide open communication with interested researchers and the public. The OAC organized a meeting in October 2000 with Gulf of Mexico environmental NGOs to involve environmental groups in the methods for sustainable offshore aquaculture. OAC researchers chaired a special Offshore Aquaculture session at the 2001 World Aquaculture Society meeting (http://www-org.usm.edu/%7Eooa/WASoffshoresession.htm). These accomplishments demonstrate the lead role OAC researchers have in Gulf regional offshore aquaculture development and the participation in national and international development of offshore aquaculture.

In addition to acquiring permits and siting and Ocean Spar Sea Station cage in U.S. federal waters (Figure 1), OAC researchers have recently completed several publications related to offshore aquaculture research and development, including:

- C.J. Bridger, B.A. Costa-Pierce, C. Goudey, R.R. Stickney and J.D. Allen. Integration of offshore oil & gas platforms and cage aquaculture in the Gulf of Mexico. In Gulf of Mexico Fish and Fisheries: Bringing Together New and Recent Research, New Orleans, LA. American Fisheries Society Special Symposium submitted.
- C.A. Goudey, G. Loverich, H. Kite-Powell and B.A. Costa-Pierce 2001. Mitigating the environmental effects of mariculture through single-point moorings (SPMs) and drifting cages. ICES Journal of Marine Science in press.
- Kristen M. Fletcher and Ginger Weston. 2000. The Legal & Regulatory Environment: Offshore Aquaculture Permitting Process in the Gulf of Mexico. http://www.olemiss.edu/orgs/masglp/offshore.htm

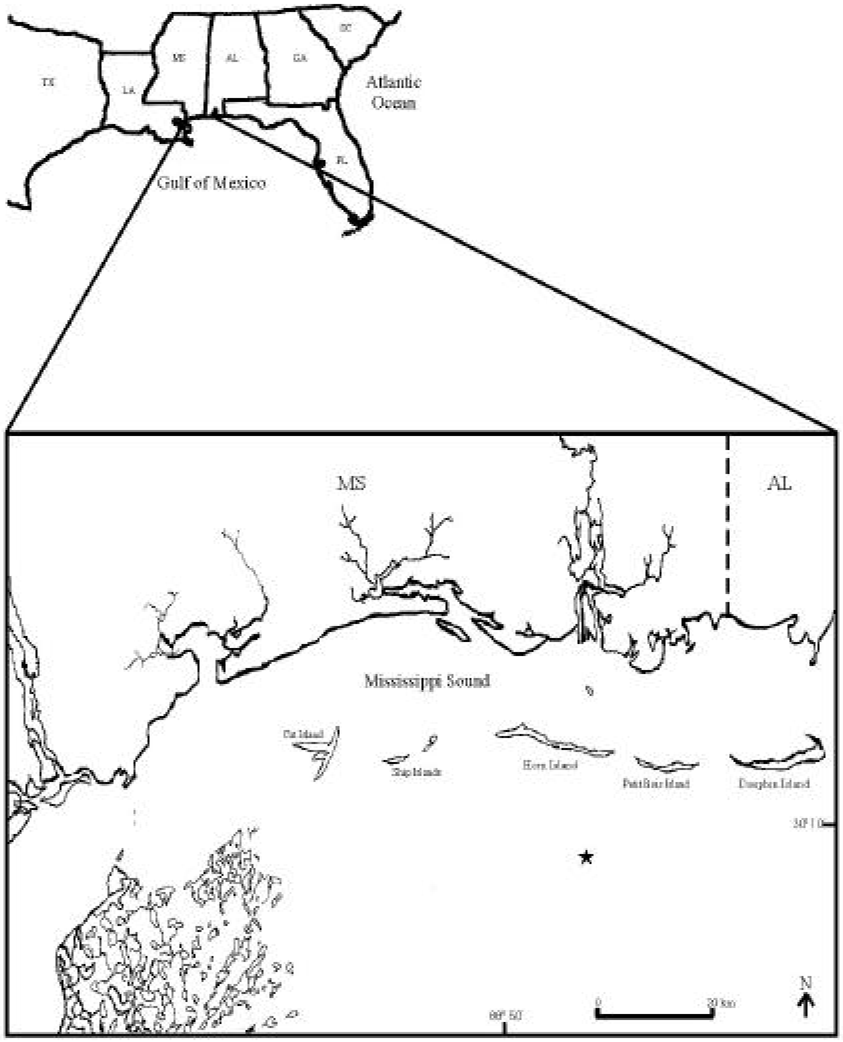

Figure 1. OAC offshore aquaculture experimental site (★) located in 26 m of water approximately 40 km off the coast of Mississippi, in federal waters (29° 58.649'N, 88° 36.297'W), near a Chevron gas platform.

The OAC is managed as a multi-disciplinary, multi-institutional research organization involving all Gulf of Mexico states and researchers from institutions nation-wide. We contend a multi-disciplinary approach is necessary to responsibly develop an offshore aquaculture industry that is socially acceptable to all Gulf users and citizens, economically viable for future investors and operators, and environmentally sound to ensure this industry exists for future generations.

Keywords: development, research, industry, Gulf of Mexico

Oral Presentation: Candidate Species and Logistics/Operations

MEASUREMENTS OF THE PHYSICAL ENVIRONMENT: WHAT HAVE WE LEARNED AND WHAT DO WE NEED?

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Since October 1997, data has been collected regarding the physical environment at and near the University of New Hampshire Open Ocean Aquaculture Demonstration Project site south of the Isles of Shoals. Collected data sets include:

- Hydrographic profiles of temperature, salinity, density, transmissivity (turbidity), fluorescence (chlorophyll), light (PAR), and dissolved oxygen using a SeaBird SBE-25 CTD. Over 30 surveys providing data at 1 m intervals from the surface to within 1-2 m of the bottom. Depending on available sampling time, high density sampling at the site has been used to resolve pen-scale variability, coupled with around-the-Shoals surveys to study coastal and/or deeper water spatial influences on the project area;

- Moored instrument suites have been used to collect time series data of ocean processes at the site. From (a) May 1999 until March 2000, and starting again in (b) November 2000, we have recorded at 10 minute intervals: temperature, salinity and turbidity at 0.5 m, 28 m and 48 m (a&b), fluorescence at 0.5 m (b), pressure at 48 m (b) and current velocity in 2 m bins throughout the water column (a&b). Current data were collected using a buoy-mounted acoustic doppler current profiler (ADCP);

- In October 1998, J. Lund occupied the OOA station for 13 hours, collecting ADCP currents and hourly CTD profiles over a tidal cycle.

Nisken bottle samples have been analyzed for suspended sediment properties, chlorophyll-a content and occasionally nutrients (these data will not be discussed here) to compliment “electronic” data sets. Environmental observations from NOAA’s Isles of Shoals CMAN station (wind, temperature, air pressure) and the nearby NOAA NODC moored weather buoys at Boston and Portland (wind, wave heights, air and sea temperature, pressure) has also been monitored and collected. The project began with the development of baseline ocean and weather climatologies for the Isles of Shoals area.

Collected data has been provided as quickly as possible on the project web pages (http://ekman.sr.unh.edu/AQUACULTURE). Data from the moored buoy are telemetered ashore and plots updated daily.

Physical ocean properties are monitored for a number of specific reasons:

- To inform biologists of the growing environment for their “crops” in case strategies must change;
- To help aquaculturists assess successes and failures;
- To keep gear engineers informed of stresses on their equipment;
- In response to requirements of government regulators; and,
- To validate and/or refine developed climatologies.

Since the inception of the OOA demonstration project, much has been learned about the area’s environment and physical processes that affect it. Collected data is considered a major enhancement to the project. It is also scientifically rich, with unique information about a regime seldom observed to this detail. A few high points, applicable to the OOA project, include:

- There is a definite seasonal cycle in water temperature, salinity, and stratification/mixing processes. This cycle should be considered when wintering over sensitive fish like the summer flounder, or placement of warm-intolerant fish in the surface layer during summer;

- The routine physical cycle is strongly influenced by weather—particularly mixing by storm winds, springtime runoff, and hot weather stratification. Ocean responses to atmospheric changes are rapid;

- Vertical mixing seems to be an important nutrient delivery process. Chlorophyll levels appear consistently healthy, and the blue mussel aquaculturists report excellent growth;

- The OOA site is at a boundary between coastal waters, carried in the Maine Coastal Current, and offshore waters that originate in Wilkinson Basin. Tidal flow consistently sweeps the boundary between these water masses back and forth across the site;

- There are interannual variations in all seasonal properties—they are often large and local, and we caution aquaculturists who might rely strictly on climatology to make environmental decisions;

- While most of the regular currents at this site are tidal in nature, there are a number of other flow influences that seem to produce large flow variations. We never observe a constant Maine Coastal Current in the records, and Ekman transport processes are hard to detect, even under steady wind conditions;

- In any case, local currents are sufficient to keep the near-bottom waters well mixed and dissipate extra food and detritus. Sediment samples have detected little change in the bottom environment.

The questions we wish to ask with this presentation include:

- Are the present measurements adequate? Are we doing too much (We suspect so) or too little?

- Which of these measurements are important for a commercial OOA project? This is an expensive operation—how could we reduce costs and still meet both aquaculturist and regulator needs? What measurements should or could be taken from fishing boats assigned to feed and tend the site?

- Are daily displays of buoy measurements, local weather, etc., useful? What is an adequate update cycle?

Keywords: water properties, environmental observations

Poster/Oral Presentation: Ocean Environmental

VERTICAL POSITIONING OF SUBMERSIBLE CAGES

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The success of aquaculture in exposed areas depends on reduction of risks inevitable for high-energy environments. Cage structures of submersible design are optimal solution for these sites especially if engineering is properly coordinated with biological requirements.

The vertical positioning of simple submersible cage versions are limited to two positions only: either at the surface or near the bottom. With the weights pulling off the bottom, the cage will rise to the surface nonstop. However, stops are necessary for the fish to decompressed and avoid incurring barotraumas.

Suspension of simple chain below the cage to serve as a guide rope with linear weight characteristics is one solution. However, this system may only be used to prevent uncontrolled surfacing or sinking of a cage provided that variable-buoyancy pontoons (or ballast tanks) are fitted with remotely or automatically controllable valves. These valves have to open or close to maintain the specified variable buoyancy value irrespective of the hydrostatic pressure. When using vertical positioning systems, however, the cage would be completely out of control, becoming incapable of either sinking or surfacing, should the valves fail.

Long term experience with submersible SADCO cages of different designs has allowed selecting an effective solution for vertical positioning based on a patented ballast system with nonlinear distribution of weight. The ballast chain suspended under the cage framework has a weight variable in length and discretely increasing in the direction from the surface to the bottom. Weight of each discrete section of the ballast chain exceeds the change in buoyancy of the variable-buoyancy reservoir owing to changes in hydrostatic pressure within the depth interval equal to the length of the discrete section.

This solution serves to provide compensation for spontaneous changes in cage buoyancy possibly due to the natural expansion of air in the ballast tanks during the raising process or, conversely, to the air compression in the tanks during the sinking process. This assures better vertical positioning of the cage and prevents uncontrolled sinking or raising.

Keywords: open ocean aquaculture, ocean engineering, mooring options, positioning

Oral Presentation: Ocean Engineering

GOVERNING OFFSHORE AQUACULTURE: A CONCEPTUAL FRAMEWORK

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A conceptual framework for considering policy options for governing offshore marine aquaculture is described. Based on the public trust doctrine, the conceptual framework considers the range of rights that may be granted to private entities engaged in aquaculture in public waters, the obligation of government to protect the rights of other users and other national interests, the implied obligation to compensate the public, and the need for fair, effective, efficient implementation.

According to the conceptual framework, public policy needs to provide mechanisms for granting a range of rights to allow private aquaculture operations in public waters, including:

- The right to use a particular location for aquaculture;
- The right to exclude others from the site;
- The right to introduce a particular species at the site;
- The right to erect structures or place equipment at the site;
- The right to discharge wastes into public waters;
- The right to introduce nutrients into public waters;
- The right to introduce chemicals into public waters;
- The right to protect private property placed at the site; and,
- The right to harvest, transport, and market the aquaculture product.

Under the conceptual framework, however, these rights should not be granted without taking into account the potential impact of aquaculture operations on the rights of other users of public waters and on the ability to achieve other policy objectives that are in the public interest. Six major uses (shipping and navigation, fishing, recreation, mineral extraction, national defense, and aesthetic enjoyment/intrinsic value) and five national priorities (fisheries management, protection of environmental quality, protection of natural resources, economic/social development, and relations with neighboring jurisdictions) are identified.

The conceptual framework indicates it may be appropriate to require the payment of compensation by the aquaculture operation in return for the loss of public access to areas of the ocean previously open to all, the risks associated with the operation (including any negative impacts on environmental quality, etc.), and the administrative costs to government. It also addresses the broader goal of promoting sustainable development of the aquaculture industry by considering the need for fair, effective, and efficient implementation of government policy.

Keywords: open ocean aquaculture, United States, policy

Oral Presentation: Marine Policy and Social/Economics

ENVIRONMENTAL IMPACT OF AN OPEN OCEAN AQUACULTURE CAGE ON THE BENTHIC INVERTEBRATE COMMUNITY OFF OAHU, HAWAII, USA.

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This study examines the effects of excess nutrification on the benthic infaunal community. Two of the goals of this study were to identify any potential indicator species and to ascertain the implications of excessive fish feed loading on sand bottoms off the island of Oahu arising from the placement of an Ocean Spar Sea Station cage system and subsequent aquaculture in April of 1999 (Figure 1). The cage was placed approximately 2 km off the south shore of the island in 31 m of water to assess the economic feasibility of open ocean aquaculture in Hawaii during two study phases (April-November 1999 and April 2000-February 2001, follow up expected). The Sea Station is the first of its kind in the state and consists of a metal frame with strong mesh netting to create a fish enclosure. The cage is anchored and completely submerged at 14 m from the surface and extends to 25 m where it hovers 5-6 m above the substratum. Soon after its deployment seventy five thousand juvenile moi (Pacific threadfin, *Polydactylus sexfilis)* were introduced into the cage. Several hundred pounds of commercial fish feed were pumped into the cage on a daily basis. As the fish grew the amount of feed increased. Excess feed and fish feces inevitably fell through the net and accumulated on the sandy bottom below and around the net.

Benthic samples were collected by divers using a PVC core (5 cm diam x 5 cm length) under the cage on the down current side (n=5, experimental) and 150 m up current of the cage (n=5,control). Samples were stored in Nalgene containers and formalin was added to each container immediately after collection. Samples were fixed for 48 hours and elutriated to remove infaunal invertebrates > 0.5 mm. Infaunal invertebrates were placed in 70% ethanol and sorted under a dissecting microscope. Collected invertebrates were separated into four major groups: polychaetes, the polychaete family Dorvilleidae, nematodes and crustaceans.

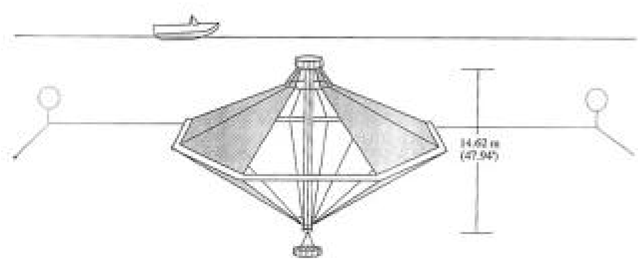

Figure 1. Ocean Spar Sea Station cage system deployed off Oahu, Hawaii.

Analysis of benthic samples showed an increase in the number of dorvilleid polychaetes, which was directly correlated with increasing feed amounts and fish size. Because if its sensitivity to environmental conditions and an opportunistic lifestyle, the dorvilleid is a possible indicator species of organic enrichment which, in this case, appears to be favorable to dorvilleids but did not affect crustacean and nematode abundance. After fish were harvested from the cage the dorvilleid population returned to previous numerical levels. No other major changes were noted in the infaunal community. Preliminary conclusions from Phase I are that nutrification of the benthos below the cage did not negatively impact the infaunal invertebrate community.

During Phase II nearly double the amount of fish (130 thousand individuals) were placed in the cage for grow-out. Infaunal data to this point show no consistently significant difference between the cage communities and the control group. Dorvilleid polychaetes previously abundant during Phase I have been absent in 6 of the 8 sampling events and present in extremely small numbers in the other two samples.

Conclusions are that less feed is reaching the bottom due to improvements in both feeding regimes and apparatus unique to Phase II. Research in progress include a study of the biofouling community on the cage and the community development of wild fish around the cage.

Keywords: benthic communities, environmental impact, nutrification

Oral Presentation: Ocean Environmental

OCEANOGRAPHIC AND METEOROLOGICAL CONSIDERATIONS FOR OPEN OCEAN AQUACULTURE IN THE PUERTO RICO-USVI PLATFORM

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The Caribbean Sea is a semi-enclosed basin bounded by the Lesser Antilles to the east, the Greater Antilles (Cuba, Hispaniola, and Puerto Rico) to the north, and Central America to the west. Passages between the various islands allow the inflow of North Atlantic, Tropical Atlantic, and Equatorial waters into the basin. The main outflow is through the Yucatan Channel between Cuba and the Yucatan Peninsula.

Caribbean waters are well stratified with depth which means that at different depths the fluid is moving in different directions, according to the sources and sinks for each water mass. In the ocean around Puerto Rico (and this varies within the Caribbean) we find the Caribbean Surface Water, the local mixed-layer, whose lower boundary is known as the seasonal thermocline (technically it is the pycnocline but these two boundaries approximately coincide in depth); Subtropic Underwater to about 180m; Sargasso Sea Water to about 325m; Tropical Atlantic Central Water to just over 700m; Antarctic Intermediate Water to 900m; and North Atlantic Deep Water reaching the bottom. Note that the island passages do not allow any Atlantic bottom water to enter the Caribbean.

The structure and composition of the Caribbean Surface Water, that in which most human activity occurs, exhibit a well-defined seasonal pattern. In the northeastern Caribbean Sea the depth of the thermocline reaches a maximum of close to 100m in the spring (January-March) and a minimum in the order of 25m in the fall (September-October). Density, temperature, and salinity follow the same seasonal pattern with temperatures ranging from 26 to 30 °C and salinities (in Practical Salinity Units) from 36.3 to 34, respectively. The large range in offshore surface salinities is due to the northwards advection-mixing of South American riverine outflow in the eastern Caribbean Sea, specially from the Orinoco River; the seasonal surface salinity range is therefore narrower northwards into the North Atlantic. While the Orinoco effect creates a seasonal north-south surface salinity gradient in the eastern Caribbean, the Amazon River outflow becomes entrained in pools or eddies that after a circuitous trajectory through the Tropical Atlantic arrive at the Windward Islands as pools of green (high chlorophyll content, low salinity) water and enter the Caribbean from the east.

The mean circulation pattern of the wind-driven surface waters around the PR-USVI-BVI shelf is in a west-southwest direction; these waters join the general western flow of the Caribbean towards Yucatan Strait. This archipelago is bounded to the east by Anegada Passage and to the west by Mona Passage, both of great strategic and economic importance to the region.

In the Caribbean Sea the meridional distribution of the zonal wind stress generates a circulation cell where deep waters are upwelled along the north coast of South America and surface waters (enriched by upwelling and by the Orinoco loading) are advected northwards into our region, especially during the fall season. Satellite images in the visible spectrum (CZCS and SEAWIFS) clearly show the meridional spreading of green water in the eastern Caribbean. The northward edge of the Orinoco plume does not extend far to the north of PR. A persistent feature of the geostrophic flow south of PR is the generally eastward transport in the upper 100m, in a direction that is the opposite of the expected westward advection of Caribbean Sea waters. Eastward geostrophic flow is limited to near surface waters, while deeper flow is generally westward. These observations are consistent with a net eastward geostrophic transport in the northeastern Caribbean, south of the Puerto Rico - Virgin Islands platform.

In the North Atlantic, the curl of the wind stress induces a large-scale Sverdrup transport towards the south that is then compensated by the intense northwards flowing Gulf Stream along the east coast of the U.S. The northeastern Caribbean receives part of this large-scale, climatological, southwestward transport. The convergence of these two distinct, Caribbean and North Atlantic, dynamical regimes defines our region as a boundary zone, with the edge of the green Orinoco plume often referred to by local researchers as the Caribbean Front.

There are no named current systems in our vicinity, which is not characterized by persistent extreme surface currents. The main axis of the Caribbean Current flows south of us, from the southeastern Antillean passages, through roughly the north-south center of the Caribbean Basin, west of Jamaica, and out through the Yucatan Channel. Seasonal changes associated with the north-south excursion of the Inter Tropical Convergence Zone (ITCZ) results in maximum mean surface currents in the central Caribbean during the summer.

Superimposed on the mean circulation, tidal currents are the dominant component of the offshore currents; this is to be expected given the oceanic character of our region. The oscillatory, usually elliptical, tidal flows are mostly cancelled (vector averaged) in the calculation of the mean flow. In the open waters of Mona Passage typical peak tidal currents are in the order of 50-75 cm/s (1-1.25 kt), corresponding to mean speeds over a tidal cycle of 25-30 cm/s, whereas the mean resultant velocity (the vector average) is only about 15 cm/s. The mean transport through Mona Channel is of 1-2 Sv into the Caribbean (one Sv = one million cubic meters per second). The tidal current ellipses in surface and near-surface waters in Mona Passage are mixed semidiurnal and rotate in a clockwise sense. Tidal currents vary in magnitude in phase with the astronomical tidal forcing cycles of perigee-apogee and lunar declination. Due to the highly stratified nature of Caribbean waters current speeds drop quickly with depth below the mixed layer.

During the passage of Hurricane Georges on September 22, 1998 currents of nearly three knots (~150 cm/s) were measured at a depth of 34 m in western Mona Passage. Additional information on coastal currents, winds, waves, and extreme events will be discussed.

Keywords: Caribbean, oceanography, currents, tides, waves

Oral Presentation: Candidate Species and Logistics/Operations

HOW THE SEMI-INTENSIVE REARING SYSTEM USED IN THE CULTURE OF JUVENILE ATLANTIC HALIBUT (*Hippoglossus hippoglossus* L.) COULD BE APPLIED IN TROPICAL MARINE AQUACULTURE.

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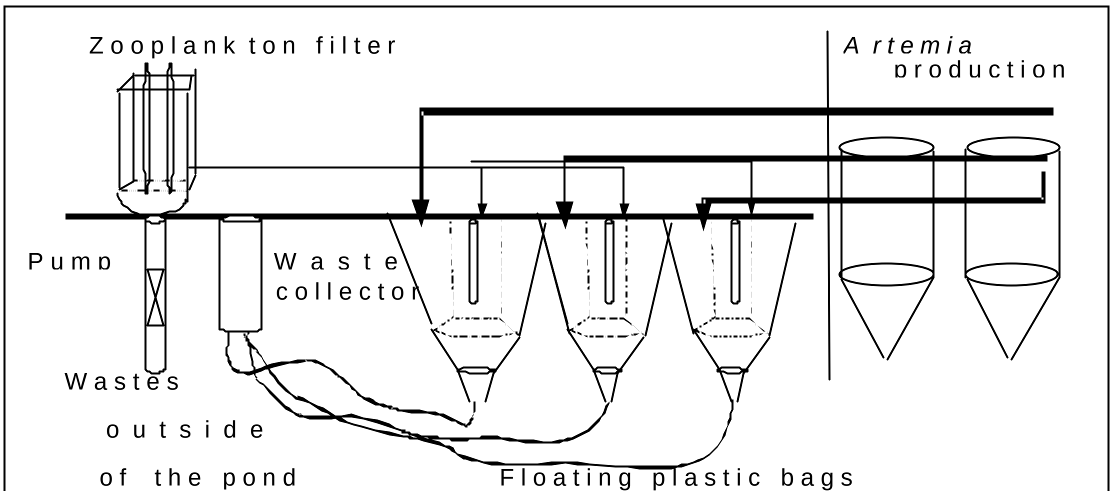
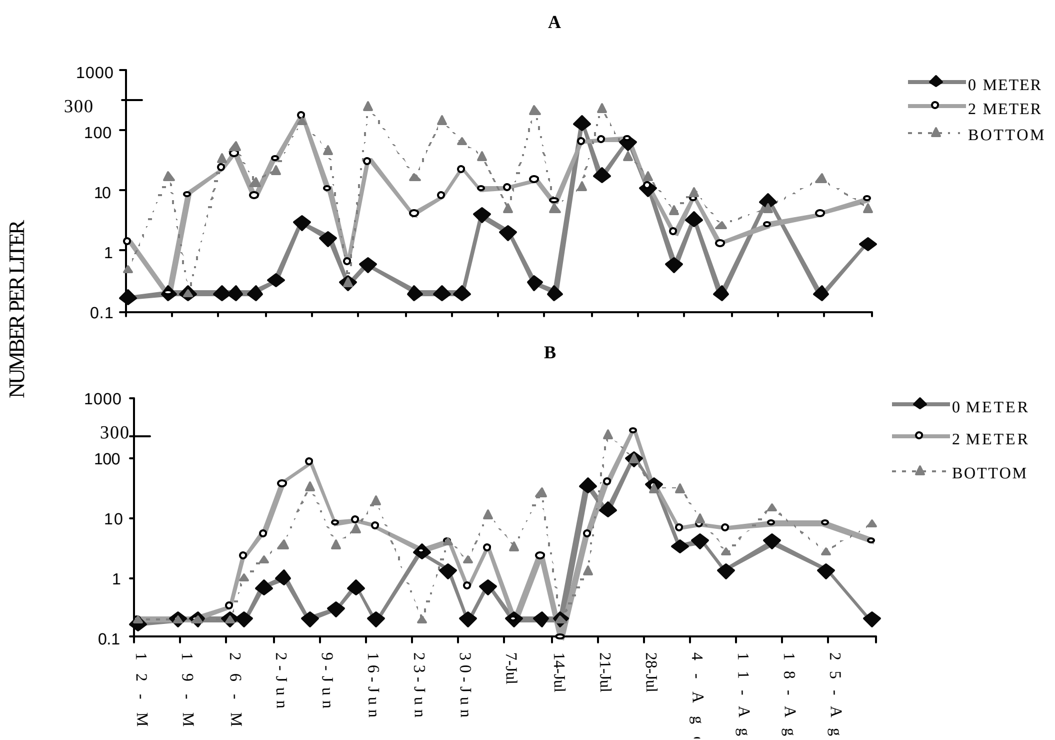
Atlantic halibut juvenile culture methodologies are reviewed with special emphasis on the semi-intensive rearing system. Analysis of the halibut biology during early stages, from larva and beyond metamorphosis, and the applied rearing techniques during all these phases, are described, giving explanations of why 80% of the Norwegian halibut juveniles are still farmed using semi-intensive rearing systems. The quality aspects of natural food (copepods) collected in the semi-intensive system versus cultured food (A*rtemia*, rotifers) used in the intensive culture system is considered. Flatfish juveniles with complete pigmentation and no deformations are associated with natural zooplankton use during first-feeding. An examination of both limitations of the semi-intensive system and advantages of implementation in tropical marine aquaculture is carried out. Identification of some possible candidates for semi-intensive production has been performed for Colombian marine fish species, emphasizing flatfish species, groupers and snappers. Finally, modifications of the semi-intensive methodology are suggested to optimize existing rearing activities in Colombia for juvenile production of selected marine fish species.



First feeding units of a halibut semi-intensive system



A. Amount of nauplii and B. Copepods at different depths in a marine pond, Makkjosen, Troms, Northern Norway (70 degrees North)

Key words: Semi-intensive, copepod harvest, unsaturated fatty acids, juvenile production

Oral Presentation: Candidate Species and Logistics/Operations

STATUS OF OPEN OCEAN AQUACULTURE IN NEW HAMPSHIRE

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In 1997, the University of New Hampshire established the Open Ocean Aquaculture Demonstration Project. The multi-year, cooperative project was funded by the National Oceanic and Atmospheric Administration to provide a commercial scale test site for applying developed culture techniques and aquaculture research. The newly developed technology can then be transferred to the private sector for commercial development.

The Open Ocean Aquaculture Demonstration Project is an integrated, multi-disciplinary effort involving biology, oceanography, engineering, sociology, economics, outreach, and education. The goals of the project include: 1) facilitating regulatory and permitting processes that now impede commercial expansion of aquaculture; 2) demonstrating reliable culture techniques to feasibly raise marketable products; 3) providing focus in ocean engineering for cage design, evaluation, and deployment; 4) creating a regional facility for experimental and educational purposes; 5) providing economic data for risk assessment for capital investors and insurance companies; and 6) building a new marine industry that attracts new potential entrepreneurs.

Presently, two Sea Station cages produced by Ocean Spar Technologies have been deployed and maintained for two years at the 36 acre commercial lease site. The Sea Station cages and mooring have been computer modeled, physical model tested, and full scale evaluation is on going. Seasonal growth studies with summer flounder (*Paralichthys dentatus*) including an intensive blood chemistry study during transport to the cages have resulted in survival rates of 92%. In addition to the fish cages, two 120 m submerged longlines for shellfish culture were deployed at the site. In the past 18 months, three cohorts of seed have been deployed in traditional mesh socking and in continuous rope core with cotton mesh sleeve. The first cohort yielded a total of 8000 kilograms of blue mussels (*Mytilis edulis*) during the first year of the project with average growth rates of 1 mm/week. An extensive monitoring program continues today utilizing comprehensive environmental sampling and *in situ* oceanographic monitoring buoy.

Future projects include physical and numerical modeling of the REFA Tension Leg Cage, evaluation of automatic feed systems developed by Massachusetts Institute of Technology, Ocean Spar Technologies and the University of New Hampshire, evaluation of the Atlantic cod (*Gadus morhua*), halibut (*Hippoglossus hippoglossus*) and haddock (*Melanogrammus aeglefinus*) for cage culture, refinement of mussel culture techniques and evaluation of sea scallop (*Placopecten magellanicus*) suspension culture in the open ocean.

Keywords: open ocean aquaculture, grow-out, cage culture, submerged longlines

Oral Presentation: Candidate Species and Logistics/Operations

THE SALMON AQUACULTURE INDUSTRY IN NEW BRUNSWICK: WHY GO OFFSHORE?

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Salmon farming is currently the most important agri-food industry in the Province of New Brunswick, Canada. Farmed Atlantic salmon (*Salmo salar*) production in 1999 was estimated as 22,000 t, worth $150 million CAD.

Salmon smolts are grown out to market size (usually 3.5-4.5 kg) in sea cages. This usually takes 18-24 months, which means that farmed salmon must spend at least one winter in sea cages. Current technology uses net cages suspended from floating collars which are anchored to the sea floor via mooring lines. Various cage types are in use, with the most common having circular plastic collars 22-32 m in diameter.

In New Brunswick, marine grow-out sites are currently confined to nearshore locations in the southwestern corner of the Province, in an area roughly 30 km by 60 km (Figure 1). Production from this small area represents 95% of the total farmed Atlantic salmon production in eastern Canada. The average site depth is 15 m; less than 5% of sites are at depths greater than 30 m. Sites are, on average, less than 350 m from shore (measured from the centre of the site).

The salmon farming industry of the eastern USA, which produced about 12,100 t in 1999, is confined to the State of Maine. Eighty percent of the Maine salmon grow-out leases are located within 50 km of the New Brunswick industry (Figure 1).

The reasons why the industry is concentrated in this small portion of the eastern coast of North America relate to the physiological and environmental requirements of farmed salmon and current cage technology. Much of this coast experiences low winter temperatures and/or ice conditions which make salmon farming extremely risky or impossible (the minimum lethal seawater temperature for salmon is about -0.7 to -0.8°C). Grow-out sites must also have adequate water exchange rates to disperse metabolic wastes and maintain high dissolved oxygen levels. At the same time, the cage technology now in use requires that currents not be too strong and that sites have some protection from storms.

The coast of southwestern New Brunswick and adjacent Maine offers selected areas with protected locations due to the complex coastline; good water exchange rates driven by the high tides in the Bay of Fundy (the tidal range averages about 8 m); less risk of winter seawater temperatures dropping below the lethal limit for salmon; and less likelihood of sea ice.

There are few suitable, nearshore locations remaining in the southwestern New Brunswick and adjacent Maine area for new farm sites. Proposals for new farms in such locations are being increasingly contested by competing interests, such as the fishing industries, recreational boaters, adjacent landowners, and environmentalists.

New sites will, however, be required if the industry is to continue growing. Furthermore, the Province of New Brunswick recently announced a new site allocation policy that requires all sites be operated as single year class operations. This means that single site operations that currently hold more than one year class, will require additional grow-out sites.

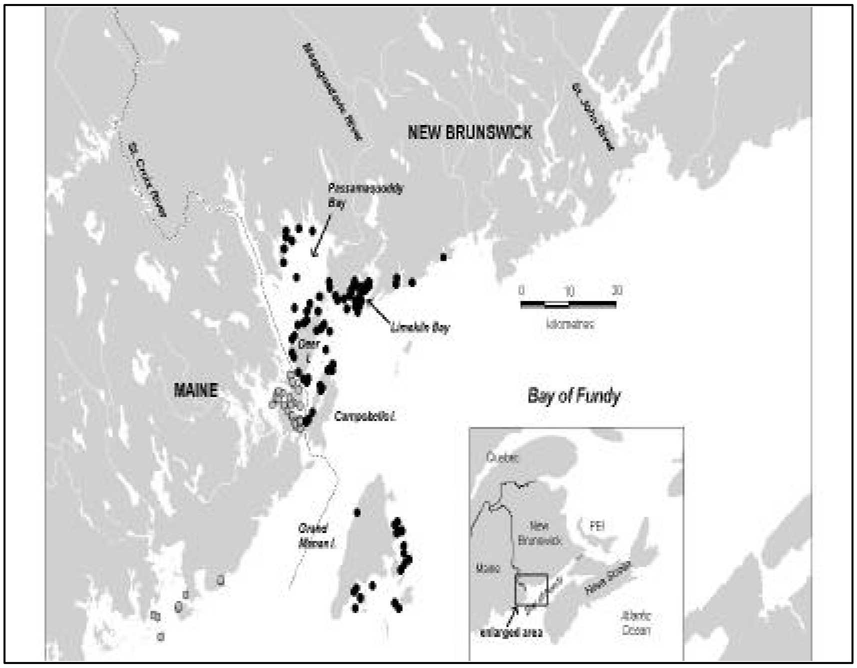

Figure 1. Map of southwestern New Brunswick and adjacent Maine showing salmon growout sites: • New Brunswick sites; • adjacent

Offshore technology may offer the opportunity for additional grow-out sites, by allowing farms to be situated in offshore and exposed areas that cannot be utilized with available technology. Concerns relating to fishing, navigation, and the environment will still have to be addressed before situating salmon farms in offshore areas.

Keywords: grow-out, open ocean aquaculture, coastal aquaculture

Poster Presentation

PROPOSED POLICY FRAMEWORK FOR OFFSHORE AQUACULTURE IN THE UNITED STATES

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The authors present a proposed policy framework for offshore marine aquaculture in areas of the ocean under federal jurisdiction, from the limits of state control to the 200-mile limit of the U.S. Exclusive Economic Zone (EEZ).

The recommendations were developed as part of a multidisciplinary, collaborative effort under the Sea Grant Technology Program. The project reviewed previous studies, assessed the current policy framework and the roles of each federal agency under existing statutory authorities, and compiled a list of "good practices" for the industry. The "good practices" were based on a review of various approaches to marine aquaculture in other jurisdictions (U.S. states and other countries with more advanced aquaculture industries), as well as guidelines for the aquaculture industry issued by international organizations such as the Food and Agriculture Organization of the United Nations. To ensure that all relevant interests were considered, the team established an advisory committee consisting of representatives from environmental, aquaculture industry, and commercial fishing organizations; congressional committee staff; federal and state agencies; and international organizations. The team also coordinated its work with the interagency Joint Subcommittee on Aquaculture as well as the Council on Environmental Quality.

The proposed framework was developed according to the following criteria:

- Encourages responsible open ocean aquaculture in the U.S. EEZ;
- Promotes a decision-making process that is efficient, coordinated, and predictable;
- Employs a precautionary approach to avoid and minimize environmental impacts and promote integration into the ecosystem;
- Applies separate criteria to native and non-native species;
- Is consistent with existing U.S. laws and agency responsibilities;
- Is equitable and fair to offshore aquaculture and to other U.S. users of the EEZ;
- Is consistent, to the maximum extent possible, with the coastal, water, environmental, and aquaculture policies of adjacent coastal states;
- Is consistent with U.S. obligations under international agreements;
- Will fit within the context of an overall framework for sustainable development of the U.S. EEZ;
- Produces a fair return to the public for the use of federal ocean space;
- Is conducted in a transparent manner with opportunities for public involvement; and,
- Is adaptive and promotes opportunities for innovation, data collection, and learning.

The recommendations cover the range of activities involved in an offshore aquaculture project: 1) Planning (including site selection, scope, and compatibility with other uses); 2) permitting (including environmental review, conflict resolution, determination of permit/lease conditions); 3) operation and monitoring of facilities and enforcement of permit/lease conditions; and 4) termination of operations (including site restoration, liability).

Keywords: federal, open ocean aquaculture, EEZ

Oral Presentation: Marine Policy and Social/Economics

THE EVOLUTION OF SUSTAINABLE OFFSHORE AQUACULTURE ECOSYSTEMS

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In 1999, the Secretary of the U.S. Department of Commerce issued an aquaculture development policy calling for the sustainable development of marine aquaculture with a focus on land-based recirculating systems and subsurface offshore aquaculture technologies. The environmental impacts of accelerated aquaculture development, especially salmon cage and shrimp pond aquaculture, have been the subject of many recent symposia and must be considered at the outset - not as an afterthought - of any new expansion of offshore aquaculture. Since the 1980's there has been a discernable change in public policy towards incorporation of more holistic "sustainability" and "ecosystems" criteria to address the public's concerns about the preservation and stewardship of the environment. As a result, coastal zone management processes that involve all stakeholders have been created in an attempt to better manage rampant coastal development, and to protect the few remaining intact aquatic ecosystems. The pollution control agenda has shifted from a "user pays" philosophy to "carrying capacity" (e.g. TMDLs) criteria for watersheds, and will shortly be applied to all state and federal marine waters. However, the methods needed for such ecosystem-level management approaches remain poorly developed, both scientifically, and in practice.

The degraded state of most aquatic ecosystems combined with public concerns about adding any "new" sources of aquatic pollution to already overburdened nearshore ecosystems will require aquaculture to develop new, ecosystems approaches and sustainable operating procedures, and to articulate a refined, sustainable, ecological pedagogy. In the 21st century, offshore aquaculture pioneers will need to spend as much time on technological advances coming to the field as they do in designing ecological approaches to aquaculture development that clearly exhibit stewardship of the environment. We propose that the appropriate framework for the development of offshore aquaculture is an ecological approach that will embrace sustainability concepts in order to develop sustainable aquaculture farming ecosystems (SAFEs) offshore.

Aquaculture developments will be certified as sustainable when they:

- use materials in continuous cycles;
- use continuously reliable sources of energy; and,
- come principally from the qualities of being human, i.e. creativity, communication, coordination, appreciation, and spiritual and intellectual development.

Aquaculture developments are not sustainable when they:

- require continual inputs of non-renewable resources;
- use renewable resources faster than their rate of renewal;
- cause cumulative degradation of the environment;
- require resources in quantities that undermine other people's well-being; and,
- lead to the extinction of other life forms.

Sustainable, ecological offshore aquaculture systems preserve and enhance the form and functions of the natural environments in which they are situated; incorporate a shift in production philosophy to produce economic gains to society without degradation of natural ecosystems; and are community-based, having positive societal impacts. Technically, the main issues/challenges for offshore aquaculture systems are:

- releases of aquaculture organisms, and "biopollution" of wild stocks;
- use of offshore aquaculture structures as artificial reefs;
- nutrient and sediment pollution; and,
- disease transfers to wild organisms.

Ecological mariculture systems will demonstrate clear benefits to marine fisheries and other stakeholders in the coastal zone; and will be shown to enhance, not degrade, marine ecosystems. These systems will integrate marine polyculture into offshore cages with new moorings that serve to attract and enhance natural marine communities, not degrade them. Ecological designs will supply inputs using underutilized and sustainable inputs, and close loops of energy and materials that can potentially degrade natural and social ecosystems. Ecological aquaculture systems will be regionally planned using systems ecology-type approaches that develop complex aquaculture production networks for various species in a highly diversified, segmented manner that plans for maximizing local employment. There will be an emphasis on local and regional benefits, with numerous interconnections to local equipment, feed, seed and other suppliers.

Long-term, applied, interdisciplinary research, education and outreach programs need to be created to develop these offshore SAFEs. Such programs would bring together the needed critical mass of expertise in comprehensive systems analysis approaches that involve experts in engineering, biology and oceanography with ecologists, economists, and social scientists. Offshore aquaculture development programs will need to incorporate concerns for the wider social, economic and environmental contexts of accelerated aquaculture development at the outset, such as plans for shore-based aquaculture communities. Social science research in aquaculture will assist industry in plans for community involvement and ensure industry commitments to equity. If large aquaculture corporations enter close-knit, rural communities as outsiders with low wages, importing all skilled labor, goods, expertise, and technology from the outside; then proceed to export all products outside of communities; leaving only degraded ecosystems with little community development and no "outreach" plans; social impacts of accelerated aquaculture developments can be severe. Clear, unambiguous linkages between offshore aquaculture and the coastal natural and social environments must be created and fostered. In addition, the complementary roles of offshore aquaculture in contributing to environmental sustainability, rehabilitation and enhancement must be developed and clearly articulated to a highly concerned, increasingly educated and involved public.

Open ocean aquaculture development must plan at the outset to: (1) become part of a community and a region; (2) plan for community development by working with leaders and stakeholders to provide needed inputs locally and regionally; (3) treat and recycle its wastes; (4) create a diversity of unprocessed and value-added products and provide local market access to these; and (5) plan for job creation and environmental enhancement on local and regional scales. Planning for offshore aquaculture developments as community development must thereby include planning for aquaculture's vital support. An ecological approach using system's thinking and adopting sustainability pedagogy (and criteria) will create new opportunities for a wider group of professionals to get involved in aquaculture. New advances will be needed not only in offshore aquaculture technology but also in information, community development, and facilitation.

Keywords: environmental sustainability, SAFEs

Oral Presentation: Ocean Environmental

LEGAL HURDLES TO OFFSHORE AQUACULTURE LEASING

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The legal and regulatory environment surrounding the offshore aquaculture industry is cited consistently as one of the major hurdles to its development in the United States. In 1978, the National Research Council found that the procedures required to obtain permits and licenses for offshore aquaculture "have been a severe deterrent" to the development of the industry. Upon passage of the National Aquaculture Act in 1980, the U.S. Congress noted the "diffused legal jurisdiction" and "lack of supportive Government policies" when it codified the national policy of encouraging development of aquaculture in the United States.

There have been numerous calls for improvements during the last decade. Individuals interested in developing sustainable offshore aquaculture face challenges in the form of a fragmented and often inconsistent permitting process among federal, state, and local agencies and questions regarding leasing, siting, and property rights. Many of these issues must be resolved before a sustainable industry can be developed. Lack of adequate leasing options for aquaculturists restricts the feasibility of moving pens offshore.

One avenue to creating an efficient and transparent permitting and licensing process is to incorporate the creation of specific sites for aquaculture leases such as a Marine Aquaculture Zones (MAZ). Zoning has been a useful land-based tool in the United States to set aside particular areas appropriate for industry development. Creation of a MAZ requires designation of one federal agency responsible for management of the zone; issuance of leases of the water column and seabed in the zone; and issuance of a permit which would incorporate concerns of other relevant federal and state agencies.

Marine zoning faces significant challenges that its land-based counterpart does not, such as boundary disputes, enforcement difficulties, and more frequent user conflicts. United States coastal waters represent a public resource for use by fishers, recreationalists, mineral exploiters, and the shipping industry. Creating a zone for exclusionary marine farming will face numerous policy and legal challenges.

Despite significant policy conflicts, coastal managers across the globe are recognizing the importance of setting aside particular areas of marine waters for specific uses. Designated areas have specific restrictions on user groups ranging from complete moratoriums to less restrictive measures. These include marine sanctuaries; areas for the creation of artificial reefs such as state fish havens; specific lease areas for offshore oil and gas exploration; and state and federal "marine reserves" or "marine protected areas" to conserve fisheries resources. These designations, along with examples of international zoning, offer models to create marine zoning in federal waters. For example, in 1999, the Gulf of Mexico Fishery Management Council created two marine reserves to protect the spawning location of gag grouper (*Mycteroperca microlepis*) and are considering using closures and marine reserves as a management tool in the future.

Federal waters currently have additional zoning that will limit the development of an offshore aquaculture industry. These include military use, shipping fairways, fish havens and artificial reef zones, which decrease the percent of total water column accessible for offshore aquaculture development. In addition, user conflicts with traditional fisheries and recreational boaters may also arise from siting aquaculture cages in seemingly haphazard fashion. Also, certain areas have been characterized as seasonally hypoxic, having high concentrations of mud-silt in the water column, sinks for fine sediments that may be resuspended during storm conditions, or seasonally stratified. For various reasons, all of these oceanographic conditions will restrict the area of suitable sites for successful grow-out of candidate species.

With optimal sites potentially limited, aquaculture zoning will ensure appropriate natural resources are accessible, increasing the likelihood of successful aquaculture ventures. Zoning would also ease the burden of site marking, with both zone perimeter buoys and individual cage lights, therefore decreasing liability issues associated with boat-cage collisions, and minimize theft and vandalism. In addition, zoning will decrease the risks associated with recreational fishers capturing reef fish attracted to the cages.

This presentation will present examples of zoning used in several countries and legal hurdles to implementing successful zoning for offshore aquaculture.

Keywords: marine policy, offshore aquaculture, aquaculture leasing

Oral Presentation: Marine Policy and Social/Economics

GENERAL ANALYSIS OF LONG-LINE CONSTRUCTIONS USED FOR CULTIVATION OF BLUE MUSSELS (*Mytilis edulis)*

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Technology used for the increasing blue mussel cultivation industry in Norway is mainly based on use of long-line systems, which consists of long ropes, held up by buoyancy with collectors attached. The ropes can be from a couple hundred to 1000 meters long, with several thousand meters of collectors attached. Earlier research has been limited with regards to the behavior of these systems, exposed to waves and current. Critical factors for the systems are initial tension of the line to avoid sagging between buoys, amount of excess buoyancy and elasticity of the system (consisting of material properties and geometrical elasticity).

SINTEF Fisheries and Aquaculture has developed a simplified 3D method to calculate the tension in and shape of these long-line systems and submersion of buoys due to current loads. The method is based on modeling the system with rod elements, using Finite Element Methods and an iterative solver to calculate the equilibrium position for the system. Shape of the collectors in current and compression of the buoys when submerged are taken into account (Figure 1).

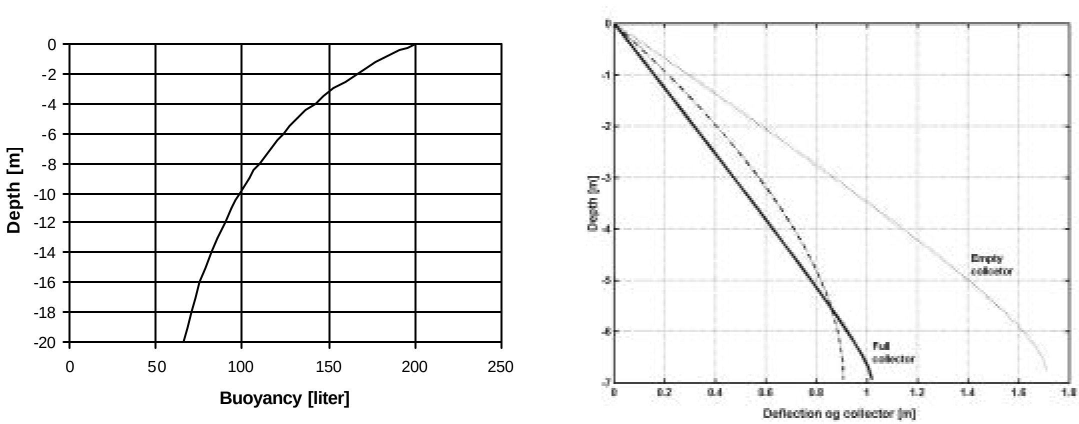

Figure 1. Calculations of effective buoyancy of a buoy as a function of submersion depth and the shape of a collector in current, as used in the numerical model.

By using this method it is possible to identify critical load conditions as a function of current velocity and direction, while varying parameters such as length of collectors, amount of buoyancy and elasticity, to design an optimal system. These results can be used to design more optimal cultivation systems with regard to construction and mooring lines, and also to study the safety aspects related to risk of collapse of the total system (Figure 2).

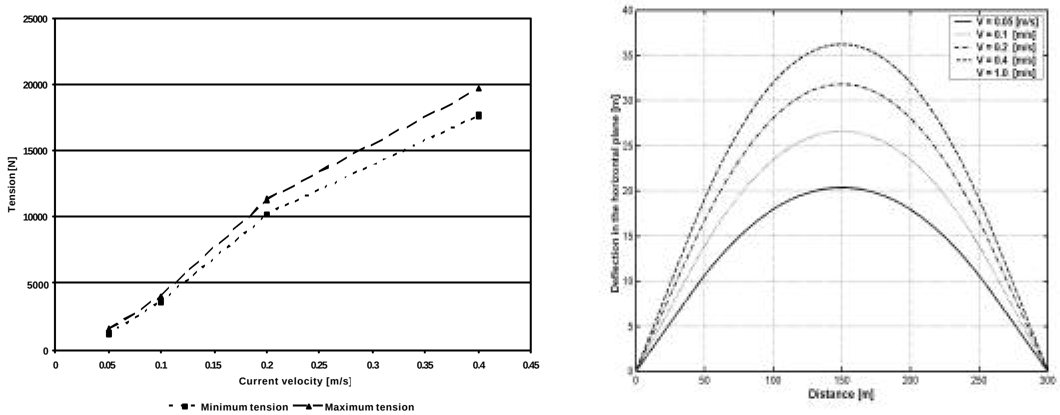

Figure 2. Examples of results from calculations of tension and shape of a long-line system at different current velocities.

A critical aspect related to a long-line system is the risk of losing buoyancy. While losing one or more buoys, adjacent buoys will be submerged, compressed and the buoyancy will decrease. This may cause a "chain reaction" where more buoys become submerged, which further decrease buoyancy, and in turn might lead to total system collapse. With a system using buoys with no excess pressure inside and 30% extra buoyancy, losing two adjacent buoys might actually be enough for the total system to collapse (Table 1).

Table 1. Number of buoys to lose, as a function of excess pressure and distance between buoys, which if lost might be enough for total system collapse.

Amount of excess	Distance between buoys (m)		
buoyancy	2.5	5	10
30 %	3	2	1
40 %	4	3	2

Keywords: numerical model, buoyancy, aquaculture installations

Oral Presentation: Ocean Engineering

FLUID DYNAMIC DRAG MODELING OF A CENTRAL SPAR FISH CAGE

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Physical and numerical modeling methods are currently being developed at the University of New Hampshire (UNH), U.S.A, to design and evaluate fish cage and mooring systems subject to both wave and current forcing. Physical models are scaled representations built for testing in the 37.5 m long by 2.66 m wide by 2.44 m deep tow/wave basin at UNH. A finite element numerical model called AquaFE is also being developed at UNH specifically for open ocean aquaculture applications. Results of physical and numerical model tests have been used extensively in the past years in the design and analysis of systems for fish cages and moorings presently deployed at the Open Ocean Aquaculture Demonstration site in the Gulf of Maine south of the Isles of Shoals near Portsmouth, NH. To evaluate physical modeling and computer simulation approaches, predictions are being compared with each other and with full-scale field measurements. The eventual goal is to obtain validated physical model test methodologies and computer models, and an understanding of the strengths and limitations of each approach.

One of the most fundamental design criteria to consider in the design of an open ocean aquaculture facility is the steady load due to fluid drag. Most fish cages are comprised of dense netting that when acted upon by a current can produce considerable drag loads on a mooring system. Representing the nets in physical and numerical models is difficult because proper simulation must take into consideration both the Reynolds number dependence and blockage characteristics.

In this study, a 1:15.2 scale physical model of an Ocean Spar Technologies Sea Station (Figure 1) was constructed and towed at constant speeds while drag forces were measured using a small load cell in the UNH tank. Netting amount was varied to simulate blockage effects of biofouling, and downstream panels were removed to quantify the drag contribution of net operating within a net shadow. Tows were conducted at a range of speeds while the fish cage was positioned at the surface and submerged (the two configurations for actual deployment). A field test was also conducted to obtain full-scale measurement of the central spar cage at various tow velocities. During the test, relative water velocity measurements were made both inside and outside of the fish cage using an InterOcean S4 electromagnetic current meter attached to the fish cage and an RD Instrument acoustic Doppler current profiler (ADCP) on the tow vessel, respectively. Towline tension was measured using an 89 kN capacity submersible load cell developed by engineers at the Woods Hole Oceanographic Institution. The field test was then simulated using both the 1:15.2 scale physical model and AquaFE computer program, which included current speed reductions at down stream components caused by net shadowing. Comparisons of these three methods were made and results will be presented.

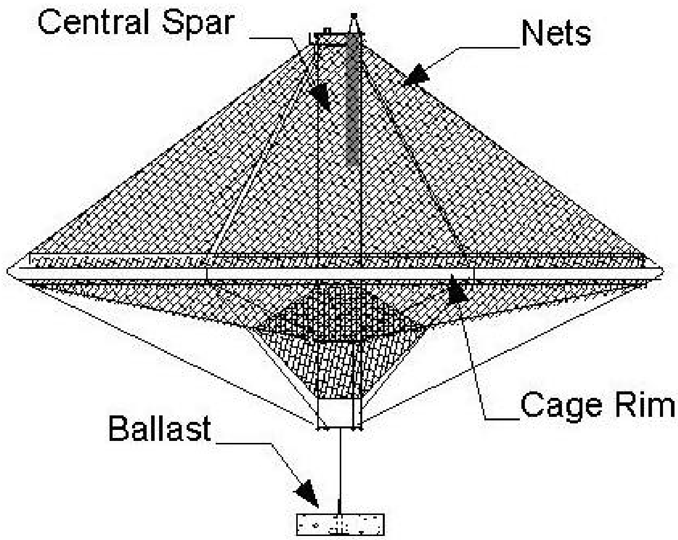

Figure 1. Schematic of the 15 m diameter Ocean Spar Technologies Sea Station fish cage modeled in this study.

Keywords: nets, tow testing, physical models, finite element analysis

Oral Presentation: Ocean Engineering

RECENT ADVANCES IN OPEN OCEAN AQUACULTURE

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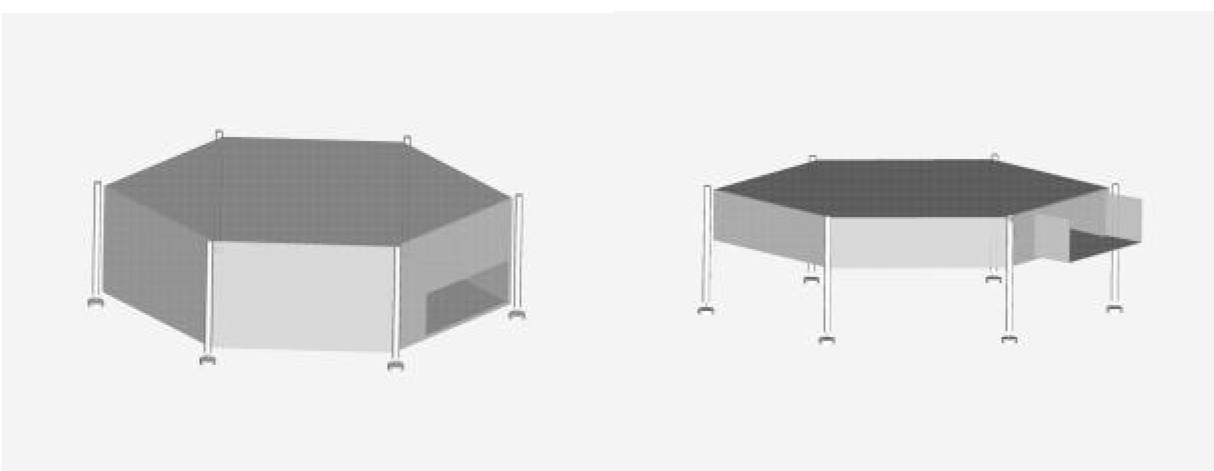
The past few years have shown significant advances in the farm management techniques of Ocean Spar anchor tensioned cages. Though this type of cage has been in use for over a decade, recent commercial installations in North America, Ireland, Spain and the Faroe Islands have allowed the opportunity to refine fish husbandry techniques such as stocking, feeding, cage cleaning, harvesting and cage maintenance. Moreover these cages have proved that open ocean aquaculture is a profitable reality.

Salmon farmers on the West Coast of Ireland approached Ocean Spar Technologies with an assortment of problems that are common to fish farmers throughout the world. Questions included: Is there an efficient way to stock and harvest cages using existing transfer cages? Is there an effective way to administer medicine to stock stricken with sea lice? Can this be achieved with large cages in high-energy sites? If so, can theses large cages provide the necessary 'jump space' that salmon may need? How does one maintain the structural integrity of cages cost effectively in adverse conditions? Working with these farmers in Ireland, Ocean Spar Technologies was able to provide solutions to these common farm management problems.

In the case of Ireland, cages with a volume of 22,000 m^3 were designed and built to take advantage of economies of scale. Dyneema® high performance fiber was used in knot-less Ultra-Cross® netting. Large openings or portals, 6 meters x 16 meters with panels that mated to existing transfer cages were incorporated into the design, so that large amounts of fish could be transferred into the net pen with a minimum amount of stress. An integrated truss system replaced traditional high-density polyethylene circles used in supporting the bird net on the top of the cage. Because this truss system does not rely on buoyancy to stay in place it is transparent to surface wave energy. Because it is held in tension and compression to the relatively stationary spars like a common bridge truss, the system contributes little to the ultimate fatigue of the net. This non-buoyant system is crucial to farmers finding it necessary to sometimes sink their cages. Washington State provides an example of this need.



Effective administration of sea lice medication to the stock and controlled harvesting of cages are both dealt with using the concept of controlled cage volume reduction. Farmers need a way to temporarily concentrate fish, so that a smaller amount of medicine is introduced into the water, sufficient to medicate all fish at the lowest possible cost with the least effect on the environment. In the case of harvesting, crowding fish to the portal area is possible so they can swim out through the portal into the waiting harvest cage. When reducing cage volume, the sides, top and bottom of the cage have to remain relatively taut to prevent fish damage. The anchor tensioned cage system offers the farmer the opportunity to use the spar as a rail to raise the bottom of the cage through a series of winches while keeping the netting tight. Farmhands gather the sides at the surface by means of integrated jack lines and loops. Harvest rings have been designed with particular attention paid to bearing surface so that this operation can be conducted successfully. When the farmer is harvesting, the final lot of fish can be encouraged to swim into the harvest cage with the use of a lightweight Dyneema® seine net.

One particular site in Ireland, Clair Island, experiences rough weather on almost a daily basis. While current is not the challenge, waves continually strike the system with little protection afforded from the weather of the North Atlantic. Because the Ocean Spar system, in terms of daily operation, is boat based, an adequate method of mooring to the cage in rough weather is needed. Mooring spars were secured 20 meters from the cage using the system's anchor lines. This enables large well boats to approach the cage safely, regardless of the direction of the weather.

Maintenance issues have also been addressed through development of a detailed maintenance schedule. The maintenance schedule takes advantage of design principles of the system, which depending on the component employs a 3:1 to 10:1 material safety factor. This provides a significant safe operating margin. The schedule keeps the farmer informed of what items need to be replaced and when. Replaceable items that wear faster, are designed to be significantly less expensive than those components that are more difficult and costly to replace.

Keywords: open ocean aquaculture, cage maintenance, harvesting, cleaning

Oral Presentation: Ocean Engineering

MANAGEMENT STRATEGIES FOR FISH CULTIVATION IN FLOATING CAGES IN THE MEDITERRANEAN SEA AND ATLANTIC OCEAN

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For decades, research and development efforts have focused on fish cultivation in floating cages. Despite this focus, and considerable private and public sector resources invested in these systems, there is a lack of economic data derived from the infinity of variables present. A reliable method of generating economic studies are through systems modeling that relates biological, environmental, technical and economic variables. This study presents results for a computer simulation of seabream production in floating cages under two scenarios: (a) representing conditions in the Mediterranean Sea and (b) for the Atlantic Ocean. An operation in the Atlantic (Canary Islands, Spain) provided the majority of data for analysis and the University of Las Palmas provided some data, also in the Canary Islands. Given the assumptions in the simulation case study, the production cost for 1 kg of seabream in floating cages is US $2.64 in the Mediterranean and US $2.90 in the Atlantic. The internal rate of return was 27% and 59%, respectively. Model sensitivity analysis results for both scenarios showed this cultivation system is more sensitive in the Mediterranean than in the Atlantic. Decreased sensitivity means that changes in system variables in the Atlantic affect it to a less degree than in the Mediterranean.

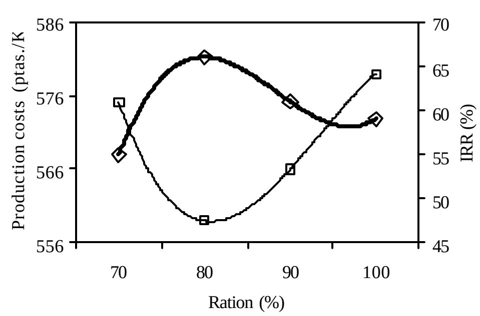

Figure 1. Effect of ration on production cost and return (IRR).

Figure 1 shows the tendencies of production costs and internal rate of return when offered feed ration is above and below values recommended in feeding tables (80%), in the Atlantic. In both scenarios, ration size was one of the variables that improved feed conversion rates. It also improved costs and profitability in greater proportions than other variables, though in different proportions. Reduction of ration below levels recommended in feed tables reduces the feed conversion rate but increase the number of days in the seabream cultivation cycle. These in turn results in higher production costs and lower internal rate of return. The analysis also showed that greater benefits and profitability could be obtained by raising production capacity through increases in final stocking density in the system.

Keywords: management strategies, sensitivity analysis, seabream, floating cages

Poster Presentation

BIOECONOMIC ANALYSIS OF THE IMPACT OF LOCATION ON GILTHEAD SEABREAM (*Sparus aurata*) CULTIVATION IN FLOATING CAGES

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A bioeconomic model was developed to evaluate production of gilthead seabream in floating cages in two locations, the Canary Islands and the Mediterranean. The model includes four sub-models: biological, environmental, production management and economic. Biological includes a growth model based on gilthead seabream physiology and commercial attributes, and experimental data from cultivation. The growth model constitutes a fundamental part of the overall bioeconomic model. It generates daily results for growth, food consumption, and food conversion rate, taking into consideration water temperature, ration size and fish weight from juvenile to commercial size.

The bioeconomic model was implemented using computer software for modeling and simulating dynamic systems, as well as the Euler integration method with a daily time step. Different farm sizes were studied, along with the production and input costs for each scale and scenario. Analysis of average costs showed decreasing costs, and the internal return rate inversion estimator showed increasing yields in both scenarios, Canary Islands (Can.) and Mediterranean (Med.) (Figure 1).

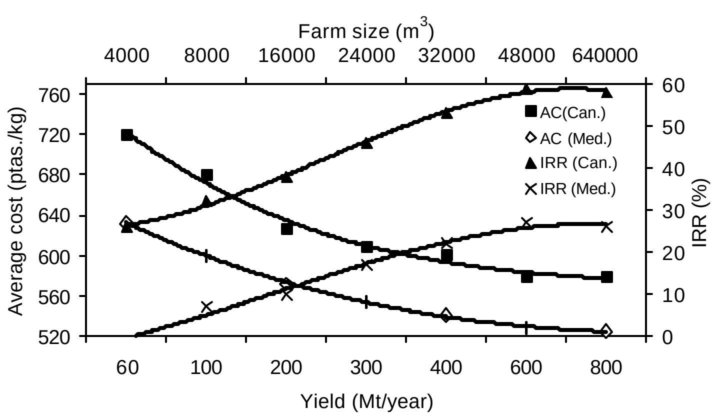

Figure 1. Average cost (AC) and internal rate of return (IRR) with farm production size for each of the studied locations.

Optimum farm size and production competitiveness was analyzed. Results revealed that input costs, and therefore product costs, were higher in the Canary Islands than in the Mediterranean. However, environmental conditions in the Canary Islands are considered more appropriate for cultivation of gilthead seabream than in the Mediterranean, resulting in more rapid growth and more profitable total production costs.

Keywords: economics, bioeconomic model, simulation, *Sparus aurata*

Poster Presentation

THE DESIGN, INSTALLATION, AND PERFORMANCE OF A SINGLE POINT MOORING FOR AN OFFSHORE CAGE

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Siting of aquaculture cages in the offshore environment presents both challenges and opportunities. Challenges center on the high-energy nature of open ocean exposure and the need for cost-competitive approaches that offer commercially-viable alternatives to sheltered-water operations. Opportunities center on relief from intense user conflicts, improved water quality, and a lack of established practices that would otherwise constrain innovation.

One area of open ocean cage system design that is particularly promising is in mooring design. The depth and current gradients often present sever constraints at sheltered-water sites where a careful balance of protection and water exchange are desired. For these reasons, conventional cages or cage arrays are typically anchored with multiple anchors, holding the system in a fixed location. At an offshore site, positioning is less critical as exposure and currents have less spatial variability. Therefore the use of a single point mooring (SPM) is possible, allowing some of the advantages that make them the preferred approach to mooring ships and other craft in open water.

This paper describes the use of an SPM to moor an aquaculture cage in the Gulf of Mexico. The cage is a 600 m^3 Sea Station™ manufactured by Ocean Spar Technologies, LLC. The site is that of the Sea Grant Gulf of Mexico Offshore Aquaculture Consortium (OAC) located in 25 m of water in the vicinity of a Chevron gas platform, 40 km offshore. The mooring system was designed to anchor this cage as against foreseeable conditions at the site. The SPM configuration used included a large concrete sinker, chain tension members, supported by a surface float. The cage was connected to the SPM using bridles running horizontally from the Sea Station™ submerged rim and intersecting the SPM chain. The overall length of chain provided a watch circle radius of approximately 70 m.

The assembly, transport, and installation of the SPM and the cage will be explained along with the associated SPM costs compared to conventional multi-anchor methods. Observations of the SPM will be reported and compared to numerical simulations of the system. These simulations were done using an interactive application of MATLAB analytical tools. We will report our results on the 2-D static configuration of the SPM under various current loads, the dynamic behavior under wave-induced forces, and a combination of current and wave loading. We will also demonstrate the effect of the mooring chain weight on the movement of the cage within the geometric limits of the watch circle.

The demonstrated and anticipated advantages of the SPM will be explained from cost, operational, and environmental impact standpoints. Lessons learned from the operation of the SPM will be conveyed, particularly with respect to hardware selection for very high-energy sites. We will also explain modifications planned for the SPM system for the 2001 deployment season and monitoring plans related to the cage's stocking with its first crop of fish.

Keywords: cage systems, anchoring, open ocean, numerical simulation

Oral Presentation: Ocean Engineering

CONFLICT FOR SPACE BETWEEN AQUACULTURE AND FISHING - THE NEW ZEALAND EXPERIENCE

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Aquaculture has been identified as having huge potential worldwide. In coastal states such as New Zealand there has been a rush of interest in accessing additional space for aquaculture. Marine farming inherently conflicts with access to traditional fishing grounds resulting in strong opposition by commercial fishers to expansion of marine farming.

In 1986, New Zealand implemented a complex fisheries management regime for many commercial fish species that allocated ITQ (Individual Transferable Quota) to individual fishermen. ITQ gives quota holders the right to take a specified proportion of the TACC (Total Available Commercial Catch) for that species within a designated QMA (Quota Management Area) and is a very valuable tradable property right. Commercial fishers argue that ITQ also inherently guarantees the right to access to sufficient areas of the sea to catch the allocated quota.

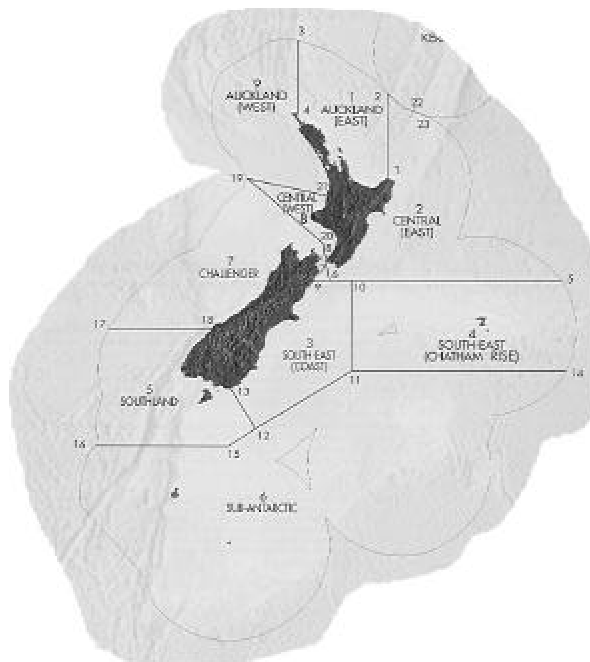

Figure 1. MAP showing New Zealand's extensive fisheries waters

The New Zealand aquaculture management regime is separate from the fisheries management regime and has severely challenged the existing fisheries management framework. There is presently no process to assess the most efficient use of a site between different marine farming proposals or against other users such as commercial fishers. The general principle is "first come first served". If an application is considered to "adversely affect" existing fishing it will be refused. If an application meets all statutory requirements it will likely be granted irrespective of whether a better use of the site is possible. There is no legislative framework for marine farming interests to negotiate with fishing interests to minimise effects on fishing or compensate fishers for any impacts aquaculture will have.

The primary criteria of "first come first served" has led to an inefficient use of resources, a rush for space between potential marine farmers, and increasing conflict with commercial fishers. This in turn has led to extensive (and very expensive) litigation as commercial fishers attempt to protect their ITQ property rights and continued ability to take fish. Because ITQ rights extend out to the 200 mile limit of New Zealand's EEZ, it is unlikely that open ocean aquaculture will overcome these difficulties, and law reform will be necessary.

The paper will consider space allocation conflicts limiting aquaculture expansion, using the New Zealand experience as an example. Consideration will be given to both inshore and open water locations. It will illustrate the need to implement a statutory regime that interfaces management of aquaculture and feral fisheries, and which includes mechanisms to accommodate and balance competing claims for space. Possible techniques for achieving this will be identified and assessed.

Keywords: space allocation, fisheries management, ITQ, New Zealand

Oral Presentation: Marine Policy and Social/Economics

ENVIRONMENTAL MONITORING IN THE VICINITY OF AN OPEN OCEAN AQUACULTURE SITE IN THE SOUTHWESTERN GULF OF MAINE: SOME PRELIMINARY RESULTS

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An open ocean aquaculture demonstration project was initiated by the University of New Hampshire in 1997 with the installation of two pens for finfish culture and two longlines for suspension culture of bivalve molluscs (primarily the blue mussel, *Mytilus edulis*). The culture site is located approximately 10 km offshore of Portsmouth, NH in the southwestern Gulf of Maine in water about 55 m deep (Figure 1). We report here on three major components of the overall monitoring program: (1) characterization of the general environmental conditions at the site including bottom types, faunal benthos, and water quality; (2) assessment of potential impacts of initial fish and mussel culture activities; and (3) development of a routine and potentially long-term monitoring protocol.

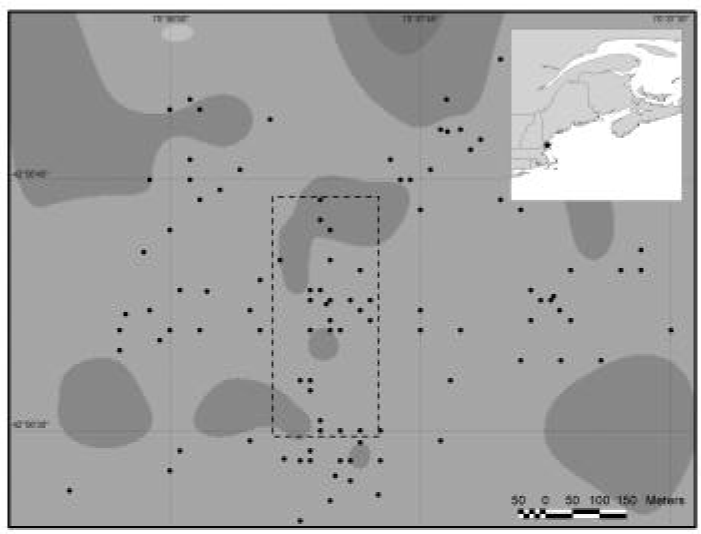

Figure 1. Open ocean aquaculture demonstration project culture site (0.5% organic content contours shown, aquaculture site delimited by dashed rectangle).

From October 1997 through November 2000, approximate monthly cruises (with winter breaks) were made to the study site. On each cruise, six to eight water column samples were taken with Niskin bottles and analyzed in the laboratory for nitrite-nitrate, phosphate, total suspended solids, and particulate organic matter. Five to eight grab (Shipek) and/or core samples (Wildco box corer) of the seabed were also taken. Infauna retained on a 0.5 mm mesh sieve from each sediment sample were sorted to major taxonomic levels, weighed, identified to the level of Family, and counted. A sediment subsample from most grab or core samples was analyzed for grain size and organics (loss-on-ignition). When fish were in the pens and mussels were on the longlines (an 11-month grow-out period from June 1999 to May 2000), two to four of these samples were taken inside a hypothetical "impact zone", and three to four were taken outside this zone. In November 1999 a sidescan sonar survey was made of the study site to provide detailed information on seabed conditions. Videographic images of the seabed were obtained from several areas using a custom-built drop camera in September and October 2000.

The seabed in the vicinity of the study site is relatively heterogeneous, including bedrock outcrops, gravel, and muddy sands (Figure 2). The majority of soft sediments at the site were poorly sorted, muddy sands with mean grain sizes of 3 to 4 phi. Fine sand composed up to 80% of many of the samples. Organic content of all samples was uniformly low, typically less than 3% (Figure 1).

Macro-infaunal communities at the study site were typical of near-shore, soft sediments in the Gulf of Maine. Four polychaete families (Spionidae, Paraonidae, Thyasiridae, Maldanidae) made up nearly 80% of the total abundances from all samples collected thus far. Of these four, spionids were the most abundant. Other dominant taxa included bivalves, crustaceans, and echinoderms. Total community densities ranged from 1,500 to 3,200 individuals / 0.1 m^2. These densities were about half those of the nearby estuarine benthos at the mouth of the Piscataqua River in Portsmouth.

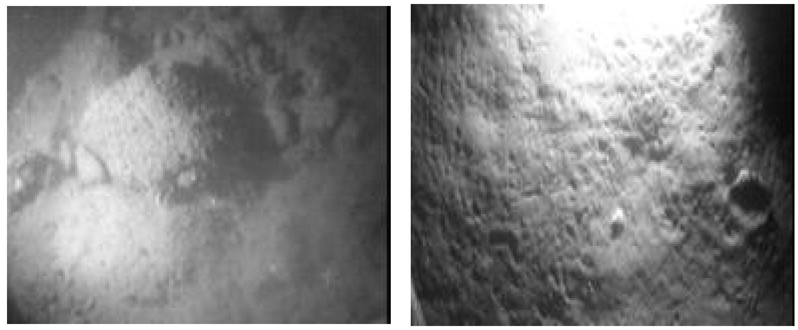

Figure 2. Seabed in the vicinity of the study site illustrating relatively heterogeneous, including bedrock outcrops, gravel, and muddy sands bottom.

Water quality measurements made thus far in the monitoring program have been typical of nearshore Gulf of Maine waters. Particulate organic matter concentrations ranged from <0.5 mg/L to ~3 mg/L. Highest concentrations occurred in spring /early summer both years, reflecting the spring phytoplankton bloom typical in this area. Nitrite-nitrate concentrations ranged from ~1 to 16 μM, with no consistent seasonal trends. Phosphate concentrations ranged from <0.5 to ~1.5 μM, also with no consistent seasonal trends.

Inspection of a time series of data means from infaunal samples taken before fish and mussels were deployed to the site and during the 11-month grow-out period indicated no differences in total community density, biomass, or taxa for the time period. Water column data also indicated no effects of the aquaculture activities on water quality. After segregating the overall benthic data set from the grow-out period into two components (samples from within the hypothetical "impact zone" on the seabed and those outside this zone), a comparison (t-test) of the overall paired means showed no significant differences in community densities, biomass, or total taxa. Further spatial analysis (ArcView GIS) of the benthic infaunal data as well as various sediment parameters also indicated no discernable patterns related to the aquaculture activities. For example, see Figure 1 of distribution of % organic content of bottom sediments at the study site (range = 1 to 3%).

In conclusion, it should be noted that no detectable impacts of the aquaculture activities at their initial level of stocking rates were expected because of the relatively low biomass of cultured animals in relation to water depth (~55 m) and hydrodynamical conditions (wind waves exceeding 5 m at times) at the site. The newly developed long-term monitoring protocol will have an enhanced mathematical modeling component.

To this point in the study, the monitoring program has sought to characterize both temporal and spatial changes in the water column and seabed to the extent possible with available funds. Seasonal and other temporal trends have been adequately characterized (but not fully reported on here) for most monitoring components. There is a need, however, for more detailed information on spatial variations. The existing monthly monitoring program is scheduled to end in August 2001. The subsequent program probably will consist of less frequent sampling but increased number of sites to provide adequate spatial resolution of sediment, benthos, and water quality variations around the culture site. Moreover, it is anticipated that the empirical monitoring approach that has made up most of the program thus far will be supplemented by further development of the mathematical modeling component. This will allow an overall monitoring protocol that consists of modeling predictions for each new stocking scenario that are testable by the empirical sampling program, and feedback between the two major components. This kind of approach is aimed in the long-term at insuring that industry development is not unduly hindered, environmental impacts are kept to acceptable levels, and all regulatory requirements are met.

Keywords: benthos, sediments, water quality

Poster/Oral Presentation: Ocean Environmental

A COMPARISON OF ACCESS SYSTEMS FOR NATURAL RESOURCES: DRAWING LESSONS FOR OCEAN AQUACULTURE IN THE US EXCLUSIVE ECONOMIC ZONE

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In its exclusive economic zone (EEZ), the United States has sovereign rights over the exploitation of commercial living resources. Unlike marine fisheries, however, the site-specific nature of ocean aquaculture operations requires the assignment of property rights to designated areas of ocean space. The allocation of rights to ocean space is a contentious issue, particularly in the absence of a coordinated national policy governing allocation of ocean space between aquaculture operations and other competing uses. Even when such allocations take place, there is now only a rudimentary system in the United States for providing access to ocean space for aquaculture purposes. Some proposals to establish an access system for ocean aquaculture have surfaced within the last few years in both the U.S. executive and legislative branches, but none has been adopted. It has been suggested that lessons might be learned from management regimes and practices both for aquaculture in other jurisdictions and for other types of public resources. We present results of a comparison of access systems for onshore public natural resources in the United States and for ocean space for aquaculture in US coastal states and other nations. Instead of choosing a preferred access system from this comparison, we emphasize the importance and potential utility of the method of comparison. In particular, we develop a characterization of access systems using generic design features that may be useful for drawing lessons from disparate systems. Further, we comment on the economic efficiency, fairness, and environmental sustainability of some of the alternative access system design features.

KEY WORDS: economics, lesson drawing, access system, management, ocean aquaculture

Oral Presentation: Marine Policy and Social/Economics

STATUS OF OPEN SEA FARMING IN INDIA

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India is endowed with an 8,129 km long coastline, which is rich in marine fishery resources. The EEZ spreads over 2.02 million km^2. Several open sea farming techniques had been developed for pearl oyster, edible oyster, clam, mussels, sea cucumber, seaweeds, mud crab, grouper, etc. Pearl oyster (*Pinctada fucata*) production technology development was the first thrust area in the seventies. Because, between 1663 and 1961 AD, there were 40 pearl fisheries along the Tamil Nadu coast from which pearls worth several millions of rupees were obtained but since then, these resources had totally disappeared from their natural sea beds. The CMFRI obtained a breakthrough in 1981 when the first batch of pearl oyster spat was produced in its Tuticorin laboratory. The technology has since been standardized and pearl oyster production in rafts in open sea emerged a commercial activity later. Hatchery technology for mass production of the pearl oysters *P. fucata* and *P. margaritifera* had been developed and the hatchery-bred seed are sea ranched for increasing wild populations. Rack and tray and rack and ren methods are used to farm edible oyster (*Crassostrea madrasensis*) in open sea and a production of 150 tones/ha/yr was obtained.

Clams are the most wisely distributed and abundant among the exploited bivalve resources of India. The brown mussel (*Perna indica*) and the green mussel (*Perna viridis)* are cultured on floating rafts in open sea up to 10 m depth on suspended ropes obtaining a production of 10-15 kg/m rope in seven months and 4-12 kg/m in five months, respectively. Methods of culturing the green mussels in nylon net bags of about one metre length in shallow coastal waters like bays have been developed. Long-line culture of mussels in open sea has also been developed and a production of 118 kg/m rope has been realised at farm level. Open sea farming of clams using hatchery seed had yielded 14.3 to 59.3 tones/ha in 3.5 to 5.5 months.

Sea cucumber (*Holothuria scabra* and *H. spinifera*) has been exported for a long time and developed of technology for sea cucumber hatchery and farming became important. A breakthrough in hatchery seed production technology achieved in 1988 enabled development of sea cucumber farming methods. Mud crab fattening is carriedout along coastal ponds using wild crab juveniles. Seaweeds are in great demand for agar and algin production and research was initiated since 1972 for this. Technology for farming *Gracilaria edulis* in calm coastal waters using specially-made coir mats or a frame of coir ropes tied to wooden poles fixed in the open sea was developed and standardized subsequently. Single-line bottom coir rope method is used to farm edible seaweed *Acanthophora specifera* recorded a growth of 2.6 to 36 fold increase in seven months. Similarly, cage culture of groupers in open sea is receiving attention currently owing to high export demand for it. This paper discusses the status of the various sea farming technologies in India, constraints and prospects for future development.

Keywords: bivalve, invertebrate, seaweed

Poster Presentation

A MODEL OF THE SOCIALLY OPTIMAL SCALE OF OCEAN AQUACULTURE

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There is a growing literature on the economics of aquaculture. Existing studies in this area may be categorized into two groups. The first focuses on aquaculture itself, including the analyses of production processes and the aquaculture product market. The second examines interactions between aquaculture and other activities, including the impacts of aquaculture on commercial fisheries and on the marine environment. We examine the interaction between a natural fishery and aquaculture using an economic optimal control model. The model is designed to determine the socially optimal scale of aquaculture in a region given that commercial fisheries already exist. In the model, a regional planner chooses both the optimal scale of aquaculture and fishing effort so that the net social benefit of fish production from both the commercial fishery and aquaculture is maximized. In the model, we examine two types of impacts of aquaculture on the fishery. First, the cost of fishing rises as aquaculture expands (e.g. due to interference with fishing operations). In addition, an expanding aquaculture area affects the carrying capacity of natural fish stocks. These are modeled as two constraints describing the dynamics of natural fish stock and aquaculture acreage, respectively. We develop two case studies. In the first case, ocean aquaculture produces the same species as the commercial fishery. In the second case, different species are produced by the fishery and aquaculture, and these products sold in different markets. Our model is an extension of a classical fishery bioeconomic model. It can be used to assess a number of important policy variables. For example, it may be used to examine the steady-state (long-run equilibrium) level of aquaculture with respect to different levels of impacts on the natural fish stock. Numerical examples are developed to illustrate the interactions between aquaculture and commercial fisheries and the optimal scale under various economic and biological conditions.

Keywords: economics, optimal control, fishery, ocean aquaculture

Oral Presentation: Marine Policy and Social/Economics

OFFSHORE MARICULTURE IN TEXAS : PAST, PRESENT, AND FUTURE

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Interest in offshore mariculture has increased tremendously worldwide in the last several years due to an increasing demand for seafood products and decline in many capture fisheries. The United States is no exception with offshore research currently being conducted in New Hampshire, Hawaii, Mississippi, and near shore production cages in Washington and Maine. Factors such as population growth in U.S. coastal zones and increased regulation regarding aquaculture effluent may result in more producers considering open ocean aquaculture in the future.

By its very nature, offshore research or production is relatively expensive owing to the logistics of obtaining supplies and working in a hostile and uncontrollable environment. Cage or net pen systems must have longer maintenance intervals and equipment failure or human error generally carry greater consequences compared to land based production. Likewise the offshore culturist will face a multitude of other challenges not encountered at an onshore facility and need to overcome these to successfully stock, grow, and harvest product. Conveniently, the Gulf of Mexico has thousands of fixed structures already in place in the form of oil and gas platforms ranging in size, water depth, and usable deck space. These platforms, whether in operation or abandoned, can be made suitable for use as moorings or as a base of operations for mariculture activity in the area and provide an accessible workspace in an otherwise limitless expanse of open water.

Among the states along the Gulf, Texas has been the location for most offshore mariculture activity to date with research beginning around 1990. At least eight different cage systems have been deployed in the last ten years ranging in size, shape, construction, and location in the water column. Water depth at the culture sites ranged from 70-270ft and distance offshore from 7-34 miles, including attempts in both state and federal waters. In all cases, research was funded by private companies and suspended when the economic benefit to the company was no longer achievable and project goals had not been attained. Results indicated that growing different species of fish in open ocean cage systems was not especially difficult from a husbandry perspective, but cage maintenance and production costs of operating offshore were contributing factors to cessation of the projects. The history of these efforts, present day proposals, and some thoughts on what the future of mariculture in Texas offshore waters might hold will be the topic of the presentation.

Keywords: open ocean, platform, cage system

Oral Presentation: Candidate Species and Logistics/Operations

PRODUCTION OF ATLANTIC COD (*Gadus morhua*) FOR OPEN OCEAN AQUACULTURE IN NEW HAMPSHIRE

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The University of New Hampshire Open Ocean Aquaculture Demonstration Project was established in 1997. Its goal is to stimulate further development of commercial marine aquaculture in New England, thereby increasing seafood production, creating new employment opportunities, and contributing to economic and community development. The first species of finfish raised in offshore net pens was summer flounder (*Paralichthys dentatus*). Although this venture was reasonably successful, we are eager to expand our efforts to include culture of cold water marine species more appropriate to our location in northern New England. Small numbers of Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) juveniles were produced in 2000, but insufficient numbers were available for stocking net pens. Our goal for this year is to produce enough juvenile cod (approximately 25,000) to stock one offshore net pen. Production began in February 2001. Broodstock cod fish were spawned at the NOAA-NMFS Narragansett, R.I. laboratory, and 397,000 eggs transported at 5 days post-fertilization (@4ºC) to the GreatBay Aquafarms, Inc hatchery. Eggs hatched after 15 additional days of incubation (temp. 6-8ºC), and 286,000 larvae were stocked into four 4,000-l larval rearing tanks. Incoming culture seawater (17ºC) was degassed, injected with oxygen, chilled to 7ºC, and allowed to flow through the tanks. Larvae were fed a combination of rotifers enriched separately with microalgae (*C. Iso*, or *Tetraselmis*), and Algamac 2000® (Bio-Marine Aquafauna Inc.) for 20 days. *Artemia* nauplii enriched with DC DHA Selco® (INVE Aquaculture) were fed to larvae when they reached 8.0mm TL (16 dph), and weaning with microdiet Biokyowa B400 was initiated at 15mm TL (27 dph). Complications with swim bladder inflation occur from 15-35 dph, and accounted for up to 30% crop mortality. Management of oxygen and nitrogen gas saturation, as well as total gas pressure of culture water, is essential to reduce mortality during this critical stage. We will discuss the effects of supersaturation during swim bladder inflation, and present growth and survival data from the hatchery.

Because tank space at the hatchery is limited, we plan to move the fish out of the hatchery when they are about 3-5g. Fish of this size will be too small to transfer directly to offshore net pen systems, so we will hold the fish in small inshore net pens (approx. 9 m^3, 4-5mm mesh size) until they are large enough to move offshore. Details of this phase of culture, as well as performance of the fish in small-mesh net pens, will be discussed.

Keywords: open ocean aquaculture, larviculture, Atlantic cod

Oral Presentation: Candidate Species and Logistics/Operations

ECONOMIC MODELS FOR OPEN OCEAN GROW-OUT OF SEA SCALLOPS (*Placopecten magellanicus*) AND BLUE MUSSELS (*Mytilus edulis*)

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We model the economics of open ocean grow-out of two species of shellfish – sea scallops (*Placopecten magellanicus*) and blue mussels (*Mytilus edulis*). Models are informed by the results of offshore grow-out experiments conducted in southern New England in the late 1990s, and illustrate conditions under which open ocean shellfish grow-out operations can be profitable.

We examine the economic viability of four alternative approaches to open ocean scallop farming: seabed seeding and three variations of cage culture (lantern cages, bottom cage trawls, and bottom cage clusters). For each alternative, we estimate capital and operating costs and revenues over a 20 year period. We assume a two-year cycle from collection of juveniles to harvest, and scale the farming operation in every case to produce 100,000 pounds of scallop meat per two-year cycle (that is, every other year).

Under baseline assumptions, the only profitable alternative is seabed seeding. A 100,000 lbs/cycle seabed seeding operation requires less than $400,000 in start-up capital and pays back the initial investment in four years. Seabed seeding requires a lease area of about 150 acres and use of a large scallop vessel about 3 months out of the year, on average. Cage operations are not profitable because higher survival rate and growth are not enough to justify added cost of buying, maintaining, deploying, and harvesting the cages and associated moorings. Although they require smaller lease areas, cage operations demand between $1 million and $2 million in startup funding. Of the three alternatives, bottom cage trawls come closest to break-even because gear costs are relatively modest.

There are several sources of uncertainty in the model, including the exvessel price for sea scallops. To help manage this uncertainty, we estimate a model of supply and demand for New England sea scallops using monthly data during the period 1985-93. The model is a linear representation of both supply and demand for "average size" sea scallops, implying a market equilibrium over the 1985-93 period of $5.42 per pound. Figure 1 illustrates the effect of price and mortality on the net present value of the farming operation.

It is useful to think of scallop production from an offshore farm as an inventory problem. At an offshore site, seed scallops grow over a period of about two years to a size that may command a premium over the average size scallop. We develop a simple algorithm to help the farmer take advantage of historical monthly variablity in sea scallop demand. If this variability persists, we find that when farm output is small relative to the market, the farmer should act as a price taker, harvesting and marketing product only in January. As potential output increases, however, the time profile of output shifts. Output of up to 150,000 pounds should be produced in January and November. When output reaches 200,000 pounds, there should be some level of production in every month except July.

We model an offshore mussel longline operation that fully utilizes the annual capacity of one service vessel (e.g. a small scalloper of approximately 20 GRT). Such a vessel requires fixed cost payments on the order of $80,000 per year. Daily variable costs (fuel and supplies) are $1400, including $800 in crew member wages. We estimate that one vessel is capable of servicing a field of 300 longlines. We assume that 150 longlines are harvested once every two years. Each year, about 225 days are spent maintaining the longlines and 38 days are required for harvesting. During years when the longlines are being deployed, an additional 38 days are required to deploy one-half the field (150 longlines).

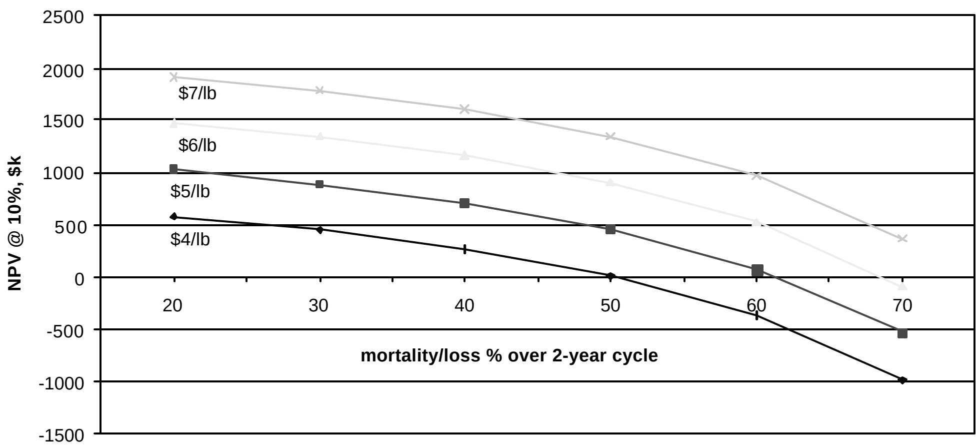

Figure 1. Scallop seabed seeding NPV as a function of dockside price and cycle mortality/loss rate.

Each longline is designed to support 25 mussel socks or grow-out ropes. Each sock produces, on average, 350 pounds of mussels over a two-year grow-out period. A longline costs $400 to deploy and $250 to maintain each year, not including the costs of running the service vessel. Each longline is designed to last ten years, at which time it must be replaced. Additional costs include those associated with processing (sorting, debearding, and cleaning), transport to the market, and management costs.

We estimate a model of blue mussel market price from the monthly distribution of the value per pound of imported Canadian cultured blue mussels during 1990-97 (averaging 91¢ per pound). We assume that price is distributed lognormally with a mean of 64¢ per pound and a standard deviation of 11¢ per pound. The mean has been adjusted downward to account for the effect of domestic production on market price.

Developing a model of production risk is more problematic in the absence of a history of offshore production activity. This parameter can be affected by storm events, predation, parasitism, disease, temperature, and availability of food, among other things. We assume that production takes an extreme value distribution with a mode of 380 pounds per sock and a scale of 50 pounds. The majority of possible values for production from a sock thus range between 80 and 480 pounds per sock.

The model predicts a marginally profitable operation with a discounted net cash flow of $300,000 over a 13 year period. This result suggests that mussel farming at an offshore location is commercially feasible. However, the possibility of losses is significant. The most significant technological hurdle remains development of inexpensive and survivable longline gear.

Keywords: shellfish grow-out, economic model, scallops, blue mussels

Oral Presentation: Marine Policy and Social/Economics

A BIOECONOMIC MODEL OF OPEN OCEAN GROW-OUT OPERATIONS FOR FINFISH

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We develop a bioeconomic model of an open ocean finfish grow-out operation. The model optimizes stocking and harvesting schedules, and projects financial flows. It allows for comparison of alternate grow-out sites based on physical characteristics (distance from shore, water temperature, water depth, waves, etc.). The model takes into account seasonal variability in the price of fish landings, as well as the effect of water temperature on fish growth rates. We illustrate the use of the model by applying it to hypothetical grow-out operations for cod, haddock, and salmon off the coast of New England.

The model's optimization procedure assumes that the grow-out operation is to produce a fixed amount of fish (v_h, by weight) each month (or in specified months only). The model determines optimal stocking time and number of fish for each harvest month. It also calculates expected financial flows and summary values such as project NPV and amount of up-front investment required.

For each harvest month h (h=1,2,3,…,12), the model uses a species-specific growth function to calculate the weight at harvest of an individual fish ($f_h(m)$) stocked as a fingerling in month m (m=h-23,h-22,h-21,…). The model then calculates the number of fish at harvest $n_h(m)=v_h/f_h(m)$, and works backward, using the mortality function, to calculate the number of fingerlings to be stocked.

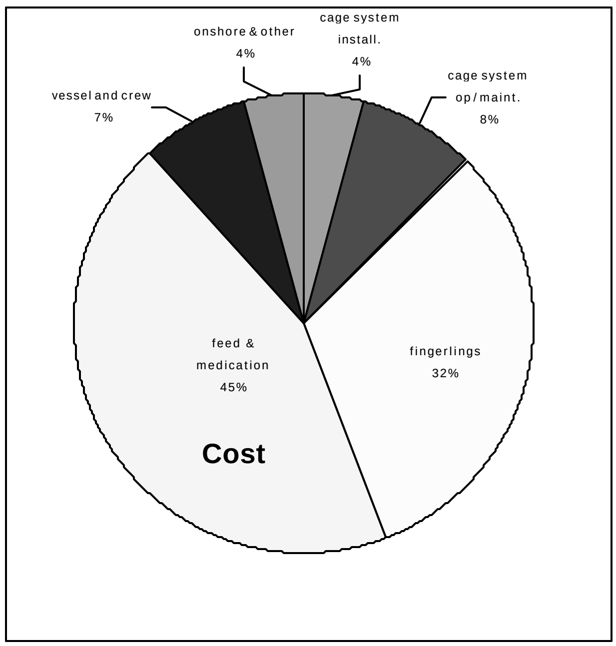

Figure 1. Associated Atlantic cod grow-out costs

For each harvest month h, the model then identifies the stocking month m that results in the maximum net revenue (discounted difference between revenue and variable cost). Revenue is the product of harvest weight and price, which varies with fish size and time of year: v_h*$p(h,f_h(m))$. Stocking months that result in sub-market-size fish result in zero revenue and are not considered. Variable costs include the cost of fingerlings, feed and medication, and harvesting, including associated vessel costs. The maximum net revenue determines the optimal stocking month (and length of grow-out), as well as the number of fingerlings.

Once stocking decisions have been optimized, the model calculates financial performance of the grow-out operation month-by-month over 15 years to determine projected cash flows, project NPV, and investment capital needed, as well as operational parameters such as vessel utilization and feed volume.

The model uses several input parameters to describe the grow-out operation. The grow-out operation is primarily defined by the amount to be harvested each month and characteristics of the grow-out site (water temperature, wave profile, water depth, and distance from shore). Biological factors are captured

NPV ($m)	0.64
financing req. ($m)	7.96
total cages	72
max vessels in use	1
avg. utilization	68
fingerlings/year	848,351
feed/year (tons)	3,461
annual production	1,805
harvest weight	
Jan	2,713
Feb	2,711
Mar	2,691
Apr	2,636
May	2,435
Jun	2,448
Jul	2,662
Aug	2,699
Sep	2,697
Oct	2,498
Nov	2,441
Dec	2,644

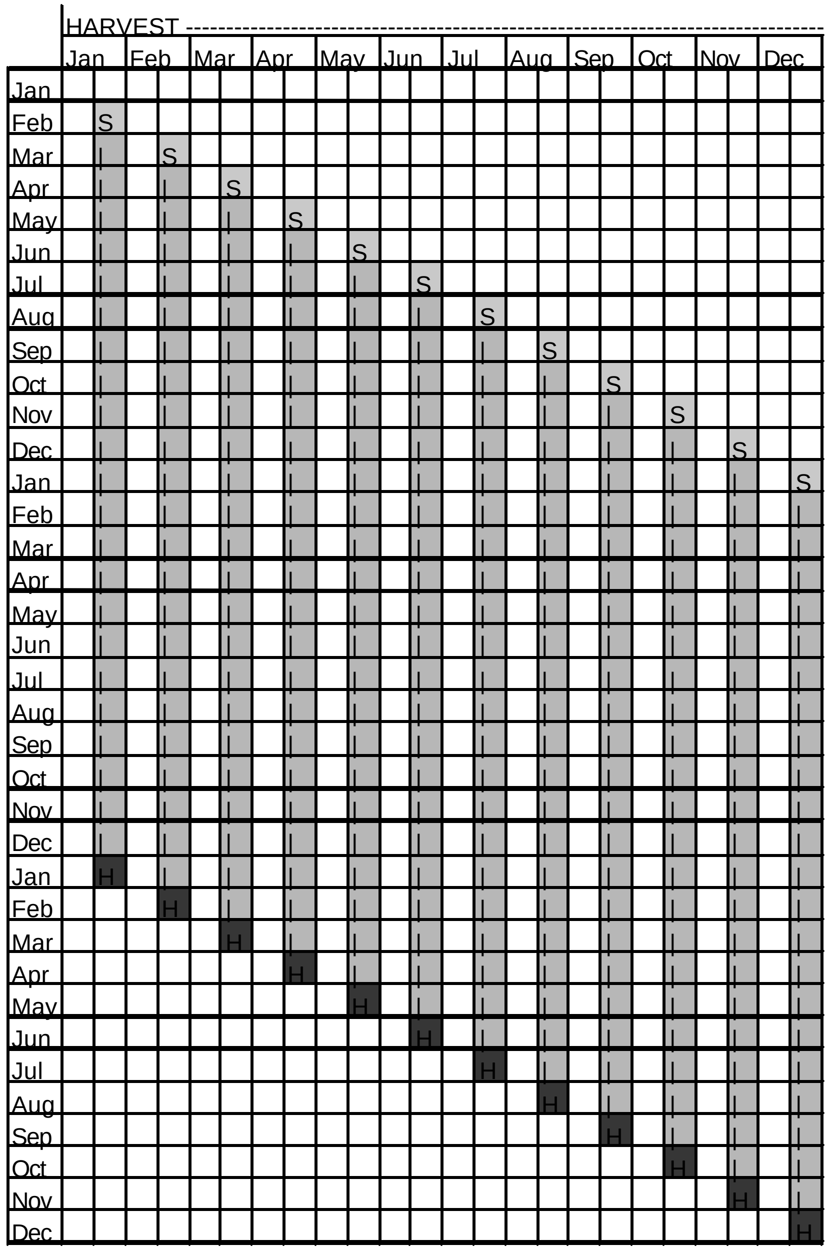

Figure 2. Sample model output

by a growth function (monthly growth as a function of fish weight and water temperature), a mortality rate, and a feed conversion ratio (the latter two are specified as a function of fish size), as well as the maximum feasible culture density (fish weight per cubic meter of water). Other inputs include cage system and support vessel capacities and costs, fingerling size and cost, and feed and medication costs. Dockside price is specified as a function of fish size and time of year.

A preliminary application of the model to grow-out of several species of finfish off the coast of New England suggests that fingerlings and feed are by far the most significant cost components (Figure 1). Cage system operation and maintenance, vessel operations, and crew expenses are also substantial, and point to the importance of automation. Other parameters that have a significant effect on grow-out economics include the maximum sustainable grow-out density, water temperature, and market conditions.

The model suggests that open ocean grow-out of finfish is economically viable offshore New England even for relatively low-value species such as cod (Figure 2). A 1800 ton/year cod grow-out operation located 6km from its shore base, for example, is potentially profitable with a 23-month grow-out, producing 2.5 kg fish at an average dockside price of $2.75/kg.

Keywords: finfish grow-out, bioeconomic model, optimization

Oral Presentation: Marine Policy and Social/Economics

MODELING OF NET STRUCTURES EXPOSED TO 3D WAVES AND CURRENT

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The fish farming and aquacultural industry is expanding, and the demand for suitable locations for fish farms is increasing. In Norway, as well as in other countries, this calls for new technological challenges, as fish farms are being installed at locations that are more exposed to waves, wind and current. In the future it is clear that more fish farms must be located offshore, as the number of suitable near-shore locations are limited. A move towards offshore locations are also motivated by environmental and aesthetic aspects of the industry, and future fish farms will most likely be in the form of large scale offshore installations, rather than small near-shore farms. Before installation of such structures, it is necessary to assess the behaviour of the structure exposed to environmental forces typical of the offshore location. In contrast to present day offshore oil installations, which are rigid body structures, fish farms are flexible structures with potential for highly complex behaviour. This makes it necessary to develop new numerical tools for simulating the behaviour of such structures.

A numerical model of a 3D net cage exposed to waves and current are being developed at SINTEF Fisheries and Aquaculture. As a first part of this work, the behaviour of simple plane nets exposed to 3D waves and current are studied and a numerical model has been developed. In this model the net is divided into plane flexible net elements, and structural and hydrodynamic forces are calculated for each element. The net cage is fixed to a floater at the top and has weights attached to the bottom. Both the floater and weight have the form of a horizontal cylinder, and are allowed to move freely as they are exposed to hydrodynamic and structural forces from the net and mooring. Lift and drag coefficients for each net element are calculated from an analytical formulation based on empirical data. Each net element is flexible with the only restriction that they remain plane throughout the simulation with the whole net otherwise allowed full 3D movement. Forces on each element are distributed to each element node and the equation of motion is evaluated in the nodes. Net movement is then calculated with time integration. A Stoke's 5^{th} order wave model is used to calculate wave velocities.

The model is used to study structural forces and movement of the net as it is exposed to extreme wave and current conditions. Different mooring and weight configurations are tested, and the net is exposed to multi component wave conditions, and time and depth varying current. Force in the critical joint between the floater and net is of particular interest and given special attention in the investigation. A preliminary simulation of a single net exposed to waves and current is shown as an example in Figure 1.

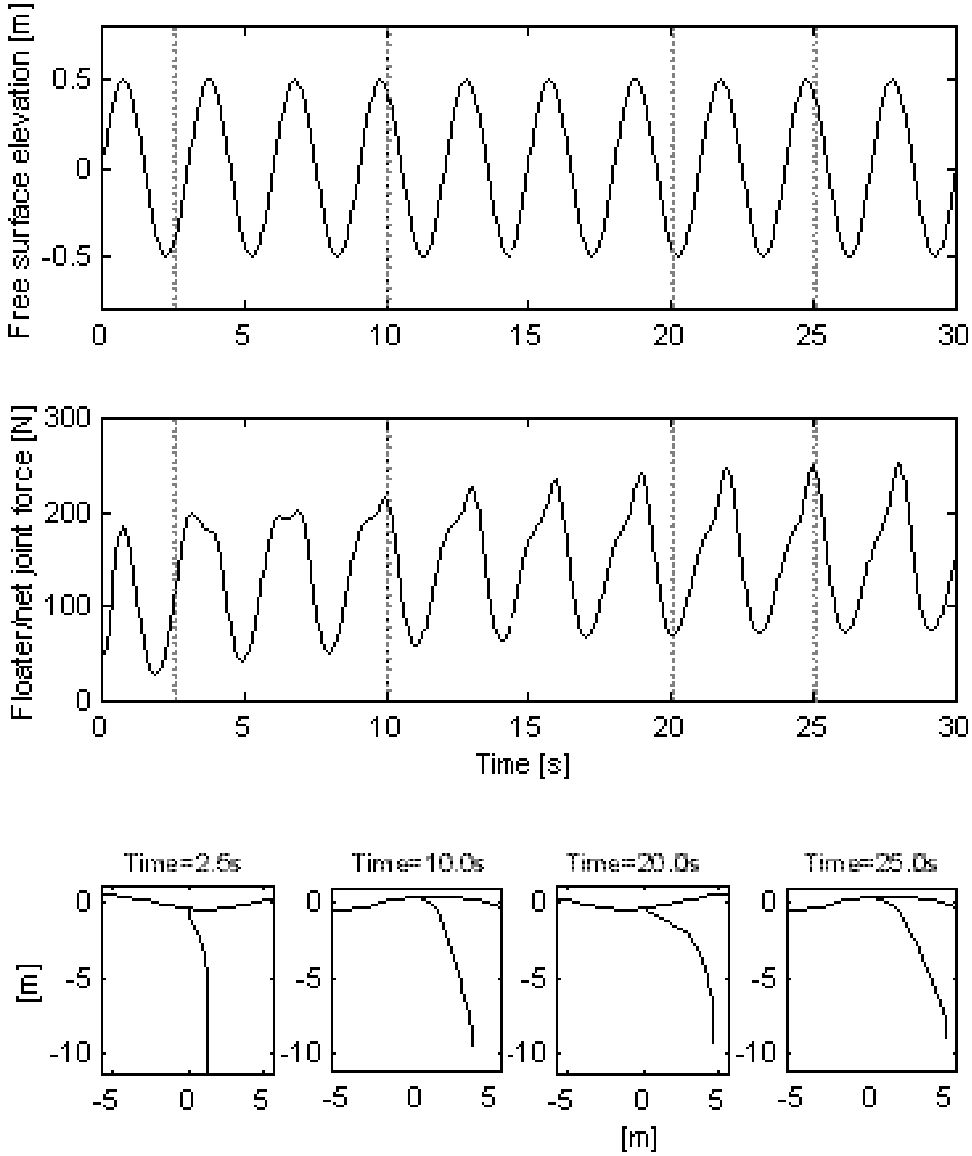

Figure 1. Example of a preliminary simulation. A net (10 m deep, 0.5 m wide, 10 kg bottom weight) is exposed to waves (T=3 s, H=1 m), and current (0.5 m/s, same direction as the waves). The free surface elevation (top) is shown together with the structural force in the joint between the floater and net (middle). Net geometry and free surface geometry are shown at four different times in the simulation (bottom).

Keywords: numerical model, aquaculture installations, exposed locations

Oral Presentation: Ocean Engineering

ADVANCES IN SUBMERGED LONGLINE CULTURE OF BLUE MUSSELS *Mytilis edulis* IN THE OPEN OCEAN

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The University of New Hampshire, in collaboration with the Portsmouth, NH, Commercial Fishermen's Cooperative, has established an open ocean aquaculture demonstration site at a location eight kilometers from shore in the open waters of the Gulf of Maine, USA. Water depth at the site is 52 m. The site is fully exposed to wind and waves from all directions and can experience significant wave heights of 9 m during severe storms. The shellfish culture component of the project consists of two anchored longlines, each approximately 120 m in length, with the horizontal headline submerged 15 m below the surface. The project was designed to identify and demonstrate offshore commercial aquaculture opportunities for local and regional capture fishing communities; therefore a fishing vessel typical of those used in near shore ocean fisheries was equipped to handle submerged longlines. Gear and technology used in inshore longline culture was modified for use in the open ocean environment.

The initial shellfish species cultured at the site is the blue mussel, *Mytilis edulis*. Mussel seed was collected on vertical rope collectors deployed from rafts and surface longlines at several inshore locations and from the offshore longline. Mussel seed was also harvested from fish pens adjacent to the offshore longline. Seed were grown to a 20-25 mm size on the collectors before removal and transfer to grow-out. Four separate deployments of mussel seed to grow-out on the offshore longlines have been made since July 1999. Seed deployments were made in July 1999, October 1999 and June 2000 using discrete vertical lengths of polyethylene or monofilament nylon mesh socking, and in November 2000 using continuous loops of fuzzy rope core with a biodegradable cotton mesh sleeve.

Seed growth (spat settlement to 20-25 mm) varied depending on location, timing of collector deployment, seed density, and fouling. Better sites produced large quantities of seed ready for transfer to grow-out in four to five months. Mussel seed (21 mm) deployed for grow-out in July 1999 reached a mean shell height of 62 mm after ten months on the longline and the October 1999-deployed seed grew from 27 mm to 54 mm in seven months (Figure 1). Growth rate of the seed deployed in June 2000 has been similar, averaging more than four mm per month. These growth rates suggest that grow-out from 20-25 mm seed to market size (>50 mm) can be achieved in seven to eight months, and that a full production cycle from spat settlement to market size can range from 12 to 15 months.

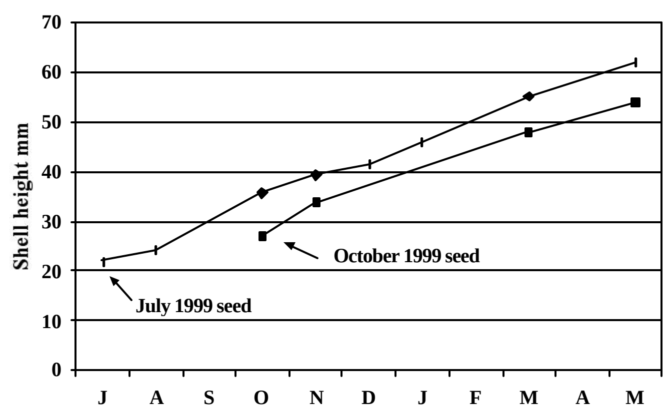

Figure 1. Growth of mussels deployed in July and October 1999 on the offshore longline.

The density of mussels on the grow-out lines averaged 500/m for the first two seed deployments and the lines yielded an average of nearly 7.5 kg of market-size mussels per meter. Densities were higher for the

June 2000 deployment (800/m) however, growth rates appear uncompromised by increased density. These results indicate that a single longline of a dimension similar to that used for this project can yield up to 7,000 kg of mussels in a seven to eight month grow-out period. Product quality and meat yield has been consistently excellent, with cooked meat weights greater than 50% of whole live weight.

Problems encountered during the project include materials failure, fouling of the seed lines, predation on mussel seed by sea stars, and difficulties maintaining proper headline depth as the mussels grow and add weight to the line. Fouling and predation issues have and will continue to be addressed by altering the timing of deployment of seed collectors. The greater headline depth associated with offshore longline culture, however, has resolved problems with maintaining proper buoyancy with commercially available and affordable floatation. Commercially available submersible floats are capable of providing buoyancy to depths of 15-17 m. Since the depth of the headline for this project begins at 15 m, even a small amount of added weight drags the buoys below their rated depth, resulting in collapse and loss of buoyancy. While steel buoys rated for greater depths are available, they are very expensive and unwieldy. More cost-effective buoyancy alternatives are needed for commercial operations.

Despite the difficulties cited, fast growth and excellent product quality indicate tremendous potential for mussel production in offshore waters. In addition to the search for alternative buoyancy options, future project activities include detailed economic analyses, development of marketing strategies, wide area site identification and classification, and continued refinement of husbandry and product handling methods.

Keywords: shellfish, offshore aquaculture, grow-out, demonstration

Oral Presentation: Candidate Species and Logistics/Operations

DEVELOPMENT OF LONGTUBE MUSSEL SYSTEMS FOR CULTIVATION OF BLUE MUSSELS (*Mytilis edulis*)

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The blue mussel industry is a rapid growing industry in Norway. The coastal area is well protected and infrastructure is well developed all along the coast. A total coastal length of more than 70,000 km gives room for a huge potential for fish farming. Mussel farming is considered by many as a simple, self-operating industry. Simply hanging ropes in the water in spring, mussel spat finds its way to collectors and grow-out is a self-perpetuated process requiring no human interference. This is unfortunately not the case.

During the period from 1999-2000 SINTEF Fishery and Aquaculture developed methods describing the physics of the floating systems. Controlled farming requires a controlled balance of buoyancy with respect to the weight of the mussels. Mussel weight increases from zero up to 10 kg/meter of collector during two years, with large local variations. Controlling buoyancy is typically continuos work. Large production units within a single location may produce up to 1500 tons. The required buoyancy is loaded stepwise and there is always a risk of damaging floats and thereby sinking the system.

Figure 1. Illustration of traditional mussel farming systems, the longline, and the new developed long-tube concept.

Traditional long-line systems require considerable work to keep structures afloat. But also sorting and harvesting operations can easily lead to an unprofitable business. A need for better industrial concepts is evident. Here we describe an alternative system developed by SINTEF Fishery and Aquaculture and the industry for which we describe both operational strategies and the dynamic behaviour. The concept uses continuous polyethylene (PEH) tubes, which replaces the longline and buoys (Figure 1). Comparative dynamic analyses of these two systems are performed.

Finite element methods developed to study dynamic riser behaviours on oilrigs were applied to study mussel farms technology. Some basic studies were initially performed in order to establish the hydrodynamic coefficients for collectors with mussels. An evaluation parameter required to compare different systems is the collector tension. Large tension variations indicates large accelerations and forces on the mussels attached to the ropes. One must especially avoid zero tension, which causes snap loads that might cause heavy losses of mussels.

Behaviour of the collector on longline systems varies upon the position of the collectors with respect to the floats. For sheltered locations, problems with snap loads occur near the float while these problems occur near the mid span in large waves. Dynamics on a long-tube system are less, and seem to be favourable compared to traditional systems (Figure 2).

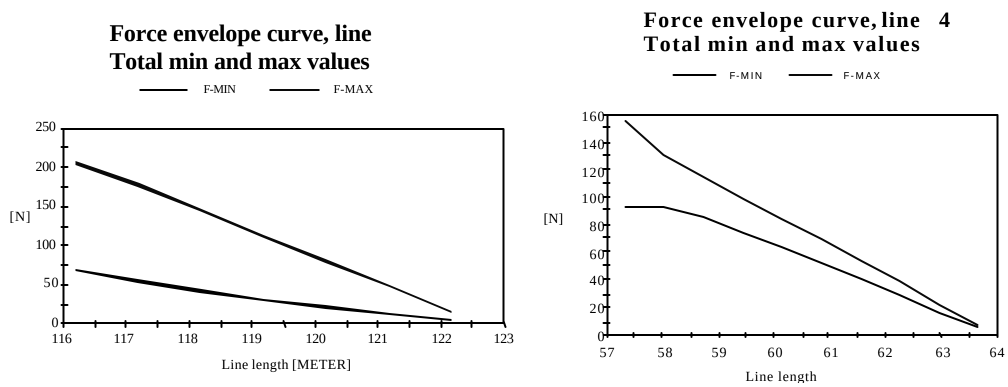

Figure 2. Tension variation along a collector at the mid span of a traditional long-line and on a long-tube at 1 m wave height.

The main advantage of a long-tube system is lower risk of failure and sinking. Further, adding solid buoyancy in the tube may be accomplished at an acceptable cost.

Some alternative methods regarding attachment of the collectors to the tube is developed. Suitability of these methods varies upon location. Drifting ice and other debris may cause problems. The investment and operational costs are closely connected to the number of components in the system. This will be further discussed.

Keywords: numerical model, long-tube, aquaculture installations

Oral Presentation: Ocean Engineering

NORTHERN NEW ENGLAND COMMERCIAL FISHERMEN AND OPEN OCEAN AQUACULTURE: AN ANALYSIS OF HOW COMMERCIAL FISHERMEN PERCEIVE THE GOVERNMENT, FISHING AND THEIR WAY OF LIFE

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Open ocean aquaculture (OOA) will occupy ocean space (surface, water column and bottom area) in the U.S. Exclusive Economic Zone (EEZ) and therefore prohibit traditional commercial fishing in that space. At the present time, there is no policy that governs OOA in the EEZ. Commercial fishermen in the Northern New England inshore fleet have expressed concerns and opinions on OOA relative to their earning a living on the ocean and federal policy makers must consider these concerns during the policy formulation stage. Commercial fishermen and government policy makers must be equal partners in establishing policy and rules that are deemed fair and workable to both government and fishermen. In the past, interface between commercial fishermen and federal policy makers has been confrontational.

The purpose of this paper is to summarize data from two sample surveys of commercial fishermen in Northern New England and provide insight to policy makers of those commercial fishermen's concerns about OOA relative to their ability to keep their way of life intact. The focus is twofold: (a) to explore, in light of OOA, costs and benefits of fishermen's personal aims and aspirations, the environment, the fishing economy and social makeup of their towns and villages; and (b) to provide policy makers those areas of concern that they should be aware of in order to make decisions leading to mutually acceptable policy.

Two surveys (1997 and 1999) were designed to measure the willingness of commercial fishermen to enter the OOA business. They were sequential in nature, the first containing only a generic definition of OOA, while the second was much more specific describing an actual ongoing OOA venture in the Gulf of Maine (the University of New Hampshire Open Ocean Aquaculture Demonstration Project). They both targeted the same population of northern New England (Cape Ann, MA to Eastport, ME, inclusively) inshore commercial fishermen who operate vessels 20 to 50 feet in length and hold federal fishing permits for 1) New England multi-species, 2) Summer Flounder, and 3) Squid, Atlantic Mackerel, and Butterfish. Both surveys were jointly developed by researchers, cooperative extension educators and industry (traditional fishing and aquaculture) representatives. These surveys contain the only data on fishermen's perceptions of OOA available.

The 1997 survey identified a total of 846 permit holders. Of these, 570 permit holders were contacted with 311 interviews successfully completed. The instrument was a 93-question telephone questionnaire. The survey provided several functions: to generate baseline demographic information; to determine how informed this group of fishermen were about the aquaculture industry; to determine the level of interest that this group of fishermen had in participating in aquaculture; and to provide an in depth idea of what fishermen perceived to be the potential characteristics (desirability, potential barriers, information and training sources, and type of employment) of the aquaculture industry.

The 1999 survey (a follow-on study to the 1997 telephone survey) identified a total of 845 permit holders with 186 responding to the survey. This survey was a self-administered, 105-question, mail survey and investigated whether and under what conditions Northern New England commercial fishermen would be willing to adopt OOA. This survey generated demographic information but mostly explored current familiarity, issues and concerns about OOA, information and training sources, OOA as a business venture, and incentive programs.

The results suggest that Northern New England inshore commercial fishermen are aware of the threats to the present industry and way of life. They also recognize the potential to retain portions of that way of life by participating in OOA in the EEZ. However, there are some significant opinions and perceptions of how the policy governing establishment of OOA ventures in the EEZ should be formulated and what that policy should be. These opinions and perceptions, rightly or wrongly, are based on past experiences of the fishermen in their dealings with the current method of scoping that leads to changing or implementing new Fishery Management Plans. The results will be made available to federal policy makers so that they are cognizant of the fishermen's concerns and perceptions of OOA policy during the formulation stage.

Keywords: open ocean aquaculture, survey research, EEZ policy, fishery policy

Oral Presentation: Marine Policy and Social/Economics

RECENT PROGRESS AND CONSTRAINTS TOWARDS IMPLEMENTING AN OFFSHORE CAGE AQUACULTURE PROJECT IN PUERTO RICO, USA

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Commercial operations raising high-value marine fish will inevitably be established within the next decade in the offshore areas of the US. and Caribbean countries. Owing to greater depth, stronger currents, and distance from shore, environmental impacts associated with aquaculture in coastal areas should be considerably lower in the open ocean suggesting that offshore cage systems are among the most environmentally sustainable methods for commercial marine fish culture. Prior to the establishment of any offshore mariculture operation, it is recommended that a detailed site assessment be conducted to evaluate parameters related to infrastructure, topography, bathymetry, meteorology, hydrology, environmental, and biological information, as well as the legal framework and social, economical and political factors. These parameters are reviewed in this paper, as they relate to offshore aquaculture development in the southeast U.S. and Caribbean region.

Beginning June 1999, Snapperfarm, Inc. and RSMAS University of Miami joined efforts to develop a project aimed to perfect and apply aquaculture technology of mutton snapper (*Lutjanus analis*) using offshore cage systems in the area surrounding Culebra Island, Puerto Rico. The site assessment criteria and feasibility study conducted included the following factors: (i) area information from GIS, satellite images, maps, hydrographic/navigational charts; (ii) areas of conflicting or prohibited use (exclusion), such as marine reserves, parks, sanctuaries, and recreational areas; (iii) elimination process narrows search areas; (iv) legal framework – regulations, licenses, permits, concessions, etc.; (v) bathymetric studies/depth profile; (vi) bottom type and soil characteristics (sand preferred); (vii) exposure to predominant wind and fetch; (viii) current measurements (velocity and direction); (ix) information on wave height and tides; (x) water quality parameters (temperature, salinity, dissolved oxygen concentration, nutrients); (xi) characterization of sources of organic and inorganic pollution; (xii) phytoplankton and zooplankton occurrence and distribution to determine potential danger of red tides, plankton blooms, and biofouling; (xiii) potential predators – sharks, crabs, birds, etc.; (xiv) infrastructure and accessibility to the site – roads, transportation, airport, port, facilities, security, communication, utilities, etc.; (xv) potential for expansion - availability of adjacent area; and (xvi) evaluation of social, economical and political issues.

These criteria were used for a site assessment conducted in Puerto Rico during the spring and summer of 2000. Combining all of the criteria, several potential sites were selected and several were eliminated due to conflicting uses. The final selected site covers 250,000 square meters in the Vieques sound, two nautical miles southwest of Culebra, Puerto Rico. The site is ideal for deployment of two SeaStation 3000 submersible cage systems and water quality parameters are within the optimum range for grow-out of mutton snapper (*Lutjanus analis*). The site does not impose on local use of the area for fishing, diving, tourism or any other commercial uses. The site lies over a predominantly sandy bottom at a depth of 30 meters, tidal driven current runs west-northwesterly at 0.25 to 1.5 knots and tidal variation is 0.3 meters, temperature ranges from 25° to 30° C, salinity is stable at 36 ppt, and oxygen level is also stable at 6-7 mg/l. The site is relatively well protected with a fetch of 1.6 km to the north, 14.5 km to the south, 3.2 km to the east and 27 km to the west.

Social, economical and educational issues were investigated in great detail when conducting this site assessment. This newly developing offshore aquaculture industry can provide a number of opportunities to small Caribbean island communities such as Culebra. Traditionally these communities are heavily dependent on the surrounding environment for their fishing needs. Generally the ecosystems surrounding tropical islands are not very productive and are unable to support the demand from the human population. Snapperfarm and RSMAS have formed a partnership with the Culebra Fisherman Association, a co-op of about 40 fishermen on the island of Culebra. Eighty percent of Snapperfarm's workforce will comprise of local fishermen and regular educational seminars will be held on the island for the community to learn more about this new developing industry.

Once the appropriate site was selected and a productive relationship established with the local community, the Federal and Commonwealth Joint Permit Application (JPA) for Puerto Rico was submitted in September 2000 and the National Pollution Discharge Elimination System (NPDES) permit application submitted to the U.S. Environmental Protection Agency in December 2000. The JPA combines all of the relevant agencies into one permit application, including the U.S. Army Corps of Engineers, the Department of Natural and Environmental Resources (PR), the Environmental Quality Board (PR), and the Planning Board (PR). Snapperfarm and RSMAS have also sought the support of the Mayor of Culebra, the University of Puerto Rico's Department of Marine Sciences, the Puerto Rico Department of Agriculture, the U.S. Department of Agriculture, the U.S. Coast Guard, the Puerto Rico Industrial Development Company (PRIDCO), the National Oceanic and Atmospheric Administration (NOAA), and the National Marine Fisheries Service (NMFS).

Due to the overwhelming support the project received from government, academic and public sectors in Puerto Rico, Snapperfarm and RSMAS anticipated a short permitting process. However, a number of extrinsic factors such as elections, holiday season and a new government taking office delayed the process, suggesting that timing of the permit application's submission was inappropriate. The project is currently being supported by the new government and Snapperfarm and RSMAS are once again anticipating a short permitting process.

The criteria and methodology used for site assessment and the feasibility study, the selected site, the progress, and constraints faced prior and during permitting and project development are presented and discussed in this paper.

Keywords: offshore cage aquaculture, mutton snapper, *Lutjanus analis*

Oral Presentation: Candidate Species and Logistics/Operations

HABITAT VALUE OF COMMERCIAL OYSTER CULTURE GEAR IN TOMALES BAY, CALIFORNIA

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Oyster growers in Tomales Bay, California, use a variety of culture systems to produce deeply cupped single oysters for the half shell market. Oyster farms use a variety of intertidal culture systems including high density polyethylene (HDPE) plastic mesh socking attached to PVC stakes, on-bottom and floating HDPE plastic mesh bags, and HDPE plastic mesh bags fastened to rebar racks which support the bags approximately 20 cm off the bottom.

This oyster culture gear and the oysters that are grown form a complex three dimensional habitat that interacts in a variety of ways with the biological and physical components of the estuarine ecosystem. One of the most significant of these interactions is the water filtration that occurs as bivalves filter food resulting in a transfer of phytoplankton and other suspended organic material from the water column to the sediments beneath the oysters through deposition of feces and pseudofeces. There is also removal of phosphorous and nitrogen from enriched waters as these compounds are incorporated into shell and tissue, and ultimately are removed from the ecosystem. In addition to these interactions influencing water quality and nutrient flow, assemblages of cultured oysters provide complex three dimensional habitat that is utilized by a myriad of fish and invertebrates. Often these invertebrates are prey species for larger commercially important fish and crabs, such as halibut or dungeness crab. These organisms are also prey species for juvenile coho salmon, and the population of threatened coho in Lagunitas Creek at the headwaters of Tomales Bay is thought to comprise ten percent of all the remaining coho in California.

In an effort to document the utilization of this complex habitat created by oysters and associated culture gear, 36 culture bags were collected after being enclosed in fine meshed screen and the fish and invertebrates occupying the bags were then collected and separated. All macroorganisms were enumerated and identified to species. Ten Phyla and 11 Classes were represented in the 51 different species identified. One oyster culture grow-out bag held over 5000 organisms, although more typically between 600 to 1,000 individuals were found in each bag.

In Tomales Bay approximately eight percent of the intertidal and sub-tidal bottom lands are leased for shellfish culture by the State Lands Commission through the Department of Fish and Game. Of this eight percent, around two percent is actively farmed. While this represents a small portion of the Bay, it is highly productive and provides complex intertidal habitat that has been lost in many areas due to erosion and resulting sedimentation. Additional work is planned to confirm the extent to which fish utilize areas adjacent to active aquaculture leases and how the productivity of habitat created by cultured oysters influences higher trophic levels.

Keywords: environment, shellfish, impacts

Poster Presentation

OFFSHORE CULTURE OF THE PACIFIC THREADFIN *Polydactylus sexfilis* IN HAWAII: RESULTS OF THE HAWAII OFFSHORE AQUACULTURE RESEARCH PROJECT (HOARP) PHASE II.

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NOAA and the National Sea Grant Office have identified demonstration of the feasibility of offshore aquaculture in the United States as a top priority to address issues of sustainability of U.S. fisheries. HOARP is a joint research effort between the Oceanic Institute (OI) and the University of Hawaii Sea Grant College Program, in partnership with state governmental agencies, commercial farmers, and seafood processors. The ultimate goal of HOARP is to provide a scientific basis for evaluation of the biological, environmental, and economic feasibility of offshore aquaculture in the Pacific region. HOARP Phase I sought to combine newly developed sea cage designs from Ocean Spar Technologies, Inc. of Washington with technologies of Pacific threadfin mass culture and fish management developed by OI. Phase I successfully demonstrated the technical feasibility of raising and harvesting large numbers of fish in an offshore containment structure under completely submerged conditions. Phase II addressed issues to increase final harvest density, improve feed utilization, lower harvest size variability, and expand environmental monitoring efforts. Phase II also addressed the economics of production.

Monthly growth of fish raised in a single 2,600m^3 Sea Station™ offshore during Phase II paralleled that of siblings raised in triplicate, onshore reference tanks at similar biomass densities (Figure 1). Peak biomass before harvest at 235 days of age offshore (mean wt. = 417.7 ± 33.0 g) was 12.1 kg/m^3, double that achieved during Phase I. The overall feed conversion ratio offshore (2.4) was higher than that achieved in onshore tanks (1.3 ± 0.1) at the end of

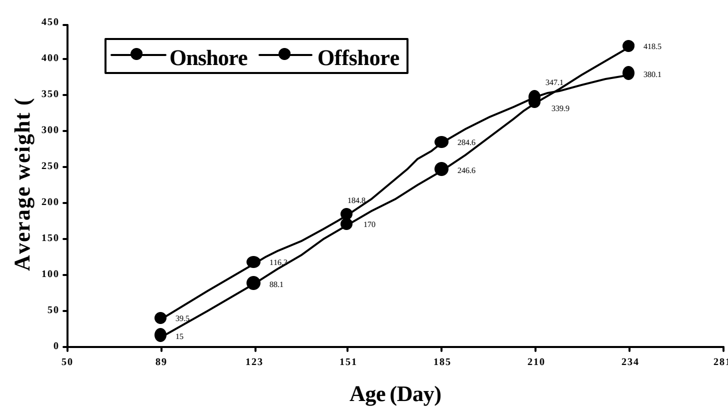

Figure 1. Growth of Pacific threadfin (*Polydactylus sexfilis*) in a 2,600 m^3 SeaStation™ and in 10 m^3 Tanks Onshore

the trial. Overall recovery of fish offshore (57.5%) was lower than that achieved onshore (90.2 ± 0.5%) owing largely to unaccounted losses. Harvested fish fell into a normal bell-shaped distribution with 66.9% of the fish falling into size classes ranging from 400 – 899 g.

Total ammonia levels measured near peak biomass and directly downstream from the cage four hours after initial feeding of the day tended to increase slightly from upstream levels and began to dilute 15 m from the cage edge (Figure 2). There were no discernable trends in total phosphorous, chlorophyll A, turbidity, and total dissolved solids in weekly or quarterly samples. The polychaete, *Ophryotrocha*, became more abundant in the benthos directly underneath the cage than at control sites indicating a community response to increased organic load. The cage also acted as a fish aggregation device sustaining approximately 800 kg of resident species near the end of the trial. Improved economic outlook of Pacific threadfin culture offshore requires increased offshore nursery survival and final harvest density, and lowered feeding costs.

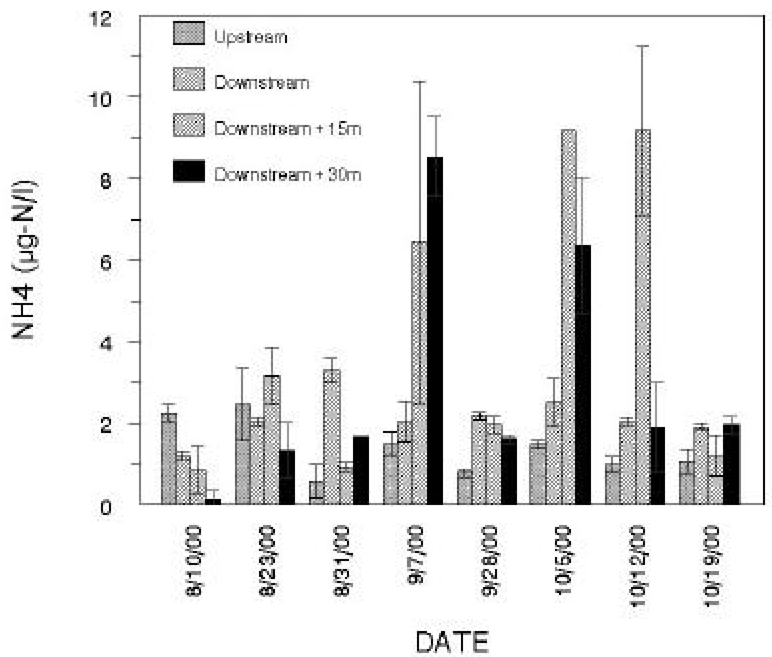

Figure 2. Total ammonia concentrations measured from upstream through 30 m downstream of a 2,600 m^3 Sea Station™ with 31,460 kg of Pacific threadfin.

Keywords: offshore, cage culture, Pacific threadfin

Oral Presentation: Candidate Species and Logistics/Operations

ECONOMIC POTENTIAL OF OFFSHORE AQUACULTURE IN THE GULF OF MEXICO

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By using a hypothetical enterprise budget model, economic potential of offshore aquaculture of finfish species in the Gulf of Mexico was evaluated. A base model was created from current information on offshore grow-out technology, biology of suitable species, costs of inputs, and ex-vessel fish prices. The hypothetical offshore fish farm consists of offshore support facilities and Ocean Spar Sea Station cages. Facilities will serve as offshore quarters for the crew and storage for feed and supplies. The 3000-m^3 cages will be deployed in offshore waters, at least 25 m deep, and expected to have a stocking density of 25 kg/m^3 of market-size fish. Two service boats will be used at the offshore farm for daily operations, maintenance, and harvesting. A supply boat and crew will be hired to allow regular crew changes and transport fingerlings, supplies, and marketable fish. Initially, fingerlings will be purchased from commercial nurseries located within the region. Slow sinking feed will be bought in bulk from nearby commercial feed manufacturing plants. A harvesting crew will be eventually employed to harvest fish from the cages on a regular basis. Office staff housed in a building sited on a 2-acre lot will undertake initial marketing of fish.

The hypothetical offshore fish farm will require an initial fixed investment of $3.40 million—$2.00 million for offshore support facilities, $0.96 million for six cages/moorings and net cleaners, $0.33 million for land and onshore support facilities, and $0.10 million for service vessels. Presently, provisions for costs of the permitting process and environmental monitoring were not included in the model. An operating capital of $1.63 million will be needed to finance repair and maintenance, fuel and oil, fingerlings, feed, labor, supply boat and crew, harvesting and hauling, liability insurance and miscellaneous expenses. Given the assumptions used in the base enterprise budget model, an estimated 0.45 million kg, harvested size of 3 kg/fish, can be produced per 9 month offshore grow-out cycle. Estimated average cost of production will be $6.25/kg, consisting of $4.02 and $2.23/kg average variable and fixed costs, respectively. The major cost items will be feed and labor for operations (Figure 1), and depreciation for fixed costs (Figure 2). At an ex-vessel price of $6.61/kg whole, fresh on ice, net return will be $0.16 million or $0.37/kg.

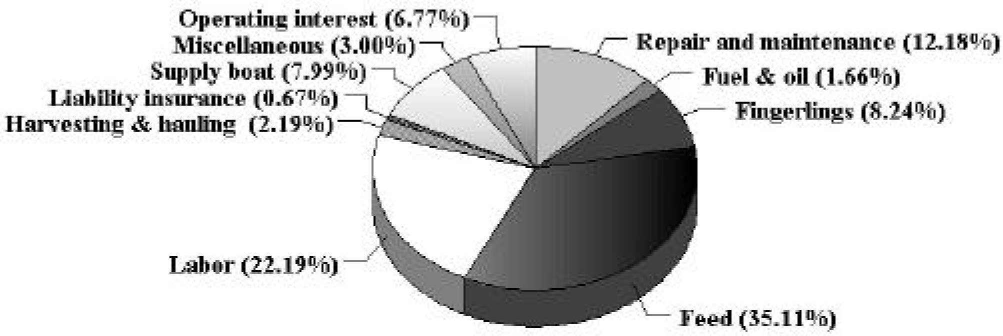

Figure 1. Variable costs associated with operating an offshore aquaculture enterprise in the Gulf of Mexico.

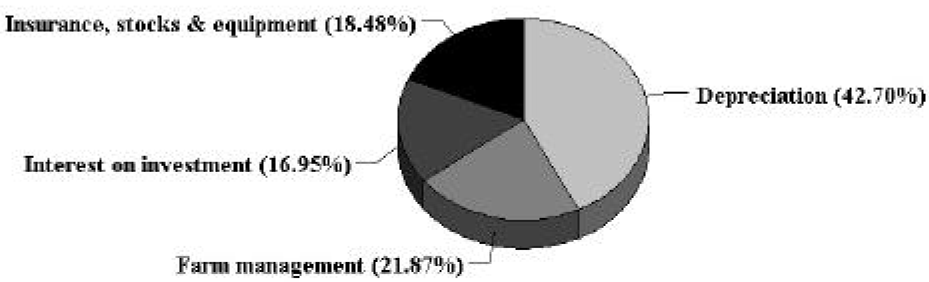

Figure 2. Fixed costs associated with operating an offshore aquaculture enterprise in the Gulf of Mexico.

Keywords: offshore aquaculture, grow-out, economics, marketing

Oral Presentation: Marine Policy and Social/Economics

POTENTIAL SPECIES FOR OFFSHORE CULTURE: LARVAL REARING OF THE RED HIND GROUPER *Epinephelus guttatus* UNDER HATCHERY CONDITIONS

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One of the most abundant grouper species reported in Puerto Rico and St. Thomas is the red hind *Epinephelus guttatus*. However, there is evidence that it is being overexploited. Past studies involving grouper species have focused on demographic analyses, migration patterns, and reproduction to improve fisheries management techniques. Production of red hind fry and fingerlings will permit initiation of programs for stock enhancement to assist the recovery of wild stocks and provide a suitable species for large mariculture operations with high economic potential in the Caribbean. The red hind *Epinephelus guttatus* and other grouper species form large spawning aggregations during December to February each year in tropical regions. The lowest water temperature and shortest days of the year characterize this period.

Larval production of red hind by hormone induction under hatchery conditions was evaluated in three different trials. The first trial determined optimal dosage of human chorionic gonadotropin hormone (HCG) to induce spawning. The second trial evaluated the effect of photoperiod on maturation and spawning of broodstock. The last trial determined maturation and spawning success of broodstock induced with HCG under optimal water quality conditions (water temperature, photoperiod, and nutrition). Each trial was made in 283 L fiberglass tanks and 60 L glass aquariums.

The first trial was performed from February 7-20, 2000 with three females averaging 860 g and two males averaging 1130 g of body weight that were injected with only one dose of HCG. Females received 450, 650, and 950 UI/g of HCG, respectively, and all males received 800 UI/g of HCG. After injection, broodstock were observed in courtship and spawning began after 60 hours in each of the female broodstock. Thus 450 UI/g of HCG was sufficient to induce gonadal maturation and spawning of broodstock. The second trial was performed from August 1 to September 20, 2000. This photoperiod simulated the remaining months for optimal maturation (December – February) with 9 days representing each month. After 45 days, no external changes were observed in broodstock. They were injected twice at 0 and 24 hours on September 7 and 8, 2000. Injection did not induce maturation, thus implying photoperiod did not provide enough stimuli to influence gonadal maturation. The third trial was made during the optimal maturation period from February 14 to 22, 2001. Nutritional aspects of the broodstock, photoperiod and temperature were optimal. During this trial gonadal maturation and spawning were successful and subsequent fertilization of the ova were reached after 48 h of hormonal injection.

Development of fertilized eggs and larvae were observed during several days to characterize ontogenetic development of the larvae (Figure 1). The eclosion of ova and larval development were delayed at lower temperatures. Eclosion of larvae at 27ºC occurred at 24 h after fertilization, while eclosion at 24ºC occurred over a six-hour period (from 30-36 h). The most important factors determining success of gonadal maturation and spawning of *Epinephelus guttatus* were water temperature and photoperiod. Nutritional aspects need further study.

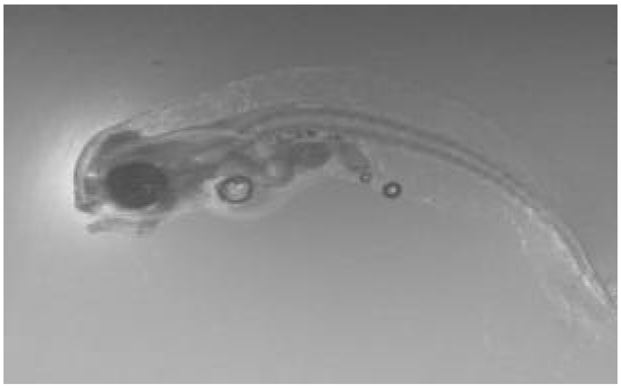

Figure 1. Red hind grouper larvae 96 hours after fertilization.

Keywords: gonadal maturation, hormone induction, photoperiod

Poster Presentation

DESIGN, CONSTRUCTION AND TESTING OF THE UNIVERSITY OF NEW HAMPSHIRE FEED BUOY

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Many factors point to Open Ocean Aquaculture (OOA) as the future of the seafood industry. It is well known that while wild stocks of many ocean species are declining, seafood demands continue to increase. At the same time, inshore aquaculture facilities are in competition with a growing coastal population and are under environmental impact scrutiny. However, before aquaculture is able to become a solution for some of these issues, it needs to become economically feasible. Many technologies need to be developed in support of OOA, each being vital to the survival of the industry. One of these technologies includes development of reliable feeding systems. Without automatic feeding, frequent trips to an open ocean site is non-economical and often not possible in adverse weather. Implementation of automatic and/or remote feeding systems also has the advantage of feeding regularly; helping to increase growth rates while decreasing feed waste.

The University of New Hampshire (UNH) is currently conducting an OOA Demonstration Project 7 miles off the coast of New Hampshire. Two mooring systems and Ocean Spar Sea Station are deployed and operational at the permitted site. Sea Stations, as well as some other cage designs, have the ability to submerge for subsurface operation. Introducing feed to a submerged cage requires that the feed be kept at the cage, or at the surface with some delivery system to the cage. Since keeping feed at the cage requires a complex mechanism to avoid flooding and restocking feed, UNH approached the design of a feed system as an automatic surface system.

The concept introduced in this poster includes a feed mechanism and hopper placed inside a buoy that maintains feed above the water line. Feed is metered out by a timing mechanism and dropped into a chamber where is it mixed with water. The resulting slurry washes down a pipe through the middle of the buoy to a feed delivery mechanism.

The feed system consists of a spar shaped buoy constructed from aluminum, ranging from 1.7 meters to 0.6 meters in diameter and 5.3 meters long (Figure 1). UNH Engineers designed the main structure of the buoy and tested system dynamics using a numerical model. After construction by Stommel Fisheries, the buoy hydrostatics was tested in an engineering tank facility at the Jere A. Chase Ocean Engineering Laboratory. The system was then deployed at the OOA demonstration site, and attached to one of the Ocean Spar Sea Stations for field testing and observation.

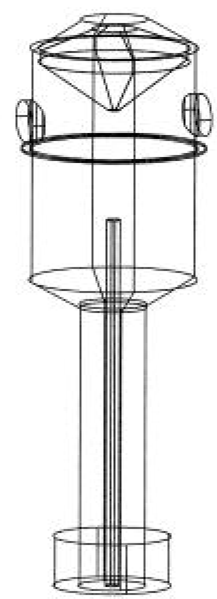

Figure 1. The buoy is made of aluminum, and shows the shell with the feed pipe and hopper.

Keywords: open ocean aquaculture, feed systems, automatic feeders

Poster Presentation

KNOWLEDGE, RELEVANCE AND ATTITUDES TOWARDS OPEN OCEAN AQUACULTURE IN NORTHERN NEW ENGLAND: A COMPARISON OF DATA FROM FIVE SAMPLE SURVEYS

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Development of a significant and sustainable marine aquaculture industry in Northern New England is largely dependent on the ability of coastal resource managers and planners, aquaculturalists, and the scientific community to design and develop the marine aquaculture industry in such a way as to represent the interests and values of a variety of "publics". To fully represent these interests, there is a need for scientific data that allows for an understanding on similarities and differences between various "publics" who have the potential to be positively or negatively impacted by development of open ocean aquaculture (OOA). These sample surveys measured respondents' self-reported knowledge of OOA, perceptions of personal relevance of OOA, and attitudes towards OOA. Results of this study will provide decision-makers, the fishing industry, and the aquaculture industry with information from the perspective of a variety of New England "publics" to include seafood consumers, commercial fishermen, coastal residents and tourists. Additionally, results will provide insight on whether or not knowledge and relevance influences attitudes towards OOA.

The purpose of this paper is to summarize results from sample survey research collected from relevant populations in Northern New England. More specifically, objectives of this research are: to document the extent respondents consider themselves to be knowledgeable about OOA; to specify personal relevance or importance of OOA for the respondents; to measure respondents attitudes towards OOA; and to examine influence of knowledge, personal relevance of attitudes towards OOA.

This paper utilizes data collected in five sample surveys (a sixth sample survey is currently underway that will be collect similar data from a random sample of marine recreational fishermen and will be included in the full paper). Data were collected from 1998 to 2000 from five different sample populations. The five sample populations included commercial fishermen owning vessels from 25' to 55' in length (n=183), tourist who took a whale watch or excursion boat or education cruise (n=360), coastal residents (n=753), persons participating in a seafood taste test experience (n=200), and persons attending the Hampton Beach Seafood Festival (n=295). Sample surveys employed a variety of methods including a mail questionnaire, telephone, and personally administered surveys. Each sample survey included a common set of questions as well as a series of questions unique for each survey sample population. This paper focuses on three sets of questions. The first set of questions measured personal relevance through a series of four questions. The second question measured self-reported

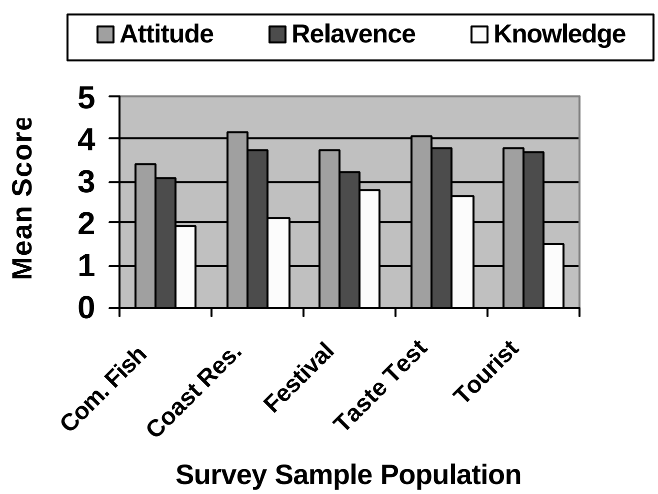

Figure 1. Results from Survey Samples

knowledge (e.g. How knowledgeable are you about marine aquaculture?). The third set of questions measure attitudes towards OOA through a standard set of three questions measuring various attitude dimensions.

Results suggest that all five sample populations have a favorable attitude towards OOA (1=low and 5=high). OOA is relevant to a majority of respondents in each of the survey samples (1=low and 5=high). A majority of each of the samples had minimal self-reported knowledge of OOA. The explanatory power of knowledge and relevance variables varied across survey sample populations (Figure 1).

Keywords: OOA, survey research, policy

Oral Presentation: Marine Policy and Social/Economics

THE USE OF MATHEMATICAL MODELS BY THE REGULATOR TO SUPPORT THE SETTING OF LICENSES OF MARINE DISCHARGES FROM THE CAGE FISH FARM INDUSTRY

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The Scottish Environment Protection Agency (SEPA) is the environmental regulator in Scotland responsible for licensing all discharges to controlled waters, which includes coastal waters. For marine aquaculture, which is principally based on Atlantic salmon (*Salmo salar*) raised in cages, this translates into a licence for the discharge of waste feed and faeces (set as a maximum stock biomass limit) and mass of chemotheraputents used for disease control.

To support SEPA in setting these licences a methodology has been developed through which mathematical models can be used to advise on limits for consent applications. The regulatory framework requires calculation of consent parameters on a site-specific basis. These cover the major chemical therapeutants, both those released in a dissolved and solid phase, and may be extended to cover benthic impacts of biomass. To facilitate this, SEPA has developed suitable modelling standards in tandem with practical predictive models which can be run on limited site-specific data and information normally available.

The paper outlines the Scottish regulatory framework, thinking behind SEPA's philosophy, types of models and standards developed, and looks at the advantages and disadvantages of the system for both the regulator and fish farmer. Finally, the way forward for future development is investigated including options of moving further offshore and thus reducing impact in the coastal zone, or greater use of technology to reduce emissions and waste entering the environment.

Keywords: aquaculture wastes, regulation

Oral Presentation: Marine Policy and Social/Economics

IONIC AND HEMATOLOGICAL CHANGES IN THE SUMMER FLOUNDER (*Paralichthys dentatus)* ASSOCIATED WITH THEIR MOVEMENT FROM A RECIRCULATING SYSTEM HATCHERY TO AN OCEAN NET PEN.

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To determine changes in blood chemistry associated with transfer of summer flounder (*Paralichthys dentatus*) (320-480g) from an enclosed recirculating system to an open ocean environment, 300 hatchery-reared fish were sampled during a 20 day period. Fish were transferred in progression from a recirculating seawater system ($22^0/00$, 22.5^o C) to a flow-thru seawater system ($31^0/00$, 20^o C), to three small coastal net pens ($33^0/00$, 15.5^o C), and finally to a large open ocean net pen ($33^0/00$, 16 ^{o} C). For this study, eight random fish were anesthetized (MS222) and bled from the caudal vein (2ml) at each progressive step (environmental condition). Transferred flounder were bled every 12 hours for 48 hours to collect plasma cortisol and glucose samples. Fish were bled every three days thereafter for osmolarity, hematocrit (Hct), hemoglobin concentration ([Hb]), mean corpuscular hemoglobin content (MCHC), glucose, cortisol and the electrolytes Cl, Na, K and Ca. Following acclimation, fish were transferred to the next condition in the series and bleeding schedule resumed. The most significant perturbations to blood chemistry ($p < 0.05$) occurred within 24 hours of initial transfer from the re-circulating to flow-thru seawater systems. Hematological parameters fluctuated then recovered to a new steady state level after six days in the flow-thru seawater system. Initial transfer produced the most profound effect on MCHC, Hct and [Hb] as a 20%, 27% and 41% increase in their respective concentrations occurred. A less profound but still significant increase occurred in plasma osmolarity (5%), and the major plasma ions sodium (5%) and chloride (7%). Plasma cortisol and glucose concentrations displayed decreasing, yet insignificant, trends after initial transfer.

Movement of fish to the coastal pens produced statistically insignificant declines in Hct and [Hb] and insignificant increases in MCHC. Likewise, the measured ions were not significantly changed in the new environment. However, transfer from the flow-thru system to coastal net pens produced significant increases in initial plasma cortisol levels, suggesting a high level of stress associated with this particular fish transfer (Figure 1; arrows denote movement of fish). Glucose levels increased, but were not significantly different from the previous values.

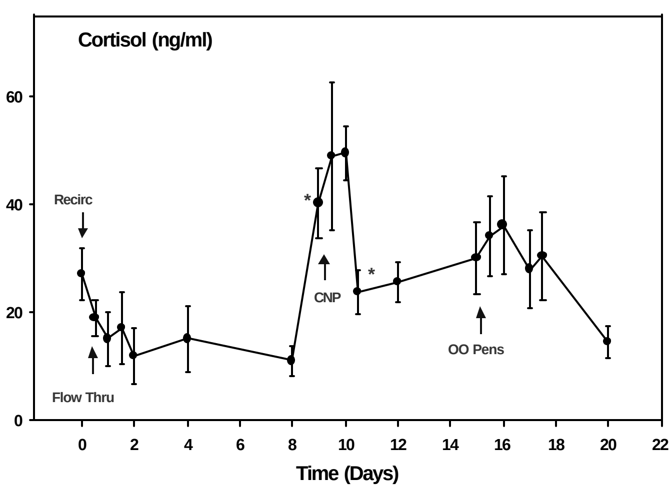

Figure 1. Plasma cortisol as a function of flounder movement

Movement of fish to the open ocean pens produced statistically insignificant changes in Hct, [Hb], and MCHC. Measured ion concentrations were not significantly changed in the new environment but did show increasing trends. Transfer from coastal to open ocean net pens elicited increases in initial plasma cortisol and glucose levels. While not significant, these results suggest an increased stress level associated with extended fish transfer (Figure 1).

In summary, transport from the recirculating (22^0/00, 22.5^o C) to the flow-thru seawater system (31^0/00, 20^o C) produced the most significant perturbations to flounder blood chemistry. Results suggest a minimum of six acclimation days is needed before blood properties reach new steady state levels and a new fish transfer can safely commence. Transfer to coastal and open ocean net pens produced increases in initial plasma cortisol and glucose levels, suggesting a high level of stress associated with extended fish transport.

Keywords: flounder, physiology, open ocean aquaculture

Oral Presentation: Candidate Species and Logistics/Operations

FINITE ELEMENT SIMULATION TO PREDICT THE DYNAMIC PERFORMANCE OF A TENSION LEG FISH CAGE

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The need for developing an offshore aquaculture industry in the waters off the coast of New England has resulted in the establishment of a demonstration site in 52 meters of water south of the Isles of Shoals, New Hampshire. The engineering component of this project involves deployment, support and performance analysis of various fish cage systems capable to survive the harsh conditions offshore and provide a suitable environment for the selected fish species. Development of an adequate computer simulation tool is needed to analyze the dynamic behavior of fish cages in the open ocean environment.

In the presented research, finite element analysis (FEA) is used to predict the dynamic response of a tension leg fish cage to regular and extreme environmental loading conditions. The regular loading condition for the site consists of a 1.2 meter wave and tidal component of the coastal current which is estimated to be 0.25 m/s. The extreme loading condition consists of a nominal 9 meter wave (with a period of 8.8 seconds) and a current which is set to change linearly from 1 m/s on the surface to 0.25 m/s near the bottom.

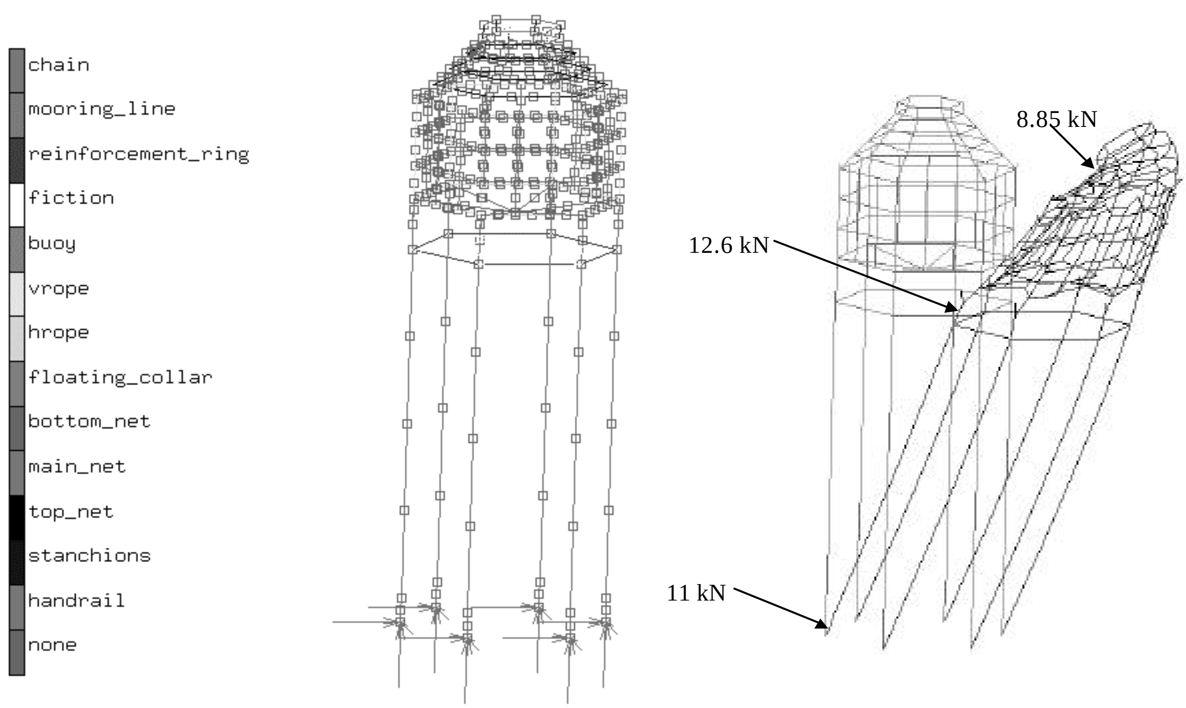

Figure 1. Finite element model of the tension leg fish cage and some values of tension for the extreme loading conditions.

FEA simulations were performed using *Aqua-FE* computer program developed at UNH. This program is an advanced computer design and analysis tool to model the dynamic response of completely or partially submerged structures in an ocean environment. Dynamics of the cage motion and forces in the mooring system and various cage components were investigated. The finite element model of the tension leg fish cage and some values of tension for the extreme loading conditions are presented in Figure 1. It was shown that the system is capable to withstand the exposed demonstration site conditions. Based on the simulations, several suggestions on the choice of cage component parameters and ground tackle selection were made.

Keywords: open ocean aquaculture, tension leg fishcage, computer simulations

Oral Presentation: Ocean Engineering

Notes