GREAT LAKES FISHERY COMMISSION

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Sea Lamprey Barriers: New Concepts and Research Needs

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SEA LAMPREY BARRIERS: NEW CONCEPTS AND RESEARCH NEEDS

(Workshop sponsored by the Great Lakes Fishery Commission)

Minneapolis-St.Paul Airport Hilton
Minneapolis, Minnesota
February 11-13, 1994

(Report to the Great Lakes Fishery Commission)

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ABSTRACT

The fourth in a series of workshops designed to develop new ideas for controlling populations of sea lampreys (Petromyzon marinus), in the Great Lakes took place on February 11-13, 1994 in Minneapolis. The purpose of the workshop was to identify and prioritize research needs that will help to advance the use of sea lamprey barriers and to stimulate new ideas and innovative strategies for solving barrier problems by using an interdisciplinary approach. Experts in related fields met with personnel from the Great Lakes Fishery Commission and its agents. Sea lamprey personnel described the history of the barrier program and its current status while experts in other areas described their research. After the presentations a list of research needs was compiled, and some research priorities were suggested.

INTRODUCTION

Although selective toxicants have successfully controlled sea lamprey (Petromyzon marinus), populations in the Great Lakes, other methods of control should be considered in any pest control program. In order to reduce the almost total reliance on toxicants and also the amount used, the Great Lakes Fishery Commission (GLFC) has sponsored a series of workshops designed to develop alternative control methods. In the first workshop, experts on sex determination and differentiation in mammals, amphibians, birds and fishes met with sea lamprey personnel to discuss the latest information and techniques available in their fields (Sower and Hanson, 1992). In the second workshop, pest control experts from the U.S. Department of Agriculture and the Ontario Ministry of Natural Resources met with personnel from the GLFC and the sea lamprey control program to discuss and evaluate the current lamprey program and to examine other control options (Seelye and Hanson, 1992). In a third workshop, personnel from the GLFC and its control agents met with experts in chemoreception science who had knowledge of the use of odorants in controlling other organisms to determine how odorants might be used in the lamprey control program (Sorensen and Hanson, 1994).

A fourth workshop was held on February 11-13, 1994 at the Minneapolis-St.Paul Airport Hilton. Experts on physical barriers, sound and electric barriers, fish passage, fish behavior, hydraulics, hydrology, and environmental impacts met with personnel from the GLFC and its control agents to examine ways barriers could be effectively used in the lamprey control program. The workshop participants are listed in Appendix A and the professional backgrounds of the presenters appear in Appendix B. Sea lamprey personnel described the history of the barrier program and its current status while experts in other fields described their research or past work and made suggestions on how various types of barriers might be useful in sea lamprey control. After all presentations were made, a list of research needs was compiled, and some research priorities suggested. Post-workshop comments were solicited and are included in this report.

BACKGROUND INFORMATION

After a brief statement outlining the objectives of the workshop by Chris Katopodis, Bill Beamish welcomed all participants to the workshop on behalf of the GLFC. After the introductions of the participants, individual presentations were made.

History of the Sea Lamprey Control Program -
(Ellie Koon - Barrier Coordinator, U.S. Fish and Wildlife Service)

Summary - Ellie Koon showed the video entitled "Great Lakes Invader - the Sea Lamprey Battle Continues" and slides depicting the life history of the sea lamprey. Restrictions on lamprey distribution such as spawning requirements, larval habitat, water quality, water temperature, and barriers to upstream migration were described. A history of the chemical control program was presented and population estimates of larvae in selected streams, before and after treatment, were described. A history of the barrier program for sea lamprey control was described and slides showing the various types of barriers (mechanical and electrical weirs, low-head dams and velocity barriers) used in the past and being considered for use in the future were shown. Advantages of barriers include fewer residual lampreys left over from treatments, reduced lampricide use, reduced lampricide cost, less stream mileage treated, less non-target exposure to lampricides, greater public acceptance, and increased trapping ability.

Portable traps and traps built into the barrier itself were shown. Trapping efficiency depends on the type of trap used (portable traps are usually not as efficient as traps built into the barrier). Benefits of increased trapping efficiency include capturing more males for sterilization, reducing or eliminating spawning above barriers, reducing spawning below barriers, and reducing the number of lampreys that would be turned away by the barrier and go elsewhere to spawn. Disadvantages of barriers include blockage of some fish migrants (non-jumping fish), increased water temperatures, siltation, blockage of canoes and boats, public opposition, and fish concentrating below barriers resulting in increased fishing pressure and violations by fishermen. The problems involving TFM (registration and chemical costs) were presented. The GLFC "Vision" statement was described, in which one of the goals is to reduce reliance on chemicals by 50% through the use of alternative methods such as barriers.

Comments and discussion - Sea lampreys will not spawn in still water, a unidirectional flow of water is needed. Also, gravel of a certain size and suitable water temperatures are required before spawning will occur. Only 480 of over 5,000 tributaries have suitable conditions in which sea lampreys will spawn successfully. Only 208 streams are regularly treated with lampricide, whereas others are treated only occasionally since successful spawning does not always occur.

Spawning run lampreys are usually attracted to streams with large discharges. There is some preliminary evidence that they are also attracted to bile salts that are released by larval lampreys in streams. Major spawning migrations occur when water temperatures approach 10°C. Migrations last about 30-50 days.

A large portion of the parasitic sea lampreys in Lake Huron and northern Lake Michigan appear to be coming from the St. Marys River, which carries the entire outflow from Lake Superior into Lake Huron. This river is very large and would be very expensive and difficult to treat with a lampricide. Some parasitic lampreys originate from lentic larval populations off the mouths of some streams, from residual populations (larvae that survive chemical treatments), and from streams that are not treated because the larval populations are considered to be small.

Although chemical treatments are effective, there are still too many parasitic lampreys in the Great Lakes. Budget constraints and the desire to use less chemical has had an effect. Streams with small larval populations are no longer treated, lentic populations (previously treated with a granular bottom formulation of Bayer 73 along with annual treatment of the river flowing into the lentic area) are no longer under control, and reduced concentrations of TFM during chemical treatments (to reduce the possibility of fish kills) all have had an effect.

Before the discovery of TFM, electrical barriers were the primary method of sea lamprey control. By 1960, 162 electrical barriers had been installed in the United States and Canada. In many instances, they were very effective and prevented lampreys from moving upstream to spawn. However, if a power failure occurred (if only for one night during the peak spawning migration) or flooding allowed lampreys to go around the barrier, the stream would become repopulated with larval lampreys. After TFM was discovered the barriers were gradually phased out, primarily because of budget constraints, the effectiveness of chemical treatments, and for safety reasons.

Studies on using low-head dams began in the 1970s. A drop of 18 inches (46 cm) with a lip was considered to be an effective barrier. Although barriers may prevent lampreys from spawning upstream, they may still spawn successfully below the barrier if suitable spawning and larval habitat exists. Large lentic populations may also result where suitable larval habitat occurs in the lentic area. The stream below the barrier and the lentic area will then have to be treated, which may take nearly as much chemical as treating the entire watershed. Much less of the stream would be exposed to lampricides however. Thirty nine low-head dams are currently in place. Stable and adequate funding is the major obstacle to the program. Costs for barriers could range from $15,000 to more than $1,000,000 depending on the size of the stream.

Portable assessment traps are often used in conjunction with low-head barriers. They are usually placed in the corners at the surface where they are most effective. Video cameras would be useful to study lamprey behavior at barriers.

There are about 250 other structures around the Great Lakes that act as lamprey barriers. There is interest in providing fish-passage structures at many of these. We will need a method of separating fish from lampreys in order to prevent lampreys from moving upstream.

Brief on Existing Barriers -
(Tom McAuley - Barrier Coordinator, Department of Fisheries and Oceans, Government of Canada)

Abstract - Mechanical weirs with traps and alternating current electric barriers were the first types of barriers specifically installed in an attempt to control sea lamprey in the upper Great Lakes in the 1950s. With the introduction of lampricide in the late 1950s, electric barriers and weirs were relegated to a secondary role of assessing migrating adults. An experimental barrier dam was also constructed on Michigan's Black River in 1950. The structure blocked lampreys when a minimum head of 67 cm (26 inches) was maintained in 1951, 1955, and 1956 (Stauffer 1964). In 1952 and 1953, with minimum heads of 40 and 50 cm (16 and 19 inches), there was some escapement of lampreys.

In 1966, a simple modification to an existing dam on the Black Sturgeon River on the north shore of Lake Superior reduced the length of TFM treatments by 62 km. In 1970, reconstruction of Denny's Dam on the Saugeen River completely eliminated future treatments in this Canadian tributary to Lake Huron. The 3 m high dam with a pool and weir fishway effected major cost and effort savings. The pre-barrier treatment had involved 84 km of river and the introduction of

11,200 kg active ingredient of TFM. Some of the early lamprey barriers such as the 2.4 m high barrier dam built in 1970 on the Echo River failed to stop lampreys.

Since the 1970s, construction of new sea lamprey barrier dams and improvements to existing dams and bedrock chutes has gradually grown in importance as part of the GLFC's sea lamprey control program. Between 1979 and 1990, 20 low-head barrier dams (max. head <1 m) were built in Ontario. The development of low-head barriers was due in part to a study in which a 30 cm (12 inches) drop proved to be a definite barrier to 3000 sea lampreys (Hunn and Youngs 1980); however, corequisite hydrological and migratory criteria are not well defined.

At the end of 1992, there were a total of 44 lamprey barriers (15 in the USA) installed on Great Lakes tributaries. These include modifications to 6 existing dams and 2 bedrock chutes and 4 electric barriers. For fish passage reasons, only one of the electric barriers is being operated. Most of the 34 barrier dams (except for about 4) have been effective in stopping lamprey runs. Many of the dams built since the early 1980s include fairly effective built-in traps.

Comments and discussion - Jumping pools below the barriers are usually about 1.25 times the height of the barrier in depth.

BARRIERS

Development of an Experimental Velocity Barrier to Control Sea Lampreys - (Tom McAuley - Barrier Coordinator, Department of Fisheries & Oceans, Government of Canada)

Abstract - Barriers that exploit the physical differences between sea lampreys and other migratory species show significant potential for use in lamprey control. One of several physical differences that can be exploited is swimming endurance. Anguilliform swimming is hydromechanically less efficient than the sub-carangiform swimming mode used by other Great Lakes migratory fish. All of the marine teleosts in tests of prolonged swimming endurance were able to swim for longer periods at higher speeds than could sea lampreys (Beamish 1974).

The idea of trying a velocity barrier as a control tool has grown out of some of the challenges and problems related to passing diverse fish species at existing barrier dams and electric barriers. It has also grown out of the search by the author for lamprey barriers that will function at minimal hydraulic heads. Lower head barriers have greater flexibility in site choices and can bring increased potential for lampricide reductions on many treated streams.

The velocity barrier idea was first mentioned by Bergstedt around 1980. It was soon considered infeasible (Hanson 1980, Hunn and Youngs 1980) when it was found that the maximum sprint velocity of lampreys was about 4 m/s. The idea was left unexploited. I assume they considered that a velocity greater than maximum swimming speed would be needed because sea lampreys can attach to surfaces while migrating through a fishway.

Eliminating the attachment advantage permits the use of lower water velocities in velocity barriers. A velocity barrier becomes simply a planned combination of water velocity flowing over a distance such that it blocks sea lamprey passage. The longer the velocity chute, the lower the velocity required to stop lampreys. Conversely, the faster the water, the shorter the barrier required. This permits a certain flexibility in design and planning. The length and velocity of a barrier can be selected according to fish passage, budget, and site criteria.

Accurate swimming performance data over the appropriate ranges of velocities and temperatures is indispensable in planning velocity barriers. Draft results from open flume swim tests for lampreys in 1991 and 1992 can be seen in Figures 1 to 4. The relation to previous work carried out on lampreys is also included in Figures 1,2, and 3. Regressions were found for sea lampreys swimming endurance and for distances attained in the various tests carried at water velocities between 0.7 and 2.8 m/s and over temperatures ranging from 9° to 21°C. Endurance was found to vary inversely as the cube of swimming velocity at 10°C. An interesting phenomenon was also uncovered. The endurance curve shifts to a new continuous upper level (Fig.3) for tests at 15° through 20°C. This appears to be due to drag reduction resulting from a swimming mode change to lower amplitude body waves. In considering the swimming performance of fish to be passed, it is important to use data from adult migratory animals at the range of water velocities considered. A search of the literature shows that this information is somewhat rare for upper prolonged and burst swimming for migratory species of concern in the Great Lakes basin (Fig. 2).

Measured swim distances (Fig. 4) include valuable information on lamprey swimming strategy. This data can be used to confirm any projections of distance achieved made from endurance data (which frequently assume rates of travel.)

Materials preventing attachment of sea lampreys were also tested. A suitable "non-attach" material was chosen from the six tested for use in the first instream velocity barrier. Hydraulic modelling of the velocity chute and overflow crest sections was carried out at the University of Manitoba hydraulics lab to confirm and improve design hydraulics.

A first, basic experimental velocity barrier (with lamprey trap) was built in 1993 on the McIntyre River in Thunder Bay on Lake Superior. The first lamprey spawning run to the barrier will be in the spring of 1994. An evaluation of the barrier's success at fish passage and lamprey stoppage is being carried out by R. Young.

For the future, there are a number of creative hydraulic structures including velocity barrier design variations, fishways, and traps that exploit both swimming and behavioral differences which could be designed and tested.

Comments and discussion - If we don't find more efficient means of separating non-target fish and lampreys we will have to use trapping and separation by hand.

Velocity barriers are expected to pass the larger non-jumping fish. Smaller fish (say <30 cm) will be stopped.

The majority (>95%) of the lamprey spawning migration occurs when water levels are between one-half and two times the mean annual discharge.

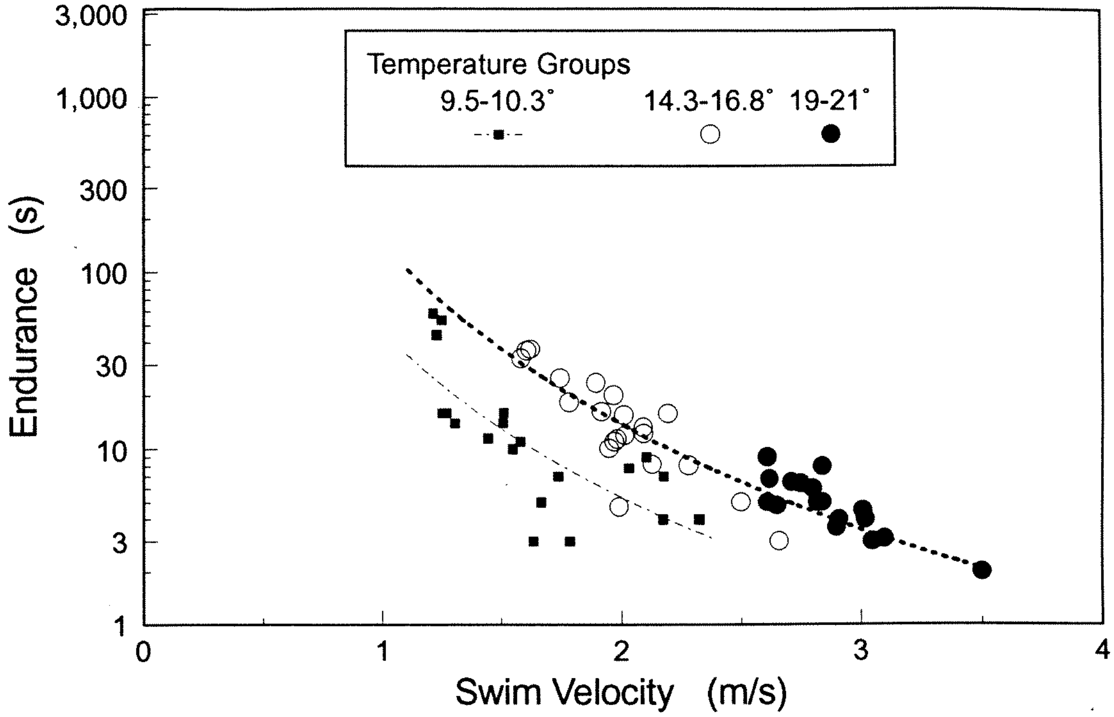

Figure 1 Swimming speed - endurance data for 45 cm long sea lampreys found in our 1991 and 1992 open flume tests.

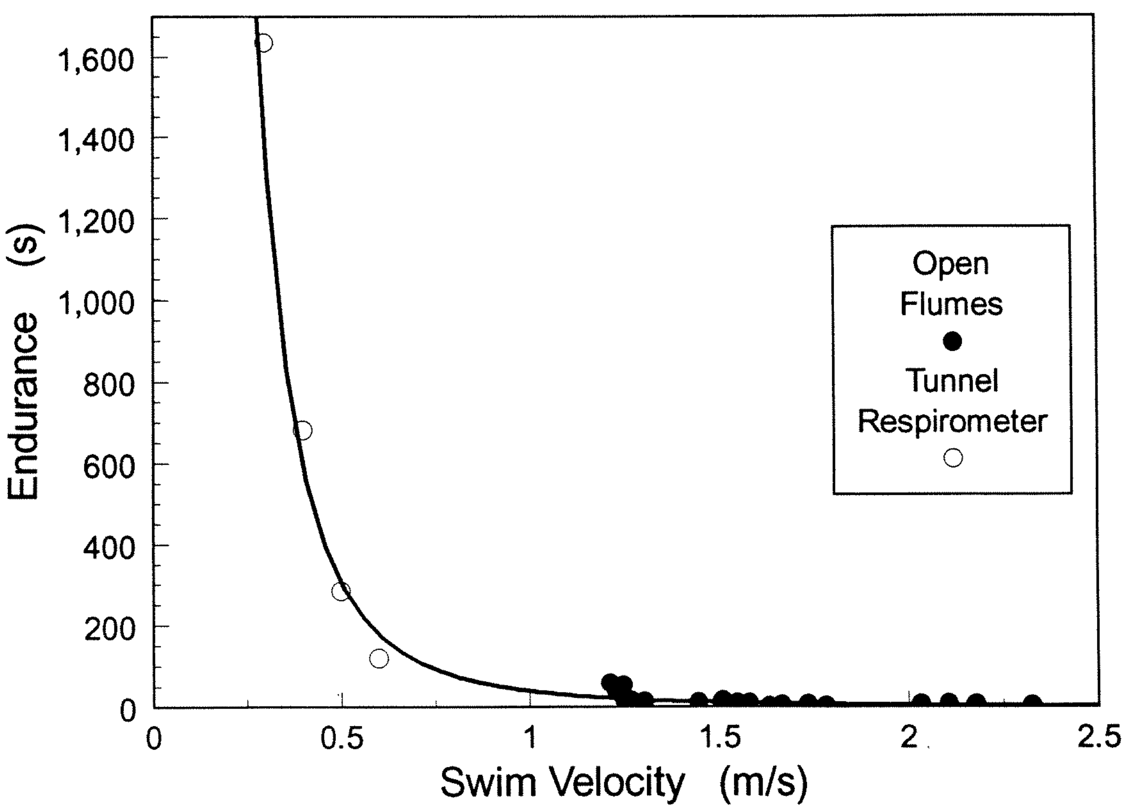

Figure 2 Swimming endurance from our flume tests for 45 cm sea lampreys at 10° (+/-1°) and endurance for similar size lamprey found by Beamish (1974) at lower velocities in a tunnel respirometer.

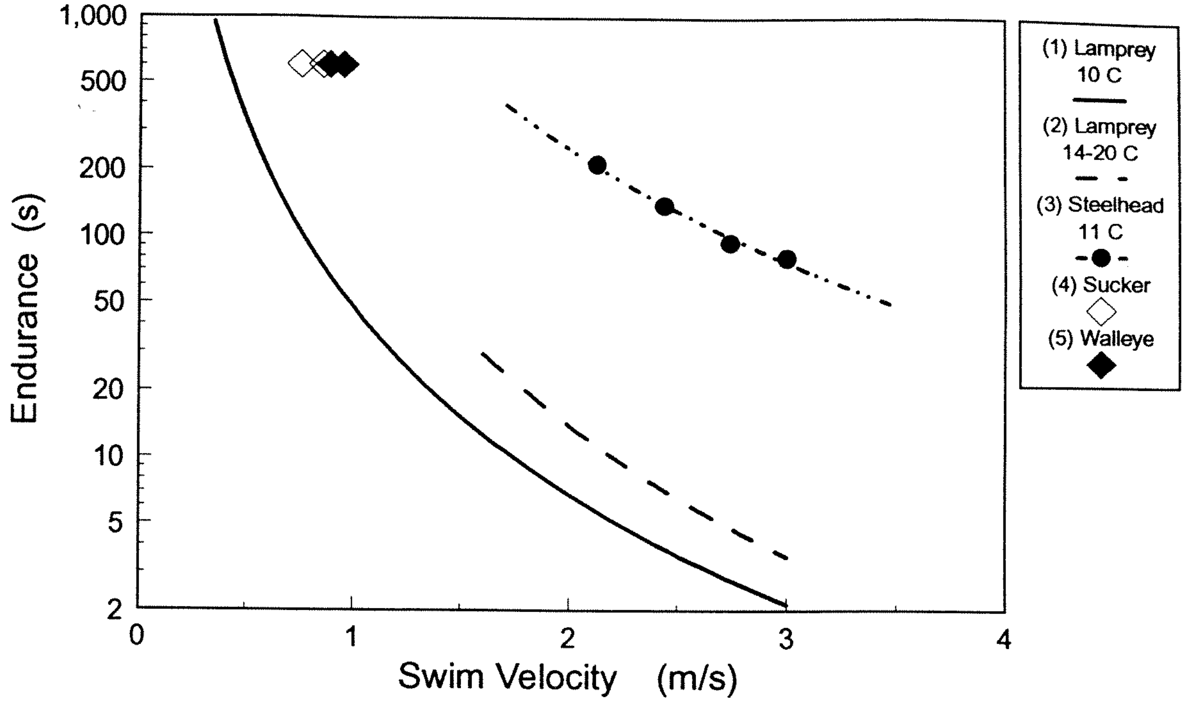

Figure 3 Comparison of swimming endurance of sea lamprey to that of some adult migratory fish common to the Great Lakes basin. Curves (1) and (2) are from regressions of Figures 2 and 1. Other sources are (3) Paulik and DeLacy (1957) and (4) (5) Jones et al. (1974).

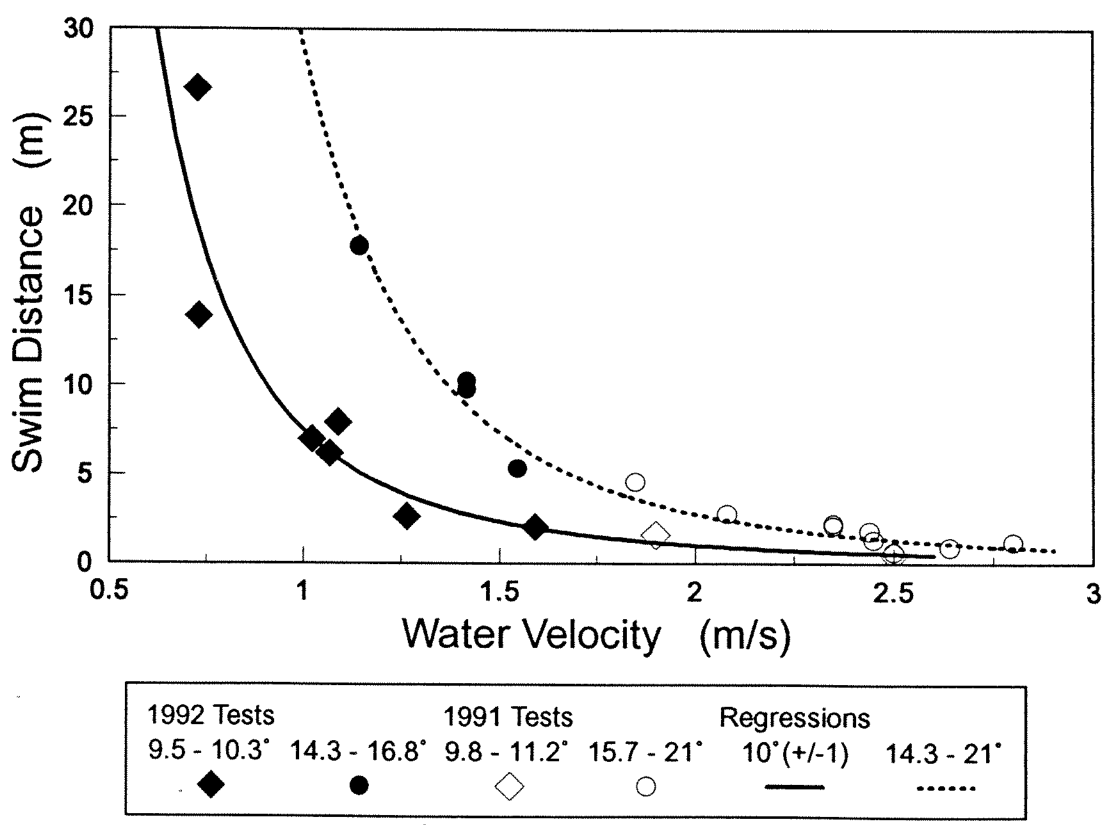

Figure 4 Swimming distance verses water velocity for sea lamprey in our 1991 and 1992 tests (median values of test groups).

Michigan Sea Lamprey Barrier Program - Discussion of two Design Problems - (Roy C. Haeusler - Professional Engineer, Michigan Department of Natural Resources).

Abstract - Michigan currently has in place seven weir-type barriers and three electrical barriers. The weir barriers were built in the late 1970's and early 80's, and the electrical barriers were constructed more recently. The barriers are located in the Upper Peninsula and in the northern half of the lower peninsula, mostly on smaller streams. In the process of designing these barriers two important problems were dealt with.

Flooding easement requirements: The construction of a weir-type barrier will increase river stages upstream of the barrier under both normal and higher river discharge conditions. These higher water levels will flood property upstream, creating a trespass condition which, under Michigan law, requires that a flooding easement be obtained. The need for flooding easements may, in some cases, significantly increase the project costs.

The process of selecting a barrier site included giving attention to

1. Picking a site, when possible, in which not only the barrier but all of the flooding was confined to publicly owned property.

2. Finding a section of the river with as steep a gradient as possible to limit the upstream extent of flooding. Being able to do this was limited by the need to place the barrier where it would be most effective in blocking the migrating adult sea lampreys.

3. Using a different type of barrier when the upstream flooding problems became unusually difficult or costly to deal with.

Determination of the Design Tailwater Elevation: Before the crest elevation of a weir-type barrier can be set, it is necessary to determine the tailwater likely to occur during the sea lamprey migration period. The height of the selected drop (Michigan currently uses 45 cm) is then added to this water elevation to get the crest elevation. Also, tailwater elevations need to be determined during the fish-migration periods so that an adequate fish-passage facility can be built.

The procedure used to determine these water-surface elevations relies heavily on the judgment of the hydrologist and the biologist in determining

1. The time and conditions under which the lamprey run is likely to occur.

2. The discharges that are likely to occur at the time of the lamprey migrations.

3. The river elevation likely to occur at that particular river discharge. This requires evaluating such variables as channel roughness and alignment and the effect of any downstream constrictions such as a bridge.

It became apparent that determining the likely water-surface elevations was not an exact science. Also, in order for the barrier to block sea lampreys as well as to pass migrating fish, the water surface elevations needed to be determined within rather narrow limits. An over-conservatively high calculation of the tailwater elevation resulted in a barrier that did a very effective job of blocking lampreys but left a very shallow depth in the jumping pool and a significantly higher jump to be made by the migrating fish.

In an attempt to solve this problem, lamprey barriers were constructed with built in crest-height flexibility. This consisted of stoplog bays, removable crest timbers, and in the case of the Albany Creek barrier, a hinged steel-sheet weir plate that could be raised or lowered as needed. The stoplogs and hinged crest plate also allowed drawing down the head pond during the summer months.

Comments and discussion - Determining water surface elevations at a barrier site is basically a science and can be done within ± .5 foot if accurate discharge information is available. The problem arises in determining discharge. Stream discharge measurements should be conducted a year or two before construction begins.

Most of the State of Michigan barriers are far enough upstream so the tailwater levels are not affected by lake levels. Tailwater levels can be adversely affected by either high or low lake levels.

Physical Barriers -
(Ken Bates - Fisheries Engineer, Washington Department of Fisheries)

Summary - Ken Bates showed slides on the evolution of salmon barriers in the state of Washington that are used primarily to capture brood stock. Concrete dams with gates, Japanese style floating racks, and a variety of rubber dams were shown.

Rubber dams with lips can be pumped up (with water) to various heights, are watertight, and can be deflated in place when not needed. Concrete or timber pads with side abutments are necessary to make the dams watertight. The dams are only about 4 inches (100 mm) high when deflated. The height of the dam can be adjusted daily if necessary. They can be made to drop automatically with deflating devices as the forebay drops but must be pumped up to raise the dam. The difference in water levels between the tailwater and forebay will be automatically maintained if water levels are dropping.

Comments and discussion - Some rubber dams are being built with picket weirs instead of a steel plate for a lip. Hydraulic cylinders in the bed of the river are used to pump it up. A dam about 120 feet (35 m) wide was built for about $180,000. There are several manufacturers of rubber dams.

Rubber dams appear to be quite durable. Dams with bullet holes in them leak quite slowly and the pump simply comes on occasionally to pump the dam back up. Holes can be repaired with rubber plugs.

Sound Barriers to Control Sea Lampreys -

(Paul Loeffelman - Energy Engineering Services (EESCO), Fort Lauderdale, Florida)

Abstract - This summary describes EESCO's applied research projects and commercial installations of full scale acoustic biological guidance and deterrence systems customized to target species and site conditions. These systems incorporate bioengineering and signal development concepts developed and field verified since the late 1980's by Paul Loeffelman and state-of-the-art underwater sound hardware manufactured by Argotec, Inc., a company providing advanced sonar systems for navies worldwide.

Our experience on the Ohio River and in Michigan, California, and the United Kingdom indicate new methods of developing signals and new sound generating equipment will predictably and reliably alter the swimming behavior of fish. This acoustic stimulus will be most effective when interlocking spheres of sound created by lightweight sound projectors are arranged to allow the fish time to react to the stimulus in the waterbody. Fish swimming speeds, water velocities, and location of the fish in the water column are important parameters for orienting the sound barrier. At one of our California barriers, diversion was increased 40% by adjusting the angle of the barrier. Bathymetry, bottom morphology, and hydraulics are key factors for optimizing the sound field. By considering these design elements, we have achieved 75-100% diversion of outmigrating salmonid smolts at water intakes. At these installations where sound was on for hours, fish did not habituate to the signal.

Besides using sound as a barrier, we have also demonstrated the use of sound to guide salmonids into traps. The behavior of 700 chinook salmon smolts in a California test in 1993 was to swim along a sound barrier into a trap with

sound on compared to 200 smolts in the trap when the sound was off. Sound could be used to increase the efficiency of lamprey traps in the Great Lakes region.

By using a new signal development process customized to the most sensitive portion of a species' hearing range, we have increased the effectiveness of the stimulus. After 5 years of research and field trials, Paul Loeffelman was granted patents for the process which involves the analysis of fishes' vocalizations (much like bird calls) and the synthesis of an artificial signal constructed with frequencies the fish will hear and other signal characteristics to stimulate the fish to change its swimming behavior. Almost all freshwater and marine fish in various life stages have vocalized in our portable recording studio we use on site. In the rare instance when a fish does not vocalize, other signal development strategies are used to construct signals to stimulate fish to change their swimming behavior.

In controlled experiments all fish species tested have reacted to this focused, biologically based approach of using sound.

Comments and discussion - The speaker system weighs about 50 pounds and puts out as much sound as a two ton speaker put out years ago. Speakers were used primarily for submarine work in the past. The other parts of the sound system (amplifier, tuners, etc.) are similar to those used in todays stereo systems.

Speakers placed in the fish ladder at a dam on the St. Joseph River near Berrien Springs, Michigan stopped 73% of the rainbow trout from moving upstream. Rainbow trout were first isolated and the sounds they made were recorded. Sound was then introduced and their behavior observed. The sound that they reacted to most intensely was introduced into the fish ladder.

Fish are not harmed by sound, they are merely repulsed.

With increases in river flow, the sound will have to be increased to be effective.

Sound screens are of no value if fish become accustomed to it. This may possibly be avoided by adjusting the amplitude and pulse rate of the sound.

Different species of fish hear different sounds. It might be possible to find sounds that only lampreys react to.

Graduated Electric Field Barriers to Control Sea Lampreys - (David V. Smith - President and CEO of Smith-Root, Inc.).

Abstract - Historically, electricity has been used for guiding and blocking fish as early as 1863, but it was not until about 1951 that electric barriers were first used in the battle to control the sea lamprey. Many problems were encountered with early electric barrier designs. Among the problems encountered were escapement of persistent lampreys through and around the electric field, excessive mortality by electrocution of migrating fishes, poor electric equipment reliability, and ice damage to electrode arrays. With the introduction of lampricide, the use of electric barriers was, for all practical purposes, discontinued around 1979.

In 1987 Smith-Root, Inc. (SRI) introduced the Graduated Field Fish Barrier (GFFB) to control the sea lamprey. Advantages to the GFFB design are that bottom- mounted electrodes do not catch debris or experience ice damage and the GFFB design provides reduced injury and mortality to migrating fishes by gradually introducing fishes to the electric field. Additionally, at some sites, the bottom electrodes have the advantage of not creating an impoundment upstream of a barrier. Four experimental GFFB barrier sites were installed between 1987 and 1989. All sites had good success at blocking sea lampreys. Three of the sites have not been in operation for the past two years because of the simultaneous blocking of migrating fishes and sea lampreys. The Jordan River site is currently operating successfully and has not shown evidence of ammocoetes upstream of the barrier for the past two years (1992-1993).

In 1993 SRI introduced the Programmable Output Waveform (POW) pulsatory system. The POW system provides means for computer control of the electric barrier pulses. Barrier pulses can be modified by variations in water condition, by internal clock timing and by remote control. Most all of the early electric barrier problems can be addressed by utilizing modern pulsators, careful site selection and installation, combining pumped fish ladders with electric barriers, and in some cases, combining low head dams with electric fish barriers.

For detailed information on Smith-Root, Inc. electrical barriers see Smith-Root, Inc., 1994a and 1994b.

Comments and discussion - High water velocities are desirable at electrical barrier sites so fish moving downstream are swept rapidly through the electrical field. A smooth deck on the river bottom will help prevent fish from collecting in the middle of the field.

The electrical field produced by the GFFB is nearly as strong at the surface of the water as at the electrodes. It also orients the field in the same direction as the fish is oriented and the fish receives the shock head to tail and receives the maximum electric shock. Fish that turn sideways do not receive much of a shock. Studies have shown that fish exposed in the fields for 10 seconds are not harmed.

Salmon and other large fish are not affected by the electrical shock when the water is shallow and their lateral lines are out of water. They can then move upstream past the barrier. This may be used to allow large fish to move upstream and still block lampreys. A barrier with a sloped deck may allow us to do this.

It may be possible to guide downstream migrating sea lamprey transformers into traps or nets with an angled electrical barrier.

A combination of strobe lights and an electrical field may be useful. Fish will get shocked and see the light as well.

FISH BEHAVIOR AND SWIMMING PERFORMANCE

Fish Behavior and Fish Diversion -
(James Anderson - Associate Professor, School of Fisheries and the Center for Quantitative Sciences, University of Washington).

Abstract - Although the prediction of the efficiency of a fish diversion system is difficult because of the flexible and often unpredictable nature of fish behavior, it is possible to mathematically model diversion effectiveness. Such models can help identify limitations and potential effectiveness of a planned diversion system. The models describe the percentage of fish diversion in terms of the five types of factors listed below.

1) System geometry - locations and dimensions of fish bypass and flow channels.

2) Hydraulics - water velocities and angles through the system.

3) Stimuli - strength and direction of stimuli that affect diversion.

4) Fish behavior - avoidance response in terms of stimulus strength, fish swimming direction, and velocity.

5) Physiological constraints - perception and swimming abilities including fish fatigue and acceleration curves.

The characteristics of the model depend on ratios of the above factors. That is, through the model the effectiveness of a diversion system can be shown to depend on specific scaling factor. For example, guidance from a low velocity water intake depends on the ratio of the fish escape velocity (a behavioral factor) to the intake velocity (a hydraulic factor).

Specific models have been developed for diversion systems that emit stimuli as a point source and as a barrier. Through these models fish behavior can be incorporated in diversion system design in terms of engineering principles.

For more detailed information see Anderson 1991.

Comments and discussion - Diverting downstream migrating smolts away from turbines using behavioral systems are not 100% effective. With a high velocity intake, it will not be possible to guide very many fish.

Sea Lamprey Barrier and Trapping Related Research Conducted at the Hammond Bay Biological Station -

(William D. Swink - Fishery Biologist, Hammond Bay Biological Station).

Abstract - Studies conducted at the Hammond Bay Biological Station (HBBS) examined the use on sea lampreys, *Petromyzon marinus*, of a pulsed-DC electrical barrier, and lights and chemicals as attractants and repellents. Low intensity lights placed in the traps on the Cheboygan River were found to significantly increase the catch of spawning-phase sea lampreys. Attempts to duplicate the success of lighted traps on the Ocqueoc River were inconclusive because all the traps filled too rapidly with suckers, *Catostomus* spp., and sea lampreys to accurately compare the catches between the lighted and unlighted traps. Work conducted by John Heinrich of the Marquette Biological Station showed that lighted traps did not increase the sea lamprey catch in a river without a barrier. Another study conducted in the Ocqueoc River found that an overhead bank of high intensity lights (~500 W each) was unsuccessful in either blocking spawning-phase sea lampreys or directing them into traps during the spawning run in May. Larval sea lampreys were also unresponsive in classical conditioning studies that used lights and electric shocks as stimuli; the system did elicit a classical conditioning response in goldfish, *Carassius auratus*. These results indicate that lights are unlikely to act as true attractants and repellents to sea lampreys. However, illumination of trap openings appears to increase the catch when used on large aggregations of sea lampreys that mill below barriers and are searching for a suitable bypass.

Work on chemical attractants and repellents were first conducted at the HBBS by John Teeter of the Monnell Chemical Senses Center. Attractant responses were detected for spawning-phase sea lampreys to larvae, male spawners to female spawners, and female spawners to male spawners. However, the one potential attractant isolated from male sea lamprey urine was thought to be a steroid, which made it unsuitable for use in the field. More recent work conducted by Peter Sorensen and Weiming Li of the University of Minnesota found that a bile salt that is produced only by larval lampreys elicited an attractant response among spawners early in the run but became ineffective as the spawning run progressed. This result agrees with Teeter's observations on the responses of spawners to larval sea lampreys. Additional work by Barbara Zielinski of the University of Windsor shows that the anterior portion of the olfactory lobe in sea lamprey spawners is only active early in the spawning run and this might affect the timing of any responses to bile salts produced by larvae. A study will be conducted in 1994 at HBBS to better determine the time when sea lamprey spawners begin to congregate off stream mouths in spring. Water samples will then be collected periodically and sent to Peter Sorensen to determine if they elicit an olfactory response from spawning sea lampreys and how far into the spawning run that response lasts.

Three years of testing were conducted on a Smith-Root pulsed-DC electrical barrier in the Ocqueoc River. Changes in design and materials allowed the barrier to effectively block the spawning migration of sea lampreys during the third year (1989). The device also blocked the migration of salmonids, but otherwise caused them no harm.

In closing, behavioral studies of sea lamprey spawners are extremely difficult to conduct in the laboratory. Even in flowing-water raceways, sea lampreys tend to attach to surfaces and not move for days. Behavioral studies must be conducted under secure, controlled conditions where sea lampreys receive natural migratory stimuli, but can still be effectively monitored.

Comments and discussion - Lampreys migrate primarily at night during the spawning migration.

Fish Behavior Information for Fish Passage or Barrier Design -
(Boyd Kynard - Research Biologist, National Biological Survey, Fish Passage Laboratory, Turners Falls, Massachusetts).

Abstract - An understanding of fish behavior is necessary to design and operate a fish passage or barrier successfully for sea lampreys or other fishes. Telemetry of up- and downstream migrants is useful for determining movement rate, spatial distribution during movements, and preferred habitats. Knowledge of

preferred habitat conditions can greatly assist in creating appropriate environments at barriers and for traps. Telemetry observations of fish at barriers and in fishways can be useful in understanding fish behavior relative to near field physical factors, especially water depth, water flow, and illumination intensity. Underwater video can provide detailed information on fish behavior in the near field at existing fishways or barriers. New equipment with IR light even enables observations of fish at night (when many sea lampreys migrate). Examples are provided from studies at fishways on American shad, blueback herring, and sea lampreys. For a serious program to develop barriers for sea lampreys, behavioral information on near field behavior to water velocity and structure will be needed that can only be gathered in the controlled hydraulic conditions of an experimental facility. An experimental facility would enable researchers to test hypotheses gained from field observations of fish behavior. The experimental facility need not be large or expensive, and a series of stream-side flumes may be all that is needed. In all fish passage or barrier studies, the best results will come from a team effort of fish behaviorists and hydraulic engineers.

Comments and discussion - Lampreys going over a weir crest generally do so where the water velocity is the slowest. Mean velocity over a weir crest is of no value.

Radio telemetry tags (about 0.5 inch in diameter and 1.5 inches long) are attached at the insertion of the front dorsal fin on lampreys. They have little resistance in water and do not appear to affect the behavior of the lampreys. They can give you a good understanding of lamprey behavior around various structures.

Any experimental facility, designed to study lamprey behavior, should be built on a stream that has a substantial natural run of lampreys so they do not have to be hauled in.

It might be possible to do some of the experimental work at the Turners Falls facility, if it would be useful and funding was available.

It will be necessary to find the best fish behavioral scientists and hydraulic engineers available to design and conduct the experiments. Stream ecologists, systems modelers, stimulus specialists and graduate students may also participate in the studies. There is a need for partnerships between government, university, and private individuals.

<u>Evaluation Methods for Upstream Fish Passage Structures</u> -
(W.C. Mackay - Department of Zoology, University of Alberta).

<u>Abstract</u> - I will review our experiences evaluating upstream fish passage structures for the northern great plains of Canada, at between 54 and 55° north latitude in Alberta and Saskatchewan. These structures facilitate upstream migrations of spring spawning fish and show differential species selectivity. All of the studies I will talk about were done in April, May, and June. The primary species involved were northern pike and white suckers (genus <u>Catostomus</u>). Discharge in these drainages is highest during spring snow melt and drops off markedly following snow melt. The fish passage structures I will discuss are primarily associated with weirs around 1.5 meters high. In this talk I will review the evaluation of fish passage structures at four locations. In three cases, two or more fishways were evaluated at a single location allowing the fish passage structures to be compared under field conditions. In one case (Fawcett Lake) the comparisons were done between years, the last two comparisons were done with the structures side by side. The first three structures were stabilization weirs on the outlets of lakes, the fourth, Siisiip, allows fish migrations into an impounded marsh.

Cross Lake - This is a pool & weir fishway that was evaluated once as an after thought. The main features concerning Cross Lake pool & weir fishway are: 1. poor location for both entrance and exit, 2. over the range of discharges (0.17-0.63 m^3/s) or heads (12-25 cm) tested flow was always streaming with little variation in nappe velocity. The biggest effect of increasing discharge was to increase attraction water for the fish that used the fishway. Attempts were made to estimate maximum swimming speed of the species involved, not a very useful parameter as it turns out. Pike were found to be superior to white suckers in both burst speed capability and performance (swimming ability) within the fishway, however the fishway was much more efficient at passing suckers (20%) than pike (6%). A very low number of tagged pike were recaptured, suggesting that few used the fishway.

Fawcett Lake - Evaluations were done in four different years to evaluate fishways; two to evaluate a pool & weir fishway and two to evaluate iterations of the Denil fishway that was subsequently installed. In one of the years the pool and weir structure was evaluated (1981), run-off was low and too few fish (28 fish over 6 weeks) used the fishway to evaluate it. The Denil was retrofitted into the old pool & weir structure with a switch back consisting of a resting pool. This allowed the entrance to be near the hydraulic jump of the weir. The fishway had two entrances with sliding doors that corresponded with the hydraulic jump at high and low discharge. The switch-backed Denil fishway had an 11 m upper leg with a slope of 7.1% and a lower 4.9 m leg with a slope of 16%. Following evaluation of the Denil, several modifications were made which were expected to increase fish passage. This mainly involved increasing depth and discharge in the fishway and lowering the entrance so that it was at or below the tailwater surface.

The essential features of the pool and weir fishway were; 1. there were a large number of fish tagged and recaptured, 2. flow was plunging in 1981 and was probably plunging in 1980 since the discharges in 1980 (0.59 to 1.05 m^3/s) were similar to those in 1981 (0.42 m^3/s) that were determined to be strongly plunging. There were strong species differences in efficiency and a general increase in passage efficiency for two species. White suckers were likely post spawning, northern pike about 50% pre-spawning/50% post spawning and long nose suckers prespawning (1982 data). Modifications to the Denil fishway reduced delay times for both species.

Lac La Biche - This fishway is associated with a stabilization weir at the outlet of a large lake. All fish were post spawning. Three fishway designs were tested side by side, two Denils in one bay and the vertical slot in an adjacent bay. Tailwater was high and not all fish were forced to use the fishway. Efficiency of passage was not measured in this study as many fish were ascending the weir itself. We obtained evidence for strong species selectivity between fishway designs--pike selected Denil fishways, suckers selected vertical slot. The 10% Denil seems to be a reasonable compromise for these species.

Siisiip Marsh - The fishways tested here, Alaska steeppass and standard Denil, both worked well with very high efficiencies and low delay time. This fishway was constructed in the bed of a small river that had been blocked by a dyke designed to expand a marsh - part of a Ducks Unlimited project. There was no associated weir so all the discharge passed through the fishway, a unique situation. At low flow, pike were more successful in ascending the standard Denil, in this case the fish entered each fishway at random. When they were allowed to select the fishway they entered on the basis of flow profile they showed no preference.

The following conclusions were made from these experiences:

1. Individual species show strong preferences for specific fishway designs.

2. Efficiency of passage and delay time are good measures of the performance of fish passage facilities.

3. When two or more fishways are being compared side by side statistical evaluations can be made of their relative performance.

4. Simple measures of swimming ability, such as burst or maximum sustained speed, for a species are not adequate to determine the design of fishways that will optimize the passage of that species.

Comments and discussion - Fish are often delayed at fish passage facilities for extended periods, which may affect reproduction in some species. Lampreys will move downstream and go elsewhere to spawn if they are unable to move upstream.

Telemetry and Fish Behavior Studies -
(R.S. McKinley - Biologist, Ontario Hydro Research).

Summary - Past studies have involved the development of behavioral strategies to minimize fish impingement/entrainment at generating facilities and the use of enhanced telemetry technology to examine migratory behavior and swimming performance of fish in the wild. The use of behavioral cues was adopted to either deflect fish from power intakes or attract fish to bypass structures. The behavioral cues investigated included sound, strobe light, and an air bubble curtain. Of these, a high amplitude, low frequency sound (38 Hz) stimulus showed the greatest promise in deflecting alewife, gizzard shad, and sockeye salmon from entering power canals. The use of strobe lights in diverting the above species was directly limited by water clarity. The strobe characteristic of the light was lost with distance and consequently resulted in a far field attraction stimulus for alewives. The effectiveness of the air bubble curtain was lost in the presence of a current or wave action. Overall these behavioral cues exhibited an effectiveness of at least 60% in deflecting fish from controlled areas. To date, we have not found a fish attractant using any of the above behavioral cues.

In the past six years, my efforts have focused on evaluating the influence of temperature and current speed on the swimming performance of fish in the field using telemetry. The impetus behind these studies has been the need for information on swimming performances of selected fish species for the proper design of fish bypass systems, culverts, and water intakes. Telemetry has been employed so that we can examine the behavior (i.e. temperature/depth preferences, diel activity levels) and swimming performance of targeted species in the field. We are presently investigating the swimming capacity of Atlantic salmon (anadromous and landlocked) and brook trout on the east coast of Canada and walleye and lake sturgeon in central Canada. These data will be used to examine the effectiveness of potential velocity barriers in selectively passing some fish species.

I have also become involved in examining the effects of dams or velocity barriers on the health of migrating fish populations. These studies examined the non-esterified fatty acid composition of fish plasma as a biochemical measurement of nutritional health. The procedure developed represents a generic, non-consumptive and direct measurement of nutritional stress in fishes. We have used this procedure for migrating sockeye salmon in the Fraser River, British Columbia and the effects of a hydroelectric peaking operation on lake sturgeon in northern Ontario.

Comments and discussion - Fish hammers were used to deflect smolts from going through turbines. They are high amplitude, low frequency amplifiers that will injure or kill fish if they get too close. Fish within 3 meters of the hammer are stunned or killed.

Behavioral cues such as sound, strobe lights, and air bubble curtains are by no means 100% effective in directing fish. They may be used to enhance any other method you might have.

Fish pumps may be of some value for moving non-jumping fish over barriers.

Rope net barriers have effectively deflected fish from water intakes.

Radio tags are being used that can give you direct physiological measurements of the fish. With this tag you may eventually get direct response of fish to velocity barriers, light, and sound.

FISH PASSAGE

Fish Passage Research -
(N. Rajaratnam - Professor of Civil Engineering, University of Alberta, Edmonton, Alberta)

Summary - Dr. Rajaratnam described his research on Denil, steeppass, vertical-slot, and other fishways.

Full-scale Denils were built in the laboratory. It was found that the velocity is very low at the bottom and very high at the surface. Small fish could easily move upstream by remaining close to the bottom. The depth also was very important.

Steep-pass fishways have an opposite velocity distribution with the high velocities at the bottom and low velocities at the top.

Vertical-slot fishways have water velocities that are equal from top to bottom and are like a water jet.

The hydraulics of offset baffle culvert fishways and culvert fishways with slotted-weir baffles were described.

Comments and discussion - It may be possible to give guidance some day as to what type of fishway would be best in certain situations for certain species of fish. This is not possible at this time.

A very small current meter (with a propeller diameter of 1.5 mm) or pitot tube probes are used to measure velocity. The probes are quite reasonable in price and can be constructed in the laboratory.

Fish Passage and Lamprey Barriers -
(Chris Katopodis - Hydraulic Engineer, Department of Fisheries and Oceans, Government of Canada)

A video on fishways was shown.

Summary - It is hypothesized that sea lampreys can be separated from most teleosts based on swimming ability and devices can be developed to prevent lamprey migrations but allow passage of other fish. Work to date on swimming performance (Beamish 1978; Katopodis 1990; Katopodis and Gervais 1991; McAuley and Young 1991 and 1992, unpublished data) indicates that lampreys are weaker swimmers than most fish. Fig. 5 provides evidence of this, as it depicts estimates of the average distance different sized fish are expected to swim without rest, when facing certain water velocities in a flume. The anguilliform group includes data on free swimming sea lampreys and burbot, while the subcarangiform group includes data on several salmonids, as well as largemouth bass, whitefish, and walleyes. Fig. 5 was derived from analysis of swimming performance data at optimum temperatures as reported in the literature for several species of fish including the sea lamprey (Katopodis 1990). Burst, prolonged, and sustained swimming are marked (Beamish 1978) and species are grouped by swimming mode (Lindsey 1978). Further tests on swimming performance of the sea lamprey and several key species are needed to improve these estimates.

The difference in swimming distance between the two groups of species, evident in Fig. 5, can be exploited to pass the subcaragiform fish while excluding the lampreys. Key to this is to maintain the difference in swimming performance by ensuring that lampreys cannot attach and rest. Devices which could achieve this exclusion would be channels with relatively uniform velocity distribution. Furthermore these channels would generally have water velocities and lengths corresponding to the prolonged range indicated by Fig. 5. Water velocities and distances within the pyramidal shaped space are the most likely to differentiate between lampreys and many other fish of the same length. Values close to the points where the two sets of lines meet, at the edge of the pyramid, would correspond to the shortest channels that may be adequate. Combinations of water velocities and swimming distances for excluding the largest lampreys (e.g. 500 mm) and allowing passage of the smallest subcarangiform fish (e.g. 300 mm) may also be estimated. The intersection of the two lines (e.g. 500 mm and 300 mm) represents the shortest channel length needed. A range of channel heights, lengths, and slopes would be needed to accommodate various species sizes and water levels at different streams.

Fig. 6 presents a schematic of a biomechanical device that incorporates a lamprey barrier dam and a velocity barrier. The intention is that lampreys would be unable to swim over the dam or through the channel and would end up in the trap. Jumping fish could overcome the dam or swim through the channel along with non-jumping fish. The cross-section of the velocity barrier channel may vary in shape to produce the target velocity distributions. The dimensions, slope, and length of the channel may vary to provide the target velocities over a range of stream flows. Fig. 7 provides typical velocity distributions in channels of several cross-sectional shapes. Such velocity distributions occur under uniform flow conditions where water depth is the same throughout the channel length. This usually is established in very long channels away from the inlet and outlet where acceleration influences the water surface levels. Mean velocities in these channels can usually be estimated with good accuracy if boundary roughness is known. Velocity distributions though can not be quantified accurately, particularly in short channels where uniform flow may not occur at all. Therefore tests are needed to quantify velocity distributions on selected channel cross-sections, lengths, and slopes.

<u>Comments and discussion</u> - There are many things we don't know about channel flow. For example, we need to know what kind of velocity distribution we get in various channels. We know that velocities are always lower near the bottom and edges and this is where fish (including lampreys) may be able to pass through a velocity barrier. Most engineers work with mean velocities, and information on velocity distributions is not available.

Although laboratory studies of fishways are limited to the study of hydraulics , a large range of variables can be studied, which can be tied in with field studies later on.

Lampreys will stick to the bottom or sides in areas of high velocity, rest for a while, and then move upstream a short distance and attach again. If we can keep them from attaching by installing surfaces they cannot attach to or by giving them an electric shock (fry their lips) they may not be able to move upstream. If we could devise a travelling screen, in which we allow them to attach and then pull them back downstream so they cannot make progress upstream, it may be useful. Perhaps we could coat the channel with something lampreys don't like the taste of.

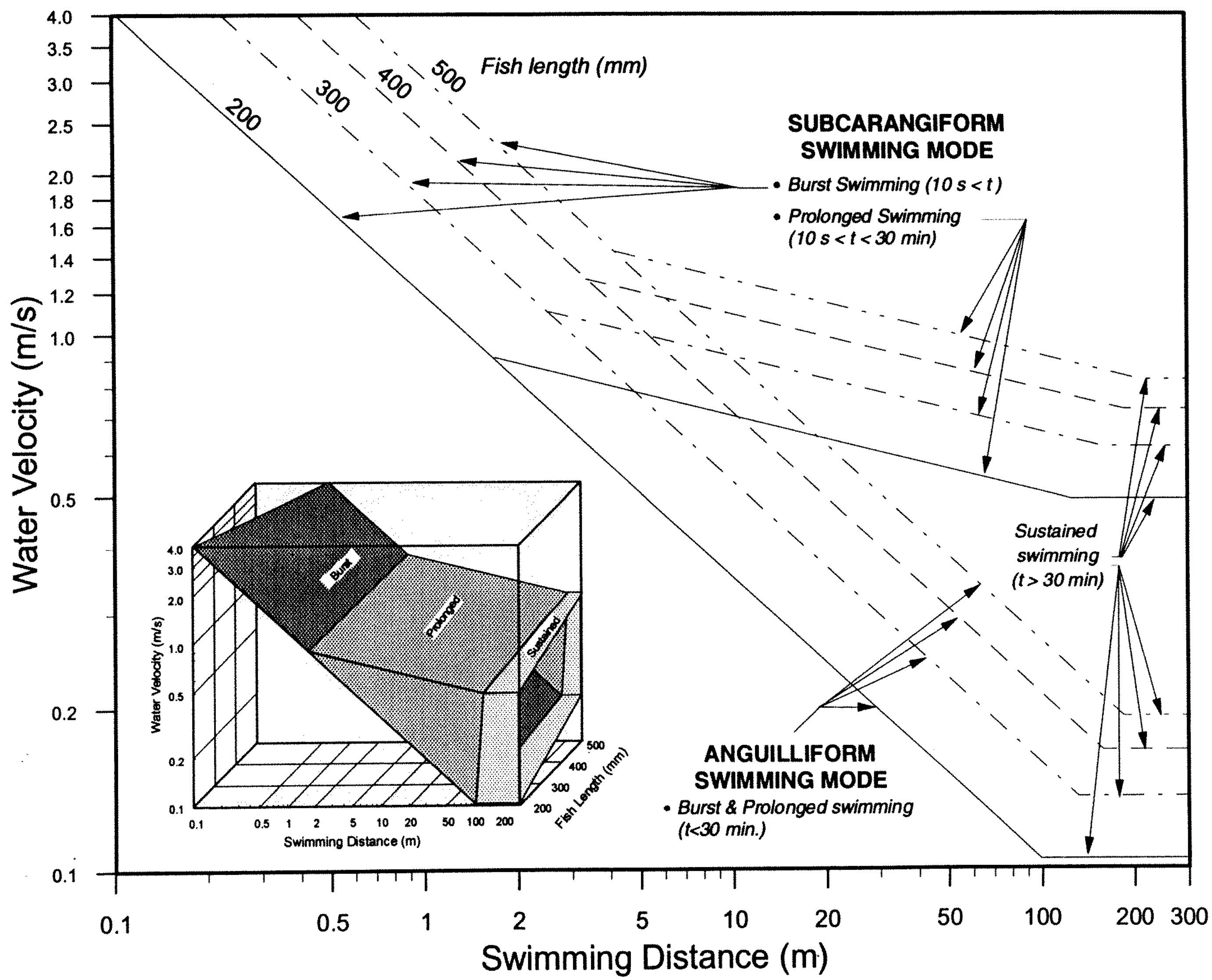

Figure 5. Estimates of mean distances various size fish of the Anguilliform (e.g. lamprey) and Subcarangiform (e.g. trout, walleye) swimming modes can travel continuously at optimal temperatures (modified from Katopodis 1990).

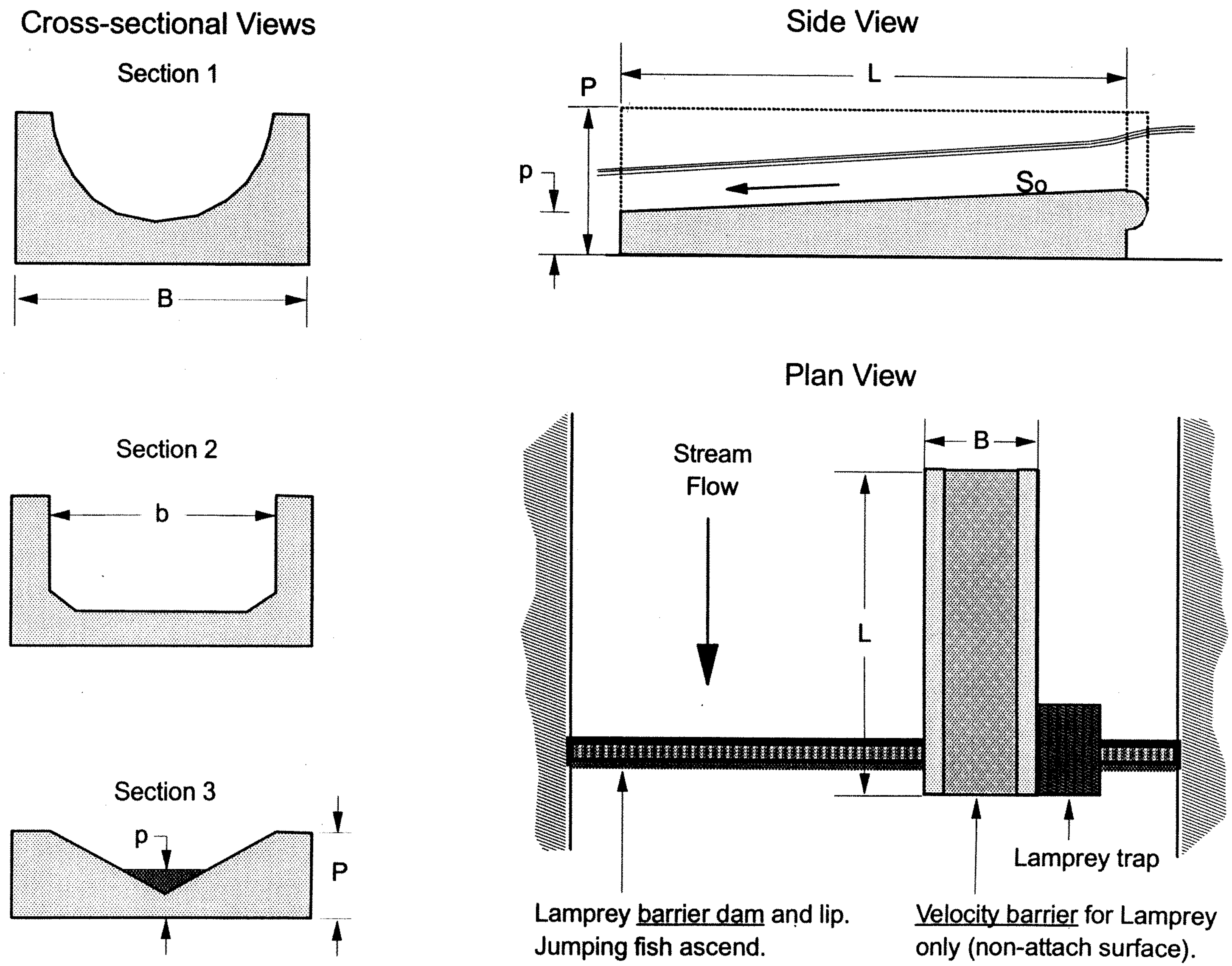

Figure 6. Examples of biomechanical controls to be tested in laboratories for water velocity distribution through scale modelling and in near prototype dimensions with lamprey and other fish.

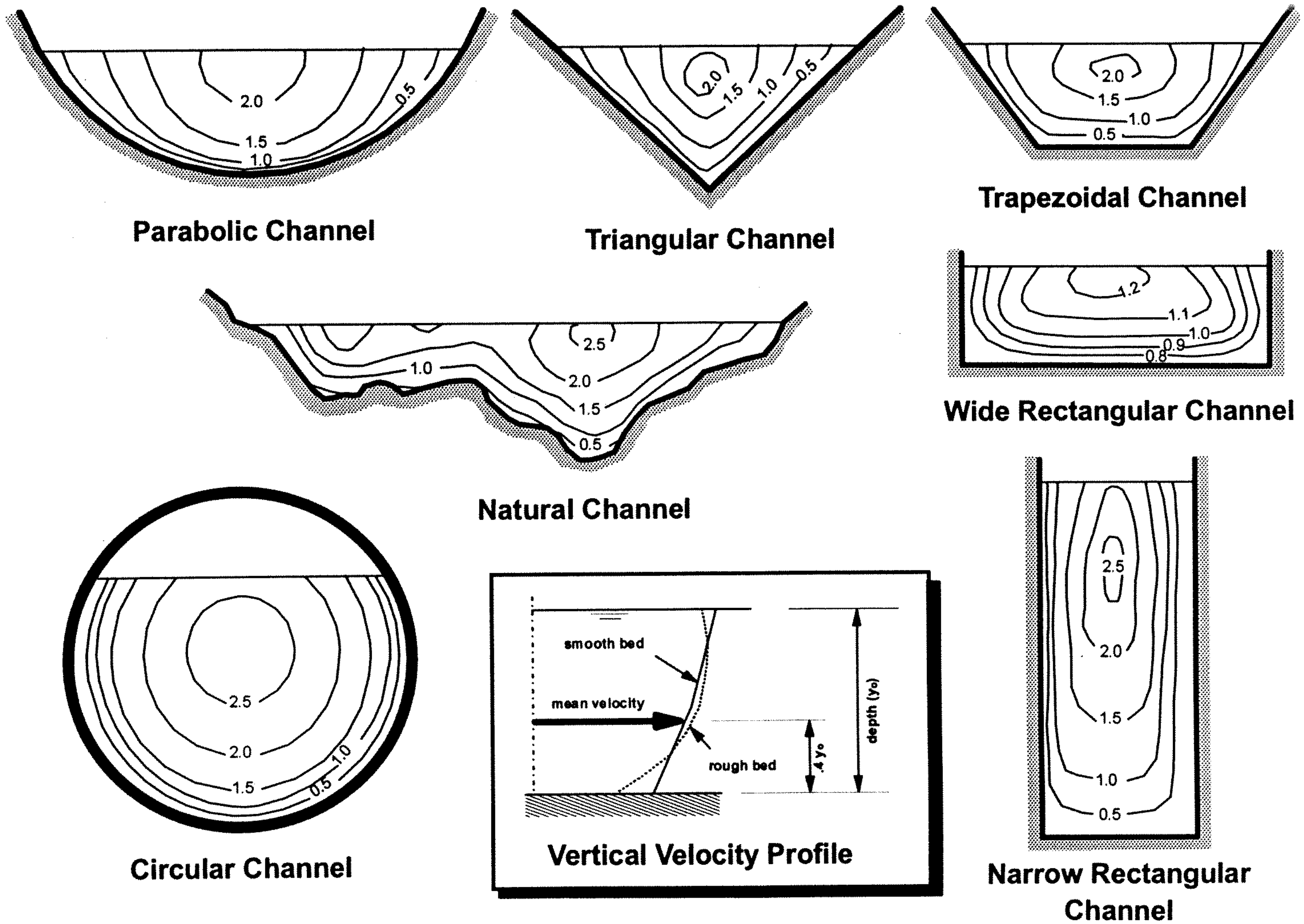

Figure 7. Velocity distributions in various channel cross-sections and vertical velocity profile for uniform flow (after Chow 1959). Uniform flow, defined as the flow when water depth is the same at every cross-section of the channel, produces non-uniformly distributed velocities due to friction along the walls and the presence of a free surface (i.e. air-water interface with no rigid boundary).

ENVIRONMENTAL IMPACTS AND IMPLICATIONS

Observations on Fish Migratory Patterns and Impact Assessment from Work on Lake Ontario Tributaries -

(L.W. Stanfield - Senior project biologist, Great Lakes Salmonid Unit, Ontario Ministry of Natural Resources).

Abstract - Since 1988, the Great Lakes Salmonid Unit has been involved in monitoring fish migratory patterns in two streams of Lake Ontario. Much of the work has centered on Wilmot Creek, a relatively small (4th order), highly productive, naturally producing trout stream (three year average of 150 kg/ha total fish biomass, most of which are salmonids). To a lesser extent we have also attempted to monitor fish movements in the much larger (5th order) Credit River, which is also highly productive (204 kg/ha), however most of the biomass in this system is in non-salmonid production. Both systems are stocked with Atlantic salmon as part of a pilot restoration program. The Credit River also receives substantial numbers of chinook salmon, rainbow trout, and brown trout stockings.

Our research has evolved around two themes relevant to this meeting. Firstly, we have been assessing populations of both systems in a way that will allow us to evaluate Atlantic salmon restoration. We are using electrofishing surveys to collect pre- and, eventually, post-population structure for all resident fish species and have developed methodologies (mark-recapture) to permit quantification of sizes of outmigrating populations. Our design will allow us to assess whether Atlantic salmon reestablishment affects resident populations.

We are also looking at areas of potential effects at a finer scale. In several studies, we have been developing techniques to permit us to assess fish utilization of various habitats in ways that permit analysis of carrying capacity of habitats and then to assess the quality of those habitats to various species.

The second area of research relevant to this exercise is our effort to design quantitative assessment techniques for determining the number of migrants, and the biological characteristics and behavioral patterns of migration, for both up and downstream migrating fish. We have tested a variety of devices, including key-hole and auger traps, a fish ladder, and a portable weir. The only device that continues to show promise is the counting fence that we have operated on Wilmot Creek since 1989. This device is generally placed in the stream in April and removed in either June or late November, depending mostly on funding. The operation has been fairly consistent for the last three years.

This device gives us very good information about seasonal and diurnal patterns of movement for a variety of fish species and age classes, including rainbow trout, coho salmon, Atlantic salmon, brown trout, white suckers, longnose sucker, longnose dace, creek chub, rock bass, and, of course, sea lamprey (adults and transformers). We have also obtained good information on biological characteristics of the migrating species and have used the device to capture and mark rainbow trout as part of a life history study.

Our efforts to quantify the number of migrants has been more challenging. For example, we now estimate that, despite our best efforts to collect every outmigrating fish, we only collect about 23%. Although this seems low, we still see and mark about 3,500 juvenile rainbow trout and 1,000 coho salmon a year. We can use the weir in conjunction with a marking program upstream to develop total estimates of outmigration. We are just beginning to assess the catchability of the weir for other species and size classes and to use the marking data to develop over winter mortality estimates.

What have we learned so far? There are considerable variations in year class strength, particularly with migratory species that are likely related to a variety of factors including the size of the spawning stock, environmental conditions, and changes in physical habitat. Year to year variations are generally consistent among sites. There also appear to be consistent differences in species distribution and abundance within a system that are most likely associated with physical habitat and species composition.

There are consistent diurnal patterns of outmigration that are repeated for each species and size class monitored. For example, most instream movement occurs at night time and between the hours of 10 pm and 2 am. We also see consistent seasonal patterns of migration. For example, larger and presumably older juvenile rainbow trout tend to leave the system before smaller fish and, depending on the year class strength, there can be a fairly substantial outmigration of YOY fish in early fall. In addition, both up- and downstream movement appear to be related to flow rates and stream temperature. For example, each spring there is typically a massive outmigration of rainbow trout juveniles as well as white suckers that occurs in mid May during a warm rain. The numbers can be so large at times as to force opening of the weir to prevent massive mortalities. During one night operation (May 16, 1990) we processed 1,100 juvenile salmonids, 516 adult rainbow trout, and 208 white suckers. We also see more movement on the rising and falling crests of storm events, although we often have difficulty sampling at extreme water levels.

There is also considerable instream movement of fishes that do not appear to be related to physiological processes or flow conditions. For example, we see extensive movements both up- and downstream of longnose dace, rock bass, and, in some seasons, juvenile coho salmon, which we speculate are driven by issues related to selection of habitat.

Behavior also seems to influence the decision of any fish to migrate. For example, migrating fish often stage in front and less commonly behind our weir. They will often remain there for several days until they either decide to move downstream, or are removed by poachers. This can be a particular problem if there is a considerable period of low, clear water conditions during the post spawning migration. Another challenge is that often many of these staging fish (often several hundred at a time) will decide to pass through the weir at the same time, causing a considerable challenge to technicians and fish alike.

Finally, despite our best efforts, our counting fence remains very labor intensive, particularly where installation and removal is concerned. It is also inoperable at high flows and is capturing a small fraction of the outmigrating population. Upstream migrating salmonids are hesitant to enter our trap, which necessitates our often having to open the gates or not operate the fence during peak migration periods (early spring).

I believe that the methodologies that we have developed, our experiences, and the lessons we have learned could be of use in assessing both the quality of habitat for lampreys and other species (at least salmonids) and in designing any assessment studies for proposed control measures.

Comments and discussion - Adult salmonids are sometimes blocked by the weir and spawn successfully downstream. As water temperatures warm the following summer, young-of-the-year fish are observed migrating upstream into cooler water. Any barrier (low-head, electrical, or velocity) placed in a stream would likely prevent these small fish from moving upstream and could have a detrimental effect on their survival.

Experience with Lamprey Barriers and Fishways -
(Doug Dodge - Biologist, Ontario Ministry of Natural Resources).

My expertise and interests about barrier dams arise from a long-term admiration and love for freshwater streams, from brook trout headwaters to the St. Lawrence, Amazon, and Rhine rivers. My earliest work at eight was poaching rainbow trout (I thought they were white suckers). My next work as a biologist involved the Sea Lamprey Control Experiment that DFO managed for the GLFC in the 1960's. I did it all, from humping chemical, running feeders and bioassays, collecting and identifying ammocoetes, assessing populations of lentic lampreys, all the way to operating electrical sea lamprey barriers along the north shore of Lake Superior.

When I resigned from DFO to go to graduate school, I chose to work on stream ecology of rainbow trout on three Georgian Bay streams (Lake Huron). After graduate school, I started work with the Ontario Ministry of Natural Resources (OMNR) managing an aquatic habitat section of the Fisheries Branch, which included stream inventory and assessment. As well, I helped with the design and installation of six fishways on Great Lakes tributaries as well as developing operational guidelines. In that process, I was also involved with DFO as it strove to design "fish-friendly" barrier-dams for sea lamprey control. One of my greatest thrills was chairing the committee that organized and presented LARS, the International Large Rivers Symposium in 1987. At this meeting world experts on large rivers like the Rhine, Amazon, Nile, Mississippi etc. presented status reports and then worked in sessions to synthesize our knowledge and understanding of these systems. I also edited the publication from the symposium.

Inevitably, if one is in the Great Lakes neighborhood and has a stream background and interest, one is slowly drawn into discussions about sea lamprey control, barriers and chemicals, and so on (I guess this may be one of the reasons all of us are gathering in the Twin Cities). I have watched the evolution of lamprey barriers from designs for monuments that were all-out blocks for all species, all the way to the velocity barrier soon to be tested on the MacIntyre River at Thunder Bay. In my responsibilities with OMNR, I have tended to be the "bad" guy when DFO wanted to build barriers. I played this role because early designs ignored other parts of the fish and aquatic communities using streams so that often the production of desirable fish declined at the same time as the sea lamprey populations.

I am now much more optimistic that this single purpose approach is gone, and more compatible designs will suit both purposes. The Workshop should be an interesting and fruitful time.

Comments and discussion - There may be a desire in some cases to create a barrier in a river without providing for fish passage. For example, it may be desired to block chinook and coho salmon from moving upstream and preserve the river for native species only. There is also some concern about the high levels of pesticides in many anadromous fish and a desire to prevent them from moving into the small tributaries where the contaminants will be released after they spawn and die.

We no longer can merely block lampreys from moving upstream. We must revolutionize trap designs and trap them out as efficiently and effectively as possible. We also need to look at how we can trap downstream migrating transformers effectively.

DEVELOPMENT OF A RESEARCH STRATEGY

After the presentations were made, Gavin Christie moderated a discussion in which the workshop participants attempted to develop a research strategy that would be helpful in developing a successful barrier dam program for sea lamprey control. A list of research or information needs was developed and suggestions on how the research should be done and who should do it were made. Participants were then asked what they consider to be the most important research needs.

RESEARCH NEEDS

Lamprey Biology and Behavior

Much basic information on lamprey behavior and biology is lacking and will be crucial to the development of more effective alternative control methods.

- Determine the stock/recruitment relation for sea lamprey. Is it necessary to prevent all lampreys from moving upstream in order to be successful or is some escapement upstream permissible? If so, how much?

- Examine behavioral traits other than swimming performance that can be used to separate lampreys from other fishes. The attachment behavior of lampreys is unique among North American freshwater fishes. Can this be used in some way ? Do lampreys respond to light, sound, or electricity differently from other fish?

- Determine the timing of lamprey migrations and the cues that induce them to migrate (water temperature, stream-flow, day-length, etc.).

- Determine the stimuli to which lampreys respond as they move upstream, for example, bile salts excreted by larvae or olfactory cues produced by other adults. How do their responses change as the spawning run progresses?

- Study the habitat use by lampreys and other fishes during their migrations. For example, is there a differential preference among species for waters of different velocities, depths, or substrates?

- Study sea lamprey behavior as they encounter and surmount a submerged low-head barrier. Do they attach to and work their way up the face of the barrier or do they enter the main flow and swim over in a single burst of swimming effort?

Fish Passage

Adequate fish passage is the primary issue that will influence the acceptance of new barriers. Further development of the velocity barrier concept will depend on increasing our knowledge of fish swimming performance, and velocity distributions for several channel shapes, lengths, and slopes.

- Test methods of passing non-target fish (other than trapping and sorting) while blocking and trapping sea lampreys. Different types of fishways should be tested and modified as needed.

- Determine more precisely the swimming performance of sea lampreys and synchronously spawning fish species such as walleyes (Stizostedion vitreum), suckers (Catostomus spp.), smallmouth bass (Micropterus dolomieui) and lake sturgeon (Acipenser fulvescens), over a wide range of flow and temperature regimes. These studies would complement work already in progress.

- Examine the effects on non-target fish as they move downstream either over or through the barrier.

- Determine the effect on fish populations if we are unable to pass any or all of the non-target fish species upstream from the barrier.

Trapping

It is desirable that built-in traps be included in barrier installations to prevent sea lampreys from moving to adjacent streams, reduce the amount of spawning below barriers, provide assessment data, and supply males for sterilization.

- Test new designs to improve efficiency and selectivity of traps.

- Determine effect of trapping and release on non-target fishes. If fish are released immediately upstream of a barrier, do they continue upstream or drift downstream? How much mortality is there?

- Optimize size, configuration, and positioning of traps in relation to the barrier site.

- Determine effect of stimuli such as electricity, light, sound, and water velocity in relation to lamprey behavior at traps and the efficiency of traps.

- Determine optimal use of attractant flow. What flow or proportion of the stream flow is needed to attract the greatest number of lampreys?

- Study use of olfactory attractants to increase the efficiency of traps.

• Design traps that are self-unloading to holding tanks that require minimal service.

• Test designs for traps using attraction water at electrical barriers, for example, plastic tubes might be placed across the electrodes and a flow of water introduced through them to attract lampreys upstream into a trap.

Physical Barriers

Although low-head barriers have been used for years, knowledge of many aspects of barrier design and operation is minimal or lacking.

• Evaluate the effectiveness of differing low-head barrier heights and lip designs under variable flow and water temperature regimes to stop sea lampreys.

• Design a lip that could be installed on low-head barriers that, when submerged, would prevent sea lamprey passage by creating turbulence, cavitation, a venturi effect, or some other hydraulic phenomenon, without preventing passage of other fishes.

• Test the feasibility of using non-attachable surfaces on low-head structures to improve effectiveness against sea lamprey migration.

• Study the effects of small impoundments behind physical barriers on factors such as water temperatures, invertebrates, siltation, etc. These effects have been studied for large hydro, flood control, and irrigation impoundments but are not documented for small, shallow impoundments typical of sea lamprey barriers. This information is required to minimize ecosystem effects from future barrier projects.

• Design barriers that will eliminate the occurrence of downstream boils that are a danger to boaters, fishermen, and others; must avoid so-called "drowning machines", yet continue to block migrating sea lampreys.

• Study the feasibility of portable or temporary barriers, such as inflatable rubber dams. The advantage of these barriers is that they would only be in the stream or operational during the spring spawning migration of sea lampreys.

• Examine concepts for modification of existing man-made barriers and natural barriers (waterfalls) to make them effective lamprey barriers.

Electrical Barriers

Graduated field electrical barriers are currently in place on three streams. The electrical fields in these barriers increase in intensity in the upstream direction. One has successfully blocked sea lampreys for the past two years and the other two are not being operated because other migrating fishes are also blocked. Electrical barriers have an advantage over low head dams in that they do not create impoundments. Much information is needed if electrical barriers are to gain greater prominence in the control program.

- Determine physiological effects on fish moving upstream and downstream through electrical fields. If improved fish passage becomes a reality, this information will become extremely important as many more fish will be exposed to the electrical field as they move downstream.

- Test ways to separate lampreys and large fish. Large fish seem to be unaffected by graduated electrical fields in very shallow water (lateral line or spine exposed). Since lampreys would be completely immersed they would more likely be blocked.

- Determine the most effective (in terms of stopping lampreys) pulse characteristic of the electrical field.

- Describe more precisely the behavioral response of lampreys and other fishes to graduated electrical fields.

- Determine the most efficient placement of the field in the stream and its relation to the orientation of fish as they move up and downstream.

- Design improvements for portable electrical barriers. Electrodes can be placed on canvas and moved from place to place.

Sound Barriers

Sound barriers have been used to guide fishes away from hydro intakes. There has been no research to date on the use of sound barriers with sea lampreys.

- Determine the range of sound frequency and amplitude that lampreys (downstream migrating transformers and spawning-run adults) and non-target fishes are capable of perceiving and what signals will affect their behavior. How is the behavior affected; can lampreys be guided to traps, do they acclimate to sound, over what distance can lampreys "hear"?

- Determine the effect of background noise on the lampreys' ability to perceive sound and devise masking methods.

• Test the feasiblity of using sound as a temporary barrier - a sound barrier could be easily turned on or off, or moved as needed.

• Examine ways in which sound could be used to improve the effectiveness of physical and electrical barriers.

Other Barriers

Other stimuli or novel combinations of existing barrier concepts might be effective in maximizing the response of lampreys and other fish and should be considered.

• Test combinations of physical, sound, or electrical barriers to make a more effective blocking device.

• Study light, air bubble curtains, air bubble curtains combined with strobe lights (light makes bubbles more visible), lasers, and electromagnetic fields.

HOW RESEARCH SHOULD BE ACCOMPLISHED

There are existing research facilities (S.O. Conte Anadromous Fish Research Center in Turners Falls, MA and Ontario Hydro in Toronto, Canada for example) where experiments may be conducted with live fish. Permission to use these facilities would be required. Such laboratory studies can provide useful information on basic biological response variables and, in some instances, may duplicate situations found in the field.

Similarly, hydraulic studies may be conducted at the above or several other hydraulic laboratories such as the one at the University of Alberta at Edmonton or the U.S. Corps of Engineers in Vicksburg (assuming cooperative agreements on use can be arranged). Such studies can be used to quantify relevant hydraulic parameters (e.g., water velocities and velocity distribution, depths, discharges, backwater effects, channel shapes, and slopes) for various configurations of barriers and provide design criteria for field installations. Hydraulic studies can help clarify hydraulic phenomena emerging from observations made in laboratory or field experiments with live fish. Such studies can be completed at any time of the year and can also serve as a think tank to organize thoughts, analyze concepts and data, direct experiments in a systematic way, and maintain efficiency and cost effectiveness in the technology development cycle.

Although existing research facilities may provide means to measure stimuli, fish reaction, and hydraulic parameters, we suggest that studies of the behavior of lampreys and fishes must be conducted in the field under controlled conditions. Existing Great Lakes barrier sites could be used in some cases or small, temporary, or mobile facilities could be developed. Each site needs to be flexible so that modifications can be made in the various stimuli (such as flow) and in the types of barriers and traps being tested. The site must allow observation that includes the response of both lampreys and fish to a full range of stimuli to develop the ability to predict behavior and improve barrier design . Large populations of spawning-run lampreys and non-target fish should occur in the stream (s) so test specimens need not be imported from other streams.

RESEARCH PRIORITIES

The GLFC receives many research proposals each year, which they must examine and then decide whether or not to support them financially. Since they have only a limited amount of funds available, it would be helpful if they could receive some input on what types of research might be most useful to the sea lamprey control program. With this in mind, each workshop participant was asked what types of research they considered to be most important for the development of a successful sea lamprey barrier program. The following is a list of these important research needs. The number of participants that listed each need is in parenthesis.

1. Behavioral studies of lampreys and non-target fish below existing electrical and physical barriers using telemetry, underwater video, and direct observations (10).

2. New designs for low-head barrier dams that would reduce the barrier height necessary to block lampreys (3).

3. Studies to optimize fish passage and lamprey trapping (3).

4. Study differential effects of acoustics on lampreys (transformers and adults) and other fish (2).

5. Study improved electrical barrier with sloped sides (2).

6. Continue work on velocity barriers (2).

7. Test combination barriers (physical, electrical, and sound) (2).

8. Conduct literature and experience review (2).

9. Study natural movement of fish and lampreys in streams (2).

10. Determine more precisely the swimming performance of lampreys and other fish (2).

11. Design suitable traps for electrical barriers (1).

12. Determine the flow or temperature cues that affect lamprey migration (1).

13. Develop side channel to pass fish around electrical barriers (1).

14. Develop barriers that don't block flow (1).

15. Use systematic approach rather than trial and error in conducting research (1).

16. Utilize lamprey attachment behavior to separate lampreys from other fish (1).

17. Determine effect of trapping on lamprey populations (1).

18. Make existing structures (man-made and natural) effective lamprey barriers (1).

19. Determine effect of barriers on non-target fish both above and below barriers (1).

20. Determine how water velocity affects behavior using side-stream research facility (1).

After the list of priorities was completed, the workshop was adjourned.

POST-WORKSHOP OPINIONS

__Lee Hanson__

The presentations and discussions at the workshop produced many ideas (some old and some new) on how barriers might be used more effectively in the sea lamprey control program and a comprehensive list of research needs was compiled. Many of the research needs that were developed are needs that have been around for nearly half a century, but for various reasons (primarily because of budget constraints and in some instances, a lack of useful ideas) have not been fulfilled. An example of this is the need to find an effective and efficient method for collecting recently metamorphosed sea lampreys as they migrate downstream. If we knew how to do this, we could easily determine where the parasitic lampreys are being produced and treat the streams as needed. Although inclined-plane traps have captured entire migrations on small streams (Applegate and

Brynildson 1952; Manion and McClain 1971) they are expensive and difficult to maintain and not practical for use on medium to large streams. Fyke nets (Hanson and Swink 1989) and hoop nets (Gabel 1984) have been used with some success but require considerable care and maintenance and capture only a small portion of the run. It was suggested at the workshop that lampreys might be led either by electricity or by sound to one side of the river where they could be captured in traps. Unfortunately, the majority of the lampreys migrate downstream during periods of high water in the fall and spring and probably will not have sufficient time to react to the stimulus as they move rapidly downstream in most rivers. However, it may be useful on some of the larger, slower moving streams and until these ideas are tested, we will not be able to predict their utility.

Some of the needs suggested at the workshop have already been at least partially fulfilled and the information may be found in the many papers and reports that have been produced by the GLFC and its agents in the last 50 years. For example, there is considerable information available on the timing of lamprey migration (upstream and downstream) and the cues that induce them to migrate (water temperature, stream flow, etc.) and there is also a tremendous amount of other information on lamprey behavior and biology available in the literature. There is also a considerable amount of information available on the use of electricity for blocking spawning-run lampreys that should be examined closely by both researchers and decision makers. Each researcher should carefully examine the literature before preparing and presenting their proposals.

A few of the research needs suggested during the workshop are of the type that may never be answered satisfactorily and might properly be labeled as "wishful thinking" (perhaps determining stock/recruitment curves for sea lampreys might fall in this category). Some needs may be of the "nice to know, but not essential" type such as determining the effect on "some" fish populations if we are unable to pass them upstream past a barrier. While it may be necessary to determine the effects of barriers on certain species of fish on selected streams, we will have neither the funds or the manpower to determine their effects on all species of fish on every stream.

However, the majority of the needs suggested were of the type that will be useful in a successful barrier research program. Some of the ideas presented were new and may produce new and useful supplemental control methods. Some of the more exciting new ideas produced include the following:

1. It could be extremely important to conduct behavioral studies of lampreys and non-target fish below existing electrical and physical barriers using telemetry, underwater video, and direct observations. There is a need to see what lampreys and other fish see and observe how they react to the barriers and traps. This in turn may lead to new designs for barriers, traps, and fishways that will optimize lamprey trapping and fish passage.

2. Another intriguing idea is the possible use of a rubber dam for blocking lampreys combined with a velocity barrier or fishway for separating lampreys from other fish. The rubber dam can be raised or lowered as needed to maintain a complete block for lampreys during the spawning run and then be deflated in place when the spawning migration is over--an important advantage over a permanent physical barrier.

3. The possible use of sound to block migrating lampreys or guide them into traps is an untested idea that may have considerable potential.

These are but a few of the many ideas formulated at the workshop and all have been included in this report. Although it is relatively easy to develop a list of research needs, it is far more difficult to set priorities and to develop research proposals that will provide satisfactory results. It is hoped that this report will make this task easier for both decision makers and researchers.

William D. Swink

Discussion at the workshop very clearly reiterated the need to examine the effects of barriers on non-target organisms (invertebrates and fishes other than sea lampreys) and environmental factors (principally temperature and flow). The need for environmental studies was noted in the 1986 Sea Lamprey Barrier Dam Task Force Report, but was never acted upon. The concern over non-target organisms should be particularly important for the barrier program, given the high priority placed on these organisms in judging the utility of the chemical treatment (TFM) program. If the effects of infrequent, short-lived, and relatively benign chemical treatments on non-target organisms are considered sufficient to threaten that aspect of the sea lamprey control program, the effect of *permanent* barriers on the migration and reproduction of the same non-target organisms should receive at least similar consideration.

Several participants in the workshop also pointed out the need to conduct *systematic* studies of new designs under adjustable flow conditions, rather than using a "hit-or-miss" approach of building a structure in a stream and seeing if it works. A facility for this systematic research is still needed, regardless of whether the facility is permanently installed on one stream or movable to different streams. If a movable test facility is adopted, care must still be taken to choose test streams that (1) provide an *adequate* natural run of sea lampreys (not just 100 or 200 animals), (2) provide water quality that is adequate for direct visual or video observations, and (3) allow easy modification of the experimental device during the spawning run. The ability to easily modify the experimental device is particularly important when that device is found to be unsuitable early in a study. Inability to modify a non-functioning test device would waste the short spawning season and force a one year delay in testing a modified device.

I believe these are the two most important points made during our discussion in the workshop. The workshop also listed a number of intriguing options for barriers that deserve further consideration. However, these options need to be thoroughly studied, which will require a firm, long-term commitment of dollars and support from the GLFC. These new options will only become operational if adequate support is consistently and continuously provided.

<u>Tom McAuley</u>

I believe we are at a turning point for the lamprey barrier program and for lamprey control. There are an estimated 90 to 120 streams in the Great Lakes watershed undergoing regular lampricide treatments that could have lamprey barriers installed cost effectively. Large scale implementation of barriers could bring about reductions in whole lake TFM use close to the 50% reduction goal of the GLFC. However, such a large number of barriers would have an equally large and important effect on the fish that use those streams.

Up to this point, low-head lamprey barriers have been designed to pass jumping fish only (salmonids) and this has been acceptable to fishery managers. About 40 lamprey barriers have been installed to date. More than 25 of these are low-head structures. Three of the highest dams (Saugeen River, Credit River, and Brule River) have pool and weir fishways for the passage of jumping salmonids.

In the future, lamprey barriers will most probably be designed to pass a greater variety of fish species and sizes. For this purpose, both research and creative application/adaptation of existing technology is very important for the barrier program. It is actually feasible at the present time to design an instream lamprey barrier that optimizes non-target fish passage. Such a barrier would make use of an inflatable bladder supporting a crest plate as a blocking mechanism; it would have a fishway (Denil or vertical slot) with an incline trap functioning with manual sorting during the lamprey run and/or a velocity chute along with a built-in lamprey trap. This ideal barrier would:

- trap 3/4 of the lamprey spawning run
- pass all fish at all times other than the lamprey run with the crest down
- pass all migratory fish > 30 or 35 cm in a velocity barrier chute during the lamprey run or
- pass smaller non-jumping fish (<30 cm) with a manual sort inline trap with Denil or vertical slot fishways during the lamprey run, and
- eliminate lampricide use in the stream if it could be located downstream of useable spawning substrate

In my next design, I intend to incorporate a number of the elements mentioned above. A barrier incorporating all the elements would be somewhat more expensive to build and operate. It would also require more sharply defined biological and hydrological information related to the lamprey spawning migration.

For rivers where constraints do not permit the use of physical barriers, I foresee a future role for the use of acoustics to repel and guide lampreys towards an array of traps. An ±80% effectiveness may by calculation prove feasible if sterile males could be introduced to further reduce reproduction.

We still have much to learn from existing barriers and assessment information. We can learn from and refer to the expertise of those gathered in the St.Paul - Minneapolis workshop where we learned about or were updated on pertinent technology as well as discussing research directions. The lamprey barrier program of the future must be directed using creativity and intelligence for the maximum benefit of Great Lakes aquatic ecosystems.

Doug Dodge

Most important research applications: behavioral traits of lamprey and how they differ from bony fish.

Most promising technology: trapping, inflatables, electrical barrier technology advances.

Most important concerns in barrier research area: that research priorities will embrace the comments from Lee Hanson that "nice to know, but not essential" for determining effects on some fish populations if they are not able to move upstream.

This idea is surely not conducive to so-called 'integrated' sea lamprey control. Few, if any, managers any longer can write-off this potential for detrimental effects for the sake of catching a few more sea lamprey. In fact, some of my associates argue that no more barriers be allowed to be constructed unless these effects are eliminated.

Ken Bates

A promising technique that we discussed is the guidance of transformers into a trap where they can be removed from the river and disposed of. Guidance would be done by sound. Lamprey would be trapped by guiding them through a velocity barrier and into a trap. Study on effects of acoustics on transformers would of course be needed. I believe that additional success might be achieved

with acoustics if sounds were selected that the lamprey cannot only hear; but that repels them because of the unique pattern or frequency. I would consider this a high priority for research.

I also consider the general behavioral studies of lamprey at barriers should be a high priority.

I have another scheme I'd like to propose. Its primary component is a tube just large enough for adult lamprey to swim into. A group of tubes would be located underwater at strategic locations near a lamprey upstream migration barrier. The tubes would be perforated at the upstream end so water would flow through and help attract lamprey to enter. Optimum attraction of lamprey to the tubes would need to be studied. Vee leads might be used to help guide lamprey to the tube.

The second key component would be a "counting tunnel" inductance monitor within the tube. This monitor would automatically determine when a lamprey has entered the tube by the disturbance the lamprey causes to an electrical field induced in the tube. This technology currently exists and is successful; it is used for counting fish passing downstream through tubes or "counting tunnels." This monitor could be calibrated to sense only lampreys; it can be sensitive enough to discern between an adult lamprey and any other fish or any debris that might enter the tube.

Once a lamprey is sensed in the tube, any of several mechanisms could be actuated. The lamprey could be shocked, injected or mechanically killed.

An electrical charge could be applied through the length of the tube to shock the lamprey to either kill or sterilize it. There would be concern to make the device safe in the water; no different from an electroshocker however. Alternatively, the device could automatically inject the lamprey to sterilize or kill it. A mechanical device could crush the lamprey to kill it.

This device has obvious research and ecological study needs. Can lamprey be attracted to the tube? Can dead lamprey be left in the stream? What type of electrical shock is required to kill or sterilize a lamprey? Will dead lamprey release and float out of the tube? What are the power needs of such a device and can it safely and legally be installed in a stream?

I never imagined I would have the opportunity to suggest such a diabolical device. Perhaps the idea will spark some creative notions.

Ellie Koon

We in the sea lamprey control program have been building barriers, experimenting with various designs, and thinking about improvements and innovations for over 40 years. Two points emerged during the workshop that many of us in the control program have perceived to be true for some time, but it was gratifying that they were emphasized and validated by outside experts:

- We have a grossly insufficient understanding of lamprey behavior. In order to manipulate lampreys, we need to have a comprehensive description of how they behave, and we need to understand the stimuli and motivations leading to their behavior. It was instructive to learn that many millions of dollars have been spent in the Northwest (45 million dollars on one project) on fish passage and smolt exclusion devices that don't work, because they were designed from the viewpoint of humans rather than the viewpoint of fish.

- We need a streamside facility in which to study lamprey behavior in a natural setting. This need not be an enormous or elaborate installation, but it does need to be located on a stream which receives a large number of spawning adult lamprey, where we can perform controlled experiments in which variables can be manipulated in a statistically valid and reproducible manner.

We have talked for a long time about the possibility of using behavioral techniques such as sound, light, air bubbles, etc. as barriers. There was a noteworthy consensus among the workshop attendants experienced with those methods that none of them would constitute a completely effective sea lamprey barrier; that animals can become habituated to them; and that spawning sea lampreys in a highly motivated state would be difficult to influence with this type of stimulus. There seemed to be general agreement that such behavioral devices might be worthwhile components in a multiple-technique barrier, or that they might increase the trapping success of adults or downstream-migrating transformers.

I believe that the most promising practical concept which could be implemented in the near future is that of a combination electrical/low-head barrier, in which the electrical component is deployed when the dam is overtopped. This is not really experimental--we know that both types of barriers work. The great advantage of such a system is that the low-head barrier could be designed with a much lower head if it didn't have to remain effective in a 10-year flood. If designed to be overtopped at annual spring high flows, the impoundments would be much smaller and the expense of fish passage devices less.

There was only one truly original idea that I heard expressed in the workshop, which was Jim Anderson's observation that the attachment behavior of sea lampreys is unique among Great Lakes fishes, and that perhaps we could use it to separate lampreys from other fishes. This was recorded in the notes humorously

as "flypaper for lampreys". We have all seen lampreys attached to structures below barriers. If we can learn what hydrologic conditions induce lampreys to attach, and what types of surfaces they prefer, we might be able to use this information to develop a new type of trap, to "break the paradigm" of the rectangular mesh trap with funnels.

The importance of research on environmental effects of barriers cannot be overstated. The environmental effects of TFM treatments are well studied. We can't convince decision-makers or the public that barriers are preferable to lampricides if the data we have consist only of assumptions or extrapolations from studies of large impoundments.

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Appendix B

BACKGROUNDS OF WORKSHOP PARTICIPANTS

ANDERSON, JAMES:

James J. Anderson is an associate professor in the School of Fisheries and the Center for Quantitative Sciences at the University of Washington. He has conducted research on fish diversion systems on the Columbia River. His current efforts are in developing resource management models for the Columbia River. The principles and models developed for fish diversion are incorporated into these models.

BATES, KEN:

Ken Bates is a fisheries engineer employed by the Washington Department of Fisheries for the last 15 years as the Chief Engineer of the Habitat Management Program and a privately contracted consultant to agencies outside of the state of Washington. He previously worked for five years with Washington Fisheries as project engineer responsible for hatchery design and construction.

As Chief Engineer Ken is responsible for research, design standards, functional and detail design, and construction of fish collection facilities, upstream and downstream fish passage facilities and evaluations of those facilities for the state of Washington. Fish passage responsibilities are for resident and anadromous species including Pacific salmon, steelhead, anadromous and resident trout, Pacific lamprey, and American shad. He is also responsible for review and design of habitat protection, restoration, and enhancement work.

Research work includes studies in preparation of preliminary designs of fish passage facilities, evaluation studies of existing facilities, and general research regarding fish capabilities and behavior related to upstream and downstream migrants. Specific research projects have included fish stamina testing, screen retention studies, fish pumping studies, and fishway hydraulics studies. Ken also represents the state in cooperative studies of hydroacoustic, radio tracking, and collection studies of upstream and downstream migrants, hydraulic model studies of fish passage facilities, electric and physical passage barrier evaluations, and trap and haul evaluations.

Fish barrier work has included the design of barriers for the collection of brood stock or for trap and haul fish passage facilities. Typical barriers are height, velocity, and electrical barriers. Barriers have been studied to preclude Pacific

lamprey from entering salmon trap and haul facilities, and special facilities for the protection of anadromous species against predator species.

HAEUSLER, ROY:

Education:

B.S. (Civil Engineering) University of Michigan, 1961
Graduate Study (Structural Engineering) University of Michigan, 1963

Professional Experience:

U.S. Navy Civil Engineer Corp; 1961-1963
Smith, Hinchman, & Grylls (AE Design Firm - Detroit), 1964-1965
Mich. Dept. of Transportation, 1965-1968
Mich. Dept. of Natural Resources, 1968 - present
Licensed Professional Engineer, State of Michigan

Major projects with the MDNR:

Sessions Creek Dam, Ionia Recreation Area
Eagle Lake Dam, Fort Custer Recreation Area
Dam Replacement, Saline Fisheries Research Station
Sixth Street Fishway, Grand River at Grand Rapids
Webber Dam Fishway, Grand River
Portland Dam Fishway, Grand River at Portland
Buchanan Dam Fishway, St. Joseph River at Buchanan
Niles Dam Fishway, St. Joseph River at Niles
Berrien Springs Fishway Modifications: St. Joseph River at Berrien Springs
Flatrock Fishway, Huron River at Flatrock
Sturgeon River Sloughs Wildlife Flooding, Arnheim
Sand River Wildlife Flooding, Harvey
West Branch Whitefish River Lamprey Barrier, Trenary
Misery River Lamprey Barrier, Twin Lakes
Pere Marquette River Lamprey Barrier, Custer
AuGres River Lamprey Barrier, AuGres

KATOPODIS, CHRIS:

Philosophy: Pursue excellence in my work; expand my knowledge, skills, and abilities; and keep adapting to the ever more rapid changes of our times.

Education:
M. Sc. in Civil Engineering (Hydraulics), University of Alberta 1982.
B. Sc. in Civil Engineering, University of Manitoba 1974.
High School Diploma, Lyceum of Lefkada, Greece 1969.

Work Experience: My experience centers on hydraulic engineering, environmental impact assessment, and fisheries mitigation/compensation measures. Responsibilities have included review of hydroelectric projects and other water resource developments or proposals, assessment of environmental impacts and mitigation plans, development of fisheries mitigation or compensation measures, and hydrological and hydraulic studies.

Since 1980, I have been spearheading efforts to conduct hydrological, hydraulic, and biological studies, including planning, funding, and contracting arrangements between federal, provincial, and university departments. The work involves directing such studies, publishing scientific papers and technical reports, developing design criteria for fish protection and conservation measures (such as fishways, fish screens, and fish habitat improvement works), preparing conceptual designs for such measures, and reviewing and approving final decisions.

Selected Publications:

Katopodis, C., G.C.B. Yaremchuk, and B.G. Sutherland. (In Press). Mackenzie River Basin: hydroelectric developments and implications for fish habitat. Can. Tech. Rep. Fish. Aquat. Sci.

Katopodis, C. 1993. Fish passage at culvert highway crossings. Highways and the Environment, Charlottetown, May 17-19, 1993. 26 p.

Katopodis, C. 1992. Introduction to fishway design. Working Document, Freshwater Institute. 67 p.

Katopodis, C. 1991. Fish screening guide for water intakes. Working Document, Freshwater Institute, 4 p.

Katopodis, C., and R. Gervais. 1991. Ichthyomechanics. Working Document, Freshwater Institute. 11 p. + appendices.

Katopodis, C., A.J. Derksen, and B.L. Christensen. 1991. Assessment of two Denil fishways for passage of freshwater species. American Fisheries Society Symposium 10: 306-324.

Katopodis, C. 1990. Advancing the art of engineering fishways for upstream migrants. Proceedings International Symposium of Fishways, October 8-10, 1990, Gifu, Japan, p. 19-28.

Katopodis, C., and N. Rajaratnam. 1984. Similarity of scale models of Denil fishways. IAHR Symposium on Scale Effects in Modeling Hydraulic Structures, September 3-6, 1984. Technische Akademie Esslingen, W. Germany. H. Kobus (Ed.). p. 2.8-1 to 2.8-6.

Rajaratnam, N., and C. Katopodis. 1994. Fish Protection. In Hino (Ed.) Water Quality and Its Control. International Association for Hydraulic Research, Hydraulic Structures Design Manual 5. p. 243-255.

Power, G., R. Cunjack, J. Flannagan, and C. Katopodis. 1993. Biological effects of river ice. In Prowse and Gridley, Environmental Aspects of River Ice, NHRI Science Report No. 5, Saskatoon, Sask. p. 97-119.

Bender, M.J., C. Katopodis, and S.P. Simonovic. 1992. A prototype expert system for fishway design. Environmental Monitoring and Assessment, Vol. 23: 115-127.

McPhail, G.D., D. B. MacMillan, and C. Katopodis. 1992. Fish habitat mitigation measures for hydrotechnical projects. Canadian Society for Civil Engineering, Proc. Annual Conference, May 27-29, Quebec City, Vol. 11: 1-10.

Rajaratnam, N., C. Katopodis, and R. Paccagnan. 1992. Field studies of fishways in Alberta. Can. J. of Civil Engrg., vol. 19, No. 4, pp. 627-638.

Rajaratnam, N., C. Katopodis, and S. Solanki. 1992. New designs of vertical slot fishways. Cdn. J. of Civil Engrg., Vol. 19, No. 3, pp. 402-414.

Rajaratnam, N., and C. Katopodis. 1991. Hydraulics of steeppass fishways. Cdn. J. of Civil Engrg., vol. 18, No. 6, pp. 1024-1032.

Rajaratnam, N., C. Katopodis, and M.A. Sabur. 1991. Entrance region of circular pipes flowing partly full. J. of Hydraulic Research, International Association for Hydraulic Research, IAHR, 29(5): 685-698.

Rajaratnam, N., C. Katopodis, and S. Lodewyk. 1991. Hydraulics of culvert fishways IV: spoiler baffle culvert fishways. Can. J. Civil Engrg., Vol. 18(1): pp 76-82.

KOON, ELLIE:

Ellie did undergraduate and graduate work at the University of Michigan, after which she served as the Collections Manager at the University of Michigan Museums, Division of Fishes for five years. Ellie has been with the U.S. Fish and

Wildlife Service Sea Lamprey Control program for ten years in various capacities. Since June, 1993 she has been the U.S. Sea Lamprey Barrier Coordinator, a newly created position. She has a strong personal commitment to alternative control methods and a great deal of optimism that research may provide new ways to manage sea lampreys.

KYNARD, BOYD:

Boyd has 25 years of experience conducting research in the field and lab on behavioral ecology of fish. Much of his research is on movements and ecology of eastern anadromous fish. A second emphasis is fish passage. He has been co-PI of studies that (1) investigated the rheotropic response of adult eastern migrants, (2) determined the behavior of eastern migrants to pass over weir crests in fish ladders, (3) determined the behavior of adult American shad to structures in a louver bypass system, and (4) evaluated the behavior of adult American shad to electrical and sound barriers in a prototype bypass system. Boyd and a graduate student studied the population characteristics and riverine movements of the anadromous sea lampreys in the Connecticut River. For the past 10 years, he has studied the reproductive biology of anadromous sea lampreys (spawning ecology and adult abundance cycles).

LOEFFELMAN, PAUL:

M.S. Zoology, Aquatic Biology, Center for Environmental Studies (Director John Cairns). Va. Polytechnic Institute and State Univ. 1976. Senior Biologist American Electric Power Company, Environmental Engineering Division, Columbus, Ohio, 1976-1992.

Sixteen years experience designing, conducting, and supervising numerous projects related to environmental statutes, regulations, and regulatory agency policies affecting coal fired, nuclear, and hydroelectric generating plants on the 7 state AEP system in the midwestern U.S. I have experience with fish passage studies in hydro relicensing and fish impingement and entrainment studies at steam electric generating plant cooling water intakes.

Representative Publications: (Reprints may be obtained from Paul Loeffelman, Gavin Christie, or Ellie Koon)

Hanson Environmental, Inc. December 1993. Report on 1993 Phase I Field Tests Guiding Juvenile Chinook Salmon at Georgiana Slough, California.

Can. J. Fish. Aquat. Sci., January 1994. A Behavioral Guidance System for Fish Using Acoustics Customized to Target Fish Hearing. Manuscript revised and resubmitted for publication per referee comments.

Hydro Review, October 1991. Using Sound to Divert Fish From Turbine Intakes.

Nat'l Workshop on Fish Entrainment and Hydroacoustics. Sponsored by Niagara Mohawk Power Corp and U.S. Fish and Wildlife Service. May 1990. Invited Paper: Rational Resolution of Entrainment Issued Through Biological Engineering.

McAULEY, THOMAS:

Tom is currently Barrier Coordinator charged with development of a strategic plan for the Great Lakes Fishery Commission for lamprey barrier deployment in the Great Lakes basin. This task is carried out in collaboration with Ellie Koon, counterpart Coordinator in the USA.

From 1980 to January 1993 as Canadian lamprey barrier program engineer he designed and engineered 20 lamprey barrier dams and worked on other cooperative barrier projects. Desiring to improve the barrier program, he initiated a study on lamprey trapping and passage at a modified Denil fishway in 1990. This was followed by the beginning of research towards development of velocity barriers including testing sea lamprey burst and prolonged swimming performance in 1991 and 1992.

Lamprey Barrier Projects

Gimlet Creek	Humber River	Still River
Duffin Creek	Carp River	Grafton Creek
Credit River	Graham Creek	Wolf River
Koshkawong River	Sheppard Creek	Normandale Creek
Stokely Creek	Lakeport Creek	Forestville Creek
Manitou River	Shelter Valley Brook	Clear Creek
L. Otter Creek	Port Britain	Bowmanville

MACKAY, WILLIAM:

Bill Mackay did his graduate research (M.Sc., U of Alberta, 1967; Ph.D., Case Western Reserve University, 1971) on the environmental physiology of fish. He did postdoctoral research in biophysics at Yale University and has been a

faculty member in the Department of Zoology, University of Alberta since 1972 where he lectures in comparative and environmental physiology.

Bill's research interests for the past 15 years have been in fish energetics, particularly the seasonal aspects of energy use. This research has involved examination of the timing and magnitude of body and gonad growth as well as various aspects of movement and activity in fish. This interest has resulted in many studies of the patterns of movements of fish, particularly northern pike and, more recently, cutthroat trout and Arctic grayling. He became involved in studies of the ability of fish to move up fishways as a result of his interest in the swimming capacity of fish, in particular their ability to recover from strenuous exercise. Bill has also been involved in a number of studies of the sublethal effects of various toxic materials (DDT, methyl mercury, copper, and, more recently, effluent from oil sands extraction) on fish.

RAJARATNAM, N.:

I have lectured at the University of Alberta for the past 25 years. I have taught undergraduate courses on Fluid Mechanics, Hydraulics, Environmental Fluid Mechanics, and applied Mathematics. I have taught graduate courses on Engineering Fluid Mechanics, Advanced Environmental Fluid Mechanics, Pipe Flow, Open Channel Flow, Hydraulic Structures, and Unsteady Flow in Pipes and Channels. I have also supervised the Graduate Hydraulics Laboratory for several years. I have also had considerable experience with hydraulic model testing. I have worked with several aspects of fishways in the past 14 years.

I have done research in several areas of Hydraulic Engineering and published over one hundred papers. My main contributions are in the areas of hydraulic jumps and energy dissipators, weirs and sluice gates, turbulent jets and wall jets, surface jets and thermal discharges, internal jumps, erosion by jets, open channel flows, hydraulics of fishways and culvert fishways, and environmental fluid mechanics. I have done consulting work over the past twenty years on several engineering projects connected with hydraulic structures, diffusers for effluent disposal in rivers, mixing and dispersion in rivers, dredge plumes in rivers, dynamic loading on stilling basins, and slurry problems.

My book on Turbulent Jets (Elsevier, 1976) has been translated into Japanese. I also wrote a chapter on Hydraulic Jumps for Vol. 4 of Advances in Hydro Science, edited by V.T. Chow and published by Academic Press in 1967. I have had research grants from the Natural Sciences and Engineering Research Council of Canada for the past 25 years. I have also had research grants or contracts from the (Canada) Department of Fisheries and Oceans, Alberta Environment, City of Edmonton, and private industry.

For detailed information on fishways, see the following papers which may be obtained from N. Rajaratnam, Gavin Christie, or Ellie Koon.

Rajaratnam, N., C. Katopodis, and R. Paccagnan. 1992. Field studies of fishways in Alberta. Can. J. of Civil Engrg. Vol. 19, No. 4, pp. 627-638.

Rajaratnam, N., and C. Katopodis. 1991. Hydraulics of steeppass fishways. Can. J. of Civil Engrg., Vol. 18, No. 6, pp. 1024-1032.

Rajaratnam, N., C. Katopodis, and S. Solanki. 1991. New designs for vertical slot fishways. Can. J. of Civil Engrg., Vol. 19, No. 3, pp. 402-414.

Rajaratnam, N., and C. Katopodis. Fish Protection. Ch. 5 of IAHR (International Association for Hydr. Res.) Manual on Water Quality, Ed. by M. Hino, 23 pages.

Rajaratnam, N., C. Katopodis, and M. Miles. 1990. Hydraulics of culvert fishways V: Alberta fish-weirs and baffles. Can. J. Civil Engrg. Vol 17, pp. 1015-21.

Rajaratnam, N., C. Katopodis, and S. Lodewyk. 1991. Hydraulics of culvert fishways IV: spoiler baffle culvert fishways. Can. J. Civil Engrg., Vol. 18, pp 76-82.

Rajaratnam, N., and C. Katopodis. 1990. Hydraulics of culvert fishways III: weir baffle culvert fishways. Can. J. Civil Engrg., August, Vol. 17, pp. 558-568.

Rajaratnam, N., C. Katopodis, and A. Mainali. 1989. Pool-orifice and Pool-orifice-weir fishways. Can. J. of Civil Engrg., Vol. 16, No. 5, pp. 774-777.

Rajaratnam, N., C. Katopodis, and N. McQuitty. 1989. Hydraulics of culvert fishways II: culvert fishways with slotted-weir baffles. Can. J. of Civil Engrg., Vol. 16, pp. 375-383, June.

Rajaratnam, N., C. Katopodis, and S. Lodewyk. 1988. Hydraulics of offset baffle culvert fishways. Can. J. of Civil Engrg., Vol. 16, pp. 1043-1051.

Rajaratnam, N., C. Katopodis, and A. Mainali. 1988. Plunging and streaming flows in pool & weir fishways. ASCE J. Hydraulic Engrg., Aug. 88, pp. 939-944.

Rajaratnam, N., C. Katopodis, and L. Flint-Petersen. 1987 Hydraulics of two-level Denil fishway. J. Hyd. Engrg., ASCE, May 1987, Vol. 113, pp. 670-674.

Rajaratnam, N., G. Van der Vinne, and C. Katopodis. 1986. Hydraulics of vertical slot fishways. ASCE, J. of Hydraulic Engrg., Oct. 1986, pp. 909-927.

Rajaratnam, N., and C. Katopodis. 1984. Hydraulics of Denil fishways. J. of Hydraulic Engrg., ASCE, Sept. 1984, pp. 1219-1233.

SMITH, DAVID:

1933 - Born Vancouver, Washington.
1950 - Graduated from Vancouver High School
1950-1953 - US Navy (Electronic Technician) Served during the Korean War on board USS Current (Underwater Rescue Ship) - trained in communications and sonar
1956 - Graduated Multonomah College, School of Electronics, Portland, OR.
1956-1960 - Tektronix, Inc. Design Engineer, specialized in the high speed sampling oscilloscopes
1960-1962 - Lockheed Aircraft Co., Vandenberg AFB, Ca., involved in launching and tracking "Discoverer" Satellites
1962-1964 - University of Washington, Physics Dept.; established and headed instrumentation lab for high energy physics experiments and carbon age dating equipment
1964 - Established Smith-Root, Inc., designed and manufactured specialty instrumentation for physics experiments (Mausbauer Effect Analyzer) used at U of Wa, Seattle, WA, U of Ca, Berkeley, CA and MIT, Cambridge, MA
1966 - Design and manufacture of sonic tracking equipment for fish passage studies, National Marine Fisheries Service, Seattle, WA
1967 - Designed and supplied fish counters for fish passage studies at Bonneville Dam, OR.
1968 - Designed and manufactured first commercial electrofisher for U of BC, Vancouver BC.
1984 - Designed and patented alpha-numeric coded wire tag and injection equipment (2)
1986 - Designed and installed electric fish barriers at 3 hatchery sites in Oregon
1987 - Installed prototype lamprey barrier on Ocqueoc River, Presque Isle County, Michigan
1987 - Installed prototype lamprey barrier on Haymeadow River, Delta County, Western UP, Michigan
1987 - Patented Graduated Field Fish Barrier (GFFB)
1988 - Installed GFFB lamprey barrier on Pere Marquette River, Mason County, Michigan
1989 - Assisted in the design of lamprey barrier on the Jordan River, Antrim County, Michigan
1988-1994 - Two additional fish barrier patents with two currently pending.

1969-1994 - President and CEO of Smith-Root, Inc. Currently employing 30 people. Designed and manufacture various electrofishing boat systems, backpack electrofishing equipment, fish counters, radio and sonic fish tracking equipment, coded wire tags, and associated equipment. Installed more than 20 GFFB barrier systems throughout the US and Canada.

STANFIELD, LES:

Les is the senior project biologist with the Great Lakes Salmonid Unit, Ministry of Natural Resources. In this capacity, he has been involved in the design and implementation of projects related to the Atlantic salmon restoration program and the unit's interest in salmonid ecology in general. Over the last several years, research efforts have focused on carrying out projects that will permit evaluation of success and impacts from Atlantic salmon restoration. He is also involved with a rainbow trout life history and production project, as well as several studies related to better understanding the relationship of habitat (and the factors which influence it) and fish production.

Prior to this, Les worked in many areas of Ontario on a variety of projects from advising public interest groups how to carry out community based fisheries projects to fisheries and habitat assessments on streams and lakes. Les has also worked as a district biologist, fisheries planner, and capital projects biologist. Les is also actively involved with the American Fisheries Society and has been involved with the organization of several habitat and hydrology based workshops, as well as the development of a watershed based report card.

SWINK, WILLIAM:

Since 1983, William Swink has conducted research on sea lampreys, particularly on fish-sea lamprey interactions and larval sea lamprey growth. He is a member of the Sea Lamprey Barrier Task Force and also participated in a prior Sea Lamprey Barrier Dam Task Force of the Great Lakes Fishery Commission.

Before joining the Hammond Bay Biological Station, Mr. Swink was employed by the National Reservoir Research Program of the U.S. Fish and Wildlife Service from 1979 to 1983. He conducted research on the effects of reservoir releases on tailwater biota and was an author of a literature review that examined the effects of dam placement and operation on stream biota downstream of dams.