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EFFECT OF THERMAL SHOCK ON DEVELOPMENTAL STAGES
OF ESTUARINE FISH

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Final Report Contract No. EY-76-S-09-0869

Project Title: Effect of Thermal Shock on Developmental Stages
of Estuarine Fish

1) Summary of Activities for the Entire Period

The experiments on the effect of acute thermal shock on the developmental stages of the estuarine fish Fundulus heteroclitus, the mummichog have yielded results which can be useful in making decisions on estuarine management. These results have been reported in a comprehensive paper published in Marine Biology. ~~a complete copy is enclosed~~. In addition, work on the energetics of the larval mummichog are in a manuscript that has been accepted with revision by Marine Biology. The revised manuscript has been returned to the editor, ~~and the preprint is enclosed~~. Studies of juvenile fish abundance were conducted for correlation of species and relevant laboratory experiments and the paper has been accepted in Estuaries; ~~the preprint is enclosed~~.

The results of these studies show that this species of estuarine fish is extremely tolerant of thermal stress in the embryological and larval stages. The young mummichog is more physiological labile than adults. The larvae grow well at higher temperatures ($26-28^{\circ}\text{C}$), although not as well as the individuals kept at optimum temperature conditions (22°C). Short-term exposure to high temperatures (10°C above ambient) would not be detrimental to this species.

Experiments on whether the thermal tolerance changed in the larva on a daily or even less than daily basis were inconclusive. I feel that this hypothesis needs to be tested further and plan to continue this series of experiments on my own.

During my recent stay in Japan, it was possible for me to obtain the larval fish of the Sea Bass Sebastes schlegeli and subject them to the experimental routine of temperature shock, at different ages. The larval fish were hatched and held at 16°C, and larva of different ages were subjected to a temperature shock of 10-12° above ambient temperature for different periods of time, from 0-2 hrs. The fish were removed from the exposure temperature at the appropriate time and examined under a microscope to determine if the heart was still beating and if the operculum moved. I also observed there was a change in the pigmentation of the eye when death occurred. Based upon these criteria, mortality percentages were calculated. The analysis of the results would indicate that there is not a significant difference in the sensitivity on a daily basis of very young (0-8 day) of Sebastes. However, it is readily apparent that even a 10-minute exposure to a temperature 10°C above ambient resulted in a very high percentage of mortality, as much as 60-80% no matter what the age. Thus, in terms of culture of these species, it is very critical to have precise mechanisms for control of the culture system that would not permit any sort of a high temperature excursion. In addition, they are near coastal spawners so a thermal effluent in their spawning area would have a very serious negative effect.

The second temperature shock experiment was conducted with the salmon, Oncorhynchus masou. The plan for the experiment was that embryos at known age post-fertilization were exposed for different periods of time at different temperatures above the incubation temperature.

Salmon spawn in shallow streams on a declining temperature gradient. This environment is a freshwater system that is subjected to thermal stress, as are estuaries. I wanted to compare the response of the salmon, a shallow water freshwater spawner, with the mummichog, a shallow water

estuarine spawner. Also, there is information available on the 5 North American species of Salmon and I wanted to see if those observations held on the Asiatic species.

Fertilized salmon eggs were incubated at 13°C . At a specified time after fertilization, the eggs were exposed to an acute temperature shock for specific periods of time. The exposure can be visualized in the following diagram.

This design was followed for exposure at 24°C , 32°C , and 40°C for 10, 40, and 60 minutes on days 1-14 after fertilization and at 2-hour intervals for the first 24 hours after fertilization. The standard fertilization procedure used in the salmon hatcheries was followed at Mori. After the eggs were put in an incubator tray and identified for age, I would move to the incubator and place the eggs in the exposure cups. This was accomplished by using a large pipette with the most gentle handling possible, and I never touched the eggs with anything other than the pipette. The exposure cups were in a large bath and all of the eggs were placed in the exposure cups within 5 minutes. The bath was then transported to the exposure system across the room. In a very short period of time (less than 10 sec) the cups were transferred to the exposure bath and the time exposure began. After the appropriate exposure period the sets of cups were moved from the exposure bath to the holding trough

until the end of the exposure period. At the same time that the exposure was accomplished, the controls were moved from the holding trough with the same amount of handling time and distance as the exposure cups and submerged again in the holding trough. After the exposure was completed the eggs were again placed in the incubator trays and moved to the incubation trough to follow their development and acquire the subsequent mortality information.

The detrimental effects of handling early embryonic stages of salmon are well known. It is quite clear from the results I obtained that the first two days are not critical for temperature shock or handling. The fish are quite tolerant. However, experimental treatments during days 3-10 were very detrimental to the embryos. It is obvious that a temperature shock during these sensitive periods compounded the handling problem. That is, a moderate shock of 24°C for a short period of time (10 minutes) resulted in significantly higher mortalities than handling alone. When compared with the handling control, exposures for even 5 minutes at 32°C and 40°C are lethal. The peak of thermal and handling sensitivity was on day 8, and after day 10 the experimentally induced mortality was reduced, until it returned on day 14 to the 0% mortality value of day 1. A thermal shock during days 3-10 of embryonic development for this species would be disastrous. This is consistent with studies done by Olson at Hanford with Columbia River Chinooks and Silver Salmon.

The conclusion that I draw from this work and related studies with other species (spot, alewife, shad, herring, striped bass, etc.) is that it is critical to know the ecological life history of the species in question before one can assess the importance of thermal stress. The species occupying each habitat are selected for and adapted to that environment on a geological time scale. Estuarine spawning fish, of

which there are relatively few in relationship to the total number of fish in the estuary, have evolved larval forms that are tolerant of higher temperatures. Fundulus heteroclitus (mummichogs) and Menidia menidia (silversides) spawn in the late spring and early summer in the intertidal zone. This enables them to reproduce in a rigorous physical environment of high productivity with reduced competition from predators. The results of this work on mummichogs is consistent with results done on silversides by a student of mine, Doug Middaugh. I think that intertidal reproduction by fish in the estuary is a relatively unique reproductive strategy. These two species, that is, mummichogs and silversides, are extremely abundant components of the summer nekton community and play a significant role in the structure of the estuarine community. Thus anything that is detrimental to their reproduction could have a much broader effect.

In contrast, the embryos, larva and post-larva stages of many of the other species that use the estuary, occur before the young fish occupy the estuary. Thus the salmon, striped bass and shad spawn in fresh water or at the highest reaches of the estuary and it is their more advanced developmental stages that are found in the lower more brackish reaches of the estuary. As an alternative, the menhaden, spot, croaker, and sea bass are offshore spawners and their post-larva and early juvenile stages are found in the nearshore and the estuarine waters. It is especially interesting that very important commercial species such as spot, croaker, and menhaden are in the estuarine nursery during the winter, the period when water temperatures are lowest, but most stable. The temperatures vary slightly from day to day but are not on a severe ascending or descending thermal gradient. Severe temperature fluctuations during that period could have serious environmental impact.

I conclude that the physiological data and ecological data shows that the few estuarine spawners have a higher thermal tolerance in the embryonic and larval stages than do the freshwater, coastal or oceanic spawning species. However, since all three groups (freshwater, estuarine, and oceanic spawners) occupy the estuary and coastal waters at different times of the year, knowledge of their physiology and ecology at different developmental or life cycle stages is critical for estuarine management decisions.

2) A list of publications:

Removed

Middaugh, D. P., J. M. Dean, R. G. Domey and G. Floyd. Effect of thermal stress and total residual chlorination on early life stages of the mummichog Fundulus heteroclitus. Marine Biology 46(1), 1-8 (1978)

Radtke, R. and J. M. Dean. Feeding, conversion efficiencies and growth of larval mummichogs Fundulus heteroclitus. Marine Biology (in press)

Bozeman, E. L. and J. M. Dean. The abundance of estuarine larval and juvenile fish in a South Carolina intertidal creek. Estuaries (in press)

A manuscript is in preparation on the salmon paper and will be sent in when it is accepted.

- 3) A comprehensive evaluation of progress in the areas of research supported by the contract.

There have been numerous literature reviews and symposia on "thermal effects" over the last several years and I will not cover that well cultivated ground. I would like to address the question of the response of organisms to temperature from my perspective. It appears that DOE does not perceive thermal effects studies as an essential mission of the agency. That may well be so for DOE, but there is still a real need to understand the response of aquatic organisms to changes in their thermal environment.

It is still a very open question as to what the mechanism of heat death is. That is a good area of future research but it will require a sustained effort by several laboratories to approach it. Since DOE has reduced its funding on thermal studies, I do not think anyone is prepared to move on that question.

There needs to be a comprehensive effort to assess the response of the different life stages of aquatic organisms to thermal stress. This should be done concurrently in several laboratories with several freshwater, estuarine, and marine species of fish. It will require the efforts of several investigators using consistent methodologies and mutually agreed upon criteria.

It concerns me that the investigators' interests change as dramatically as the agency missions change. That will simply not lead to the level of understanding of biological systems that is necessary for future decisions or management of aquatic ecosystems.

I plan to continue my own work and its relationship to future thermal effect studies. Through the DOE support I have received, my lab is well equipped to pursue these efforts. Specifically, I plan to redesign the

experiments on the daily change in thermal sensitivity of Fundulus larva and will attempt that work this spring. In collaboration with D. Middaugh (EPA) we will also examine the thermal responses of young silversides, Menidia menidia.