Final Report

Development of Commercially Viable Aquaculture Industries in New England Based on Cod and Haddock

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Introduction

Groundfish populations in the western North Atlantic and Gulf of Maine have declined dramatically over the last several years. This has resulted in an economic crisis for many commercial fishers, and a scarcity of product for market. Aquaculture has the potential to provide both high quality, fresh fish to the market, and career opportunities for displaced commercial harvesters. Two of the most prominent candidate species for commercial aquaculture in the Northeast U.S. are cod (Gadus morhua) and haddock (Melanogrammus aeglefinus). There is an long history of cod aquaculture in Norway, and many of the techniques used are transferable to New England. Although haddock have never been grown to harvestable size, their close relationship with cod suggests that much of what has been learned for cod will be applicable to haddock. Further, haddock have a high market value which makes them an attractive candidate for aquaculture.

The major biological impediments to the development of successful cod and haddock aquaculture industries in New England include lack of information on broodstock collection and management, larval rearing systems, and first-feeding, weaning and juvenile diets. In this proposal we developed a coordinated research project designed to facilitate the development of cod and/or haddock aquaculture industries in New England.

Objectives

To foster and facilitate development of commercial culture of cod and haddock in New England, we proposed a project with the following objectives:

1) To maintain a cod broodstock to supply eggs for researchers in this project.
Excess eggs would be made available to interested researchers and commercial producers in the northeast U.S. and Canada.

2) To develop a haddock broodstock and determine the conditions necessary for maximum survival and spawning success.

3) To determine if the spawning period/duration of cod can be altered by photoperiod manipulation.

4) To investigate the use of temperature manipulation for delaying development of cod embryos. Similar to Objective 3, the goal was to increase the period of embryo availability.

5) To assess the suitability of commercial formulated feeds for juvenile cod.

6) To develop four types of microparticulate diets for early weaning of cod larvae.

7) To determine the earliest stage of development that cod larvae are able to accept and digest four types of microparticulate diets.

8) To determine the effect on growth of four types of microparticulate diets introduced at three different developmental stages.

9) To determine the effect on growth and survivability of different ratios of docosahexaenoic acid (DHA) to eicosapentaenoic acid (EPA) in a microparticulate weaning diet for cod larvae.

10) To determine if the type and level of lecithin in the diet affects growth and survival of cod larvae.

11) Test two different start-feeding diets (cultured vs. wild food), and determine how they effect larval growth and survival.

12) Test two different larval culture systems (tanks vs large polyethylene bags), and determine which system promotes the best growth and survival.

13) Determine the efficacy of feeding local, wild zooplankton to first-feeding cod larvae.

Results

Objective 1. This objective was fully met. Techniques for collecting, holding and manipulating
broodstock, and prolonging embryological development were developed. A cod broodstock was maintained through the duration of the project and millions of eggs were obtained. Production of embryos and larvae occurred nearly year-round, and these were distributed to project investigators, as well as to a host of other scientists in both the US and Canada. The value of this broodstock, which is the only one in the US, cannot be overestimated, particularly in light of new research initiatives (e.g. the UNH Open Ocean Aquaculture program).

Objective 2. This objective was fully met. A haddock broodstock was acquired in the first year, and maintained through the duration of the project. The broodstock produced eggs between December and May. Egg diameter was largest during the middle of the spawning season when water temperature was at a minimum. An inverse relationship was observed between egg diameter and water temperature in both species. Egg quality was high, as evaluated by buoyancy, fertilization rate, regularity of early cleavage, and percent viable hatch. As with the cod, millions of eggs were obtained and widely distributed each year.

Objective 3. This objective was fully met for both cod and haddock. Atlantic cod (Gadus morhua) and haddock (Melanogrammus aeglefinus) broodstock were maintained under altered regimens of temperature and photoperiod, and were stimulated to spawn up to 7 months per year. Cod broodstock produced viable embryos from October through June and haddock broodstock produced viable embryos from December through May.

Objective 4. This objective was fully met for both cod and haddock. Low temperature incubation of cod and haddock eggs extended the embryonic period. Cod embryos were found to be very tolerant to low temperature, hatching in 59 days at -1°C. Cod embryos incubated at 1°C hatched in 38 days, and were shown to be comparable in quality (viability) to eggs incubated at 6°C that hatched in 14 days. In a separate experiment, embryos were incubated through hatch at either 1°C or 6°C, and the larvae from both groups reared at 6°C. Growth and early survival of larvae were comparable in both treatments. Haddock embryos were not nearly as tolerant to low temperature incubation. High mortality (>90%) was observed prior to hatching in haddock embryos incubated at 1°C.

Objective 5. This objective was fully met. Several commercial diets were evaluated. Diets with high protein and low lipid levels were found to promote the best survival and growth.

Objectives 6 through 10 - The critical problems of developing and testing feeds for all of the early life-history stages were addressed in a series of experiments. They were designed to develop a
feeding regime that would enable the production of commercial-scale quantities of juveniles that could be transferred into grow-out systems. Although not part of the original research plan, experiments were first conducted to develop a protocol for the intensive culture of cod using a recirculation system with artificial seawater. Two studies investigated the effect of larval stocking density on survival and growth of cod larvae. Stocking densities (50-300 larvae/L) were higher than previously reported and no significant differences in survival, length, or dry weight were detected through 36 days-post-hatch (dph) when food was not limiting. However, there is greater risk of mortality at the highest density (300 larvae/L) because water quality parameters can rapidly deteriorate with the high feeding levels required to maximize larval growth rates. Next, the effect of continuous motion within the larval rearing tank was investigated. Survival was significantly higher when high motion was used (29.2%) compared to tanks with low motion (8.7%). Through repeated trials, we also confirmed that cod larvae could be cultured through metamorphosis without the use of "green water", which alleviates the need for fresh algae cultures.

Once an intensive rearing protocol was established, weaning trials were conducted to determine how early a microparticulate diet (BioKyowa) could effectively replace live food organisms and support growth through metamorphosis (Objectives 7 and 8). A microparticulate diet was introduced on 8, 15, 22 and 29 dph. The larvae received only rotifers until weaning; a fifth treatment was offered Artemia for 10 days and weaned at 29 dph. The microparticulate diet was able to completely replace live prey long before metamorphosis and larvae were weaned by 8.5 mm standard length. With the earliest introduction of the microparticulate diet on 8 dph, we observed 35% survival through 71 dph (21 mm). Survival of larvae from the other treatments was not significantly different and ranged from 33-39%. Weaning time did not have a significant effect on growth of cod larvae. However, supplementation of Artemia for 10 days had an immediate and significant effect on growth compared to the larvae receiving the microparticulate diet without Artemia.

A weaning trial was conducted to investigate the effectiveness of experimental microparticulate diets (micro bound and micro coated) with and without lipid-walled capsules. The experimental diets were compared to the commercial (BioKyowa) diet and a live food control. The diets were evaluated by measuring physical parameters of the diet in the water column (leaching and settling rate), palatability of the diet (intestinal fullness), performance of the diet (survival and growth), and digestibility of the diet (histological examination of the diet in the larval intestine). Survival to 39 dph ranged from 5-10% with the experimental diets, 22.9% with the BioKyowa diet, and 36.5% with live prey. Histological examination suggested that all the diets were digested and absorbed, but we were not able to provide quantitative data. Based on observations of intestinal fullness, the experimental diets appeared less palatable than the BioKyowa diet and resulted in higher mortality during weaning.

Although not part of the original research plan, two weaning experiments were conducted using larval haddock. Unlike cod, haddock did not wean effectively onto the commercial diet.
until 42 dph. Studies continue with haddock to determine the reasons behind the rejection of this diet. Histological and morphological evaluation of the digestive tract and associated organs of haddock were made from hatching until day 64.

Objectives 9 and 10 were not completed because of the lower palatability of the experimental diets. Current studies are investigating ways to improve consumption of these diets.

Objectives 11-13. Cod larvae were cultured at the UNH Coastal Marine Lab. in each year of the project (1994-1998). A number of rearing techniques were tried, with varying degrees of success. In the first two years, eggs and larvae were incubated in small (30 liter) kriesels, held in temperature controlled water baths, and maintained under static conditions except for daily water changes. No green water (microalgae) was added. Success with this methodology was very limited, probably due to poor water quality. In subsequent years, we experimented with the addition of microalgae, with the use of larger tanks (300 liter), and with the use of flowing seawater, and found that these simple practices significantly improved our ability to rear larvae. Once we had the capability of routinely raising large numbers of larvae, we were able to undertake a number of experiments designed to meet the stated objectives.

Objective 11. An experiment was designed to test the hypothesis that there is no difference in growth and survival between first feeding cod larvae fed live, laboratory cultured diets (Isochrysis galbana, Brachionus plicatilis and Artemia salina nauplii) and those fed a diet of natural phytoplankton and zooplankton. Both the Artemia and rotifers were enriched with DHA Selco to improve their fatty acid profiles. Results of this experiment indicated that both live diet types promoted good survival over the first four weeks of feeding, and that differences in this response variable were not significantly different. Larvae fed wild zooplankton (primarily copepod nauplii) were, however, significantly larger after 4 weeks (about 40%), suggesting that wild zooplankton provided better nutrition.

Objective 12. An experiment was designed to evaluate the use of mesocosms to rear relatively large numbers of cod larvae. Two, 5 m³ mesocosms, modeled after those successfully in Norway, were designed, manufactured, and deployed near the UNH Coastal Marine Lab. A companion piece of equipment, designed to filter, size separate, and concentrate naturally occurring zooplankton was also built. It was capable of processing 150 gallons of seawater per minute, and collecting and storing 3 separate size classes of zooplankton (81-250, 251-500, and 501-1000 microns). It was deployed on the same dock as the mesocosms which contained the cod larvae, with the intention of feeding the various size fractions of concentrated zooplankton to the larvae. The mesocosms and the plankton concentrator were deployed in both 1997 and 1998, and yolk-sac stage cod larvae (n=25,000) were stocked in each mesocosm in each year. Feeding, sampling and experimental duration's were as described in the proposal. Results of these experiments were very
disappointing, in that we saw lower than expected survival and growth. The principal difficulty was that cod in our area spawn in May, June and July; a period when water temperatures are increasing rapidly. We found that by the time we had collected eggs at sea, and incubated them in the laboratory through hatching, that incubation temperatures in the mesocosms, which were by definition those of ambient seawater at the inshore, protected site where they were deployed, were too high (15-17°C). We believe, however, that the system is viable if it could be used earlier in the spring when water temperatures were cooler.

Objective 13. In association with the experiment used to meet Objectives 11 and 12 (above), we determined that using wild, locally collected zooplankton as a food source was a viable alternative for raising small numbers of cod larvae. Sufficient numbers could be collected each day, and there were no problems associated with naturally occurring toxic dinoflagellates.

Two other, related experiments were undertaken at UNH. The first was designed to determine if two types of live food which differed in size (Artemia nauplii and rotifers) effected the growth and survival of first feeding cod larvae. An equal mix of the two diet types (numerical basis) served as a third treatment, while starved larvae served as a control. Results of this experiment clearly showed that the smaller live food (rotifers) promoted the highest survival and growth, and that Artemia nauplii were ineffective (too large) as a first feeding diet. The second was designed to determine the suitability of three different, commercially available formulated diets for juveniles. It was undertaken because we were raising large numbers of juveniles, because we were informally trying a number of diets, and because the experiment would integrate well with the work being done by other researchers associated with the project. The three diets chosen were BioKyowa (manufactured in Japan), Ziegler (a U.S. company), and Moore-Clark (a Canadian manufacturer). The three diets were identical in particle size, and were fed in equal amounts, but they differed in both protein and fat content. Cod juveniles utilized were 95 days old at the start of the experiment (mean weight = 4g), and the experiment continued for 7.5 weeks. Results of the experiment found no significant differences in weights between treatments, but trends in the data make it likely that the Ziegler diet would have proven inferior had the experiment lasted slightly longer.

Graduate Students Supported:

Hamlin, H. 1998. The culture, weaning and histological analysis of the digestive tract and associated organs of larval haddock, Melanogrammus aeglefinus, throughout ontogeny. MS, Univ. of Maine.

Chatham, C. 2000 (anticipated). Factors influencing feed consumption of micro-particulate diets by Atlantic cod, Gadus morhua. MS, Univ. of Maine.

King, N.J. 1999. Fingerling production of summer flounder: commercial scale experiments studying hormonal manipulation of broodstock, larval stocking density, and weaning diet performance. MS, Univ. of New Hampshire.


This project also provided part-time support to the following students at the Univ. of Rhode Island: Robert Krauss (Fisheries, Animal and Veterinary Science), Steven Seretelli (Marine Biology), Amy Lapolla (Graduate School of Oceanography).

Related publications (completed and in progress):


Related Presentations:


Baskerville-Bridges, B. and L.J. Kling. Successful rearing of cod (Gadus morhua) larvae up to metamorphosis is a closed recirculating artificial seawater system at high stocking densities. Aquaculture Canada 96. 13th Annual Meeting of the Aquaculture Association of Canada, 2-5 June 1996.


Fairchild, E. and W.H. Howell. 1998. How important is the green crab, Carcinus maenas, as a predator of YOY winter flounder, Pseudopleuronectes americanus. Flatfish Biology Conference, Mystic, CT (abstract).


Professional Development:

Each year we trained as many as 10 undergraduate students at each institution to work on this project. Most of these students were majoring in either aquaculture, biology, marine science, natural resources or zoology. These students learned the techniques of rotifer and brine shrimp production, phtoplankton production, marine larvae feeding and maintenance, image analysis techniques, experimental design, data analyses, as well as recirculating seawater system technology.

Outreach or Industrial Impacts:

Results of this project, and others to which we have supplied embryos, have demonstrated that large-scale culture of cod and haddock is possible in North America. While there is still no commercial production of cod or haddock in the United States, the work that was supported by this grant allowed significant advancements to be made in both the larviculture of cod and especially of haddock. Completion of this project represents a significant step toward commercial aquaculture of cod and haddock. An outgrowth of this project has been the development of the
UNH Open Ocean Aquaculture demonstration project. While summer flounder were grown in the first year, cod and haddock will be grown in the second and third years. The same group of investigators will be involved with that work, and the techniques learned in this study will greatly benefit the next round of studies. As a direct result of the success we experienced with larviculture of haddock, a Canadian salmon aquaculture company, Connors Bros., is now moving towards commercialization of this species.
Project Title: Development of a commercially viable aquaculture industry in NE based on cod and haddock

Investigator and Institutions: Linda J. Kling, University of Maine, School of Marine Sciences

Start Date: 02/01/95 End Date: 01/31/98

Amounts: Year One: $61,915 Year Two: $49,933
Year Three: $50,348 Year Four: $162,196
Total Project Funding:

Status:

A. PUBLICATIONS:

1. Peer-reviewed publications


2. Published abstracts:


B. Baskerville-Bridges and L.J. Kling, 1996. Early weaning of cod (Gadus morhua) larvae onto a

3. Other publications and technical reports: none

4. Presentations at meetings:


5. Publications in progress: none

B. STUDENTS

Hamlin, Heather, Masters of Science, December 1998. Thesis title: The culture, weaning and histological analysis of the digestive tract and associated organs of larval haddock. This student received an assistantship funded by this project. This student is now employed by Mott Marine Laboratory as a research associate in their aquaculture division.

B. Baskerville Bridges, Doctor of Philosophy, May 1999. Thesis title: Studies on rearing and early weaning of Atlantic cod (Gadus morhua) larvae onto commercial and experimental microparticulate diets. This student's research work was supported by this project. This student is now employed by the University of CA, Davis as a post-doctoral student working on a project with Delta smelts.

Each year of this project we employed numerous undergraduate students to help with the care of the animals, to produce live food organisms, to measure water quality and to process sample analysis. Most of these students have now graduated but I do not know their current employment status.

C. TECHNICIANS, POST-DOCS AND OTHER PROFESSIONALS

none
D. RELATED GRANTS AND CONTRACTS

1. Other support:

Maine Agriculture and Forest Experiment Station, (MAFES)

2. Subsequent support received as a result of this project:

NOAA, Saltonstall and Kennedy, A study to investigate culture techniques to rear fingerling-sized Atlantic cod and larval/fingerling-sized haddock for use in production aquaculture and for use in a public restoration project to study the efficacy of restoring natural cod stocks in the Gulf of Maine. $477,773

NOAA, Sea Grant, Demonstration of net pen culture of haddock, cod and black sea bass, UM share, $100,000.

E. OTHER IMPACTS

I have receive several e-mails from people employed by industry requesting information on rearing and weaning protocols for cod and haddock.
Development of a commercially viable aquaculture industry in NE based on cod and haddock

Experiments were conducted to develop a protocol for the intensive culture of cod and haddock using a recirculating sea water culture system. We specifically identified the benefit of water motion during egg incubation and during the early larval stage for increased survival. High stocking densities were achieved without detriment to survival or growth. We also demonstrated that cod larvae could be cultured in recirculating seawater systems through metamorphosis without the use of green water. We have reported the earliest successful weaning of cod larvae onto a commercial diet using a live food co-feeding strategy. Early weaning of haddock larvae however was not successful and resulted in high mortality. Subsequent studies using a modified co-feeding strategy, however, has been more successful. We were only marginally successfully in developing an experimental microparticulate diet for early weaning of cod. Work is continuing in this area.