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Collaborative Research: Origins of Cods on Georges Bank: Contributions of Early Developmental Stages for the Scotian Shelf

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Project Participants

Senior Personnel

Name: Townsend, David
Worked for more than 160 Hours: Yes
Contribution to Project:
Principal investigator and project coordinator

Name: Kornfield, Irving
Worked for more than 160 Hours: Yes
Contribution to Project:
Co PI

Name: Kling, Linda
Worked for more than 160 Hours: Yes
Contribution to Project:
Co PI

Post-doc

Graduate Student

Name: Jordaan, Adrian
Worked for more than 160 Hours: Yes
Contribution to Project:
Graduate research assistantship

Undergraduate Student

Technician, Programmer

Other Participant

Research Experience for Undergraduates

Organizational Partners

Dalhousie University

NOAA National Marine Fisheries Service

Other Collaborators or Contacts

Richard Radtke of the University of Hawaii, and co-PIs on the U.S. Globec program (e.g., David Mountain of NOAA, Woods Hole).

Activities and Findings

Research and Education Activities:

Introduction:

Earlier work in the Georges Bank-Gulf of Maine by Globec investigators has shown episodic fluxes of Scotian Shelf Water (SSW) from the Nova Scotian continental shelf to Georges Bank. One such flux episode was observed in March of 1997 in satellite imagery and from shipboard hydrographic sampling on Georges Bank. Qualitative at-sea analyses of ichthyoplankton sampled on the March cruise revealed a remarkably tight association between abundances of gadid eggs and the distribution of SSW suggesting, along with other lines of evidence, that most of those eggs were spawned on the Scotian Shelf and were advected with the SSW water mass to Georges Bank. This observation raised a fundamental question: To what extent are cod on Georges Bank imported to the Bank as early development stages by advection from Canadian waters to the east?

We proposed to address the above question by performing retrospective elemental analyses of otoliths from archived larval cod samples, as well as of ichthyoplankton samples to collected in 1998 and 1999 as part of the regular Georges Bank Globec program. The otoliths were to be analyzed for Sr/Ca ratios. In addition, we proposed to assess the feasibility of determining the genetic identity of cod larvae relative to larval and adult populations from Georges Bank and from the Scotian Shelf, using nuclear DNA microsatellite techniques.

Our attempts to verify earlier work by our Canadian colleagues that suggested viable genetic markers for use in population analyses failed. This line of research, which included a subcontract to colleagues at Dalhousie University, was abruptly halted. Remaining funds were reprogrammed internally at the University of Maine to allow continued work with microsatelite markers with the hope of finding temporally stable markers for use in discriminating cod populations in the Scotian Shelf û Gulf of Maine û Georges Bank region.

The larval otolith work was based on laboratory rearing experiments at the University of Maine, where a new recycling sea water system was constructed with refrigeration units that allowed for controlled, replicate experimental rearing chambers for evaluating the effects of four temperatures (2, 4, 8 and 12?C), developmental stage, and differing feeding regimes on the Sr/Ca ratios in the otoliths. Following the rearing experiments, larvae were sent to the University of Hawaii and Dr. Richard Radtke's lab where he and Dr. David Shafer performed the electron microprobe analyses for elemental composition.

This grant provided support for a full-time UNiversity of Maine graduate student, Mr. Adrian Jordaan, who complted an M.S. thesis on the laboratory rearing work.

Findings: (See PDF version submitted by PI at the end of the report)

Training and Development:

Adrian Jordan has produced a M.S. thesis project based on our larval cod rearing experiments.

Outreach Activities:

Early ideas based on field collections of larval cod were presented at a meeting of fishing industry representatives, private foundations and members of the New England Fisheries Management Council in May 1999.

See also citations in section on 'Findings'.

Journal Publications

Callan, C., Jordaan, A. & L.J. Kling., "Reducing Artemia use in the culture of Atlantic cod (Gadus morhua).", Aquaculture 219(1-4): 585-595. , p. 585, vol. 219, (2003). Published

Thomas, A.C., D.W. Townsend and R. Weatherbee, " Satellite-measured phytoplankton variability in the Gulf of Maine", Continental Shelf Research, p. 971, vol. 23, (2003). Published

Books or Other One-time Publications

Townsend, D.W.,A.C. Thomas, L.M. Mayer, M. Thomas and J. Quinlan, "Oceanography of the Northwest Atlantic Continental Shelf Waters", (2004). Book, Accepted
Editor(s): A.R. Robinson and K. Brink
Collection: The Sea
Bibliography: Vol 14 Harvard Univ Press

Web/Internet Site

URL(s):

Description:

Other Specific Products

Contributions

Contributions within Discipline:

Jordaan, A. & L.J. Kling. The effects of temperature on vital rates of cod (Gadus morhua) during early?life histories. Accepted by: The Big Fish Bang: Proceedings of the 26h Annual Larval Fish Conference.

Jordaan*, A. & L.J. Kling 2001. Temperature induced changes of early life-history traits in Atlantic cod (Gadus morhua). Canadian Conference for Fisheries Research. Toronto, Canada.

Jordaan*, A., Callan., C & L.J. Kling 2001. Reducing Artemia use in the culture of larval marine fish: an experiment using Atlantic cod (Gadus morhua). Aquaculture Association of Canada Annual Meeting. Halifax, Canada.

Jordaan*, A., Hayhurst, S. & Linda J. Kling. 2001. The effect of temperature on early life-history traits of Atlantic cod (Gadus morhua) larvae. 25th Annual Larval Fish Conference. Sandy Hook, NJ, United States.

Jordaan*, A., Hayhurst, S. & Linda J. Kling. 2002. The consequences of temperature change for developing cod (Gadus morhua) larvae. Canadian Conference for Fisheries Research. Vancouver, Canada.

Jordaan, A. 2002. Elucidating the effects of temperature on the vital rates during the early life of cod (Gadus morhua). 26h Annual Larval Fish Conference. Bergen, Norway.

Contributions to Other Disciplines:

Contributions to Human Resource Development:

Contributions to Resources for Research and Education:

Contributions Beyond Science and Engineering:

Categories for which nothing is reported:

Any Product

Contributions: To Any Other Disciplines

Contributions: To Any Human Resource Development

Contributions: To Any Resources for Research and Education

Contributions: To Any Beyond Science and Engineering

Influence of Water Temperature on Strontium Inclusion in Otoliths of Laboratory-Reared Larval Atlantic Cod, Gadus morhua

Larval cod were hatched from eggs reared at a constant temperature, then transferred and reared for a variable number of days at 2°, 4°, 8°, and 12°C in seawater tanks at the School of Marine Sciences, University of Maine. Three different rearing trials were conducted. The first trial used artificial seawater, which did not have adequate concentrations of strontium. The next two trials used ocean water, and produced all the larvae used for this study. Larvae were reared to ages ranging between 9 and 39 days post-hatch. Larvae from different temperature treatments were not reared to the same ages because of high mortality at some temperatures. Mortality was especially high in the 12°C rearing treatment. This complication resulted in departure from the idealized experimental design of analyzing otoliths from same-age healthy fish. Most surviving larvae demonstrated poor growth rates.

Larvae were preserved in ethanol and shipped to the University of Hawaii. Standard length of larvae was measured (n=193) and the sagitta and lapillus were dissected and mounted onto glass microprobe stubs. Otoliths were ground to the approximate center and polished. Samples were chosen for trace element analysis based on several criteria including: 1) the preparation included a plane in the otolith from the core to the edge, and 2) the preparation produced a plane with a smooth surface (no cracks). In addition, the oldest individuals in each temperature category were preferentially chosen to maximize otolith size. The lapillus is larger than the sagitta in young cod larvae. After about 5-15 days post hatch, the sagitta grows larger than the lapillus and remains larger for the rest of life history. Because this work focused on young larvae, the lapillus was preferentially chosen for analyses.

Weight percentages of strontium (Sr) and calcium (Ca) were measured in otoliths using a wavelength dispersive electron microprobe at the School of Ocean and Earth Science and Technology, University of Hawaii. A beam size of 5μm was used to sample otoliths at the core

and at various sites along the edge. A typical design usually included one measurement at the core, and four measurements along the edge (at 0°, 90°, 180°, and 270°). In larger otoliths, two rings (Edge 1 and Edge 2) of sample sites were sampled (with 4 probe sites in each ring). Sr/Ca ratios from each site in a ring were averaged. Measurements were excluded from calculations if the measurement site was compromised by poor preparation or structure, or if the measurement

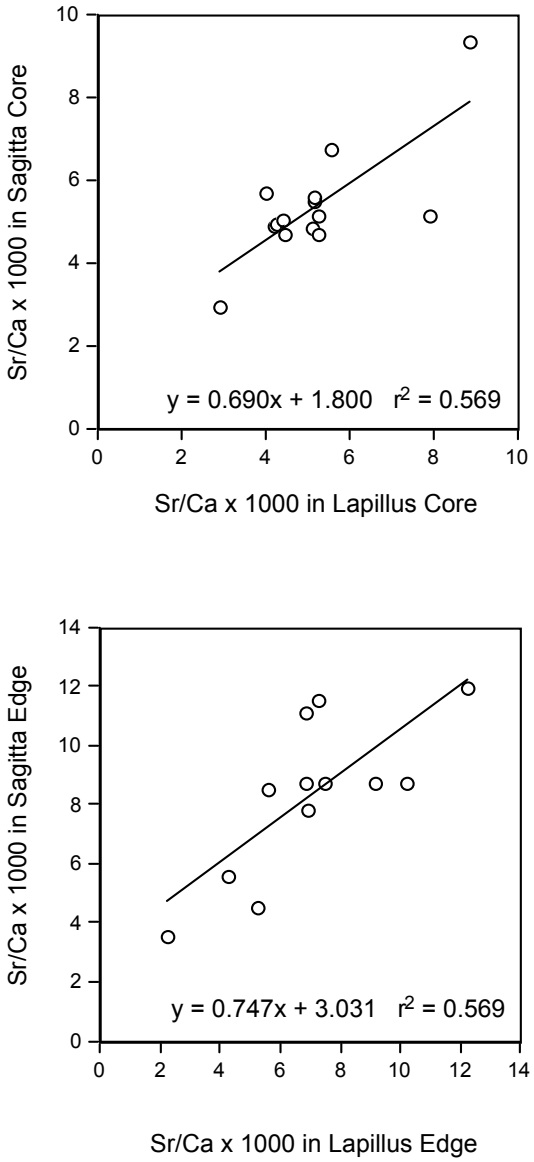

Figure 1. A (top panel): Comparison of Sr/Ca ratios in the cores of the sagetta and lapillus otoliths of larval cod; B (bottom panel): same but for the edge of the otoliths.

of % weight Sr was below the theoretical detection limit of the microprobe. Many otoliths were only sampled at the core and at one or two locations along the edge.

Sr/Ca ratios were variable within an otolith, among otoliths in the same individual

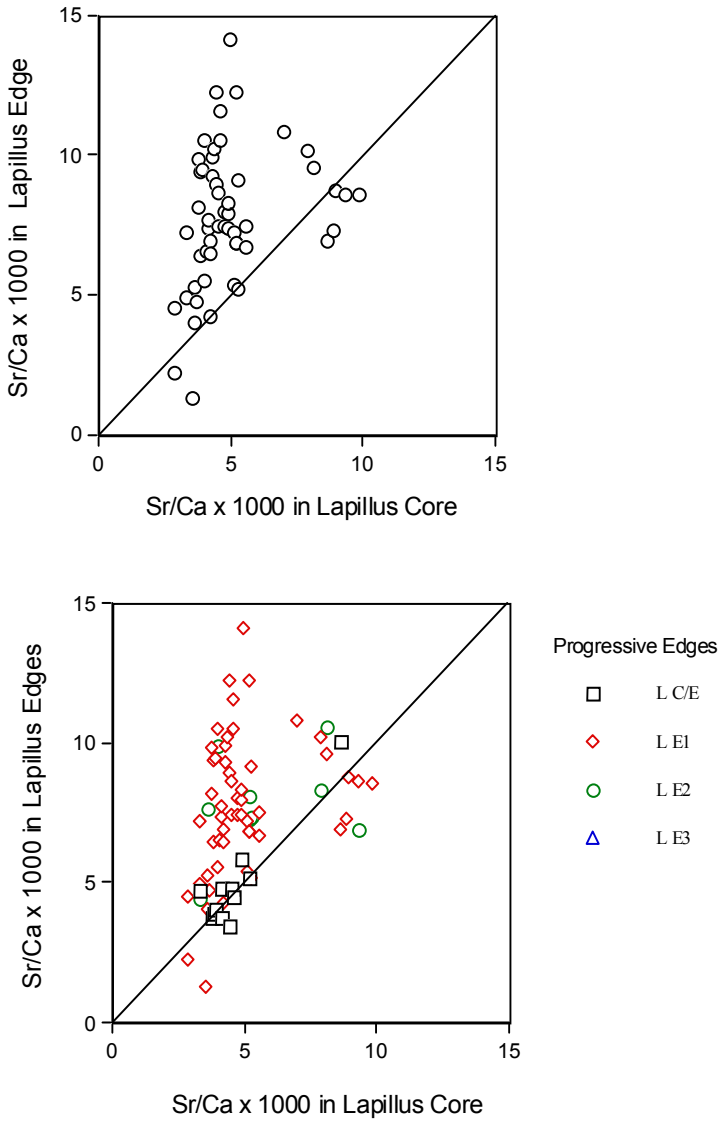

Figure 2. A (top panel): Comparison of Sr/Ca ratios in the laillus core and lapillus edge; a 1:1 line is given. B (bottom panel): Sr/Ca ratios in the lapillus core and various other locations toward the lapillus edge. Samples were taken just outside the core (L C/E), and at locations progressively closer to the edge (LE1, LE2, LE3). Small otoliths have only LE1. The 1:1 line is given.

(sagitta vs lapillus), among individuals in the same temperature treatment, and among temperature treatment groups. Variation in strontium incorporation into otoliths may result from environmental, physiological, and genetic differences among larvae in addition to differences due to sampling protocol including (1) measurement error, (2) preparation/otolith artifacts (cracks, uneven surface), (3) otolith type (sagitta vs lapillus), and (4) the developmental history sampled (core vs edge).

Sr/Ca ratios were similar in the cores of the lapillus and the sagitta from the same fish, although not identical (Figure 1a). Also, Sr/Ca ratios were similar at the edges of the lapillus and

sagitta from the same fish, though not identical (Figure 1b). Only about half of the variation in sagitta core or sagitta edge was explained by the variation in the lapillus core or edge, respectively. Differences between Sr/Ca ratios incorporated into the sagitta and lapillus of the same individual may result from several factors, including measurement error, preparation artifacts, differential growth rates in the specific otolith structure, and variable increment widths (and hence variable temporal references at each 5µm probe sampling site).

Within an otolith, Sr/Ca ratios varied according to sample location. Sr/Ca ratios tended to increase from the core to the edge in both the lapillus (Figure 2a,b) and the sagitta (not shown). Increasing Sr/Ca ratios from the core to the edge may result from ontogenetic changes in growth rate, changes in the proportion of protein in the otolith, ontogenetic changes in physiology, or other causes. Another contribution to the observed ontogenetic change in Sr/Ca ratio was due to experimental rearing conditions. Eggs were reared at the same temperature before hatched larvae were transferred to temperature treatments. However, ontogenetic increase

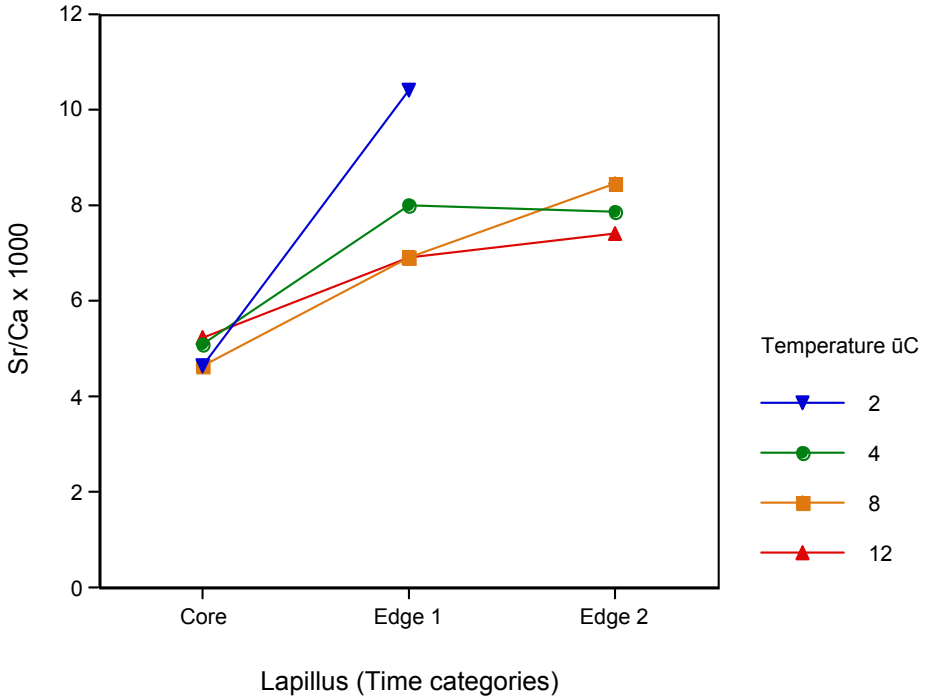

Figure 3. Ontogenetic increases in Sr/Ca ratios from the lapillus core to the edge for larvae reared at different temperatures.

in Sr/Ca occurred in the lapillus (and sagitta) at all experimental temperatures (Figure 3).

There was no clear relationship between temperature and Sr/Ca ratio in the lapillus core; however, heteroscedasticity appeared to increase with increasing temperature (Figure 4a).

In the rearing protocols, cod eggs were reared at the same temperature. After hatching, larvae were transferred to different temperature treatments. Similarity of Sr/Ca ratios in the lapillus core among all larvae may reflect, in part, this shared embryonic environment. Increasing dispersion (heteroscedasticity) of Sr/Ca ratios with temperature (especially in the 12˚C treatment) may result from increased stress at higher temperatures. Mortality was especially high in the 12˚C treatment.

Sr/Ca ratios in the lapillus edge may be weakly inversely related to temperature (Figure 4b). This is especially true if the 12˚C treatment fish are excluded from consideration. Interpretation of these results can not rule out a more complex relationship between temperature and Sr/Ca ratios (e.g., an weak inverse relationship between Sr/Ca ratio and temperature between

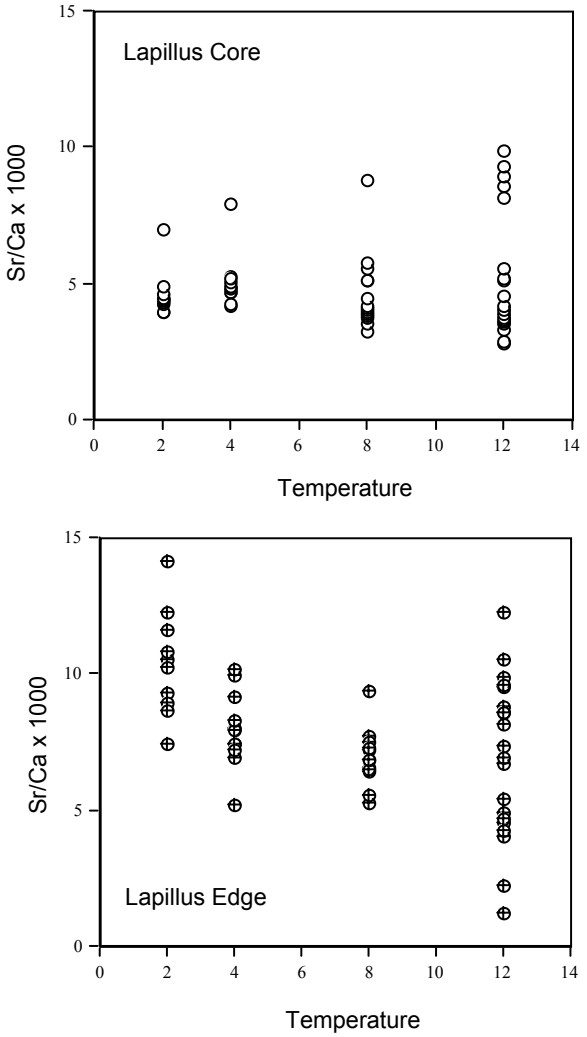

Figure 4. Relationship between Sr/Ca ratio in lapillus core (top panel) and edge (bottom panel) as a function of temperature. Sample sizes for lapillus core are n=11, 11, 15, 20 for temperatures of 2, 4, 8 and 12°C treatments, respectively, and for the edge: n = 10, 11, 12 and 20.

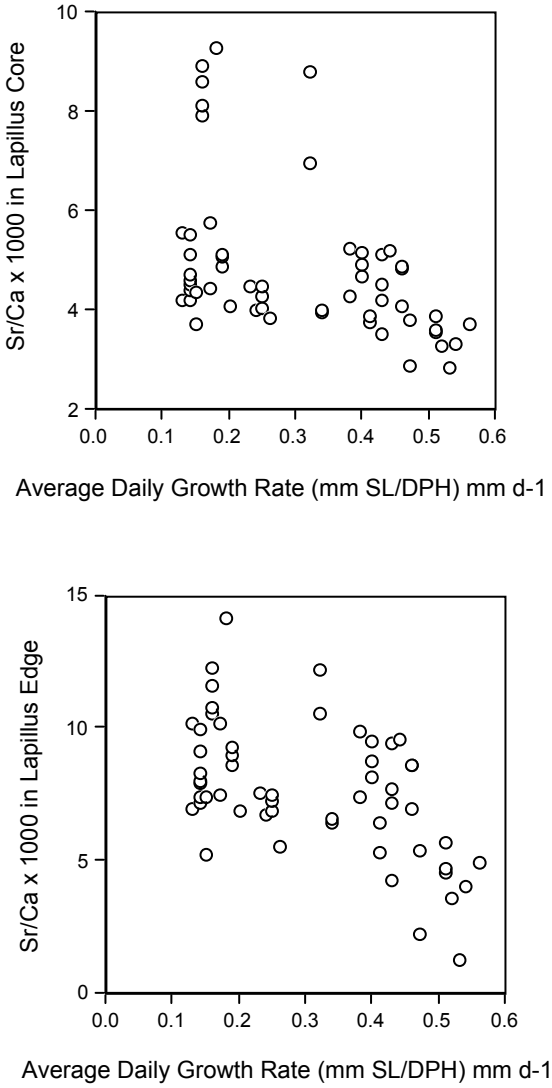

Figure 5. Relationship between Sr/Ca ratio in lapillus core and average growth rate (top panel) and Sr/Ca ratio in lapillus edge and average growth rate (bottom panel). Growth rate was estimated as standard length divided by days post hatch.

2-8˚C and a weak positive relationship for temperatures between 8-12˚C). Also, Sr/Ca ratios may be inversely related to growth rate (Figure 5).

Discussion

Townsend (et al. 1995) reported an inverse relationship between Sr/Ca ratios and temperature in 80 day old cod. Larvae analyzed in this study were only 9, 14, 17, 31, and 34 days post-hatch. High mortality during rearing precluded the analysis of older larvae for this present study. Because Sr/Ca ratios appear to increase with ontogeny (Figures 2,3), it is important to analyze fish of similar ages. Sr/Ca ratios appear to be inversely related to growth rate. Differential growth rates at each temperature, and stress may have resulted in high variation in Sr/Ca ratios within a temperature treatment. Variable growth rates (and resulting variable daily increment widths) may also have resulted in sampling complications where the 5 micron beam of the microprobe collected information over different spans (numbers of days) of life history.

In summary, Sr/Ca ratios were variable within an otolith, within an individual, and within and among temperature treatments. Poor larval growth rates during rearing protocols may have contributed significantly to highly variable Sr/Ca ratios. Sr/Ca ratios did not consistently differ in the lapillus/sagitta core among temperature treatments; however, heteroscedasticity of Sr/Ca ratios increased in the lapillus core with temperature. Sr/Ca ratios were weakly inversely related to temperature in the lapillus edge. Sr/Ca ratios in the lapillus increased with ontogeny at all temperature treatments. High variation of Sr/Ca ratios within each rearing temperature treatment does not support the use of Sr/Ca ratios in larval cod otoliths as a precise temperature analog for reared larval cod. The principal finding of this study are:

1. Sr/Ca ratios vary within an otolith as a function of ontogeny. Sr/Ca ratios increase from the core to the edge in larval lapilli of cod less than 34 days old.
2. Sr/Ca ratios vary within an individual between the lapillus and sagitta, although not in a consistent manner.
3. Sr/Ca ratios vary within a rearing treatment. Heteroscedasticity in Sr/Ca ratios increases in the lapillus with increasing temperature. The range of Sr/Ca ratios within a temperature appeared highest for the 12 degree C rearing treatment. This may indicate stress.
4. For the lapillus and sagitta core, no clear relationship was evident between Sr/Ca ratio and temperature.
5. For the lapillus edge, Sr/Ca ratios appear to be weakly inversely related to temperature, although a more complex relationship may exist.
6. Sr/Ca ratios appear to be weakly inversely related to growth rate.

Exploration of the Origin of Larval Cod Collected Off Georges Bank

Cod larvae were collected from a station located just off Georges Bank (Station EL9905: 63, 40 47'N, 12 12'W). Waters on Georges Bank typically range between 4-8 C. Waters off the Scotian Shelf typically range between 0-2 C. If larval cod collected off Georges Bank at station EL 9905:63 had originated in colder Scotian Shelf waters, Sr/Ca ratios in their otoliths (especially their cores) might be expected to reflect the colder waters of the Scotian shelf.

Although a precise relationship between Sr/Ca ratio and temperature was not validated in rearing experiments, a weak inverse relationship between Sr/Ca ratio and temperature in the lapillus edge was suggested, at least at temperatures between 2 - 8 C. Sr/Ca ratios appeared to be relatively higher in otoliths of fish reared at 2 C compared to otoliths of larvae reared at

warmer temperatures. Specifically, mean Sr/Ca ratios ranged between 7-14 (mean ± SD, 10.4 ± 2.0) in the lapillus edge of larvae reared at 2 C, and decreased with warmer temperatures. Thus, if fish collected off Georges Bank originated in colder Scotian Shelf waters, then mean Sr/Ca ratios (x1000) in the lapillus might be expected to be relatively high (at the higher end of the range of 7-14).

Sr/Ca ratios (x1000) in the lapilli of wild cold larvae collected off Georges Bank ranged between 3.77 – 7.21 (mean = 5.24, n = 7) in the lapillus core, and between 5.15 – 7.63 (mean 6.27, n = 7) at the lapillus edge. Sr/Ca ratios in the lapillus core (ANOVA, $F=34.96$, $p<0.0001$) and edge (ANOVA, $F=25.9$, $p<0.0001$) of wild larvae collected off Georges Bank were significantly different than Sr/Ca ratios in the lapillus edge of larval cod reared at 2 C. These data do not support a conclusion that cod larvae collected off Georges Bank had originated in colder waters.

Publications:

Jordaan, A. 2002. The effect of temperature on the development, growth and survival of Atlantic cod (Gadus morhua) during early life-histories. M.S. Thesis, The University of Maine.

Callan, C., Jordaan, A. & L.J. Kling. 2003. Reducing Artemia use in the culture of Atlantic cod (Gadus morhua). Aquaculture 219(1-4): 585-595.

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Thomas, A.C., D.W. Townsend and R. Weatherbee. 2003. Satellite-measured phytoplankton variability in the Gulf of Maine. *Continental Shelf Research* (In Press).

Townsend, D.W.,A.C. Thomas, L.M. Mayer, M. Thomas and J. Quinlan. 2004. Oceanography of the Northwest Atlantic Continental Shelf Waters. *The Sea*. Vol. 14. Harvard Univ. Press.

Presentations: (presenter marked by asterisk)

Jordaan*, A. & L.J. Kling 2001. Temperature induced changes of early life-history traits in Atlantic cod (Gadus morhua). Canadian Conference for Fisheries Research. Toronto, Canada.

Jordaan*, A., Callan., C & L.J. Kling 2001. Reducing Artemia use in the culture of larval marine fish: an experiment using Atlantic cod (Gadus morhua). Aquaculture Association of Canada Annual Meeting. Halifax, Canada.

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