PRELIMINARY INVESTIGATION OF SPAWNING HABITAT CONDITIONS AND REPRODUCTION OF LAKE TROUT IN EASTERN LAKE MICHIGAN NEAR PORT SHELDON, MICHIGAN

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INTRODUCTION

Why stocked lake trout apparently fail to reproduce in most areas of the Great Lakes remains a perplexing biological question. Lack of natural reproduction interjects considerable instability into the management of this valuable species (Rybicki and Keller 1978). Researchers have implicated a variety of factors in lake trout reproductive failure (Table 1). Our recent studies (Dorr et al. 1981; Jude et al. 1981) in Lake Michigan suggest that eutrophication, numerical insufficiency or inappropriate behavior of spawners, maladaptation of eggs to site-specific incubation conditions, and predation (by fish and crayfish) remain plausible causes of reproductive failure. Conflicting laboratory evidence has been presented regarding effects of toxic substances (PCBs, DDT) on trout reproduction and progeny survival (Stauffer 1979; Willford 1981). Quite likely, several of the above processes may act synergistically to reduce reproductive success.

The only locations in Lake Michigan where fry have been observed since the stocking program began in 1965 are areas of artificial substrate (primarily riprap). Wagner (1980) observed fry during spring 1978 and 1979 at Elmwood Marina in Grand Traverse Bay, Lake Michigan. Jude et al. (1981) trawled larvae and fry near the J. H. Campbell Power Plant at Port Sheldon, Michigan. Lake trout spawning on the newly placed artificial reef near Muskegon, Michigan is currently under investigation (W. Biener, personal communication, Michigan State University, East Lansing, Mich.). Studies (Colunga and Stone 1974; Smith 1978; Walton 1979; Dorr and Jude 1980) have shown that not only do artificial reefs concentrate fish and increase the biological productivity of an area, but that peak species abundance and diversity of colonizing organisms on marine and freshwater reefs occur during the first few (2 to 3) years following construction of the reef.

Causes of lake trout reproductive failure and solutions to this critical Great Lakes fishery problem remain unknown. However, considering the scope, expense, and duration of the Lake Michigan lake trout stocking effort and gillnetting of trout in Michigan waters of the upper Great Lakes, it has become critical to reevaluate the feasibility of efforts to reestablish self-sustaining stocks in the lakes. Trout remain sufficiently abundant in the southern basin of Lake Michigan to permit some reproductive success, as evidenced by fry observed during 1980 near Port Sheldon, Michigan. Thus, it is vital that an in-depth, in situ study of trout reproductive biology and spawning requirements be conducted in the southern basin before the conditions of the spawning reefs deteriorate or the lake trout population is reduced by exploitation.

A stepwise evaluation of the entire reproductive process is necessary to adequately investigate the causes of reproductive failure. Assessment of in situ spawning efforts, fertilization rates, and overwintering and developmental success of eggs and larvae is crucial to this evaluation. Likewise, environmental parameters (e.g., substrate depth and composition, siltation and sediment oxygen demand, oxygen availability, predation, etc.) affecting spawning behavior, incubation, and hatching success must also be examined so that existing and potentially favorable spawning areas can be identified.

Prior in situ investigations (Wagner 1980) have documented limited lake trout reproductive success in Lake Michigan. Our investigation of lake trout reproduction was prompted by capture during April-August 1980, of 60 lake trout fry ranging in total length from 22 to 62 mm, in inshore southeastern Lake Michigan near Port Sheldon, Michigan (Jude et al. 1981). An additional motivating factor was the wealth of data available from other studies. Since 1977, with the support of Consumers Power Company (Jackson, Michigan), we have been conducting extensive studies of adult, juvenile, and larval fish abundance, distribution and biology near the J. H. Campbell Power Plant at Port Sheldon. The benthic community in Lake Michigan near the plant has also been studied intensively (Jude et al. 1978; Winnell and Jude 1979, 1980). Physical characteristics (e.g., percent interstitial space) of the reef are known, and visual (via divers) monitoring and assessment of reef ecology, colonization, and succession have been conducted since the final phase of reef construction in 1979. Extensive data gathered during these ongoing studies can be interfaced with data obtained from a study of lake trout reproduction thus permitting an in-depth assessment of both the biological community and physical characteristics (e.g., water temperature regime, ice cover and scour, current, etc.) of the study area. A comprehensive study such as this may provide additional insight into factors that were conducive to trout reproduction at this location.

The Michigan Sea Grant Program funded a pilot study of lake trout reproductive biology during fall 1980 at Port Sheldon, Michigan. Goals of this study were, 1) to conduct and assess sampling methodologies, and to evaluate the feasibility of study objectives and, 2) to provide a superficial but immediate data base on lake trout spawning effort and associated environmental conditions on the Port Sheldon reef. This data base could provide some continuity for future in-depth investigation of trout reproduction at the study site.

Early in the study, objectives were established (Table 2) that we anticipated would be sufficient for an in-depth evaluation of the research problem. Our intention was to explore, assess, and accomplish as many of these objectives as resources would allow. Field observations and data obtained from this pilot study would provide background information on lake trout reproductive biology in the study area, and experience

2

gained would enable us to refine future sampling methods and design.

During studies previous and subsequent to this study, we collected data on physical and chemical characteristics of the water, predation, habitat description, and seasonal occurrence of spawning fish. Based on these data, we plan to construct a model to predict spawning success given a set of environmental conditions associated with an area. This model might range in structure from a set of descriptive criteria to a mathematical relationship (e.g., a discriminant function or regression equation) that would clarify factors affecting spawning effort and hatching success. Although the model would be constructed according to the specific system studied, it would have more general application. The following sections discuss results and recommendations and outline promising directions for future research.

METHODS

The study area was located near the J. H. Campbell Power Plant (fossil fuel) on the eastern shore of Lake Michigan in Port Sheldon Township (T6N, R6W), Ottawa County, Michigan (Fig. 1). Directly south of the plant is Pigeon Lake, the collecting basin for the Pigeon River before it enters Lake Michigan. A portion of the plant cooling water is drawn through intakes (converging to a common pipe) situated 1000 m offshore at a depth of 10.5 m; the remainder is drawn through an intake canal connected to Pigeon Lake. All circulated water, however, is returned to Lake Michigan through a common pipe to discharge structures located 600 m offshore at a depth of 6 m. Intake and discharge pipes are adjacent, and parallel each other, and extend perpendicular to shore. Pipes are buried below lake level and are covered by an extensive (about 52,000 m^3) riprap field that extends from shore to a depth of 10.5 m and varies in width from 9 to 18 m. The riprap is composed of variable-sized (predominately 0.3-1.0-m diameter, 225-900 kg), crushed limestone.

Two areas in this riprap field were sampled. One (station A) was halfway between shore and the discharge structures (7 m) and the other (station B) was 100 m lakeward from the discharges (i.e., between the intake and discharge structures) at 10 m (Fig. 1). These two different depths and distances offshore were chosen in an attempt to locate sampling sites where selective spawning may have occurred.

Replicate experimental gill nets 18.3 m x 1.8 m (60 ft. x 6 ft.), composed of 12 panels (1.5 m long) of nylon bar mesh ranging from 1.3 cm (0.5 in.) to 10.2 cm (4 in.) were set perpendicular to shore to sample fish, but severe weather limited our gillnetting efforts. On 4 December 1980 one net was set from 0200 to 1700 h at station A (inshore riprap) and station C (reference). Scuba divers collected limnological samples,

3

conducted visual analyses, and hand sampled for sediment, trout eggs, and periphyton, but diver sampling of potential demersal trout egg predators (fish and crayfish) was not conducted. Analyses for PCBs were not performed because insufficient numbers of trout, eggs, and larvae were collected during the study.

Eleven dives were performed (Table 3) during the study period 23 October–5 December 1980. The early dives (dive nos. 1-7) primarily involved site survey, evaluation, selection and placement of egg collecting containers. The inshore station (station A) was sampled once for presence of eggs on 25 November 1980 (dive no. 8). The offshore station (station B) was sampled during the period 4-5 December 1980 (dive nos. 9-11). The sampling regime was reduced because of prolonged severe weather during much of the study period.

Surface personnel measured water temperature and transparency (via Secchi disc), estimated wave height and direction, and measured or estimated wind direction and speed, barometric pressure, air temperature, and percent cloud cover. However, the limited scope of operations and small number of samples collected limited interpretation of results and did not justify extensive correlation with physical and/or limnological parameters. In addition to the above, four factors were examined to assess water quality or elements that might affect the environment in which the eggs incubated. These factors were: sediment present on the riprap and the rate at which it accumulated during the study, sediment oxygen demand (SOD), presence and composition of periphyton, and dissolved oxygen (DO) levels at different locations in the water column.

Sediment depth was measured with a ruler held by a diver. Two acrylic collecting tubes 5 cm in diameter and 57 cm in length were suspended 1 m off bottom. A chamber filled with formaldehyde was attached to the bottom of each tube and separated from it by a 0.22-micron Millipore filter. This sampling mechanism collects sediment that falls out during transport, and the formaldehyde that diffuses through the filter preserves the organic component of the sediment. The amount, rate of accumulation, composition, and inorganic/organic component ratio of the sediment can then be determined through laboratory analysis. A pair of sediment collecting tubes was installed in the lake on 24 October 1980 (dive no. 4), but was subsequently damaged during a storm. A replacement pair was installed on 4 December 1980 (dive no. 9) to remain in the lake over winter.

To assess the SOD overlying the incubation substrate, three samples of sediment were collected (dive no. 4) by scuba divers utilizing 2-liter slurp guns hand-held suction tubes – see Gilligan 1976 for a general description of the apparatus). Each sample consisted of all sediment contained within a 100-cm² area delineated by a wire hoop. The samples (slurp gun contents) were discharged into 4-liter plastic jugs and transported to the

laboratory for analysis within 2 h of collection. Low ambient temperatures (about 10 C) and rapid analysis probably inhibited significant oxidation of organics within the sediment prior to laboratory analysis.

Laboratory analysis of SOD was conducted at our field station. Sediment samples collected by divers (dive no. 4) were placed in a 350-ml Plexiglas chamber containing lake water. An Orion DO electrode was inserted into the chamber and the chamber was sealed. A magnetic stirrer provided vigorous mixing within the chamber. Experiments were conducted at room temperature. Experimental conditions were selected to provide a "worst-possible case" to test the hypothesis that SOD could impair development of trout eggs. Unfortunately, the data were misplaced and only general observations made at the time of sample analysis were available.

One 5-cm diameter piece of riprap was collected (dive no. 4) from the reef to analyze composition of periphyton. The sample was preserved in 5% buffered formaldehyde and four wet-mounted slides were prepared and examined with a microscope (J. Barres, personal communication, Great Lakes Res. Div., Univ. Mich., Ann Arbor, Mich.). Qualitative analysis of periphyton composition was performed. Algal composition of periphyton of this sample was compared with the algal composition of periphyton collected from an 8-yr-old, artificial (riprap) reef 90 km south of Port Sheldon in Lake Michigan at the D. C. Cook Nuclear Plant near Bridgman, Michigan.

Five water samples were collected (dive no. 4) at each of three locations in the water column at offshore station B: at the mid-depth stratum (5 m), within the interstitial spaces of the riprap (10 m), and at the water-sediment interface (10.5 m). Water was drawn into 30-cc syringes held by a diver, a sampling method that permitted reasonably exact sampling at selected microlayers of water. Care was taken not to disturb the water or sediment during sampling. Water samples were fixed and analyzed for DO concentration using a micro-Winkler technique adapted from Broenkow and Cline (1969) and described by Klinger (1978).

To collect and quantify numbers (no./m^2) of lake trout eggs deposited on the riprap, wooden boxes 9 cm deep, with 0.5-m^2 of bottom area were constructed, transported to the lake bottom, and filled with riprap. Twelve boxes were placed inshore on the riprap at station A (7 m) and 24 were placed offshore on the riprap at station B (10 m). The inshore boxes were filled with a mixture of new and old riprap (taken from the existing reef) 10-30 cm in diameter. The offshore boxes were filled exclusively with old riprap similar in dimensions to that placed in the inshore boxes. Our original intention was to fill some boxes at each location (station A, 7 m; station B, 10 m) with new (clean) riprap and the remainder with old riprap to evaluate substrate effects of accumulated sediment and periphyton on incubation of eggs. But transportation and deposition of sufficient new riprap

proved to be beyond the resources of the pilot study. Approximately 52,400 m^3 of bottom area covering the Campbell Plant intake and discharge pipelines are covered by riprap and the study was designed to sample an area of 16 m^2. This represented a sampling effort of 0.031%; an enormous increase in sampling (i.e., no. of boxes deployed) would have been required to significantly increase the sampling effort.

RESULTS

Although data related to sedimentation rates and composition were not available during the study period at the site, collecting tubes of identical design were deployed at another location farther south at the D. C. Cook Nuclear Plant (Bridgman, Michigan) between 25 May and 16 June 1977. Sampling depth and substrate (riprap) were nearly identical to those of this study. At the end of the 21-day sampling period, 74 mm of sediment were collected, indicating a substantial rate of sedimentation, although some fraction of the material was undoubtedly resuspended sediment (unpublished data, Great Lakes Res. Div., Univ. Mich., Ann Arbor, Mich.). Most (90% or more) of the sediment collected was organic material. Crayfish and fish (burbot) were also collected in the tubes indicating active habitat exploration and potential exploitation by lake biota.

Only limited analysis of SOD data was possible because results of the experiments were misplaced. However, based upon initial observation, the sample analyst believed that SOD of samples collected would not significantly affect DO levels in zones 1-3 (overlying water, Fig. 2) at the study site. But it was likely that eggs that settled into the actual sediment (zone 4, Fig. 2) would be subjected to conditions of severe oxygen depletion.

Twenty-one algal taxa were identified during sample analysis including 21 diatom taxa, 3 green alga taxa, and 2 blue-green algal taxa (Table 4). Approximately a dozen Hydra, two leeches, and one snail were also noted. The algal component of the periphyton analyzed was relatively depauperate, and absence of the green alga Cladophora was notable. The riprap field associated with the D. C. Cook Nuclear Plant located farther south in Lake Michigan is similar in location and composition to that of the Campbell Plant. Cook Plant riprap was placed during 1972. Periphyton samples have been collected at the Cook Plant since 1975 and analyzed in a manner similar to that described in this study. Numbers of algal taxa identified each year in Cook Plant samples were respectively: 1975, 97; 1976, 67; 1977, 97; 1978, 117; and 1979, 131. About 56 of these taxa (including Cladophora) constitute the basic periphytic algal community at the Cook Plant along with about 60 rarer taxa that are taken much less frequently (Ayers 1980). The previous observations support our contention that Campbell Plant riprap was relatively uncolonized and free of periphyton during the fall 1979 and 1980

lake trout spawning periods. This contention has important ramifications related to egg incubation stress, reef ageing and succession, and substrate suitability for trout egg incubation which will be discussed later.

Analysis of water collected on 24 October 1980 at mid-depth, 1 m off bottom, from interstitial spaces, and at the water-sediment interface revealed no significant differences in dissolved oxygen (DO) concentration at any location (Table 5). Additionally, oxygen levels approached saturation (11.1 mg/l for pure water at 11.0 C) at all locations including the water-sediment microlayer. However, lake-surface conditions were rough (wave heights exceeded 1 m) at the time of sampling and the water column was undoubtedly well mixed in addition to being isothermal.

One round whitefish was gillnetted at the reference station (station C), and one yellow perch, one trout-perch, and three round whitefish were netted at the inshore riprap station (station A). Stomach contents of these fish were examined and no lake trout eggs were found. Supplementary gillnetting was conducted previously on 5 November 1980 in conjunction with the ongoing environmental survey at the Campbell Plant. Three round whitefish (two at a sampling location directly adjacent to station A, and the other at 3 m in the vicinity of station C) were captured which had eaten 35, 4, and 46 lake trout eggs, respectively. These observations document round whitefish as a trout egg predator in the study area and more clearly define the trout spawning period.

Examination by month of the gonad maturation pattern of trout captured in gill nets, trawls, and seines during Campbell Plant environmental monitoring studies (Table 6) revealed that most females had well developed gonads during October. Spawning probably did not begin until November and was likely completed by the end of the month. However, gillnetting and seining were not conducted during December so analysis of gonad maturation cannot be extended beyond November.

Of the 12 wooden egg collection boxes placed on the bottom at station A (inshore riprap, 7 m), only one box was sampled for eggs (dive no. 8) because of sampling time constraints. No eggs were collected from this box. At station B (offshore riprap, 10 m), 15 of 22 boxes set in place were sampled; 11 on 4 December 1980 (dive nos. 9-10) and 4 on 5 December 1980 (dive no. 11). Two of the 15 boxes sampled each contained one dead trout egg. A third box contained eight eggs; two were alive and embryogenesis had proceeded to development of the primitive streak. The remaining six eggs were dead and one was covered with Hydra. It was undetermined if the presence of Hydra contributed to egg mortality or if colonization occurred after the egg died. These data suggest that egg densities ranged from 0 to 16/m². Of the 10 eggs collected, two (20%) were alive at time of collection. However, during sampling of the box that contained the eight

eggs, the diver observed that some eggs were ejected from the
rear of the sampling device (slurp gun) and lost. Additionally,
water turbulence and currents may have dislodged eggs from the
boxes. Therefore, our samples may have underestimated the
densities of eggs actually present in the boxes.

DISCUSSION

Collection of live fertile eggs from the riprap area
combined with presence of trout eggs in fish stomachs and
analysis of maturation of trout gonads provide direct and
supporting evidence that lake trout spawning occurred on Campbell
Plant riprap during fall 1980. Evidence also suggests that
larval and juvenile trout captured in the vicinity of the plant
the preceding fall (Jude et al. 1981) were also spawned on this
riprap area.

We believe that reproductive success of trout at this
location may be attributed to several factors. Obviously,
spawners concentrated and spawned enough eggs to provide an
observable level of reproductive success (recruitment of pelagic
fry) despite intrinsic and extrinsic mortality factors. These
spawner densities may have been facilitated by the structural
layout of the reef which stretched from shore outward thereby
maximizing the probability of encounters by fish moving
alongshore. The riprap provided an abundance of deep protected
crevices where the eggs could fall and wedge. Also, the
relatively "clean" and uncolonized (i.e., periphyton and sediment
free) state of the substrate may have improved incubation
conditions and increased egg and larval survival by reducing
effects of impaired water circulation, suffocation, and disease.
Finally, observation of spawning and recruitment of trout at this
location in particular may have been partly the result of the
extensive and intensive environmental monitoring program
conducted at the Campbell Plant. The combination of repeated
intensive sampling in the immediate vicinity of the reef with
plankton nets, larval sleds (see Yocum and Tesar 1980), trawls
with fine- and coarse-mesh nets and gill nets may have produced
the scope and overlap of sampling effort necessary to capture
larvae and fry present in densities that were low relative to
densities of other larval species (e.g., alewife, spottail shiner
- see Jude et al. 1978, 1979, 1980, for density estimates of more
abundant species of larvae).

A prime objective of this study was to examine possible
effects of lake eutrophication on survival of trout eggs. The
smothering effect of sediment combined with its SOD and that of
the periphyton may impair water circulation and gas exchange at
the egg membrane-water interface as well as reduce DO levels in
the microlayer of water and sediment in which the eggs rest
during incubation. If SOD and BOD (biological oxygen demand) of
the periphyton could be measured or predicted, DO levels or
gradients during quiescent periods (winter) might be projected

and a determination made whether or not incubating eggs might face an oxygen deficit.

Our studies and those of Jude et al. (1981) did not permit in-depth analysis of the oxygen deficit question, but they did indicate that DO levels on this reef during 1979-1980 were adequate for trout egg incubation. However, our study also suggested that continued sedimentation and accumulation of periphyton could possibly create future temporary DO deficits at the water-substrate interface. Virtual depletion of DO at night has been observed in Cladophora beds near Saginaw Bay, Lake Huron (M. Auer, personal communication, Univ. Mich., Ann Arbor, Mich.). Repeated sampling over a range of lake conditions (including nighttime and during ice cover and thermal stratification) at a variety of reefs encompassing conditions of maximum and minimum sediment overburden and colonization would provide insight into the potentials for DO depletion.

Fish (e.g., round whitefish, sculpins, etc.) and crayfish should be included as potential trout egg predators. In addition, presence of Hydra, fungal and bacterial infection must also be considered during analysis of stress upon incubating trout eggs.

Numerous studies have documented that peak species abundance and diversity of colonizing organisms on marine and freshwater artificial reefs occurred during the first few years (2-3) following reef placement. The bulk of the riprap at the Campbell Plant was deposited during summer-fall 1979 but some deposition continued through fall 1980. Therefore, the reef at the Campbell Plant was undoubtedly quite barren during the 1979 and 1980 spawning seasons. It was characterized by absence of sediment overburden and periphyton. Few demersal predators (sculpins, darters, crayfish) were observed, particularly during 1979. These conditions served to decrease egg and larval mortality. Whether the substrate will become unsuitable to incubation of trout eggs as the Campbell Plant reef continues to age and ecological succession occurs remains to be seen. Only if monitoring studies are continued at this location will we have this information.

In our study, egg densities ranged from 0 to 16/m². Hindley et al. (1977) observed lake trout egg densities of 8-69/m² in Lake Simcoe, Ontario and 70% of eggs collected were alive. Peck (1978) found egg densities ranging from 0 to 13,000/m² with an average of 450/m² on artificial substrate (riprap) associated with the Upper Peninsula Power Company Presque Isle Power Station, in Presque Isle Harbor, southern Lake Superior. Seventy-five percent of the eggs that he collected were fertile and less than 1% of the fertile eggs were dead. In Lake Michigan, Wagner (1974) collected 10 eggs from a 21.2- m² area (0.38/m²) and Stauffer and Peck (1976) collected 23 eggs from a 297.3-m² area (0.07/m²), although both investigators expressed concern that some eggs may have been missed during sampling.

Sampling that we conducted during 1978-1979 on a natural moraine reef 3 km south of Saugatuck Harbor, Lake Michigan, revealed egg densities ranging from 0 to 13/m³ and that 31% of the eggs collected were alive (Dorr et al. in press). Limited lake trout hatching and swim-up success have been observed in Grand Traverse Bay (Peck 1980), but prior to our studies at the Campbell Plant significant reproduction beyond the swim-up stage had not been observed in Lake Michigan.

Since both the Lake Simcoe and southern Lake Superior trout populations are fully to partially self-sustaining, the preceding data suggest that egg densities and survival may be critically low on Lake Michigan reefs. No estimate of egg densities were available for the Campbell Plant reef during the 1979 spawning season that produced recruitment of larvae and fry during spring-summer 1980, but egg densities were probably at least equal to densities calculated during the 1980 study. In all probability, 1979 egg densities may have been higher than 1980 densities.

Recent laboratory studies by Willford et al. (1981) revealed that extended exposure of lake trout fry to concentrations of PCBs and DDE similar to those present in offshore waters and zooplankton of Lake Michigan resulted in fry mortality (40.7% at 6 mo) twice that of unexposed (control) fry. Preliminary analysis of laboratory studies conducted by U. S. Fish and Wildlife Service biologists suggests that viability of Lake Michigan lake trout eggs may be significantly lower than that of eggs from other sources (Great Lakes, hatchery broodstock) in the Great Lakes, and related to higher concentrations of contaminants (PCBs, DDT, dieldrin) in Lake Michigan lake trout eggs (J. Seelye, personal communication, Great Lakes Fishery Laboratory, Ann Arbor, Mich.).

Density (or numbers) of eggs required to compensate for egg and larval mortality and to produce significant recruitment probably varies with conditions specific to each spawning location. However, with adequate investigation, some approximate minimal egg densities might be established which in turn could provide a mechanism for predicting incubation and spawning success at a given location.

CONCLUSIONS AND RECOMMENDATIONS

1) Lake trout spawning occurred on the J. H. Campbell Power Plant riprap field during fall 1979 and fall 1980.

2) The need exists to continue monitoring and sampling at the Campbell Plant to gather evidence supporting or refuting hatching and larval recruitment from 1980 spawning, and to document future spawning effort and success of lake trout in this area of Lake Michigan. Through measurement of selected physical and biological parameters a relationship may be established between the biological condition of a reef and

10

the probability of successful incubation and hatching of trout eggs. Hatching success is undoubtedly linked to environmental conditions during incubation.

3) In situ studies of lake trout spawning, incubation, and hatching success must include both fall (spawning) and spring (hatching) sampling and monitoring. Fall studies require a combination of gear including diver observations and hand sampling, and gillnetting. Spring studies should include diver sampling for eggs, deployment of emergent fry traps, and trawling with fine-mesh nets for larval fish. Use of plankton nets and benthic sleds is desirable but not critical, since net avoidance capabilities of trout fry are high.

4) Results of this pilot study show that, with minor adjustments, the methodology described in this report will adequately sample or measure desired parameters. Sampling and field logistics are complex and expensive; use of some gear (scuba) requires special equipment and technology. Weather conditions during the fall sampling period (October-December) often preclude rigid sampling schedules. Sampling designs must be flexible, opportunistic, and intensive. Allowance must be made to ensure a sampling period and frequency adequate to repeatedly sample the study area and bracket the spawning period. An experienced field staff is paramount to project success.

5) Because field studies are inherently complex and expensive, it is prudent to conduct such studies in areas where the probability of desired data return (in this case, observable reproduction) is high. This study demonstrates the value of interfacing data and observations from other related studies to obtain additional insight without added cost or effort.

6) Future studies (at the Campbell Plant and elsewhere) related to lake trout reproduction in Lake Michigan should emphasize in situ sampling or monitoring of adult spawner densities and densities and survival rates of embryonic stages. Key environmental parameters should be monitored, including dissolved oxygen concentrations associated with incubation microhabitats, particularly during winter, interstitial flow velocities, siltation rates, and sediment oxygen demand. Effects of exposure of eggs to turbulence, currents, and predation should also be determined. Given these data and some knowledge of optimal incubation conditions, areas exhibiting incubation conditions most conducive to lake trout reproductive success might be predicted and verified. Subsequent trout planting and management efforts could then be concentrated in these identified areas.

11

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Figure 1. Scheme of the study area near the J.H. Campbell Plant showing Lake Michigan and three sampling stations (A,B, and C) established for monitoring.
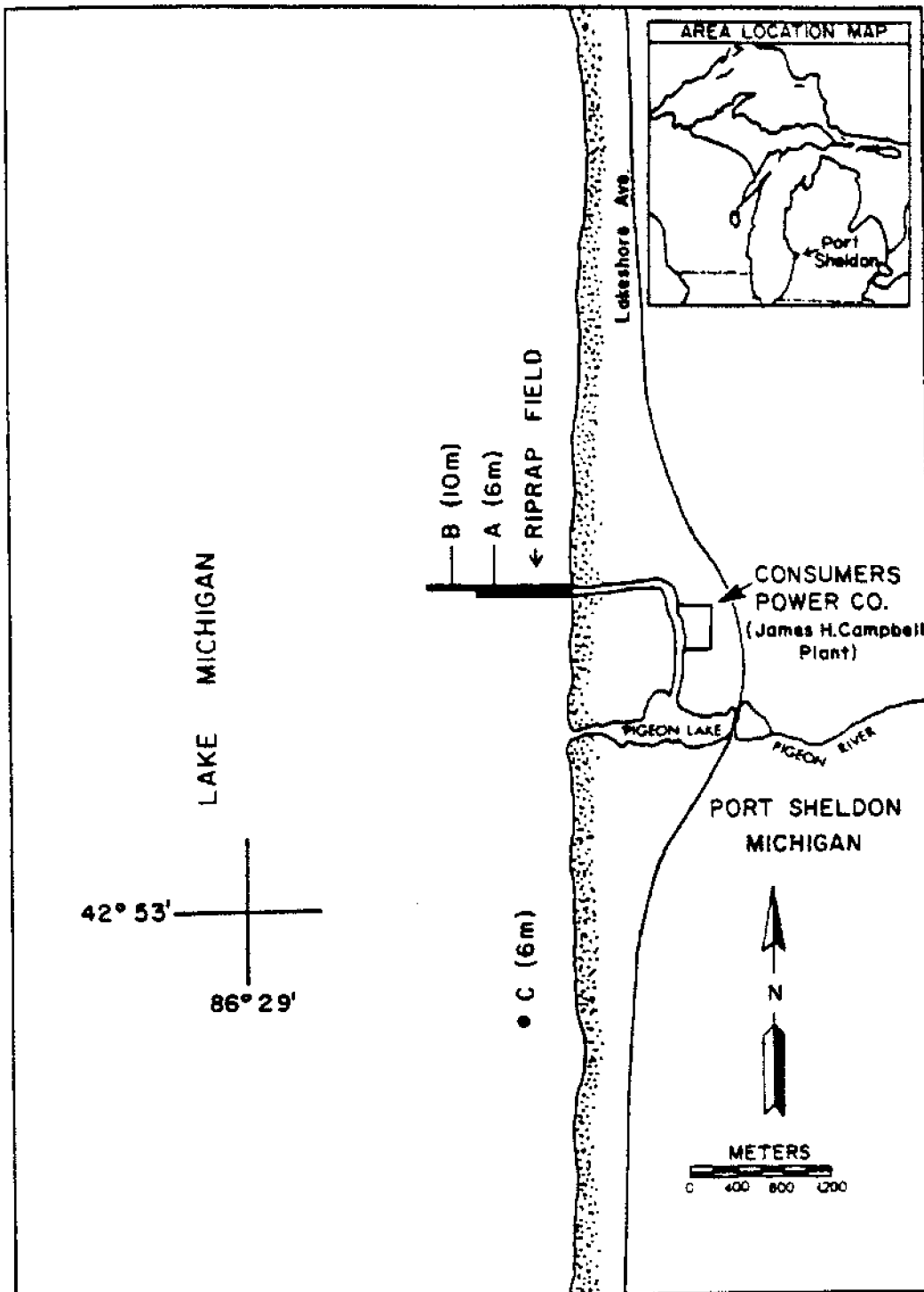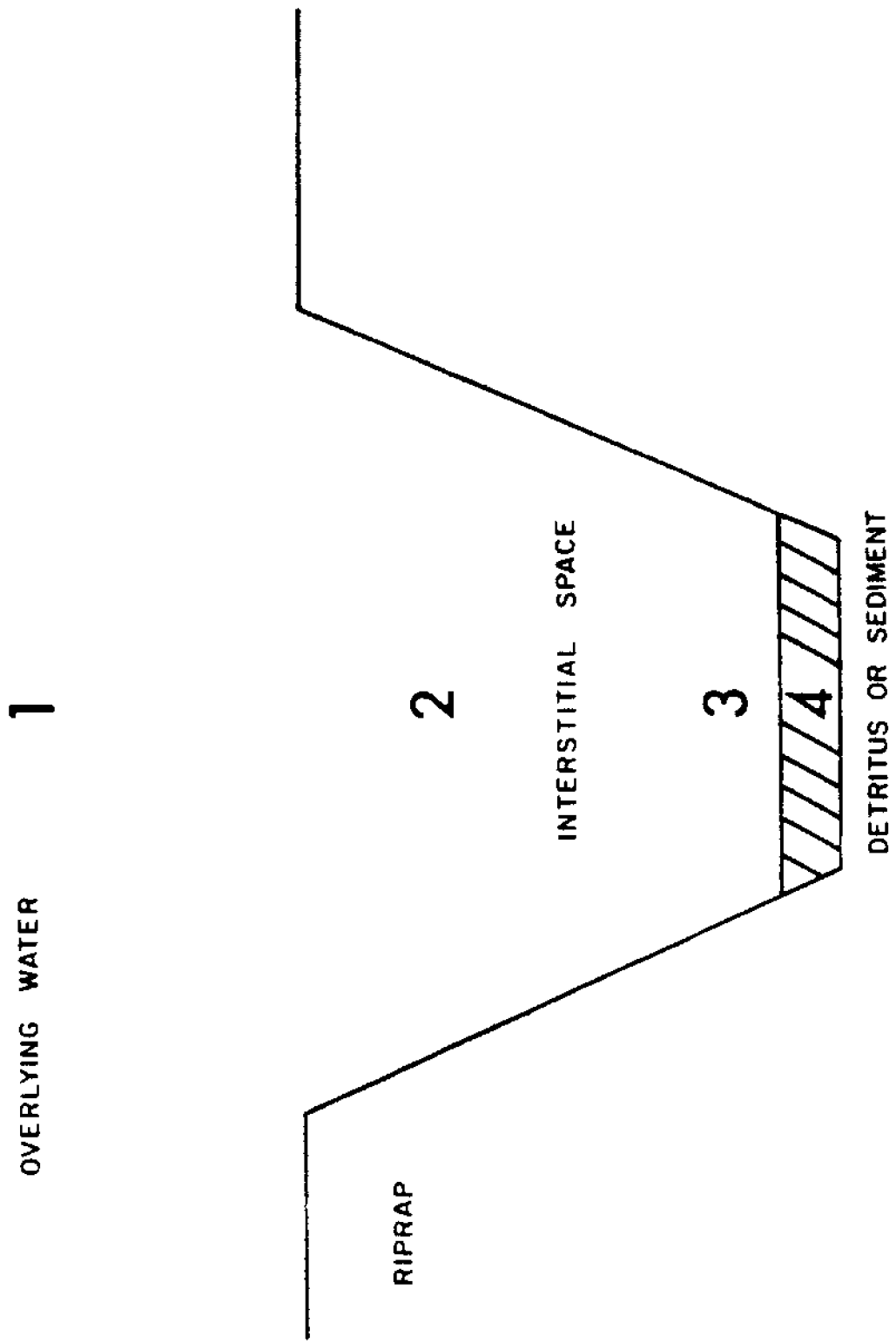
Figure 2. Scheme of the water-layer zonation in relation to substrate (riprap) configuration at the J.H. Campbell Power Plant near Port Sheldon on Lake Michigan.

Table 1. Summary of some suggested causes of lake trout reproductive failure in the lower Great Lakes.

1.   Inadequate numbers of spawners (Peck 1974; Rybicki and Keller 1978)
       a. Inadequate numbers of fish stocked or occurring on spawning reefs
       b. Inadequate lamprey control
       c. Overexploitation by commercial and sport fishers

2.   Reduction of egg viability (Martin 1957; Foster 1977; Stauffer 1979; Willford et al. 1981).
       a. Pollutants such as DDT or PCBs -- internal burden developed in adults is transfered to embryo, or assimilated directly from environment
       b. Plant toxins (e.g., Cladophora)
       c. Disease -- bacterial or fungal (Saprolegnia)

3.   Predation (Scott and Crossman 1973; Stauffer and Wagner 1979; Horns and Magnuson 1978)
       a. Fish
       b. Invertebrates (primarily crayfish)

4.   Eutrophication of spawning habitats (Martin 1957; Martin and Olver 1976; Stauffer and Peck 1976)
       a. Siltation--increased BOD, decreased circulation leading to suffocation and increased vulnerability to disease
       b. Periphyton -- effects similar to siltation

5.   Inappropriate fish stocking methods (Pycha 1972; Rybicki and Keller 1978)
       a. Inappropriate locations -- non-traditional reefs, harsh inshore conditions for incubation
       b. Planted at wrong age (planted after imprinting stage)

6.   Maladaptation (behavioral, anatomical, physiological) for reproducing in the selected habitat (Swanson 1973; Loftus 1976; Scholz et al. 1976; Horrall 1977)
       a. Failure to return to appropriate spawning locations--lacking or inappropriate imprinting pheromones, redolence of reef or spawning area
       b. Spawning (incubation of eggs) in areas of excessively harsh environmental conditions--wave action, currents, turbulence, ice scour, abrasion by sediments
       c. Spawning and incubation in areas of highly variable water temperatures
       d. Evolution of genetically controlled, area-specific adaptations to sets of environmental incubation conditions in conjunction with the development of geographically separated subpopulations of lake trout. Mixing of gene pool in hatcheries resulted in loss of area-specific adaptations resulting in increased egg mortality.

7.   A combination of the above factors -- e.g., numerical insufficiency, habitat degradation, and maladaptation to a specific set of environmental conditions.

Table 2. Objectives for in situ study of environmental parameters associated with a specific spawning area and the effect of these environmental parameters on lake trout reproductive biology and success.

1. Characterize the spawning/incubation habitat including:
   a. Siltation rate and composition (percent organics) and potential sediment oxygen demand
   b. Dissolved oxygen levels at the water/substrate interface (i.e., the incubation microhabitat)
   c. Growth and composition of the periphytic community associated with the incubation substrate
   d. Depth and physical characteristics (composition, percent interstitial space, size, etc.) of the substrate

2. Observe, describe and evaluate aspects of lake trout reproductive biology including:
   a. Behavior, distribution, and movement of spawners
   b. Sequential spawning effort over time
   c. Survival (rates) and densities associated with various developmental stages from spawned eggs through fry
   d. Developmental stages where reproductive failure might most likely occur and establish cause-and-effect relationships
   e. PCB levels in spawning fish, ovarian eggs, fertilized eggs collected on the substrate, overwintered eggs and emergent fry. Establish baseline levels of PCB concentrations for comparison with prior studies to assess possible effects of observed PCB burdens on developmental success.

3. Evaluate several plausible causes for lake trout reporductive failure including:
   a. Numerical insufficiency of spawners or spawn (i.e., egg density)
   b. Maladaptation (behavior or physiology) of adult fish, eggs, and fry to conditions associated with spawning habitat
   c. Predation effects (fish and crayfish)

4. Relate study observations and conclusions to management of lake trout with emphasis on the feasibility and direction of efforts to reestablish self-sustaining stocks including:
   a. Spawning habitat requirements
   b. Minimization of factors adversely affecting spawning and incubation success
   c. Direction and level of current and future stocking efforts

20

Table 3. Summary of project diving activities at the J. H. Campbell Power Plant, eastern Lake Michigan, 23 October - 5 December 1980.

Dive	Date	Station	Depth (m)	Duration (min)	No. of Divers	Activity*
1	23 Oct.	A	7	45	2	1
2	23 Oct.	A	7	60	5	3
3	23 Oct.	B	10	20	3	1
4	24 Oct.	B	10	120	6	3, 2
5	24 Oct.	B	10	20	2	3
6	7 Nov.	B	10	180	5	3
7	12 Nov.	B	10	135	5	3
8	25 Nov.	A	7	20	2	4
9	4 Dec.	B	10	45	6	4, 5
10	4 Dec.	B	10	20	4	4
11	5 Dec.	B	10	45	5	4

*Activity definitions: 1 = Site evaluation and selection.
2 = Diver collection of sediment, water, periphyton.
3 = Placement of egg collection containers on bottom.
4 = Sampling of collection containers for lake trout eggs.
5 = Gill nets set concurrently with diving activities.

Table 4. Taxonomic composition of periphyton on one sample of riprap collected by divers at the J. H. Campbell Power Plant, eastern Lake Michigan, 24 October 1980.

BACILLARIOPHYTA
     Amphora spp. (1)
     Amphora calumetica (1 dead)
     Cyclotella spp. (3)
     Cyclotella comta (1 dead)
     Cyclotella comensis (1)
     Fragilaria crotonensis (220/4)
     Gomphonema spp. (1)
     Melosira iscandica (10/1)
     Melosira granulata (37/3)
     Nitzschia spp.(1)
     Navicula spp. (1)
     Stephanodiscus alpinus (1)
     Stephanodiscus spp. (5)
     Synedra spp. (1)
     Synedra ulna (1)
     Tabellaria fenestrala v. intermedia (1 dead)

CHLOROPHYTA
     Scenedesmus spp. (8)
     Scenedesmus quadricanda (4)

CYANOPHYTA
     Gomphospheria lacustris (150/2)
     Oscillatoria spp. (1)

MISCELLANEOUS
     Coelenterata (Hydra) - 12
     Hirudinea (Leech) - 2
     Gastropoda (Snail) - 1

Number of cells or number of cells/number of colonies examined indicated in parentheses. All cells were alive except where noted.

Table 5. Dissolved oxygen levels (mg/l) measured in water samples collected at station B (offshore riprap, 10 m) near the J. H. Campbell Power Plant, eastern Lake Michigan, 24 October 1980.

Sampling Location	Sampling Depth (m)	Replicate	Dissolved Oxygen (mg/l)
Midway in water column	5.0	1	10.4
		2	10.6
		3	10.4
		4	10.8
		5	10.8
			$\bar{x}$ = 10.60 - 0.04
1 m off bottom	9.0	1	10.5
		2	10.1
		3	11.0
		4	10.8
		5	10.8
			$\bar{x}$ = 10.64 - 0.07
Within interstitial spaces of riprap	9.5	1	10.4
		2	10.4
		3	10.4
		4	10.8
		5	10.4
			$\bar{x}$ = 10.48 - 0.04
At the water-substrate interface	10.0	1	10.4
		2	10.4
		3	10.1
		4	10.4
		5	10.8
			$\bar{x}$ = 10.42 - 0.05

Water temperature was 11.0 C at all depths; oxygen saturation at 11.0°C is 11.1 mg/l. Mean ($\bar{x}$) and standard error (SE) were calculated for each sampling location.

Table 6. Monthly gonad conditions of lake trout caught in Lake Michigan near the J. H. Campbell Power Plant, eastern Lake Michigan, 1980.

	Gonad condition	June	July	Aug.	Sept.	Oct.	Nov.
Males	Slight development	3			2	2	0
	Mod. development	7			4	38	9
	Well developed			2	26	61	18
	Ripe-running					3	36
	Spent						3
Females	Slight development	1				1	4
	Mod. development	5			1		0
	Well developed	1		3	27	98	17
	Ripe-running					3	24
	Spent						8
	Absorbing						
Immature		10		2			
Unable to distinquish		1		3			

All fish examined in a month were included except poorly received specimens. These samples were collected in association with an ongoing environmental study at the Campbell Plant (unpublished data, Great Lakes Research Division, University of Michigan, Ann Arbor, Michigan).