WORKING PAPERS DEVELOPED AT THE AUGUST 1983 CONFERENCE ON LAKE TROUT RESEARCH

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Great Lakes Fishery Commission

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The Great Lakes Fishery Commission was established by the Convention on Great Lakes Fisheries between Canada and the United States, which was ratified on October 11, 1955. It was organized in April 1956 and assumed its duties as set forth in the Convention on July 1, 1956. The Commission has two major responsibilities: first, develop coordinated programs of research in the Great Lakes and, on the basis of the findings, recommend measures which will permit the maximum sustained productivity of stocks of fish of common concern; second, formulate and implement a program to eradicate or minimize sea lamprey populations in the Great Lakes.

The Commission is also required to publish or authorize the publication of scientific or other information obtained in the performance of its duties. In fulfillment of this requirement the Commission publishes the Technical Report Series, intended for peer-reviewed scientific literature, and Special Publications, designed primarily for dissemination of reports produced by working committees of the Commission. Technical Reports are most suitable for either interdisciplinary review and synthesis papers of general interest to Great Lakes fisheries researchers, managers, and administrators or more narrowly focused material with special relevance to a single but important aspect of the Commission's program. Special Publications, being working documents, may evolve with the findings of and charges to a particular committee. Sponsorship of Technical Reports or Special Publications does not necessarily imply that the findings or conclusions contained therein are endorsed by the Commission.

INTRODUCTION

This special publication is a companion document to Technical Report No. 40, the formal proceedings of the Conference on Lake Trout Research (CLAR) held in August 1983. The materials presented here are working papers developed before and during the conference, and they have not had the degree of review that Technical Report No. 40 has had. Nevertheless, the conference participants felt that their working papers would be of interest to other researchers, and accordingly, they are aggregated here in Appendices A-G as a special publication. Background information on CLAR is given in Technical Report No. 40, which is available from the Commission.

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28 May 1985

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APPENDIX A

POPULATION DYNAMICS AND SPECIES INTERACTIONS

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LABORATORY STUDY ON THE EFFECTS OF SEA LAMPREY PREDATION/PARASITISM ON LAKE TROUT

I. ISSUE

The relationship between sea lamprey wounding and Take trout mortality is not well defined nor fully understood. Most of the evidence linking sea lamprey attack marks to lake trout mortality is circumstantial because trout killed by lampreys are seldom found, and little is known about lake trout survival after the lamprey detaches.

II. HYPOTHESIS STATEMENT

A. Background Information

Part of the assessment work carried on in the field is designed to estimate lethal lamprey attack rates from the observed frequency of lamprey inflicted marks among samples of surviving lake trout. More precise estimates of sea lamprey-induced mortality to lake trout can be obtained from field data if direct information on the relation between lamprey wounds and their lethality can be obtained.

B. Central Hypothesis

Lethality of single sea lamprey attacks on individual lake trout is a function of size of the host, its physiological conditions, and the attack site. A laboratory derived relationship between wounding rate and mortality rate can be used to determine lamprey-induced mortality in the wild, given a measure of wounding rate in the wild.

C. Alternate Hypothesis

Wounding rate in the wild is strongly influenced by variations in the predator-prey ratio and thus does not directly reflect (as an index) the realized lamprey-induced mortality.

III. METHODOLOGY

A. Experimental Design

Individual lake trout of three size categories will be confined with a single parasitic stage lamprey (transformer) in laboratory tanks containing flowing Lake Huron water at selected controlled temperatures. Sea lampreys will be allowed to remain attached until they either kill the fish or detach. The experiment will be continued through the feeding season until the lampreys cease feeding or they approach sexual maturity.

1. If death occurs while the lamprey is attached, the death will be attributed to the attacking lamprey. If the fish is weakened at the time of detachment, and dies within a specified period, this death also will be attributed to lamprey attack. Duration of attachment, type of wound inflicted and healing time will provide information on what type of wound is lethal, relationships between attachment times and death, and physiological responses of the fish to lamprey feeding.

2. **Relate** survival (as evidenced by healing wounds) to realized mortality by size category.

3. Once the initial "one on one" study progresses to a point where our methodology is considered workable, other factors that may affect mortality can be examined. Among those that could be considered are:

   a. predator/prey ratios
   b. effects of multiple wounding
   c. possible acquired immunity/susceptibility
   d. effects on reproductive behavior and fecundity
   e. comparative mortality/survival values may be obtained from observed attack rates on different strains of lake trout, i.e. Seneca versus upper Great Lakes stocks. Is there a genetic or environmental accommodation between lake trout stocks which make them more or less prone to lamprey-induced mortality?

B. Research Site - Hammond Bay Biological Station

C. Principals - U.S. Fish and Wildlife Service

FIELD MANIPULATION EXPERIMENTS ON EFFECT OF FURTHER SEA LAMPREY REDUCTION ON TOTAL MORTALITY OF LAKE TROUT

I. ISSUE

The selection of optimal strategies for rehabilitating lake trout is hindered by a lack of the ability to predict the magnitude of reduction of lamprey-induced mortality on lake trout resulting from a given increase in sea lamprey control effort.

II. HYPOTHESIS STATEMENT

A. Background Information

Sea lamprey populations have been reduced to less than 10% of their peak abundance of the late 1950s in the Upper Great Lakes through the use of chemical controls that selectively destroy stream-dwelling larvae. Although the present level of control appears adequate to allow restoration of some important stocks of fish (e.g. lake whitefish and bloater chubs), lake trout stocks have accomplished significant natural reproduction only in some areas of Lake Superior. Many biologists attribute this failure to develop self-sustainability to a lack of significant multi-age spawning stocks resulting from exploitation and predation by residual sea lamprey populations.

B. Central Hypothesis

Changes in sea lamprey-induced mortality of lake trout resulting from changes in sea lamprey control effort can be estimated. A relation between mortality and degree of control can be established to determine the cost-effectiveness of various control levels.

C. Alternate Hypothesis

Variability in estimates of mortality components resulting from incomplete catch reporting, sampling techniques, and environmental "noise" are sufficient to mask changes in lamprey-induced mortality resulting from moderate changes in level of sea lamprey control.

III. METHODOLOGY

A. Experimental Design

1. Experimentally alter the predator-prey ratio by changing the number of parasitic-phase sea lamprey in a given area or select two or more areas of the Great Lakes where sea lamprey abundance is known to be the only major variable affecting lake trout survival.

2. Measure lamprey density, prey density, lamprey attack rate (size specific), lamprey-induced mortality in lake trout and alternate prey.

3. Repeat with another level of predator-prey ratio.

4. Relate lamprey-induced mortality in lake trout to abundance of sea lamprey and alternate prey.

R. Research Sites

The proposed experiment can be carried out in three ways. If conducted in an inland lake, numbers of lampreys, lake trout, and alternate prey could be controlled directly, but the relation between sea lamprey control and escapement of transformers could not be tested unless a self-sustaining lamprey population was established. Alternatively, it could be conducted in the Gull Island-Michigan Island refuge in Lake Superior, where fishing mortality would not confound the experiment and where lamprey control effects can be altered. A third possibility is Lake Ontario, where reasonable lamprey assessment effort is in place and a change in control effort is planned, but where fishing mortality would be a confounding factor. The following table summarizes the degrees of control over experimental variables attainable in each location (where (+) means controllable, (-) not controllable, and (x) irrelevance):

SITE FACTOR	Inland Lake	W. L. Superior	Lake Ontario
Prey size	+		
No. of prey	+		
No. of lamprey	+	+	+
Alternate prey	+(?)		
Fishing	+(?)	+	
S. lamprey control effort	x	+	+

(?) denotes that controllability of these factors depends upon selection of the lake.

C. Principals

U.S. and Canadian Sea Lamprey Control Units, WDNR or NYDEC and/or OMNR, appropriate GLFL field stations.

IMPROVEMENT OF STOCK ASSESSMENT BY DETERMINING POST-STOCKING AND JUVENILE SURVIVAL OF LAKE TROUT

I. ISSUE

Present stock assessment for Great Lakes lake trout could be substantially improved if known recruitment through planting could be projected to the adult population. Post planting survival rates for lake trout have not been determined, nor have natural mortality rates for yearling through size at vulnerability been established beyond reasonable doubt. Survival rates for these juvenile size-groups are central to estimating standing stocks of lake trout which are dependent upon the hatchery product to sustain the population.

II. HYPOTHESIS STATEMENT

A. Background Information

Adequate stock assessment is critical to a successful Great Lakes lake trout rehabilitation program. Management and research agencies now require more complete, precise estimates of standing stock, survival and partitioned losses.

B. Central Hypothesis

Significant unknown natural mortality between time of planting and size at full vulnerability prevents accurate estimation of standing stocks.

III. METHODOLOGY

A. Experimental Design

1. Trawls, either bottom or mid-water, calibrated for area or volume searched, and gill nets, calibrated for size selectivity, will be used to estimate abundance.

2. Gear calibration will be accomplished by determining catchability coefficients for bottom and/or mid-water trawls. Gear specialists could provide essential information on: (1) operating dynamics of Great Lakes trawl gear and (2) the avoidance response of juvenile lake trout. Selectivity of gill nets may be determined by established methods. An alternative approach to evaluating gear selectivity may be fishing the gear in a limited area on a known population of juvenile fish.

3. Annual experimental fishing to determine size-specific mortality from post-planting through full vulnerability will be accomplished during the 2-3 weeks immediately following planting for at least 8 years. During this period, techniques will be refined for routine application.

4. Size-specific estimates will be converted to age-specific estimates annually by applying stock-specific size-at-age observations.

B. Research Site - Southeastern Lake Michigan and west-central Lake Huron (replicates)

C. Principals - USFWS and MDNR

EVALUATION OF COMPETITION BETWEEN LAKE TROUT AND NON-NATIVE SALMONIDS

I. ISSUE

Competition with introduced salmonids may reduce lake trout growth rates. Fast growing fishes are vulnerable to size dependent mortality sources (fishing, lamprey) sooner, but slow growing lake trout may experience both delayed sexual maturity and increased size dependent mortality because they spend longer at a vulnerable size.

II. HYPOTHESIS STATEMENT

A. Background Information

Because fecundity and age at first reproduction are size dependent, reduced growth rates in lake trout may lead to reduced total egg deposition by the population. Slow growth delays recruitment to existing fisheries (and to lamprey vulnerability), but increases the total time that lake trout are vulnerable to size dependent mortality agents.

Although lake trout do not consume a substantial portion of the alewife forage base (Stewart et al. 1983), the salmonid assemblage as a whole may do so (Stewart et al. 1981). Given the fluctuations common to clupeid populations, the idea that forage might become limiting may not be unreasonable. Available diet data for lake trout, chinook, and coho salmon suggest a high degree of diet overlap; furthermore, as judged by thermal preferences, habitat overlap may also be great. The potential for competition resulting in reduced growth is high, particularly if recently reported declines in alewife abundance (Wells and Hatch 1983) continue.

Both absolute and relative numbers of lake trout and non-native salmonids planted in Lake Michigan have fluctuated in recent years as the result of changes in stocking policy and problems in hatchery production. Routine assessment of the salmonid stocks, carried out by several agencies, and available estimates of forage biomass provide a data base that can be explored for evidence of competition at various levels of salmonid abundance.

B. Central Hypothesis

Competition with non-native salmonids may reduce growth rates of lake trout, and thus increase the time that lake trout are vulnerable to size-selective mortality.

C. Alternate Hypothesis

Lake trout and non-native salmonids use substantially different resources and lake trout growth rates are unaffected by non-native salmonids.

III. METHODOLOGY

A. Experimental Design

Extract from existing data bases information on the vital statistics of lake trout and exotic salmonids during periods when the biomass of exotic alewife and smelt forage has been low, medium, and high. Determine whether any or all of the following indicators of competition have occurred as density of non-native salmonids has increased relative to lake trout and to fluctuation available forage.

1. Reduced growth rates and condition of lake trout and exotic salmonids
2. Increased age to maturity in lake trout
3. Diet diversity should increase with inclusion of smaller or more variably sized prey
4. Habitat shifts of one or more salmonids

B. Research Site - Southern Basin, Lake Michigan. Forage dynamics assessment is excellent and salmonid growth, diet, and habitat information can be readily obtained as part of regular assessment programs by agencies and samples of sport-caught fishes (Salmonid Diet Survey Program).

C. Principals - USFWS, Ann Arbor, Univ. of Wisconsin, State DNRs

INFLUENCES OF SMELT ABUNDANCE ON GROWTH OF LAKE SUPERIOR LAKE TROUT

I. ISSUE

Reduced growth of lake trout in Lake Superior increases their age at maturity thus exposing them to increased mortality, and reduces potential production from its former level.

II. HYPOTHESIS STATEMENT

A. Background Information

1. Historical accounts of the lake trout fishery in Lake Superior suggest that lake trout once inhabitated most or all of the lake. Before the massive changes in the fish community brought about by fishing and exotic species introductions, pelagic lake herring used offshore zooplankton and were, in turn, fed on by lake trout. Since the early 1960s, lake herring have been relatively scarce and rainbow smelt have made up the majority of food eaten by lake trout. Smelt are found mainly around the periphery of the lake and its nearshore islands and lake trout distribution appears to have become associated with that of smelt. In 1978-79, smelt populations began to decline sharply and by 1982 smelt biomass averaged only 7% of that in 1978 (3% to 20% in various areas). During the fall and winter of 1982 and spring of 1983, lake trout in Wisconsin waters exhibited poor condition and reduced growth.

B. Central Hypothesis

Growth of lake trout in the Great Lakes is related to a few key forage species. For example, lake trout growth in Lake Superior is directly related to the abundance of rainbow smelt.

C. Alternate Hypothesis

Lake trout growth rates are not affected by variation in smelt abundance.

III. METHODOLOGY

A. Experimental Design

1. Estimate abundance and production (growth) of smelt.

2. Estimate total consumption of smelt using the lake trout bioenergetics model.

3. Contrast smelt production with consumption.

4. Contrast current growth of lake trout with traditional values and with values obtained during periods of high smelt abundance.

B. Research Site - Wisconsin waters of Lake Superior

C. Principals - GLFL Ashland Biological Station and Great Lakes Indian Fisheries Commission, University of Wisconsin

DEVELOPMENT OF SPAWNER-RECRUIT RELATION FOR LAKE TROUT*

I. ISSUE

Abundance and/or age structure of spawning stocks appear insufficient to produce progeny at a rate that will result in an exponential increase in lake-produced adult lake trout.

II. HYPOTHESIS STATEMENT

A. Background Information

In most parts of Lake Superior, total annual mortality is sufficiently high that very few lake trout reach sexual maturity and fewer still have the opportunity to spawn more than once. Although the proportion of lake-produced trout in assessment catches has risen steadily, absolute abundance of spawning-size fish, as measured by CPUE has not increased (Pycha 1982). In Lake Michigan, lake-produced adult lake trout form a statistically insignificant component of the small proportion of the stock reaching sexual maturity, even after 17 years of stocking. Many workers feel that the abundance of spawners is insufficient to overcome environmental pressure (a "critical mass" has not been achieved) and thus to "get over the hump" impeding population increase. As Walters et al. (1980) stated, "The equilibrium manifolds of catastrophe theory result when the equilibria show large, discontinuous changes with small changes in the control variables." Thus it is possible that a small increase in survival rate of adults might result in a significant increase in lake-produced progeny reaching spawning age.

B. Central Hyposthesis

Existing spawning stocks of lake trout produce too few eggs to significantly increase lake trout abundance at current rates of natural and fishing mortality.

C. Alternate Hypothesis

Density independent factors (e.g. contaminants, competition from non-native salmonids) limit larval and/or juvenile survival of lake-produced lake trout, thus preventing accumulation of sufficient spawning stock.

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*This hypothesis statement was generated in response to issues referred to the Population Dynamics Session by the Integrative Group late in the Conference. It was not sufficiently developed for peer review and has not been assigned a priority ranking.

III. METHODOLOGY

A. Experimental Design

Three approaches providing information bearing on the central hypothesis could be carried out simultaneously by several principals:

1. Historical approach

   a. From the historical record of a period in which lake trout were known to be self-sustaining, compute indices of abundance based on gear that can be duplicated today.

   b. Assess present day stocks in several areas using the same gear.

   c. Compare present densities with historical densities, including age distributions within the mature component if possible.

2. Comparative approach

   a. Develop indices of abundance, age and size distributions, sex ratio, and fecundity in stocks known to be self-reproducing (certain areas of Lake Superior and inland Canadian lakes).

   b. Develop similar indices for Great Lakes stocks that are not self-supporting (other areas of Lake Superior and heavily planted historic spawning reefs of Lakes Michigan and Huron).

   c. Compare the results, using spawner-recruit relations developed from the self-sustaining stocks to estimate the number of spawners necessary to accelerate rehabilitation.

3. Manipulative approach

   a. Significantly increase survival of adult lake trout in areas of prime historic spawning habitat (by creating refuges wherein fishing mortality could be controlled or eliminated) or significantly increase (on a per unit area basis) planting in areas of prime historic spawning habitat.

   b. Measure abundance of lake-produced trout reaching maturity in these controlled areas and compare with areas wherein survival or planting rate remains at its present level.

B. Research Sites

1. Historical approach: Michigan and/or Wisconsin waters of Lake Michigan (because of availability of historical records).

2. Comparative approach: Gull Island Shoal, Stannard Rock, and Island in Lake Superior; South Fox Island, Isle aux Galets, and Clay Banks in Lake Michigan; Keller Lake, Great Dane Lake, and Lake Opeongo in Canada.

3. Manipulative approach: Existing and proposed lake trout refuges in Lakes Superior and Michigan.

C. Principals - Various, depending upon approach chosen

APPENDIX B

STOCKING PRACTICES

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SPAWNER BIOMASS EFFECTS

I. ISSUE

Natural reproduction is being prevented due to an inadequate number of spawning adults.

II. HYPOTHESIS STATEMENT

Increasing the area1 density of stocking to insure that the critical mass of spawners will be present may enhance reproductive behavior and achieve successful spawning.

A. Background Information

In most parts of Lake Michigan the total annual mortality is sufficiently high that few fish reach sexual maturity (GLFC reports). This combined with potential problems of homing and/or failure to find/recognize suitable spawning substrate may be resulting in an insufficient number of eggs being laid to facilitate an increase in the lake trout population. Egg deposition might be insufficient to offset losses due to natural mortality, predation and exploitation.

In Michigan waters of Lake Superior during the late 60s and early 70s two million fingerling lake trout were stocked. This higher stocking rate seemed to generate natural reproduction (personal communications, R. L. Pycha, USFWS). There was an increase in the number of unmarked fish, which possibly could have originated from these larger stockings. When the stocking numbers were reduced to 1 million in the mid 70s, the appearance of unmarked fish stabilized with even some sign of that group decreasing in number. No doubt some of the reduction in number could be attributed to exploitation. Some of the exploitation could be controlled by stocking in refuge areas. The “Big Bang Approach” stocking density experiment may provide us with unequivocal results, that is, there is a treatment effect.

B. Central Hypothesis

Increased density of stocking will result in “disproportionate" gain in natural reproduction.

C. Alternate Hypothesis

Increased density of stocking won’t result in a disproportionate gain in natural reproduction.

III, METHODOLOGY

A. Experimental Design

1. Two shoreline stocking zones, each comprised of three lo-minute grids, separated by at least 70-80 km will be used.

2. One zone will be stocked at the current rate (300,000) and the other at three times the current rate (900,000) for three successive years, and then the rates switched for the next three years.

3. Yearling trout (20/lb) of one genetic strain should be raised in a single hatchery. If it is necessary to use a second hatchery, the fish from each will be planted proportionally in each zone.

4. The experiment will be evaluated by the amount of natural reproduction in each zone. Variables to be measured/estimated will include survival rates, growth rates, lamprey marking, spawner abundance, distribution, and YOY production.

5. A food supply will be conducted throughout the experiment to estimate forage utilization and cannibalism.

6. Forage abundance will be monitored. (See population dynamics section proposals.)

7. Lake trout and forage stock status will be evaluated prior to conducting the experiment.

8. The experiment could be enhanced by having replicate zones.

9. The experimental design may be improved by reviewing "historical" data bases.

B. Research Site - Lake Superior and possibly Lake Huron

C. Principals - State or provincial agencies with cooperation from academia and federal research facilities.

STOCK EARLY LIFE STAGES

I. ISSUE

Life stages of stocked fish.

II. HYPOTHESIS STATEMENT

Stocking lake trout eggs or sac fry on specifically targeted ancestral spawning reefs might solve the problem of lack of imprinting and homing by stocked yearling lake trout.

A. Background Information

Selection of spawning areas by mature lake trout might involve a homing orientation guided by early experience, possibly including chemical imprinting (see Horrall 1981, for review). If so, hatchery rearing followed by transplantation confuses the site selection mechanism. Hatchery rearing might have other disadvantages, including inadvertent selection for inappropriate genetic traits, adverse effects of hatchery experience on later growth or behavior, and high cost.

Hatchery rearing might not be necessary. Swanson (1982) has shown that very low egg mortality can be achieved among eggs incubated in protective enclosures on natural lake trout spawning grounds. This raises the possibility of large-scale stocking of eggs for stock rehabilitation purposes.

The Lake Michigan Lake Trout Technical Committee has endorsed research in that area (LMLTTC 1983).

Several questions remain regarding the utility of such large-scale stocking of eggs: can egg stocking methods be improved? What proportion of the fry that survive to emerge from the shelters will survive to maturity? What is the cost, per surviving adult, of stocking eggs? Will surviving adults return to suitable spawning substrate? Will they reproduce successfully?

Ongoing research by the Wisconsin Department of Natural Resources (WDNR) will help answer these questions. In the fall of 1982, approximately 500,000 newly-fertilized (green) eggs were stocked in artificial turf sandwiches on Devil's Island Shoal, a barren area of western Lake Superior. The WDNR hopes to stock 1,000,000 more in 1983. If we assume (a) that survival to swim-up (by sheltered eggs) is ten times the expected survival of naturally spawned eggs, and (b) that an average adult female produces 5,000 eggs, this number of stocked eggs (1,000,000) will yield approximately the same number of swim-up fry as 200 spawning females. The WDNR will attempt to monitor short-term survival through spring and summer sampling and, later, will assess long-term survival and homing by capturing adults returning to Devil's Island Shoal.

Other work is being done in the general area of stocking eggs **and** sac fry. Another possible technique for reestablishing lake trout in barren reefs is to plant sac fry. This work was started in the fall of 1980. The project was supervised by R. Horrall, University of Wisconsin-Madison, and funded by the University of Wisconsin Sea Grant Institute and Wisconsin% Coastal Management Program.

The objectives of this project, relative to stocking practices, are to experimentally plant sac fry at a designated site (Horseshoe Reef) in Green Bay and test for natural imprinting and natal homing in lake trout. The Michigan DNR has planted large numbers of eyed eggs without protective shelters near Drummond Island, Lake Huron. Experimental work with stocking eggs in artifical turf sandwiches has been done at the Center for Great Lakes Studies, University of Wisconsin-Milwaukee. University of Michigan Sea Grant has stocked sac fry experimentally in Lake Michigan.

B. Central Hypothesis

Adults derived from eggs stocked in protective shelters on a natural spawning reef will return to that reef to spawn.

C. Alternative Hypothesis

It won't work.

III. METHODOLOGY

A. Experimental Design

The basic experimental design has been established by the WDNR as described above. The experiment could be conducted by the WDNR or another of the experienced groups mentioned above. The design can be enhanced in the following ways.

1. During the first year plant lake trout eggs experimentally so as to further develop methods of stocking eggs

   a. Measure the relative survival of green vs. eyed eggs

   b. Compare alternative sizes and shapes of protective enclosures

   c. Measure percent survival relative to stocking density

   d. Explore methods for deployment of enclosures

   e. Compare survival of different strains of eggs

2. Increase the number of eggs planted

3. Expand the number of returning adults (utilize genetic markers, if possible)

4. Assess the number of returning adults (utilize genetic markers, if possible)

5. Conduct supplemental homing experiments

6. Assure isolation of the experiment from other experimental field manipulations

7. Use eggs from native populations when they are available

8. Assess number of adults spawning on the experimental reef each year, beginning with the year of stocking

B. Research Site - Great Lakes

C. Principals - To be announced

CONDITIONING OF SPAWNING REEFS

I. ISSUE

Homing enhancement. Condition natural reef to enhance utilization for natural reproduction.

II. HYPOTHESIS STATEMENT

Chemical, physical and biological conditioning of the spawning reef will attract spawning adults and result in increased natural reproduction.

A. Background Information

Conditioning spawning reefs before stocking to improve the physical, chemical, and biological conditions may effect spawning activity and survival of the eggs and fry. By preconditioning spawning reefs, improvement might be gained in the attraction of spawners to the area, the imprinting of the young to their natal reef, or the survival of eggs or fry on the reef.

Some evidence of successful reproduction over areas of freshly laid "clean substrate" suggest that such preconditioning could be useful (Peck 1984).

The presence or absence of spawning adult or early life stage odors or pheromones may be necessary at a certain critical level to enhance spawner attraction or imprinting of the young.

B. Central Hypothesis

That preconditioning of reefs will enhance their utilization for natural reproduction.

C. Alternative Hypothesis

That preconditioning won't enhance natural reproduction.

III. METHODOLOGY

A. Experimental Design

1. Identify which chemical compounds and hatchery by-products elicit the strongest spawning related behavioral response.

2. Measure the response relative to different concentrations, and select the optimum attractant and concentration that would be used as a reef conditioning device.

3. Determine the feasibility of using egg mat incubation devices in conjunction with non-productive reefs to produce native-like fish, and incubation by-products such as pheromones which may attract both native and hatchery spawning lake trout to these underutilized natural reefs.

4. Employ physical manipulation of reefs, including addition of new rock, cleaning old rock or reef reconfiguration by dynamite to attract spawners.

B. Research Site - Great Lakes

C. Principals - To be announced

APPENDIX C

GENETICS

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INVENTORY OF LAKE TROUT GENETIC VARIATION

I. ISSUE

The loss of genetic stocks, or genetic variation within stocks, and hence total species variation and adaptive potential to maximum habitat range could severly compromise rehabilitation efforts. Hence, a good understanding of genetic differentiation of lake trout is required.

II. HYPOTHESIS STATEMENT

A. Background Information

Sympatric and allopatric stocks of lake trout are genetically differentiated (Dehring et al. 1981; Ihssen unpublished data). It is believed that this genetic differentiation is associated with adaptation to local environments. Hence, the loss of lake trout stocks is associated with the loss of suitable stocks for reestablishing lake trout in former lake trout habitats. A better understanding of the genetic structure of populations is necessary for the preservation of genetic stocks of lake trout. Also, information on the genetic variation within stocks or hatchery strains is required because it has been demonstrated that the loss of such genetic variation is associated with loss in fitness (Kincaid 1976). Stocks or strains that have lost fitness due to inbreeding, for example, may not be suitable for reestablishing naturally reproducing lake trout populations.

Information on the genetic differentiation within populations also provides a basis for understanding natal homing and the colonizing ability of stocks.

An inventory of genetic variability will provide the data base for addressing other genetic issues. For example, genetic variability useful for genetic marking needs to be identified.

B. Central Hypothesis

A significant proportion of the total genetic variation of lake trout in the Great Lakes area is among populations.

1. Subordinate Hypothesis

Sympatric stocks of lake trout are significantly genetically differentiated.

C. Alternate Hypothesis

Lake trout populations of the Great Lakes are not signficiantly genetically differentiated.

D. Subordinate Alternate Hypothesis

Sympatric stocks of lake trout are not significantly genetically differentiated.

One can also formulate hypotheses regarding the development of new techniques such as chromosome banding for studying genetic variation of lake trout. For example, one can ask the question whether Q, C and NOR chromosome banding polymorphisms will provide a useful method for studying genetic variation among lake trout stocks.

III. METHODOLOGY

A. Experimental Design

1. Materials

For some studies (electrophoresis, DNA sequencing), fish tissue samples are suitable material. Some enzyme systems can be studied electrophoretically after prolonged (years) frozen storage. For the Cytogenetic work, live fish or eggs are required. To study sympatric stocks of large lakes, samples should be collected at spawning time when the stocks are segregated on their spawning shoals. Smaller lakes inhabited by single stocks can be sampled throughout the year. Hatchery stocks need to be examined as well for application such as genetic marking and the study of inbreeding effects.

2. Methods

Electrophoresis has been the preferred method recently for the study of genetic differentiation among fish stocks. For lake trout, only very limited information has appeared in the literature. Levels of heterozygosity have been comparatively low for the lake trout enzyme systems examined to date. For the study of sympatic stocks, especially, more polymorphic systems need to be found to make electrophoresis a more precise tool for studying intra-lake spawning segregation of stocks. Loci with higher levels of heterozygosity are also desirable for breeding genetic markers into stocks.

Cytogenetic methods (particularly G-banding and NOR markers) may be useful for applications where electrophoresis has failed to uncover sufficient genetic variation. The disadvantage of these techniques is that live material has to be used. Early indications are (Phillips and Ihssen unpublished data) what chromosome banding polymorphisms can differentiate among stocks for which little electrophoretic differentiation has been found.

Morphological or physiological methods may be useful to study the genetic differentiation of lake trout (Ihssen and Tait 1974), although ususally genetic and environmental effects cannot be separated. Morphological methods can be used to study the environmental history of stocks. Also, as more information on the genetic control of morphological characters becomes available, morphology (especially meristics) can be used to differentiate among genetic stocks. Morphological variation may even be used for genetic marking if environmental effects can be separated from genetic effects.

B. Research Site

Universities or government research lab.

GENETIC MARKING

I. ISSUE

Traditional marking methods are impractical for early life history stages of lake trout such as eggs and fry. Also, marks such as fin clips, tags, brands, etc. are ussually only identifiable for part of the life cycle and are not passed on to succeeding generations. Genetic markers introduced at fertilization, on the other hand, can be read not only throughout the ontogeny of one generation, but indefinitely into succeeding generations.

II. HYPOTHESIS STATEMENT

A. Background Information

It has been suggested that the hatchery rearing environments used for salmon and trout may impose irreversible physiological and behavioral changes that have a detrimental impact on survival and reproduction in the wild (Ihssen 1976; Bilton 1978; Vincent 1960; Barns 1979). However, the effectiveness of early life history plantings has been difficult to assess, because very small fish and eggs cannot be marked by using traditional methods. Genetic markers can be introduced into fish stocks at fertilization (Ihssen et al. 1981). The genetic interaction of stocks in the wild could be studied using such genetic markers. Some stocks carry natural marks that can be used for this purpose. Further research is needed to uncover more of this naturally occurring genetic differentiation among lake trout stocks. Generally, however, sufficient genetic differentiation for such markers may not be present. Also, it may be desirable to compare different life history stages of the same stock. For such applications, it may be possible to breed genetic markers into a stock. These markers could be isozyme or chromosome variants. Before genetic marking can be applied routinely, however, the practicality and biological effects of breeding fish with such marks needs to be assessed.

B. Central Hypothesis

Is it possible and practical to produce genetically marked lake trout stocks that can be used to assess early life stage plantings and natural reproduction.

C. Alternate Hypothesis

1. Genetic marking of lake trout stocks is not practical because of the rarity of isozyme and chromosome variants in lake trout stocks, and the long life cycle of lake trout.

2. Selecting lake trout for rare isozyme and chromosome markers changes their fitness to the extent that they are not useful for rehabilitation projects.

III. METHODOLOGY

A. Experimental Design

1. Screen lake trout stocks used in the rehabilitation program (and possibly others) for isozyme and chromosome variants useful for genetic marking.

2. Take biopsy samples from brood stocks; mark fish (branding, tagging); determine genotype; and select those fish useful for breeding stock of genetically marked fish.

3. Produced genetically marked and control stocks (randomly selected unmarked fish from the same stock). Test these stocks for differences in survival, growth, etc. in the hatchery and the wild (matched planting experiments).

B. Research Site

Great Lakes, large inland lakes.

C. Principals

1. Principal Investigator - University or government research lab.
2. Sample Collection - U.S. and Canadian hatchery and wild Great Lakes lake trout stocks.

ENVIRONMENTAL MATCHING OF STOCKS - EMPIRICAL APPROACH

I. ISSUE

Lake trout rehabilitation usually involves transplanting donor stocks into non-native habitats. Frequently, such transplantations have resulted in lower fitness of the donor stock in the non-native environment. Hence, the need for matching stocks to their receiving habitats.

II. HYPOTHESIS STATEMENT

A. Background Information

Little is known about the adaptation of lake trout stocks to their native habitats. Variation in stock characters such as seasonal spawning time, growth rate, age of maturity, choice of spawning site or substrate, and seasonal depth distribution cannot be easily related to fitness. It is not generally known whether such character differences represent adaptation to local environmental conditions or whether they are different responses of the same genotype to different environments. Although in the long-term it is important to study the adaptive significance of individual character variation in detail, in the short-term it is more expedient in our view to employ an emperical approach involving a suite of characters.

B. Central Hypothesis

Rehabilitation of lake trout stocks will be facilitated by matching stocks to characters of the receiving environment.

III. METHODOLOGY

A. Experimental Design

A data base on naturally reproducing stocks of lake trout should be developed. Each stock should be described for an many characters as possible such as seasonal spawning time, age of maturity, seasonal depth distribution, growth, etc. Similarly, the corresponding native habitat of each stock should be described for characters such as water quality (pH, hardness), temperature regime, predator/prey characters, spawning shoal characters, etc. On the short-term, stocks can be matched to receiving habitats using non-statisical methods for a few characters. Matched planting, on the basis of a few characters, should involve as many stocks as possible in one area. As the data base becomes sufficiently large (10 or so stocks, 10 or so stock characters, 20 or so environmental characters) miltivariate techniques such as canonical correlation analysis can be employed to match a stock to a particular environment. This procedure would involve paring the character sets (stock, habitat) down to those that give the most significant relationships. Using the functional relationship between stock and habitat variables, the stock that gives the highest correlation between its variables and the variables of the receiving habitat can be chosen. The stock of choice should be tested against a control stock in a matched planting experiment to validate or refute the matching procedure.

B. Research Site

Area of Great Lakes where adequate assessment is possible such as eastern Lake Ontario.

C. Principals

Joint U.S. government and O.M.N.R.

ENVIRONMENTAL MATCHING OF STOCKS - DEDUCTIVE APPROACH

I. ISSUE

Genetic differences among stocks for physiological, morphological and behavioral characters are associated with fitness differences. An understanding of the adaptive significance of the variation for a single stock character may be of overriding importance in the rehabilitation of lake trout in a particular habitat.

II. HYPOTHESIS STATEMENT

A. Background Information

It has been demonstrated that there are genetic differences among lake trout stocks for physiological characters (Ihssen and Tait 1974; Plosila 1977; MacLean et al. 1981). Also, evidence is accumulating that different genetic stocks of lake trout planted into the Great Lakes perform differently in terms of survival and behavior (Schneider 1982; Horrall 1982; Swanson 1982). Careful comparative studies to separate environmental from genetic effects for lake trout stocks have rarely been carried out, however. Clearly, if such genetic variation can have a large impact on lake trout rehabilitation efforts by affecting survival, growth and reproduction, a better understanding of such variation is required. Studies that have been carried out in the past can be characterized as follows:

1. those that have measured genetic variation directly using gell electrophoresis (Dehring et al. 1981), also more recently, chromosome banding polymorphisms (Phillips and Ihssen 1983);

2. those that have measured characters related to fitness, such as deep diving ability (Ihssen and Tait 1974), survival, growth and movement (Plosila 1977; MacLean et al. 1981).

Since the linkage between 1 and 2 has been made for only very few characters (Allendorf et al. 1983; Leary et al. 1983; DiMichele and Powers 1982), both types of variation need to be studied to obtain a realistic picture of the genetic differentiation of lake trout stocks.

B. Central Hypothesis

Lake trout stocks are genetically differentiated for physiological characters that affect their fitness in the wild.

C. Alternate Hypothesis

The physiological differentiation, noted among lake trout stocks, is non-genetic and of no consequence to the lake trout rehabilitation program.

III. METHODOLOGY

A. Experimental Design

1. Test different lake trout stocks for genetic differences of physiological characters under laboratory conditions. Breed individual families of full and half sibs to measure genetic and environmental components of variation.

2. Measure characters such as growth rate at various temperatures, standard O_2 consumption, temperature tolerance and preference, deep diving ability, seasonal spawning time, and age of maturity.

3. If genetic differences are found, compare different physiological stocks in the wild using matched planting experiments.

B. Research Site

Great Lakes or large inland lake trout lakes.

C. Principals

1. Principal Investigator - University or government lab.

2. Sample Collection - eggs from lake trout stocks held under controlled conditions.

HYBRIDIZATION AND SELECTIVE BREEDING

I. ISSUE

Genetically appropriate stocks of lake trout may not be available for successful introduction into some environments, particularly for those environments heavily impacted by man's activities and exotic species. If new combinations of desirable phenotypic characters were identified, then new stocks could be developed for such environments.

II. HYPOTHESIS STATEMENT

A. Background Information

It has been suggested that for lake trout rehabilitation in some areas appropriate stocks may not be available. For example, under very heavy fishing pressure, insufficient numbers of fish survive to maturity to create self-sustaining populations. For such application, it may be desirable to produce a slow growing, early maturing lake trout strain that becomes vulnerable to the fishery only after spawning. In situations where little success has been achieved with standard hatchery products, it may be desirable to try intraspecific lake trout hybrids as suggested by Krueger et al. (1981). Intraspecific hybrids would have larger genetic variation and the environment could select genotypes of the highest fitness. Such an approach would be long-term, however, since several generations of selection would probably be needed before any appreciable change in fitness occurs.

B. Central Hypothesis

Characters or combinations of characters necessary for successful introduction of lake trout and lacking in stocks presently available, can be identified. Selective breeding and intraspecific hybridization will permit the development of lake trout strains with the required characteristics.

III. METHODOLOGY

A. Experiment Design

1. Identify the biological characteristics of lake trout that are necessary for successful introductions (especially natural reproduction) into specific enivornments (as per proposals 3 and 4).

2. Develop the necessary stock by selective breeding and hybridization programs.

3. Test the new stock in a matched planting experiment in the receiving environment.

B. Research Site

Area of the Great Lakes for which introductions of lake trout has been unsuccessful.

C. Principals

U.S. or Canadian government agency or institute.

APPENDIX D

PHYSIOLOGY AND BEHAVIOR

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IDENTIFICATION OF IMPRINTING LIFE STAGE

I. ISSUE

Homing to spawning sites in lake trout.

II. HYPOTHESIS STATEMENT

A. Background Information

There is evidence of repeat spawning at same site in lake trout (MacLean et al. 1981, Swanson and Swedburg 1981). Natal spawning site homing is known in other salmonines (Hasler 1966), Brannon 1981). Observational data for lake trout and circumstantial evidence of stocks.

B. Central Hypothesis

Lake trout stocked at sizes or ages beyond some identifiable period in their life cycle will not exhibit an appropriate homing response; however, life stages stocked before this key size or age will imprint to precise locations and mature fish from such plantings will home to those locations to spawn.

c. Alternate Hypothesis

None

III. METHODOLOGY

A. Experimental Design

1. Use site where two or more disorete spawning sites exist. Determine spawning sites by following first with ultrasonic tags. Characterize fish genetically (e.g. electrophoresis). Collect fertilized eggs from spawning sites and characterize young by some genetic technique(s).

2. If there are not genetic markers, mark young fish in each spawning site. Look for marks in adults on spawning sites in subsequent years.

B. Research Site - Killala Lake, Ontario, Lake Superior (?)

C. Principals - joint study OMNR, Wisconsin (?)

ARTIFICIAL IMPRINTING

I. ISSUE

Mechanism for homing of adult lake trout to spawning sites.

II. HYPOTHESIS STATEMENT

A. Background Information

Olfactory imprinting and homing salmon (Hasler et al. 1978, Scholz et al. 1976). Evidence from variety of other fishes also shows olfactory basis for variety of behavioral responses.

B. Central Hypothesis

Adult lake trout use odors as orientation cues in homing to breeding areas.

C. Alternate Hypothesis

Adult lake trout use other cues to detect and move to spawning areas (geomagnetism, depth, light, substrate, or other mechanisms).

III. METHODOLOGY

A. Experimental Design

See Scholz et al. (1975) for experimental methodology on artificial imprinting to synthetic chemicals.

B. Research Site - Clay Banks and Black Can, Lake Michigan, Apostle Islands, Lake Superior

C. Principals - U. of Wisconsin-Madison, Wisconsin DNR, USFWS Jordan River NFH

PHEROMONES

I. ISSUE

Mechanism for lake trout finding and using suitable spawning sites.

II. HYPOTHESIS STATEMENT

A. Background Information

Martin (1955) suggested that spawning lake trout were attracted to traditional spawning sites by some characteristic odor. Field and laboratory experiments on a closely related species (S. alpinus) (Døving et al. 1980) indicate that odors produced by immature fish were attractive to conspecific adults. Foster showed similar response in lake trout (Great Lakes Fishery Laboratory, unpublished).

B. Central Hypothesis

Adult lake trout use conspecific odors (pheromones) emanating from specific areas of substrate in selecting spawning sites.

C. Alternate Hypothesis

Some other cu's) are involved, or pheromones are not involved.

III. METHODOLOGY

A. Experimental Design

1. One or more small island lakes that have one or more observable spawning sites.
2. Net spawning adults from traditional spawning sites, collect gametes and rear fry in laboratory (year I).
3. Collect odorant materials from young in laboratory (year I).
4. Year II - establish monitoring stations at each of:
   a. traditional spawning sites
   b. pheromone (fecal material, mucus, etc. from fry) scented sites
   c. control sites
5. Year II - put one or more egg baskets at each site
6. Year II - monitoring stations to include behavioral observations by one or more of: low-light level television and video recording, sonic tags with sensor to indicate actual spawning events, direct observation of color-tagged fish, recording via hydrophones.

7. Year II - compare:

   a. movements of spawning adults
   b. egg deposition in egg baskets
   c. viability of eggs in egg baskets

B. Research Site - suitable inland Ontario lakes

C. Principals - USFWS Ann Arbor Lab, in collaboration with OMNR

HATCHERY INFLUENCE

I. ISSUE

Hatchery influence

II. HYPOTHESIS STATEMENT

A. Background Information

Longevity of hatchery lake trout less than native lake trout (Swanson, pers. Comm.) movements are atypical. Hatchery experience appears to change a number of aspects of performance and survival (Vincent 1960, Noakes 1978, Miller 1956(?)). Different hatchery treatments may produce different postplant behavioral responses-shallow depth preference in pond-reared juveniles vs. deep water preference in darkened raceway-reared juveniles (Casselman, pers. comm.).

B. Central Hypothesis

Lake trout reared under normal hatchery conditions have reduced longevity compared to those reared in hatcheries under simulated lake conditions.

C. Alternate Hypothesis

Hatchery selection and production techniques are having no detrimental effect on potential of planted fish to survive to reproductively effective age.

III. METHODOLOGY

A. Experimental Design

Paired plant approach - compare post plant survival to effective reproductive age in otherwise identical lots of fish reared under the following pairs of contrasting conditions simulating hatchery vs. wild environment, respectively:

a. high light intensity vs. low light levels
b. constant, elevated temperatures vs. fluctuating lake temperature regime
c. high flow velocities vs. low flows
d. lack of substrate vs. simulated natural substrate

2. Compare stocked fish with native fish with regard to:

   a. growth rate and energy budget
   b. mortality and longevity to examine implications of slower growth, later maturity, and greater longevity in native fish in context of reproductive potential
   c. compare selected physiological and behavioral characteristics if fish reared under contrasting sets of conditions
   d. this study would evaluate advisability of establishing small on-site experimental hatcheries (pumping stations, etc.) to provide ambient lake water conditions for incubation and rearing

B. Research Site - Hatchery and lake environments Great Lakes region

C. Principals - U. of Wisconsin-Madison; OMNR; USFWS, Ann Arbor

SPAWNER DISTRIBUTION AND SITE SELECTION

IV. ISSUE

Failure of hatchery-stocked lake trout to produce detectable number of recruits.

V. HYPOTHESIS STATEMENT

A. Background Information

Hatchery-stocked lake trout survive when planted in lakes, grow to maturity and produce viable, competent gametes (Rybicki and Keller 1978). Other salmonies home to natal areas (Hasler et al. 1978, Brannon 1981), and aggregate at spawning sites. If do not find sites, investigate physiological constraints.

B. Central Hypothesis

Most hatchery produced lake trout in the Great Lakes do not spawn on sites appropriate for reproduction.

C. Alternate Hypothesis

Planted lake trout have produced progeny but resource assessment researchers

1. Have not looked in right places
2. Have probably not used appropriate gear
3. Densities of recruits have not yet built up to a point where they are detectable

VI. METHODOLOGY

A. Experimental Design

1. Biotelemetry of mature adults to determine if and where they spawn (including sensor to detect actual spawning events).

2. Sample spawning sites to detect fertilized eggs and/or developing embryos.

B. Research Site - Develop methodology in inland lake, then use Great Lakes site: Lake Michigan (?)

C. Principals - U. of Wisconsin-Madison; cooperative DNR Wisconsin, USFWS, Ann Arbor

APPENDIX E

CONTAMINANTS

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REPRODUCTION

I. ISSUE

Lake trout egg quality and embryo-larval viability is impaired by maternal contaminant transfer.

II. HYPOTHESIS STATEMENT

A. Background Information

The duration of lake trout stocking in Lakes Michigan and Superior is such that yearling progeny from introduced stocks should be appearing given successful reproduction. However, evidence of successful recruitment (presence of unmarked yearlings) exists only in Lake Superior. Monitoring of stocked lake trout year classes indicates that sexually mature and ripe adults can be found on spawning shoals. Recruitment failure therefore suggests that the reproductive cycle is disrupted by poor gamete viability and/or mortality during the first year of life. Evidence of poor embryo-larval survival related to high contaminant levels in adults and eggs (Willford, 1982) is consistent with the subsequent absence of their yearling progeny in the lakes.

B. Central Hypothesis

Contaminants in spawned products, as a result of parental transfer, impair embryo-larval development and survival.

C. Alternate Hypotheses

1. Contaminants in adult lake trout inhibit their ability to produce viable gametes.
2. Contaminants in eggs inhibit critical larval transition to free swimming form.
3. Contaminants in environment impair embryo-larval development.
4. Contaminants in eggs impair survival of juveniles to the yearling stage.

III. METHODOLOGY

A. Experimental Approach

1. Feeding of. hatchery adults with forage fish collected from a "clean" source (i.e. Lake Superior) and a "contaminated" source (i.e. Lake Michigan) would provide "low" and "high" contaminated gamete groups

with which to compare embryo-larval development and survival. Intermediate exposure regimes will allow estimation of threshold effect levels. This study addresses the central hypothesis and alternative hypotheses 1, 2, and 4.

2. Raising eggs from hatchery and planted fish in astroturf located on clean and contaminated shoals (in situ) and in the laboratory to confirm the role of parental transfer of contaminants and environmental exposure of contaminants in reproductive impairment. This study addresses the central hypothesis and alternative hypotheses 2 through 4.

B. Research Site

C. Principals

BIOLOGICAL MONITORING

I. ISSUE

There is a pressing need for fisheries agencies to adopt and develop methods for measuring the effects of contaminants on lake trout and to employ these procedures in a systematic effects monitoring program. Unfortunately, clinical methodology is in the developing stage and agencies who wish to assess contaminant effects must select appropriate methods from research literature or rely on more obvious and possibly irreversible indicators of contaminant effects at the population or ecosystem levels.

II. HYPOTHESIS STATEMENT

A. Background Information

Development of clinical methods for effects monitoring was one of six research needs identified by the Scientific Advisory Board (1979). Other fisheries agencies have experienced similar concerns and published reviews describing physiological, biochemical, pathological and behavioral techniques for measuring chemical stress (I.C.E.S., 1978; McIntyre and Pearce, 1980). Clinical tests are specific to classes of contaminants or in some cases, to individual chemicals and while they provide some degree of early warning, their relevance to population health is unknown. Similarly, population indicators of stress are relevant to population success but they do not provide an early warning and are usually too far removed from the chemical source to be useful in cause effect determinations. An effects monitoring program should contain elements of both early warning and population relevance and the choice of clinical and population indicators of chemical effects depends on the perceived problem. Clearly, the selection of methods for measuring contaminant effects should respond to different chemical stressors and reflect new research in chemical stress indicators. What is more urgently needed by Great Lakes fisheries agencies, is a workable strategy for developing an effects monitoring program which incorporates a variety of clinical and population stress indicators.

B. Central Hypothesis

Methods are available for routine biological monitoring to assess individual fish health and differentiate between biological and chemical stressors.

III. METHODOLOGY

A. Experimental Design

1. An effects monitoring program should be developed on a pilot scale to establish workable procedures before efforts are made to implement a basinwide program.

2. Identify the type and concentrations of chemicals (organic and inorganic) which may impact on the population (with a careful selection of study sites and populations, much of this information may already be available).

3. Identify a number of clinical and population estimates of lake trout health.

   a. General chemical stress indicators
   b. Indicators of specific chemicals or classes of chemicals

4. Monitor lake trout populations using clinical and population stress indicators.

5. Detecting adverse effects of contaminants or other stressors in wild populations of lake trout will lead to laboratory studies to determine cause and effect.

B. Research Site

C. Principals

CONTAMINANT DYNAMICS

I. ISSUE

Contaminant fate and behavior in lake trout

II. HYPOTHESIS STATEMENT

A. Background Information

If lake trout responses (growth, survival, reproduction) to contaminants are unrelated to whole-body concentration or concentration on a lipid basis, then:

1. We need to determine what factors are correlated with lake trout responses to contaminants.

2. No differential lake trout response should be inferred from:

   a. Variations in lake trout contaminant concentrations among lakes
   b. Variations in lake trout contaminant concentrations through time
   c. Variations among fish species in contaminant concentrations

   (However, these variations may be important from a human health perspective.)

3. Information on the responses of other species to contaminants may not apply to lake trout, unless factors correlated with response are known.

   If lake trout responses to contaminants are correlated with whole-body contaminant concentrations or concentrations on a lipid basis, then:

   a. Factors influencing contaminant concentration in lake trout will be useful in estimating/understanding responses to contaminants. Determination of the major factors influencing contaminant behavior and fate in the individual lake trout (especially at critical life stages) will be needed.

B. Central Hypothesis

Information on contaminant fate and behavior in lake trout is essential to understanding contaminant effects.

III. METHODOLOGY

A. Experimental Design

1. Perform a literature review of contaminant dynamics in fish (including uptake, deposition, metabolism, transfer to spawned products); and major factors influencing these processes, e.g., body size, lipid level, water temperature, octanol-water partition coefficient).

2. If information is not available on lake trout, studies must be undertaken on the above.

3. Determine the effects during lipid mobilization, including changes in metabolites, excretion, and lipid redistribution.

B. Research Site

C. Principals

CLINICAL MEASURES OF HEALTH

I. ISSUE

Selection of clinical indicators of fish health must have relevance to population success and predict effects on lake trout stocks.

II. HYPOTHESIS STATEMENT

A. Background Information

Fish respond to chemical stress by eliciting a primary stress response which usually consists of increased corticosterioid production and behavioral changes. Primary responses are non-chemical-specific and temporary and are quickly reversed when the stress is removed. If chemical exposure continues, the fish may develop secondary indicators of stress characterized by further physiological and biochemical changes and associated tissue changes. For the most part, important body functions continue due to compensatory mechanisms within the fish. However, if the exposure continues or is increased and exceeds the compensatory ability of the fish, severe irreversible disruptions occur in important life processes such as reproduction, respiration, osmoregulation, etc. and with adverse effects on the individual and ultimately, the population (tertiary effects).

Clearly, a model is needed which will identify relevant clinical tests (primary, secondary and tertiary effects) which are good estimates of factors controlling population success.

B. Central Hypothesis

Clinical measures of individual health are quantitatively related to growth, reproduction, and survival within lake trout populations.

C. Alternate Hypothesis

1. Individual measures of fish health cannot be related to population success or failure because of compensatory density dependent mechanisms within the population.

2. Monitoring appropriate population parameters can provide useful indicators of life stages or processes which may be impacted by chemical stress.

III. METHODOLOGY

A. Experimental Approach

1. Identify biochemical, physiological, and pathological measures of individual fish health which have obvious quantifiable consequences on individual survival, reproduction, growth or behavior.

2. Develop several population models describing how each of the above factors (growth, reproduction, etc.), influences population success.

B. Research Site

C. Principals

SPECIES SENSITIVITY

I. ISSUE

The sensitivity of lake trout to contaminants is impeding natural reproduction and survival.

II. HYPOTHESIS STATEMENT

A. Background Information

Although stocked lake trout are failing to reproduce successfully in Lake Michigan, other fish species appear able to reproduce successfully. Alewife populations have remained generally high (with fluctuations), and both smelt and bloaters are increasing in numbers. Some other stocked salmonids are apparently able to complete natural reproduction. Lake trout adults taken from Lake Michigan are capable of producing eggs that hatch as well as eggs of lake trout from three other sources (Willford, GLFC Annual Meeting, June 9-10, 1982, Agenda Item 14.c.). However, fry survival in the laboratory from Lake Michigan trout was substantially less than fry from the three other sources (Willford, ibid.).

B. Central Hypothesis

Differential species sensitivity accounts for the greater effect of contaminants on reproduction and survival in lake trout than in other species.

C. Alternate Hypothesis

Exposure accounts for the greater effect of contaminants on lake trout reproduction and survival.

D. Supplemental Hypothesis

More tolerant strains of lake trout are available.

III. METHODOLOGY

A. Experimental Design

1. Conduct a toxicology literature review and compile the acute and chronic toxicity data for lake trout and other fish species to quantify the relative sensitivity of lake trout to other Great Lakes fishes.

2. Compile the available data on contaminant concentrations in eggs and fry of Great Lakes fish species and compare these exposures with corresponding toxicity data in part 1, above.

3. Determine the sensitivity of various lake trout strains to the major Great Lakes contaminants using standard acute toxicity testing techniques.

B. Research Site

C. Principals

APPENDIX F

HABITAT

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SITE STUDIES OF HABITAT DEGRADATION

I. ISSUE

Habitat degradation in the Great Lakes, especially in the nearshore zone, is identified as a potentially important factor inhibiting reestablishment of self-sustaining lake trout stocks.

II. HYPOTHESIS STATEMENT

A. Background Information

Despite stocking large numbers of lake trout in Lakes Superior, Michigan, Huron, and Ontario, for many years, catch data indicate that reproduction by these introduced fish is extremely low, and that successful "rehabilitatior" has not yet been achieved. Both during and after the loss of most native lake trout stocks from the Great Lakes, there have been major changes in the quality of nearshore and main lake waters, and it is thought that many areas of formerly used habitat have become degraded; however, the unique characteristics of Great Lakes environments which make them suitable as spawning habitats have not been clearly ‘defined.

B. Central Hypothesis

The present lack of adequate reproduction by stocked lake trout is, at least, partly due to widespread deterioration of available spawning habitat.

C. Alternate Hypothesis

The lack of in-lake reproduction by stocked lake trout is not caused by present availability of suitable spawning habitat but, instead, is caused by a low level of fitness among hatchery reared stocks and inappropriate biological responses to external stimuli. (See also Physiology and Behavior.)

III. METHODOLOGY

A. Experimental Design

Comparative site data are required to demonstrate differences between degraded and non-degraded spawning sites, and (if possible) to quantify them. In the present context, degraded means that spawning occurs but there is no recruitment; non-degraded means that spawning occurs and there is substantial recruitment.

1. Select a number of sites (from within and around the Great Lakes where lake trout spawning presently occurs or has been historically documented. Measure appropriate habitat parameters at each site such as particlesize, shape, depth and geological origin of substrate; contour, slope, currents and water depth; shoal orientation, wind fetch,

sedimentation (both organic and inorganic), and water quality (including temperature, dissolved oxygen, major ions, nutrients, and contaminants). In addition, the community components (Kerr and Ryder 1977) of spawning shoals should be determined and quantified. Where appropriate, the numbers of spawning lake trout, densities of deposited eggs, embryo and fry survival and the temporal and spatial patterns of fry dispersal also should be recorded.

2. At selected sites (based on records of historical spawning and present "optimum" habitat conditions), carry out in-lake incubation of eggs and/or introduce alevins, and raise a genetically marked strain which will enable an investigation of the imprinting hypothesis (see Physiology and Behavior). Subsequently, determine the reproductive success of this stock in relation to continued introductions of other hatchery stocks.

B. Research Sites

Sites of shallow and deep-water spawners, and early and late hatches, in high and low wave energy environments where there also are differences in water quality, in the Great Lakes and some inland waters of the United States and Canada.

C. Principals

United States and Canadian federal and state/provincial agencies and universities, located near the Great Lakes and other inland waters. The extent to which problems may exist over a wide range of habitats suggests a binational collaboration of groups under the coordination of the Great Lakes Fisheries Commission.

DETERMINATION OF REPRODUCTIVE REQUIREMENTS

I. ISSUE

Rehabilitation of lake trout populations would be greatly facilitated by directing more attention towards matching of the environmental requirements (niche) of lake trout and the physico-chemical characteristics of the actual habitat (Ryder et al. 1981). Historical records indicate the general location of redds at spawning time, but few records accurately document the exact sites which would allow description of the micro-habitat. It is probable that many important historic spawning sites are now degraded. Accordingly, it is necessary to understand the conditions required for their successful restoration. Further, spawning habitat characteristics must be defined (e.g. Dorr et al. 1981) for the design of artificial habitats in “new” locations.

II. HYPOTHESIS

A. Background Information

Based on a better understanding of the environmental requirements of lake trout embryos, alevins and juveniles and of physical, chemical and biological characteristics of spawning habitat, it may be possible to identify the most suitable sites for rehabilitation, to restore degraded sites, to enhance other sites and to construct artifical spawning habitat at new locations.

B. Central Hypothesis

Spawning sites and early life habitats must provide a we&defined set of physico-chemical conditions if spawning, embryonic development, hatching and post-hatching survival of lake trout are to be successful.

C. Alternate Hypothesis

Physico-chemical conditions of spawning sites and early life habitats are not critical for the reproductive success of lake trout; other factors can explain the low reproductive success of introduced lake trout stocks.

III. METHODOLOGY

A. Experimental Design

Since, already, there is substantial effort directed toward the study of contaminant effects, field observation and laboratory tests should be applied to determine the extent of natural physio-chemical and biological constraints. Possible existence of physiological differences between shallow and spawning stocks should be considered (see Genetics).

1. Lake temperature data should be collected to describe fall-spring regimes, at different depths, on representative spawning sites.

Dissolved oxygen data should be collected to define over-winter changes in the water immediately above a spawning bed and at depth equivalent to egg entrapment in the substrate. Laboratory studies should simulate these variations to determine if embryo development is modified enough to cause mortality or deformation, or to hatch at an inappropriate time, particularly with regard to food availability (Lasker 1975).

2. Since water depth is an important control on substrate stability, particle-size and fetch data should be used to predict the depth at which gravel may be set in motion on different shorelines. Ice reconnaissance and direct survey observations should be used to determine locations and depths subject to ice-scour. Frequency of rock slides on spawning substrates should be determined; because of the possibility of high mortality of developing eggs caused by motion, steep and unstable substrates may not be suitable habitats.

3. Lake trout eggs and fry are subject to predation by many species and spawning sites should be further identified according to the predators within their communities (Horns and Magnuson 1981; Stauffer and Wagner 1979). Field and laboratory data should be obtained to quantify temporal and spatial aspects of predation of eggs and fry, and to determine conditions under which predation is least. Laboratory experiments should determine which artificial substrates offer best survival.

4. Survival of newly hatched lake trout is believed to be dependent upon availability of suitable food supplies during the transition from yolk absorption to exogenous feeding (Hjort 1914; Toetz 1966). Available information should be supplemented by additional field and laboratory data on the types and amounts of food required, Variations in the natural food supply should be related to both thermal and nutrient fluctuations.

B. Research Sites

As previously noted.

C. Principals

As previously noted.

NECESSITY OF NURSERY AREAS

I. ISSUE

Characteristics of the nursery areas adjacent to spawning sites may be of major importance in determining reproductive success of lake trout.

II. HYPOTHESIS

A. Background Information

A "nursery” area for young-of-the-year (Y-O-Y) lake trout has been discovered and sampled (J. Selgeby, pers. Comm.). The area is a sand plain at depths of less than 17m, with a steeply descending perimeter (Keillor 1980). While there was little structural cover for lake trout (Y-O-Y), there also appeared to be few benthic predators (burbot, sculpin, crayfish) of young lake trout. The area is located adjacent to the Michigan/Gull Island spawning ground in southwestern Lake Superior, and down current from usual water motion.

B. Central Hypothesis

Proximity of suitable nursery areas, with adequate food supply and few predators, enhances the success of lake trout spawning grounds.

C. Alternate Hypothesis

The distribution of lake trout fry is random; their dispersal is widespread and nursery areas are not likely to be discrete sites.

III. METHODOLOGY

A. Experimental Design

Locate and survey lake trout spawning areas where significant numbers of Y-O-Y lake trout, from native populations, are found. Determine features which may explain presence and survival of lake trout, when compared with nearby areas which lack significant numbers of Y-O-Y lake trout.

1. Determine likely time of alevin swim-up, given the thermal regime of a site and the stocks of native lake trout using it.
2. Track alevins and fry from the time of hatching to determine the pattern of dispersal from spawning sites and the location of nursery areas.
3. Identify alevin food resources and dietary patterns.
4. Identify and evaluate predation and potential species competition.

B. Research Sites

Selected Lake Superior sites where lake trout populations are known to successfully reproduce at a self-sustaining level. A minimum of two widely separated (additional) sites are needed.

C. Principals

As previously noted.

APPENDIX G

SOCIO-ECONOMICS

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ANGLING PUBLIC

I. ISSUE

Further regulation of angling in conjunction with lake trout rehabilitation will have varying effects on overall angler effort, satisfaction, and the reactions of Great Lakes sport angling organizations.

II. HYPOTHESIS STATEMENT

A. Background Information

The rehabilitation of lake trout in the Great Lakes will in all likelihood, include the regulation of the fish harvest taken by both commercial and sport anglers. The regulation of commercial fishing interests may include the use of licensing, fees, and/or the restriction of fishing techniques. Sport and charter anglers may be affected by the regulation of bag limits. All angling interests may additionally be affected by regulations which restrict fishing in specific areas.

The regulation of angling activities can be expected to have effects on: (1) anglers, (2) agencies and organizations involved in lake trout rehabilitation activities, (3) communities along the regulated lakes, and (4) others who have an interest in the waters in which these regulations apply.

The overall socio-economic research problem concerns the specification and estimation of the effects of lake trout rehabilitation on individuals and organizations that have an interest in lake trout rehabilitation strategies.

B. Central Hypothesis

Certain groups of Great Lakes anglers (beginning salmonid anglers, “meat” versus "sport" anglers, and others wanting the option to catch lake trout) will be adversely affected by more restrictive regulations and will more strongly oppose them.

C. Alternate Hypothesis

In areas where several salmonid species are available, adverse reaction to further regulations will be limited.

D. Alternate Hypothesis

The degree of support of angling organizations for rehabilitation will closely mirror organizations’ confidence in their respective state agencies.

III. METHODOLOGY

A. Experimental Design

1. Additional analysis of 1980 USFWS survey and available state angler surveys.

2. In-depth surveys in selected areas bordering the Great Lakes, stratified by ready availability of several salmonids versus primary availability of lake trout only, among salmonids.

3. Surveys of the leadership of angling organizations.

4. Content analysis of editorials and articles related to lake trout rehabilitation in outdoor publications.

B. Research Site and Principals

Individual research proposals contained herein do not contain specific suggestions for research sites and principals. While a few exceptions exist, most of the socio-economic expertise related to fisheries management lies within universities, and in the U.S. with individuals who have previous experience via funding from Sea Grant programs, state agency, or Great Lakes Fishery Commission funded research. Where secondary analysis of existing data are suggested, any of a number of individuals are qualified to conduct the research. Where primary data are called for over all or much of the Great Lakes system, a regional approach is suggested, in which a team of investigators is assembled, each of whom is familiar with lake trout issues in his/her state.

NON-ANGLING GROUP

I. ISSUE

The activities and processes associated with lake trout involve conditions and principles which transcend the fishery and its immediate uses. Water quality, for example, appears to be related to the potential for lake trout rehabilitation. Natural reproduction of lake trout may be negatively affected by water contaminants. In addition, water quality affects the consumability of lake trout.

Lake trout policy affects not only anglers, but also consumers, taxpayers, and the combination of private enterprise and governmental agencies at all levels that provide recreational services. These affected publics have varying degrees of understanding of lake trout rehabilitation and related water quality parameters.

II. HYPOTHESIS STATEMENT

A. Background Information

The rehabilitation of lake trout in the Great Lakes will in all likelihood, include the regulation of the fish harvest taken by both commercial and sport anglers. The regulation of commercial fishing interests may include the use of licensing, fees, and/or the restriction of fishing techniques. Sport and charter anglers may be affected by the regulation of bag limits. All angling interests may additionally be affected by regulations which restrict fishing in specific areas.

The regulation of angling activities can be expected to have effects on: (1) anglers, (2) agencies and organizations involved in lake trout rehabilitation activities, (3) communities along the regulated lakes, and (4) others who have an interest in the waters in which these regulations apply.

The overall socio-economic research problem concerns the specification and estimation of the effects of lake trout rehabilitation on individuals and organizations that have an interest in lake trout rehabilitation strategies.

B. Central Hypothesis

The degree of support or opposition of non-angling groups to rehabilitation strategies will depend heavily on group perceptionsof impacts on local economics and group understanding of the primary issues and factors related to lake trout rehabilitation.

C. Alternate Hypothesis

Non-anglers with low levels of understanding of the water quality/lake trout rehabilitation dynamics will oppose or be neutral to trout rehabilitation efforts.

D. Alternate Hypothesis

Non-anglers with low levels of understanding of the relationship between stocking programs and lake trout rehabilitation with oppose or be neutral to angling restrictions on lake trout.

E. Alternate Hypothesis

People in communities along the Great Lakes in which angling restrictions are used to accomplish lake trout rehabilitation will be negatively affected by the restrictions, and will oppose them.

III. METHODOLOGY

A. Experimental Design

1. Survey of samples of non-anglers (individuals, business and community leaders) to determine knowledge and attitudes regarding lake trout rehabilitation.

2. Survey of Great Lakes shore communities to specify and estimate socio-economic impacts of commercial and sport fishing activites.

3. Estimation of the incremental impacts of the changes in regulations for lake trout fishing.

B. Research Site and Principals

Individual research proposals contained herein do not contain specific suggestions for research sites and principals. While a few exceptions exist, most of the socio-economic expertise related to fisheries management lies within universities, and in the U.S. with individuals who have previous experience via funding from Sea Grant programs, state agency, or Great Lakes Fishery Commission funded research. Where secondary analysis of existing data are suggested, any of a number of individuals are qualified to conduct the research. Where primary data are called for over all or much of the Great Lakes system, a regional approach is suggested, in which a team of investigators is assembled, each of whom is familiar with Lake Trout issues in his/her state.

COST/BENEFIT ANALYSES

I. ISSUE

Agencies whose activities include and are directly related to lake trout rehabilitation will incur widely varying costs, and receive varying economic benefits from lake trout rehabilitation. The costs and benefits will also be realized over somewhat different time periods. These costs and benefits should be carefully assessed and incorporated into a broader overall cost/benefit analysis.

II. HYPOTHESIS STATEMENT

A. Background Information

The rehabilitation of lake trout in the Great Lakes will in all likelihood, include the regulation of the fish harvest taken by both commercial and sport anglers. The regulation of commercial fishing interests may include the use of licensing, fees, and/or the restriction of fishing techniques. Sport and charter anglers may be affected by the regulation of bag limits. All angling interests may additionally be affected by regulations which restrict fishing in specific areas.

The regulation of angling activities can be expected to have effects on: (1) anglers, (2) agencies and organizations involved in lake trout rehabilitation activities, (3) communities along the regulated lakes, and (4) others who have an interest in the waters in which these regulations .

The overall socio-economic research problem concerns the specification and estimation of the effects of lake trout rehabilitation on individuals and organizations that have an interest in lake trout rehabilitation strategies.

B. Central Hypothesis

Long-term social and economic benefits realized from stable, productive, and self-sustaining lake trout stocks and their harvest can be attributed to rehabilitation.

C. Alternate Hypothesis

A substantial investment of time and funds has been expended up to the present which would be lost should current lake trout stocks fall for any reason, requiring renewed efforts to return to current conditions.

III. METHODOLOGY

A. Experiment Design

1. Perform a cost analysis of total investment to date of Great Lakes lake trout program. Given current level of knowledge, obtain best estimate of costs needed to initiate a new program from a total lack of stocks to several incremental stages up to current levels.

2. Estimate long term savings of not having to rear lake trout in hatcheries, using a sensitivity analysis of conversion rates from hatchery rearing to natural reproduction.

3. Perform full benefit/cost analysis of conversions to, and long-term natural reproduction versus continued hatchery rearing of lake trout.

4. Arrive at a consensus of additional social benefits of rehabilitated lake trout.

5. Using the alternatives of administration estimates and indirect economic valuation techniques, estimate the long-term economic values of benefit-cost estimates derived earlier.

B. Research Site and Principals

Individual research proposals contained herein do not contain specific suggestions for research sites and principals. While a few exceptions exist, most of the socio-economic expertise related to fisheries management lies within universities, and in the U.S. with individuals who have previous experience via funding from Sea Grant programs, state agency, or Great Lakes Fishery Commission funded research. Where secondary analysis of existing data are suggested, any of a number of individuals are qualified to conduct the research. Where primary data are called for over all or much of the Great Lakes system, a regional approach is suggested, in which a team of investigators is assembled, each of whom is familiar with lake trout issues in his/her state.

COMMERCIAL FISHING GROUP

I. ISSUE

The taking of fish for market and the provision of guide and/or charter boat services represent the major Great Lakes commercial fishing enterprises. In some cases their activities involve fishing specifically for lake trout. In other cases, the fishing activities are more indiscriminant or involve the "incidental" taking of lake trout. The degree of commercial dependence on lake trout, by geographical area, and alternative species available to guide/charter and commercial fishermen need to be assessed.

II. HYPOTHESIS STATEMENT

A. Background Information

The rehabilitation of lake trout in the Great Lakes will in all likelihood, include the regulation of the fish harvest taken by both commercial and sport anglers. The regulation of commercial fishing interests may include the use of licensing, fees, and/or the restriction of fishing techniques. Sport and charter anglers may be affected by the regulation of bag limits. All angling interests may additionally be affected by regulations which restrict fishing in specific areas.

The regulation of angling activities can be expected to have effects on: (1) anglers, (2) agencies and organizations involved in lake trout rehabilitation activities, (3) communities along the regulated lakes, and (4) others who have an interest in the waters in which these regulations

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The overall socio-economic research problem concerns the specification and estimation of the effects of lake trout rehabilitation on individuals and organizations that have an interest in lake trout rehabilitation strategies.

B. Central Hypothesis

Charter businesses fishing specifically for lake trout and commercial fisheries for other species that experience severe bycatches of lake trout may be forced out of business or reduced to part-time status by regulations related to rehabilitation.

C. Alternate Hypothesis

Charter boat businesses, while generally opposing more restrictive regulation, will be less negatively affected by lake trout restrictions than will those fishing for market.

D. Alternate Hypothesis

Restrictions on commercial fishing for lake trout will reduce the number of full time commercial anglers and increase the number of part-time commercial anglers.

E. Alternate Hypothesis

Part-time subsistence commercial anglers will be more negatively affected by restrictions on commercial angling than will other commercial anglers.

III. METHODOLOGY

A. Experimental Design

1. Survey of commercial anglers (both market and guide/charter).

2. Use of available sales data and trip records for establishing total sales/income.

3. Analysis of market for commercial sales including non-angling consumers of commercially caught lake trout.

B. Research Site and Principals

Individual research proposals contained herein do not contain specific suggestions for research sites and principals. While a few exceptions exist, most of the socio-economic expertise related to fisheries management lies within universities, and in the U.S. with individuals who have previous experience via funding from Sea Grant programs, state agency, or Great Lakes Fishery Commission funded research. Where secondary analysis of existing data are suggested, any of a number of individuals are qualified to conduct the research. Where primary data are called for over all or much of the Great Lakes system, a regional approach is suggested, in which a team of investigators is assembled, each of whom is familiar with lake trout issues in his/her state.