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December 13, 1973

Dr. Robert J. Behnke
Colorado Cooperative Fishery Unit
Colorado State University
Fort Collins, Colorado 80521

Dear Bob:

Enclosed are two of the papers that you mention in your letter of December 5. Our supply of these is low but you are very welcome to them. According to our records we sent #145 on July 3, 1961, but we have no record of having sent #177.

Unfortunately we have only a desk copy of each of the two large papers: Hubbs, Greeley and Tarzwell, Methods for the Improvement of Michigan Trout Streams; and Hubbs and Eschmeyer, The Improvement of Lakes for Fishing. Carl will gladly lend these two if you wish, but he would like them returned. Let me know if you would like to borrow these two.

Thanks for the reprint items you sent.

Sincerely,

Laura

Laura C. Hubbs

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[1932]
145

THE IMPROVEMENT OF TROUT STREAMS

BY

CARL L. HUBBS

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The Improvement of Trout Streams

What Michigan Is Doing to Shorten the Time Between Bites

By Carl L. Hubbs

This is the first of two articles dealing with the work of the Institute for Fisheries Research of the University of Michigan, in the improvement of trout waters by the establishment of environment attractive to trout. The second article by Dr. John R. Greeley and Mr. Clarence M. Tarzwell of the Institute will appear in an early issue and will present in more detail the methods being used on Michigan streams and the experience gained to date.—Editor.

VERY little has been done in America in the way of improving our trout streams. All trout fishermen are familiar with sections of streams that are not worth fishing, because there are no good pools in which trout can live. Men who know their streams take short-cuts across bends, passing by the fishless stretches. If all the energy spent in the long treks between pools could be devoted to the improvement of the water that is skipped, trout fishing would bear less resemblance to golf. Do you care for long walks after you reach your trout stream? Or would you rather spend more time in actual fishing? Less distance between pools means "less time between bites"—the ideal which President Hoover has set for us.

Little Beaver Creek, in Osceola County, Michigan, is a good example of a trout stream with natural cover.

There are four means of improving trout streams and thereby conserving and upbuilding trout fishing. First, trout may be introduced into waters in which they are not native. This has been done in Michigan, with great success from the standpoint of trout fishing. The most famous brook trout streams of the state, such as the Pere Marquette, Manistee, Boardman, Au Sable, Au Gres, Rifle, were devoid of trout within the memory of old lumbermen and settlers still living. They contained no trout until they were introduced in the seventies and eighties. And of course the rainbow trout, native to our Pacific Coast, and the brown trout, native to Europe, were introduced. This first, simple method of improving trout streams, or rather making trout streams, has been carried well toward its limit in Michigan, for trout of some species occur in nearly every stream in the state capable of supporting trout life.

Second, trout conditions may be improved by giving protection to the trout during the breeding season and in nursery waters. Third, the trout supply may be maintained in large part by giving protection to the eggs and fry by methods of fish culture. With intense fishing, regulatory measures are necessary, to prevent serious depletion of the stock, and hatchery and rearing-station operations are an important means of adding to these stocks. The diligence with which these two methods of trout improvement have been developed and expanded by the Michigan State Department of Conservation is reflected in the relatively satisfactory condition of trout fishing at the present time, following years of very heavy catches. But it becomes increasingly difficult each year, to conserve the trout supply, that is, to hold it on a level. If much progress is to be made beyond mere conservation in actually increasing the trout supply in the face of ever growing depletion, we must turn our attention to the improvement of living conditions for the trout.

Thus we come to the fourth method of adding to the trout supply, and the one which is most truly and specifically the improvement of trout streams. Neither introduction, nor protection, nor stocking, can grow fish. To do this a suitable environment is required. Without proper environments, cur game fish must dwindle or disappear. The requisite conditions are: adequate spawning beds; enough shelter; sufficient food. The improvement of trout waters by environmental control is the main point of this article.

Although it is very apparent that the basic principle of environmental control is sound in theory, very little practical application of this principle has been seen in this country. It has long been recognized in Great Britain that many steps could be taken to improve existing conditions in trout waters. A large fund of practical experience has been built up during generations of attention to streams by their keepers or owners. Several excellent books dealing with stream improvement have been published in Great Britain, notably the books of Malloch, Armistead, Mottram and Platt.

In Michigan and surrounding regions, we in our pioneer efforts may well consider facts learned from the longer experience of others. At the same time, we must bear in mind that our streams are mostly very different from those of other countries. The majority of British streams are under an intensive system of private control, which allows the employment of some methods which are not practical in the vast lengths of our public water. Moreover, our climate creates great danger from high water temperatures, an important point to consider in planning our stream improvement methods. The climate of the British Isles makes it possible for streams there to be more exposed to the sun than ours can safely be.

In a recent work, "*Better Trout Streams*," Mr. Hewitt has given excellent attention to some problems of environmental control in American streams. Many good ideas have been put in practice on streams controlled by that author. On the other hand, some of the methods which are successfully employed on these streams, located in the Catskill region of New York State, are not applicable to the usual Michigan conditions. Successful work in our waters depends upon the adoption of methods which are successfully used elsewhere, but only after we make sure that these are suited to the needs of the streams to which they are to be applied. It is sometimes necessary to devise new means to accomplish certain purposes in our waters.

The Michigan Department of Conservation has been trying out methods of trout stream improvement for several years. Particular attention has been given to the problem of providing cover, or shelter for trout. Dr. Jan Metzelaar began studies of the "re-snagging" of streams several years ago and many of the log shelters which he built have created good trout pools and have remained solidly in place. With the creation of the Institute for Fisheries Research, early in 1930, plans were made for the expansion of this field of investigation. Mr. Clarence M. Tarzwell, who holds a fellowship under the Institute, has devoted two seasons' work to the experimental improvement of trout streams by the introduction of pool-producing devices, and shelters. Since stone as well as log work is being employed, the term "re-snagging" which has been somewhat used, is hardly a good word for this type of work.

In 1930, by means of an appropriation for an improvement project on the Little Manistee River, the Department of Conservation made possible the first really large-scale work that has been undertaken in the waters of the state; probably the first in any of the public waters of the country. Through the cooperation of conservation officers, a crew of three men, experienced in handling logs, was secured. The planning and study of the methods and effects of the improvement work was done by the Institute. During 1931, the Department, in connection with the Pigeon River Forest project, engaged the Insti-

Good natural cover is also provided at Baldwin Creek, in Lake County, Michigan. Streams where this is lacking, can be improved by intelligently applied modern methods.

A current deflector installed in Pigeon River in the course of the stream improvement investigative work in Michigan. Note the great speeding up of the current and additional cover lodged on the barrier. Clarence Tarzwell, in charge of this work, is standing on a bar behind the barrier.

A splendid trout hole has been added to the stream by the installation of a deflector on the Pigeon River. Note the apparent depth of the hole dug by the artificially deflected current.

tute to carry on similar stream improvement there. During 1931, Mr. Tarzwell undertook the planning and study of two separate undertakings on privately controlled streams, where the expenses were borne by the landowners. In this way, it was possible to expand the study quite materially. In addition, a few other experimental improvements have been built directly by the Institute, in waters open to public fishing.

At the present time 875 numbered improvement devices are under observation, distributed in the following streams: Little Manistee River in Lake County, Pigeon River in Otsego and Cheboygan counties, the East Branch of the Black River in Montmorency County, Gamble Creek in Ogemaw County, Huron River in Washtenaw County, and the River Rouge in Wayne County. All of these streams are trout waters, with the exception of the Huron River.

These experiments in trout stream improvement have proved to us that it is possible and practical to increase the supply of trout by improving the spawning facilities, the shelter and food for the trout, where needed. The experiments have taught that it is possible to modify the stream for the better, at a low cost, and in a lasting way. Without going into the details of the methods of improving the streams, or of the design of the various devices to modify the current, depth, bottom and food supply of the water, I will very briefly indicate how a stream can be modified so as to increase its trout production. The details of methods and designs will be dealt with in a bulletin on "Methods for the Improvement of Michigan Trout Streams," now being published by the Institute for Fisheries Research of the University of Michigan.

Many of our Michigan trout streams, or long sections of them, are devoid of natural spawning grounds. It is of course important to supplement stocking of these waters by natural reproduction. It has proved possible to produce the gravel conditions fit for spawning where they did not formerly exist. One method which has been tried with success is the hauling of gravel into a feeder stream devoid of natural gravel. Another method of proved utility has become apparent from our experimental work on the Little Manistee River. Here a number of log and stone constructions have speeded up the current so as to wash out the sand and thus expose the original gravel bottom of the stream. And trout have already utilized these artificially exposed gravel stretches for their spawning activities.

Many of our Michigan trout streams, or portions of them, are sadly lacking in cover, and trout will not remain where they have no place to hide or to call their home. Every angler knows stretches of familiar streams which contain no shelter and no trout. We have taken such stretches, provided shelter therein and have proved that trout have taken quickly and readily to the homes made for them. An example is a long bend of the Little Manistee River in which there were no trout holes and no trout. Anglers wise to the stream avoided this long unproductive stretch by cutting across a narrow neck of land. As an experiment this stretch was improved in 1930. Log devices were installed to deflect or concentrate the current and to force it to dig holes such as trout love to lie in. Other shelter was provided. In the spring of 1931, good catches of trout were made in this formerly unproductive stretch. Now the wise angler will not skip this mile of the stream, which has cheaply and effectively been made to add to the trout catch of the river. This experience has been general. Hundreds of miles of now troutless or nearly troutless stream courses in Michigan can be made habitable for trout.

Trout can not grow well unless they have the proper amount of natural food. Since very little trout food grows in a soft sand bottom and much develops on gravel, every one of our devices which removes sand and exposes gravel has increased the food growth. Still more productive of food are the weed beds in the stream. It has been proved possible, both in Europe and in Michigan, to increase the weed beds where they are too few, and so increase both food supply and shelter for the trout. Furthermore, the log and brush shelters put in the streams provide such food, for insects hatch and crawl about on this material in great quantity.

Why do our trout streams need improvement? They have been made in response to various natural laws and not for trout; but knowing what conditions make for trout existence, multiplication and growth, we are able to make these streams more suited to trout life than they naturally were. Logs lying in a stream may merely pile up sand or become covered, without benefit to the trout, but the same logs intelligently fixed in the stream so as to increase the current, dig holes and to provide cover and food for the fish, will make the trout production of the stream markedly greater.

Further, many of our streams have been all but ruined by human agencies. Cutting of forests and agriculture have often made the streams too warm and have caused sand to wash in and to smother the food. Often the streams have been cleared of all snags or other trout cover to facilitate the floating of logs or pulp wood. At times the streams have been cleared of fish shelter in the mistaken idea that so doing improves the appearances of the stream. Not only the natural but also the artificial shelters and current modifiers may greatly increase the charm of the stream by diversifying the water course, current, surface and bottom. The riffles produced often increase the attractiveness of the stream by adding to the music of the flowing water.

There are many whole streams, and long sections of others, which can be made to produce more trout if they are properly improved. Probably none of our streams are incapable of producing more fish and more fishing if they are properly improved. And better trout fishing means more health, more happiness and more income to the far northern part of our country. That is vital, for the very life of our northlands is dependent upon the development of its greatest resources: its pure air, its open spaces and its wild life.

C.C.C. STREAM IMPROVEMENT WORK IN MICHIGAN

CARL L. HUBBS, CLARENCE M. TARZWELL, AND R. W. ESCHMEYER
University of Michigan, Ann Arbor, Michigan

INTRODUCTION

CARL L. HUBBS

The only time I ever inserted a political remark into a talk was some time ago in Indiana when I was addressing the Annual Meeting of the Izaak Walton League of that state, in which I made the comment that it was a fortunate circumstance that whichever of the two candidates for the presidency at that time were elected, the conservationists of the country would probably be satisfied. I think that remark has been justified by the first act which was taken by the newly elected president in his drive to restore prosperity, which was the inauguration of the so-called C.C.C.—Civilian Conservation Corps. The emergency conservation program was then put in charge of officials in Washington, while the work was undertaken, as you know, by the various conservation officials in the several states.

I think most of us here will look upon this work as one of the wisest of the moves that have been taken for the restoration of prosperity. The "fish men," administrators and investigators, and the fishermen themselves, were rather disappointed that in the drawing up of the activities in connection with this emergency conservation work being carried out by the C.C.C., fish improvement questions were not considered. The improvement of fishing conditions through the C.C.C. labor is such an obvious public benefit, since much of this work does involve chiefly labor, with relatively low cost materials, that it was probably more a matter of oversight than anything else that this fish work was not included in the original program. Despite this fact, a number of the enthusiasts throughout the country submitted proposals for work of this sort—for lake and stream improvements, the construction of hatcheries and rearing ponds, and other work which, by making for an increase in the fish population, would lead toward a betterment of fishing conditions. Any projects of this sort which were approved were approved in a qualified way, always with the restriction that only a very small part of the labor in any one C.C.C. camp should be devoted to this work. Finally, and very fortunately from our standpoint, the Emergency Conservation headquarters in Washington formally approved this type of work as one of the legitimate functions of the C.C.C., and from that time on the work has proceeded a little more above board and on a larger scale; and I think it can be prospected for the future on a still larger scale.

This work is expanding very rapidly. In almost every mail word comes in to us referring to new work along the line of lake and

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INVESTMENT BUILDING, WASHINGTON, D. C.

stream improvements being started, generally in connection with the C.C.C. program, from one end of the country to the other. The states in which this is being done are numerous; I can recall offhand either activity or proposals in Connecticut, New Jersey, West Virginia, Michigan, Iowa, Arizona, Pennsylvania, and a considerable number of other states.

In the work with which we are most familiar, that in our own state, a certain organization was built up. The Department of Conservation of our state naturally had charge of the local work in the state, acting as agent for the Emergency Conservation program in this respect. For the lake and stream improvement work, naturally a number of skilled workers were needed to direct and plan and check on the work as it was done. Several of these skilled workers are now busy in our state, having under them a series of construction foremen, one in each camp, directing the work of these boys. Certain of the better workers among the boys, the more intelligent of them, have been placed in charge of squads, and in that way the organization has been carried down to the laborers themselves. The Institute for Fisheries Research, which since its incorporation has taken a very considerable interest in developing this field of lake and stream improvement, had some men available who had had experience along this line, and these men were, in part, taken over by the organization in our state. Two of these young men will briefly tell you something of the work which has been done in Michigan: one, Mr. Tarzwell, representing the stream work, and the other, Mr. Eschmeyer, representing the lake work.

Stream Improvement

Clarence M. Tarzwell

The organization for trout stream improvement work in Michigan has been partly explained by Dr. Hubbs. At present in the stream improvement work we have three skilled workers: Mr. MacClure in charge of the work in the Upper Peninsula; Mr. Johnston in charge of the work on the Pere Marquette River, and myself, in charge of the work in the Lower Peninsula. In each camp there is a foreman having direct charge of the crew. The crews which have been working vary in number from twelve to forty-four. Before any work is undertaken on the streams a preliminary survey is made, which includes the taking of temperatures, a study of the spring feeders, a study of the food supply, a list of the number of sand banks in which erosion has to be prevented, a study of the present trout population, a study of pools and shelter. Trout stream improvement is needed where shelter and pools are insufficient in number, or where food conditions are poor, and this may require improvement

Grace Conzon
922 Nelson Avenue
Trail, BC V1R 3H2
Fax: (604) 368-6491
July 22, 1996

Dr. Robert Behnke
Colorado State University,
Dept. of Fisheries and Wildlife Biology
Fax: (970) 491-[redacted]5091

Dear Dr. Behnke,

I recently contacted the editor of Trout magazine, Mr. Peter Rafle, in the hopes of finding information about the pros and cons of large-lake fertilization programs--specifically, the Kootenay Lake Fertilization Program (KLFP) here in south eastern BC. (I have attached my original letter below.) Mr. Rafle handed it over to N. LeRoy Poff, Ph.D., Senior Scientist to Trout Unlimited. Dr. Poff tried to respond to my concerns regarding this experimental program, and listed several scientists who might be better able to answer my questions. You, obviously, were among them.

If you are able, could you please take the time to read my letter to Mr. Rafle, answer the questions I have asked and respond to the concerns I have raised? I have discussed these issues with the local fisheries biologists, but I would like to hear from scientists who are not connected to this experimental program in any way. If you wish to speak with me, please call in the evenings [(604) 368-3059], when you'll have the best chance of catching me at home.

Thank you.

Yours Truly,

Grace Conzon

Grace Conzon

Grace Conzon
922 Nelson Avenue
Trail, BC V1R 3H2
July 17, 1996

Peter A. Rafle, Jr.
Editor
Trout Unlimited
1500 Wilson Boulevard, Suite 310
Arlington, Virginia 22209-2310

Dear Mr. Rafle,

I am the Fisheries Director for the Trail Wildlife Association, and I'm one of three public representatives on the Steering Committee for the Columbia Basin Fish and Wildlife Compensation Program (CBFWCP). The latter is a joint BC Hydro-BC Ministry of Environment Lands and Parks initiative that is meant to offer compensation for fish and wildlife losses due to the development of hydroelectric dams on the Columbia River in south-east BC.

The reason I am writing is that I need some help on some fisheries concerns related to the CBFWCP. Right now, we are funding the last year of a five-year experimental fish enhancement project on Kootenay Lake, a large (107 kilometres long by 4 kms wide; mean depth more than 100 meters) lake in the southeast corner of BC. This is being done in an attempt to reverse a "crash" in the kokanee stocks there. The unique, world-renowned "Gerrard" strain of rainbow trout in the lake are dependent on kokanee as their major food source.

The argument put forward in favour of this fertilization program (KLFP) is that the hydro electric dams (Libby dam controls inflow on the south arm of the lake and Duncan dam on the north; the Lardeau River and numerous creeks also flow into the lake) are blocking the majority of the flow of nutrients into the lake, and that the fertilization program is necessary to replace those missing nutrients. It is said that the economy of the communities on the shores of the lake are dependent on the fishery for kokanee and Gerrard rainbow trout.

I must confess that I personally have a bias against this program since I feel it only addresses one of the problems in the lake's overall ecosystem functioning. However, I want to make sure that I do the right thing when it comes to voting on whether or not to spend a substantial chunk of the CBFWCP fish budget on KLFP. What I'm asking is: are large-reservoir fertilization programs worthwhile--effective and sustainable--both in terms of biology and economics? This program currently costs $494,000 (Canadian dollars) per year.

My concerns are the following:

--One of the main problems--in fact the start of the kokanee stock "crash"--was the introduction of *mysis relicta*, some time ago. At first, they were a great boost to the lake's productivity, providing feed that helped kokanee grow bigger than usual. Then they began competing with kokanee fry for food.

--The lake is no longer a lake; it's devolved into a reservoir, with the resultant changes in the *natural* hydrological cycle.
--Residential development along the lake has destroyed much of the riparian habitat.
--Cominco stopped dumping wastes from it's mine into the south end of the lake, significantly reducing phosphate inflow into the south arm of Kootenay Lake.
--Fishing pressure has increased; and fishing regulations are not strictly enforced.

The KLF program only addresses one of these impacts to the resource, and that's what I object to the most: the fact that a single costly, and environmentally (in my humble opinion) unsound fertilization program is being touted as the *only* way to address the problem of depressed kokanee numbers.

The Okanagan Lake (west of Kootenay Lake in southern BC), kokanee population is also depressed, and the blame there has been placed primarily on *mysis relicta*. A workshop was held to discuss remedial strategies, and the consensus was that they would *not* fertilize the lake. Instead, they are going to try and reduce the mysis population--they're still trying to figure out how to do that.

I would like to know what the experts, the scientists, the fishers, the folks who know about fish biology and enhancement, think about the concept of fertilizing a lake the size of Kootenay Lake in order to increase fish production. Does large-lake fertilization really work? Does it produce results? Is it worth spending big money on an annual basis? What other methods or activities could be tried? What are the implications for the lake ecology--short-term and over the long run? Is whole-lake fertilization a sustainable practice? Is this being done on a comparable scale anywhere else? Who's paying for it? Why is it being done?

I'm also in a hurry for answers to these questions. The CBFWCP Steering Committee meets in early September, and we'll begin discussing the future of the fertilization program. Can you at least provide, in broad terms, the pros and cons of large-scale fertilization to mitigate the problems that face the Kootenay Lake ecosystem?

I can be reached at (604) 368-3059 during the evenings; my fax number is (604) 368-6491. I hope you can help!

Yours in Conservation,

G Conzon

Grace Conzon

Bob - thanks: this is a concise and informative answer to a tough question. As I said, CDOW (Pat M.) is in this boat regarding Dillon Reservoir.

Brett

Colorado State University

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July 23, 1996

Ms Grace Conzon
922 Nelson Ave.
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Canada

Dear Ms. Conzon:

The questions concerning fertilization of Kootenay Lake and the implications of the presence of Mysis, invoke a scenario of theories on how aquatic ecosystems function. These would be wonderful topics for my graduate student seminar in fisheries-limnology (LeRoy Poff once was a student in this seminar).

You, however, need a prediction with a practical cost:benefit answer. If a certain amount of money is invested to enrich the lake with phosphorous, will it result in significantly increased economic values from large increases in abundance of kokanee and the kamloops rainbow dependent on kokanee? I can only tell you that due to inherent unknowns and uncertainties, no one can make a precisely accurate prediction of the outcome. Only, to try it and see what happens.

I will enclose copies of abstracts from our 1994 seminars which pertain to the subject. Malenna Jorden reviewed the studies on enrichment of Canadian lakes. Overall, results were variable, but there is a strong trend for increases in salmonid fishes, particularly sockeye salmon (and kokanee), after phosphate enrichment. The fishery agencies, however, concluded that the cost:benefits were unfavorable; the increased value of the commercial catch was less than expenditures of the fertilization programs. Kootenay Lake, however, is a different situation. It's fishery is recreational and increased catch relates to increased recreational days that translates into much greater economic value associated with additional fish in the catch of anglers. Kootenay is also different in that Mysis can be a trump card, disrupting the energy flow pathways from phosphorous - phytoplankton - zooplankton - kokanee and large rainbow trout. This is a typical "bottom-up" scenario. Mysis can affect a "top-down" scenario to counteract the best intentions of a fertilization program. Phosphorous stimulates increased primary production (phytoplankton) which increases production of primary consumers (zooplankton--mainly Cladocera, especially Daphnia, the main food of kokanee). According to the bottom-up scenario, all would be going according to plan to this point.

With an abundant Mysis population, however, the most valuable forage zooplankton, the larger Daphnia, would likely go into Mysis instead of kokanee. The Mysis, unless spilled over into the shallow west arm of Kootenay in great numbers are not consumed to any extent by kokanee or trout because of their daily retreat to the bottom during the day. The "surplus" Mysis contribute to detritus when they die, few going directly into fish (unless co-evolved Mysis predators such as lake trout, lake whitefish, arctic charr, and burbot) occur in a lake.

Mysis control can be attempted by another "top-down" strategy--introduction of a Mysis predator. This, however, becomes an example of "managing with exotics--a game of chance" (title of famous paper). In Horsetooth Reservoir, Colorado, Mysis became established via a feeder canal. They virtually eliminated larger species of Daphnia (the basic food supply of the fishery). Smelt were introduced and in about four years, they eliminated Mysis (no Mysis found in the past three years). The smelt changed their diet from Mysis to zooplankton reducing the main forage organisms to very low levels. Walleye responded to the great abundance of smelt and produced the largest walleyes in the state. For the past five years, however, there has been no successful reproduction of walleye because the newly hatched young starve for lack of zooplankton. This is an example of the unknowns and uncertainties that make any predictions on the outcome of manipulation of aquatic ecosystems speculative. I cannot make an honest and correct prediction for the question: will fertilization of Kootenay Lake result in more benefits than costs? There are too many unknowns and uncertainties. Or in the terminology of statistical analysis, stochastic (random, unknown) events can overwhelm deterministic events, and the best laid plans of mice and men can go astray.

One question that comes to my mind is: if the Cominco Mine is still operating, can its phosphorous wastes be used to fertilize the lake for free, as occurred many years ago?

Sincerely,

Robert J. Behnke
Professor

RJB:dm

Nov. 7

Malenna M. Jordan
10/11/95
FW 692 AV Seminar - Fishery Biology

Grass Carp: An Effective Aquatic Weed Control Agent

Abstract: Experiments involving the addition of nutrients to lakes to increase primary productivity are based on two principles. First, phosphorous and nitrogen are colimiting nutrients in phytoplankton growth. Second, by adding phosphorous and nitrogen to a lake, phytoplankton biomass will increase. The application of these principles has been used in Canada to successfully enhance salmonid populations. The LeBrasseur et al. (1979) study of Great Central Lake, British Columbia demonstrates this point. Although salmonid production was positively enhanced, causing a lake to eutrophy could create serious side effects. Negative effects of eutrophication include algal blooms, excessive growth of rooted aquatic plants, fish kills, and alteration of phytoplankton and zooplankton communities. Eutrophication in Great Central Lake was prevented by the application procedure. No single nutrient when combined with the amount of nutrient already present in the lake was added to exceed winter nutrient levels. The fertilizer addition increased phytoplankton and zooplankton biomass without altering their community assemblages. Enrichment also enhanced sockeye salmon production. If eutrophication is not prevented a few mitigation options are available. These include a mechanical, chemical, water level manipulation, and/or biological method. Insects, fungi, snails, manatee, and carp are some organisms that have been used as biological control agents. Grass carp (<u>Ctenopharyngodon idella</u>) is the most widely used fish species for aquatic weed control because it is a voracious feeder on a wide variety of plants. Grass carp can tolerate a wide range of environmental conditions and are unlikely to breed naturally outside its native habitat. Successful aquatic weed management with grass carp is influenced by water depth, water temperature, grass carp density, predation, palatability of plant species, and size of the stocked fish. Stocked grass carp have not been found to significantly effect other fish populations, water quality, or phytoplankton. To ensure that grass carp won't effect existing fisheries, sterile grass carp are used. Grass carp can be sterilized by the removal of gonads, hybridization, gynogenesis and sex reversal, and induction of tetraploidy or triploidy. Grass carp are a highly effective biological weed control agents that do not negatively effect the environment they are introduced into.

Outline

Trophic organiz
Top down
bottom-up ?
→ structure

I. Eutrophication
- A. Define
- B. Negative effects of are:
  1. algal blooms
  2. excessive growth of rooted aquatic plants
  3. fish kills
  4. alteration of phytoplankton and zooplankton communities

5. impede movement of water
6. hinder navigation
7. interfere with hydroelectric generation
8. increase sedimentation by trapping silt particles
9. increase water loss by evapotranspiration
10. increase health hazards by creating habitats favorable to vectors of human diseases.

II. Mitigation
- A. mechanical
  1. Define
  2. Pros
  3. Cons
- B. chemical
  1. Define
  2. Pros
  3. cons
- C. water level manipulation
  1. Define
  2. Pros
  3. Cons
- D. biological

V. Utilization of Grass Carp for weed control
1. Factors which influence successful aquatic weed management with grass carp.
   - A. water depth
   - B. water temperature
   - C. grass carp density
   - D. predation
   - E. palatability of plant species
   - F. size of fish stocked

2. Effects of introducing grass carp
   - A. fish populations (Bailey 1978)
   - B. water quality (Lembi et al. 1978)
   - C. phytoplankton (Lembi et al. 1978)
   - D. reproduction
     1. sterilization techniques
        - A. surgical removal of gonads
        - B. hybridization (ex. between Grass Carp and Bighead Carp)
        - C. gynogenesis and sex reversal
        - D. induction of triploidy or tetraploidy

3. Effectiveness of grass carp in controlling aquatic weeds.

Selected References:

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Z692 FV: Application of Principles, Paradigms, and Methods for Aquatic Analysis

Limnology Graduate Seminar, Fall 1994

Lake Enrichment to Enhance Salmonid Production

Malenna M. Jordan

Abstract (in brief): The paradigm that phosphorous is a limiting nutrient in phytoplankton growth has been accepted universally. However there is still debate on the role of nitrogen in limiting phytoplankton growth. Elser et al. conducted a comprehensive literature review on lake enrichment experiments and discovered that phosphorous and nitrogen are colimiting phytoplankton growth in lakes. By increasing phytoplankton growth through phosphorous and nitrogen additions to Great Central Lake, British Columbia, Lebrasseur et al. successfully enhanced sockeye salmon (Oncorhynchus nerka) production.

Outline:

I. Nutrient Limitation

A. History
1. Liebig
2. Blackman

B. Causes of nutrient limitation
1. changes in the organisms responsible for nutrient recycling
2. salmon carcasses

C. Phosphorous limiting phytoplankton
1. agreement

D. Phosphorous and Nitrogen colimiting
1. study by Elser et. al.

Pyramid N limited

N:P 10:1

Skeena - Babine - steelhead

II. Great Central Lake

III. If time allows
1. Nozha hydrodrome
2. Sweden

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FACTORS INFLUENCING THE RELATIVE STRENGTH AND DIRECTIONALITY OF BOTTOM-UP AND TOP-DOWN FORCES IN AQUATIC ECOSYSTEMS

MIKE WISE

ABSTRACT: The concept of bottom-up (BU) and top-down (TU) forces as major elements driving ecosystem community structure and function has become a paradigm in recent ecological theory. As with any model, there are assumptions that must be considered when evaluating the model's robustness. Furthermore, factors which may confound interpretation of the influence of BU/TD forces in ecosystems must also be taken into account. Abiotic environmental factors such as water temperature and thermal stratification exert interactive effects on BU/TD forces. Disturbances can interfere with or truncate trophic cascades. Biotic interactions such as interference competition for food or for another resource such as territory or cover diverts energy that could have been spent foraging and thus weakens top-down forces. Predation avoidance behaviors by prey species, and reduction of prey abundance via the foraging of upper level consumers also weaken top-down forces. The trophic level of a system is another factor modulating the strength of BU/TD forces. Investigators and modelers must keep these interactive and confounding factors in mind when interpreting observations and experimental results. Multi-factor causation must be considered and alternative hypotheses developed before arriving at conclusions.

OUTLINE:

I ASSUMPTIONS

A) Equilibrium at all trophic levels

1) Lentic systems can generally be assumed to function in a state of dynamic equilibrium .
   - a) communities recovering from a disturbance will likely have different community structure than at "equilibrium". (Power 1992 quote)
   - b) be aware of occurrence of "regression artifacts"
   - c) pre- and post disturbance records should be taken (Power 1992 quote:Cornell and Sousa 1983)

3) Lotic systems are more likely to be strongly influenced by stochastic forces.

B) Importance of not assuming that observations are caused by what you have hypothesized. The "I wouldn't have seen it if I hadn't believed it " syndrome.

II FACTORS INFLUENCING THE STRENGTH OF BOTTOM-UP/TOP-DOWN FORCES

A) Trophy level of the system (McQueen et al.1986)

B) Factors that weaken TD forces (Power 1992)

1) Predator interference competition for food or for cover,territory

2) Predation avoidance behavior by prey species

3) Prey quality or availability may change with depletion

4) Time lags (Power 1992 quote)

C) Heterogeneity

1) Habitat heterogeneity (Power 1992 quote)

2) Variability in sizes of a predator cohort = larger range of prey species consumed = stronger top-down forces

a) Adams and DeAngelis (1987): less intraspecific competition in LMB cohorts of variable size. (more prey species consumed by the cohort collectively = stronger top-down forces)

D) Effects of water temperatures on strength and directionality of BU/TD forces

1) Temperature effects on trophic level biomass

a) winter-kill of shad (prey species):strengthens BU force: low abundance of shad has a stronger influence on bass biomass than bass would on shad biomass (Adams et al. 1982)

b) favorable temperatures for LMB spawning and early fry growth followed by an extended cool period delays shad spawning and give bass a size advantage over prey: increases strength of TD force (Adams and DeAngelis 1987)

c) water temperatures are an important factor in sockeye salmon growth and production in nursery lakes (Burgner 1987, Goodlad et al. 1974)

1) Downing and Plante (1993) found sockeye growth to be significantly correlated with mean annual air temperature: populations at MAA temps. of 20C were 3X as productive as those at 0C

2) Temperature effects on prey availability

a) by regulating growth rate of prey: window of size vulnerability;Utah chubs in Flaming Gorge were vulnerable to lake trout predation 3X longer than kokanee (Yule and Luecke 1993)

1) "...when [sockeye] density was high or temperature very cold, some proportion of the juveniles (rarely over 50%) held over [in the nursery lake] for another year" Rogers 1987).

b) by determining suitable thermal habitat: degree of overlap between predator and prey (behavioral thermoregulation)

3) Temperature effects on trophic level energy exchange

a) effects on consumer capture rate/handling time efficiency

1) perch capture rate increased and handling time decreased significantly with increasing temperature (Bergman 1987)

2) sockeye prey consumption is maximized at 17C but conversion efficiency is low(Brett 1971)(strengthens TD forces)

3) lake trout highest consumption, gross conversion efficiency, and growth occurs at 11C (Stewart et al. 1983)

b) Temperature effects on food to biomass conversion efficiency

1) sockeye convert best at 11.5C but don't consume as much (high conversion efficiency and simultaneous low consumption strengthens BU forces)

III CONCLUSION:
Investigators must be aware of a multitude of factors that can interact with BU/TD models in complex ways

A) Possibility of more than one cause for observed phenomena

1) winterkill of shad (prey) species could have been mistakenly interpreted as a top-down effect

2) Threlkeld (1987) and Drenner et al. (1986): enhanced phytoplankton production in the presence of high planktivore biomass may be due to increased nutrient regeneration rather than from a trophic cascade
   a) foraging planktivores
   b) nutrient release from dead, decomposing fish

(Threlkeld 1987 quote)

3) Hugh Smith Lake Alaska: lake fertilization increased PP and ZP production but there was no change in smolt production as had been observed in other lakes. Reason: sockeye smolts remained at the 7C isopleth throughout the year for some unknown reason.

B) Investigators must maintain a healthy state of doubt when looking for cascading effects

1) develop alternative hypotheses as was done by Threlkeld (1987) and Drennen et al. (1986)

Trophic cascade modeling is powerful tool that can be used to help explain ecosystem structure and function. Like all models, assumptions must be met and possible confounding factors considered in the analysis.

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ASSUMPTIONS;DISTURBANCE AND EQUILIBRIUM:
"As communities recover [from a disturbance] community structure and accrual of trophic level biomass may reflect historical accident, differential dispersal capabilities and population growth rates of early colonists" (Power 1992 page 738)

(or of residual species on an exponential rebound from near extirpation)

During a recovery phase there could be transient assemblages much different from those found at equilibrium

"Connell and Sousa (1983) propose that pre- and post disturbance records at least as long as the turnover time of the longest lived species in an assemblage are the minimum required to assume that a community perturbed from equilibrium has regained it" (Power 1992 page 738)

TIME LAGS:
"Discrepancies between demographic an behavioral time scales (Arditi and Ginzburg 1989, Hanski 1991), and the decoupling of food availability for one consumer life history stage from the survival or fecundity of another life history stage (Mittelbach et al.1988, Neill 1988) can reduce consumer efficiency in both tracking and suppressing prey populations" (Power 1992 page 736)

HETEROGENEITY:
"When patches of different productivity are smaller than home ranges of consumers, consumer behavior affects their instantaneous density" (Power 1992 page 740)

THRELKELD:
Enhancement of phytoplankton is proportional to fish biomass and not to zooplankton depression.

"Changes in nutrient loading associated with manipulation of planktivorous fish (nutrient regeneration, accidental fish mortality) may be fundamental to phytoplankton responses" (Threlkeld 1987 page 171)

Z692 FV : Application of Principles, Paradigms, and Methods for Aquatic Analysis

Limnology Graduate Seminar, Fall 1994

Application of the Guild Concept to Stream Systems

Sen-Her Shieh

ABSTRACT / Since Root (1967) developed the guild concept, there has been a steady rise in use of the concept in ecological literature. In streams, Cummins (1973) coined the term functional group to refer to guilds of aquatic insects. The term has been accepted as synonymous with guild.

The guild concept has been used in several ways. The use of guilds reduces the number of community components and variability, facilitating quantification of structural attributes and organizing processes, and generating predictive models. Investigating the importance of interspecific competition in communities also benefits from the guild concept, because guild members are the most likely potential competitors. In addition, the guild concept has been used in comparisons of community structures because of the relationship between guilds and functional roles performed within the community. Moreover, because guilds are based on patterns of resource use, the guild structure of a community or ecosystem may provide a qualitative index of the trophic structure or food web within the system. Finally, the guild concept has been used to assess the impact of human-induced perturbations on stream systems.

The guild concept presents a useful method for ecological analyses. However, validity and usefulness of the guild concept depend on the user's knowledge of the particular system under study; they are compromised to the extent that users are unware of implicit assumptions and limitations of the concept. Only with thorough knowledge of both its benefit and limitation is it possible to fully use the guild concept for understanding organizational processes in communities and ecosystems and for assessing environmental impacts.

Outline of Talk

A. Definition:

1. Guild: a group of species that exploit the same class of environmental resources in a similar way (Root 1967).

2. Functional group: a group of species that perform the same function or set of function within the ecosystem (MacMahon et al. 1981).

B. Methods of partitioning a community into guilds:

1. A priori classifications: assigning species to investigator-defined, resource-based guilds.

2. A posteriori descriptions: using quantitative methods including PCA, cluster analysis, canonical correlation, and so on.

C. Application of the guild concept:

1. Three advantages in the use of guilds:

a. Guild focuses on all sympatric species involved in a competitive interaction, regardless of their taxonomic relationship.

b. Guild concept represents clustering of species which overlap significantly in niche dimensions.

c. Guild concept may be useful in the comparative study of communities.

2. Application:

a. Guilds as arenas of interspecific competition.

b. Community and ecosystem analysis.
i) Guild composition of communities reflects the availability of resource types.
ii) Ecosystems contain many functionally redundant species all capable of performing the same ecosystem function.
iii) Guild structure may be more predictable and stable than either the abundance of individual species or species composition.
iv) Guild concept provides a conceptual birdge that might unify community and ecosystem approaches to ecology.

c. Guild concept as a mechanism for biological monitoring.
i) Physical and chemical monitoring
ii) Biological monitoring: indicator species, diversity indices, and biotic indices.

D. Conclusion:

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Application of the Index of Biotic Integrity to Segment 15 of the South Platte River.

John Hoppner

Abstract:

The Metro Wastewater Reclamation District is required to reduce the amount of ammonia is the effluent being discharged in the the South Platte River

Low D.O. concentrations in pools along the South Platte are thought to be a limiting factor to healthy fish populations.

Biological sampling and monitoring was started in 1986 to assess status and trends of the fish community. 8 sampling locations were selected based on similar habitat.

IBI results show improvements and stabilization in the fish community coinciding with improvements made to the effluent. However, some stations showed higher scores that other suggesting water quality may not be the limiting factor.

Outline:

- The South Platte
  - physical characteristics
  - History of degradation
- Metro Wastewater Reclamation District
  - Purpose
  - Biological Monitoring
- Index of Biotic Integrity
  - How it works
  - Application to Segment 15
- Discussion

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Environmental Gradients
and the distribution and abundance of organisms

Daniel J. Cappellini

Abstract: Environmental gradients place limitations on the distribution and abundance of organisms in ecosystems. Any given species has upper and lower limits of survival and reproduction relative to each abiotic factor in their environment. These limitations are best described by the Hutchinsonian n-dimensional hyperspace. By overlapping all the environmental gradients effecting a species we define an abstract n-dimensional hypervolume of ecosystem parameters. When we include respective survival and reproductive thresholds for each environmental gradient we define an abstract n-dimensional hyperspace of potential existence for the given species: its fundamental niche. When we include one or more other species we may have overlapping n-dimensional hyperspaces through shared resource needs. Because of this overlap, each individual species' hyperspace will not be entirely available and they will not be able to realize their full potential, hence, the realized niche. Within their respective hyperspace each species has an adaptive center which maintains ideal conditions surrounded by isopleths of conditions less and less favorable. This allows for a gradual replacement of species along environmental gradients rather than abrupt changes in species composition. Since the formulation of Hutchinson's concept, ecologists have been applying the concept to limnological research. The formalization of complex environmental gradients (gradients which integrate changes in several gradients, i.e. elevation, salinity, depth, latitude, turbidity, etc.) are usually required for realistic gradient analysis. However, with the advent of the computer, studies involving complex multivariate statistical analysis are now being used more often to investigate the distribution and abundance of organisms along environmental gradients.

I. The Hutchinsonian N-dimensional Hyperspace
   1. The Fundamental Niche
   2. The Realized Niche
   3. Hypothetical Example

II. Whittaker and Fairbanks (1958): copepods, salinity, oligotrophy, and impermanence (complex gradients) in the Columbia Basin, WA
   1. Species Populations vs Total Salts
      a. spp. in lakes
      b. spp. in lakes and ponds
      c. spp. in ponds
   2. Total Organisms vs Total Salts for Ponds and Lakes
   3. Plexus: Community types (6 groups) by measure of percent similarity
      a. three gradients
      b. characteristic copepod, mean total salt, mean standing crop

   4. Distributional Overlap

5. Plexus: Distribution by measure of percent co-occurrence
    a. three gradients
    b. center axis (salt folds back)
    c. solid to scale, dotted not
6. "demonstrates a complex pattern of distributional overlaps in which each spp. has its own, distinctive environmental relation."

III. Makarewicz and Likens (1975): Niche analysis of zooplankton (depth and season as complex gradients), Mirror Lake, NH

1. Population Response Surface
    a. depicts little niche overlap
    b. in E overlap but food size difference
2. Complex Gradient of Season
    a. gradual species replacement
3. "the limnetic zooplankton community of Mirror Lake can be conceived as a system of interacting populations whose adaptive centers have evolved toward dispersion in relation to the complex gradients of food size, depth, and time"

IV. Hart (1990): Zooplankton and the complex turbidity gradient, Lake le Roux, South Africa.

1. Sampling Sites
2. Environmental Gradients and the Gradient in Biota
3. Chemical Characteristics
    a. no change
4. Mean Values for a Sample Day
5. Distribution of Zooplankton Spp. and Percent Composition
6. Relationship to Marzolf's (1984) Hypothetical Variables
    a. diversion from model - cascading reservoirs

V. Anderson et.al. (1993): Diatoms surface samples, and environmental gradients, dilute northern New England lakes.

1. Study Area
2. Percent Abundance vs pH and Alkalinity
3. Spearman Rank-Order Correlation
    a. significant variables related to pH
4. Express concerns with overestimating importance of a variable because sample design excludes systems with other important variables not as powerfull in your examples.

VI. Dixit et.al. (1991): Diatom core samples, environmental gradients, and reconstructive modelling, Sudbury (Canada) dilute lakes.

1. Study Area
2. Canonical Correspondence Analysis Ordination
    a. longer arrows = stronger influence
    b. proximity to axis shows influence on axis
3. Accuracy of Regression (Ability of Statistics to reproduce Data)
4. Historical Reconstruction of pH Regime in Region

VII. Blinn (1993): Diatoms, environmental gradients, North American saline lakes.

1. H' Diversity vs Specific Conductance
2. Specific Conductance Indices and Ion Indices for Diatom Spp.
    a. strong relationship between anions from sea water
    b. dist and abund most robust in waters similar to sea water
3. Diatoms are more sensitive to pH from acid to neutral waters than in neutral to basic waters

VII. Conclusion

1. Hutchinson's concept is robust and makes for a valid paradigm in modern ecology and leaves the avenue of scientific method and approach open to the mind of the researcher.

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Relations of Fecundity, Maturation, and Body Size of Lake Trout, and Implications for Management in Northwestern Ontario Lakes

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Abstract.—The life history traits of lake trout *Salvelinus namaycush* in six lakes that vary in conductivity are described, and an adaptive management strategy that is based on differences in lake trout growth, fecundity, and maturity schedule is recommended. Lake trout in low-conductivity lakes exhibited slower somatic growth, matured at an older age, attained maturity at similar or smaller body sizes, and were less fecund than lake trout in high-conductivity lakes. To prevent overfishing of fecund components of lake trout populations, managers may need to restrict the harvest of females larger than 550 mm in fork length from low-conductivity lakes, whereas in high-conductivity lakes, regulations should limit removal of females that are 600 mm or larger in fork length. Extreme interpopulation differences in adult size structures support a change in management strategy, a change from a single regionwide regulation to lake-by-lake regulations that reflect lake conductivity and prey type base.

Lake trout *Salvelinus namaycush* is a coldwater, stenothermic teleost fish that is widely distributed across northern North America (Scott and Crossman 1973) and has an especially high concentration of populations in northwestern Ontario (Martin and Olver 1976). Lake conductivity, a close correlate of total dissolved solids, varies extensively across northwestern Ontario (Ryder 1964), correlates positively with invertebrate and fisheries production (Northcote and Larkin 1956; Johnson 1974; Donald et al. 1980), and is a function of watershed bedrock composition and surficial geology (Ryder 1964; Brousseau et al. 1985). Lake trout in high-conductivity lakes in this region tend to exhibit rapid somatic growth, partly because of the rich forage bases in these bodies of water (Trippel and Beamish 1989, in press). It is possible that egg production of lake trout is also elevated in these fertile, high-conductivity lakes, as somatic and gonadal growth are often positively correlated (Iles 1984; Trippel and Harvey 1989).

The further development of lake conductivity as a coarse predictor of lake trout maturation schedule and fecundity could assist fisheries managers in planning regulations to prevent anglers from severely reducing fecundities of many remote lake trout populations in northwestern Ontario for which only limited biological data are available. Assessment and conservation of population fecundity are particularly relevant to lake trout management because of the limited ability of this slow-growing, low-fecund species to rebuild populations by generating strong year-classes from relatively few spawners (Healey 1978a, 1978b; Johnson 1983; Matuszek et al. 1990).

The objective of this study was to assess lake trout abundance, growth rate, age and size at sexual maturity, egg weight, and fecundity (age-specific, size-specific, and relative population fecundity) in six northwestern Ontario lakes representing a range of conductivities that spans nearly an order of magnitude. Common prey organisms of lake trout, *Mysis relicta* and ciscoes *Coregonus artedii* (Trippel and Beamish 1987), were present in each lake. Lake trout management options are discussed on the basis of conserving population fecundity.

Methods

Fish were sampled from mid-June to late August of 1986 and 1987 in six northwestern Ontario lakes (Table 1). Experimental, multifilament nylon gill nets were used. Each net was 68 m long and 2 m high and was composed of nine 7.6-m panels (one panel of each of the following mesh sizes [stretched measure]: 25, 38, 51, 64, 76, 89, 102, 114 and 127 mm). Twenty net sets were made along the hypolimnetic bottom of each lake over a 2–4-week period, such that the combined effort for each lake totaled 400 h. Nets were set between 1500 and 2100 hours and were lifted between 1000

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A COMPARISON OF THE PALATABILITY OF HATCHERY-REARED AND WILD BROOK TROUT[1]

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ABSTRACT

Objective organoleptic tests scoring for aroma, flavor, texture, and moisture, were made for eight samples of wild brook trout (*Salvelinus fontinalis*) from two streams and for seven samples of hatchery-reared brook trout from two rearing stations. Samples were obtained during May, June, July, and August, were cooked separately by the same method, and identified by the judges by code number.

Average scores of six judges showed all samples acceptable but values for wild fish from both streams were significantly higher than for hatchery-reared trout. The color of the flesh and the overall appearance of the wild trout were also more attractive.

The possibility of improving the eating quality of hatchery trout through better nutrition was suggested.

INTRODUCTION

There has been considerable discussion of the relative palatability of wild trout *versus* those recently liberated from fish hatcheries. This discussion is of vital interest to those responsible for fish-management policies. The recent trend in Michigan toward planting legal-sized trout in streams shortly before and at intervals during the fishing season has resulted from studies of the survival of hatchery-reared fish stocked at various times of the year, (Hazzard and Shetter, 1939; Shetter, 1946). These studies indicate that the angler catches a greater percentage of the fish stocked when legal-sized fish are planted just prior to and during the fishing season. This trend, however, has intensified the controversy as to the comparative eating qualities of wild and hatchery-reared fish.

The present study was organized in an effort to evalute as objectively as possible the relative palatability of hatchery-reared and wild brook trout (*Salvelinus fontinalis*). It was organized and carried out jointly by the Institute for Fisheries Research, Michigan Depart-

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ment of Conservation and Michigan Agricultural Experiment Station and Departments of Food and Nutrition and Zoology, Michigan State College.[2]

Materials and Methods

Brook trout from four sources were used in the experiment. The wild trout were obtained from Hunt Creek and the East Branch of the Au Sable River in the northern part of the lower peninsula of Michigan. No brook trout had been planted in these streams for several months or longer and the fish were regarded as wild. The hatchery-reared brook trout were obtained from the Grayling State Fish Hatchery and the Harrietta State Fish Hatchery. All fish had the entrails and gills removed at the time they were killed. They were then wrapped in waxed paper, packed in cracked ice and shipped to the Zoology Department of Michigan State College, East Lansing. Shipments were by express and were in transit only 10 to 12 hours. All lots except one arrived in good condition with ample ice. The last shipment from the Harrietta Hatchery, which was delayed, arrived without ice and was discarded. The fish were forwarded by previous arrangement in order that the judges might be available and the workers ready to prepare them.

The samples were collected at intervals of about one month throughout the period of the open fishing season. Four samples were judged during the course of the summer of 1944 as follows: May 23, June 16, July 14, and August 17.

Upon arrival in East Lansing, the fish were cleaned, prepared for cooking, and wrapped in vegetable parchment for delivery to the home economics food laboratory. The cooking was done by one person except for the trial on August 17. The preparation consisted of washing and drying the fish, then salting them lightly inside and out.

The brook trout were cooked over a low flame in heavy iron skillets containing 1½ to 2 tablespoonfuls of melted hydrogenated vegetable fat. They were cooked until brown on one side, then turned and cooked until brown on the other. The fish from each source were fried separately. Special attention was given to the selection of trout of a uniform size. The cooked fish were served to a panel of judges who had been chosen and assembled for the purpose of scoring them. Each judge was provided with score sheets on which were listed four factors: aroma, flavor, texture, and moisture. Each factor was followed by seven columns headed by adjectives describing the factor in descending order from very desirable to very undesirable. The columns were numbered one to seven, one being the lowest possible score and seven being the highest. This sheet was modified from the

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[2]Fish were captured, dressed, and shipped by members of the Conservation Department. The fish were prepared for cooking and the panel of judges notified and assembled by P. I. Tack of the Zoology Section of Michigan Experiment Station. The fish were prepared, cooked and served and the scoring supervised by Miss Helen A. Baeder of the Food and Nutrition Department of the Michigan Experiment Station.

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Characterizing Piscivory from Ingested Remains

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Abstract.—A series of linear regressions was generated to estimate live length from partially digested ciscoes *Coregonus artedii,* yellow perch *Perca flavescens,* and slimy sculpins *Cottus cognatus* recovered from formaldehyde-preserved stomachs of lake trout *Salvelinus namaycush.* Back calculation of original size of prey involved four body dimensions (total length, fork length, standard length, and tip of snout to posterior margin of last vertebra) and lengths of four skeletal parts (axial skeleton, two vertebrae, and the first hypural). Sample size and forage size range were increased through use of the full array of regressions over those from a single measurement. This technique should be considered for ecological studies that require detailed diet analyses to examine trophic dynamics, growth, energetics, or production.

Size-selective predation by top-level piscivores is an important mechanism in determining structure of aquatic ecosystems (Eck and Brown 1985; Tonn and Paszkowski 1986). Furthermore, fish growth rates are directly associated with size of prey (Martin 1966, 1970; Paloheimo and Dickie 1966; Kerr 1971). However, provision of a quantitative dietary profile for ecological studies is complicated due to the partially digested state of many ingested organisms.

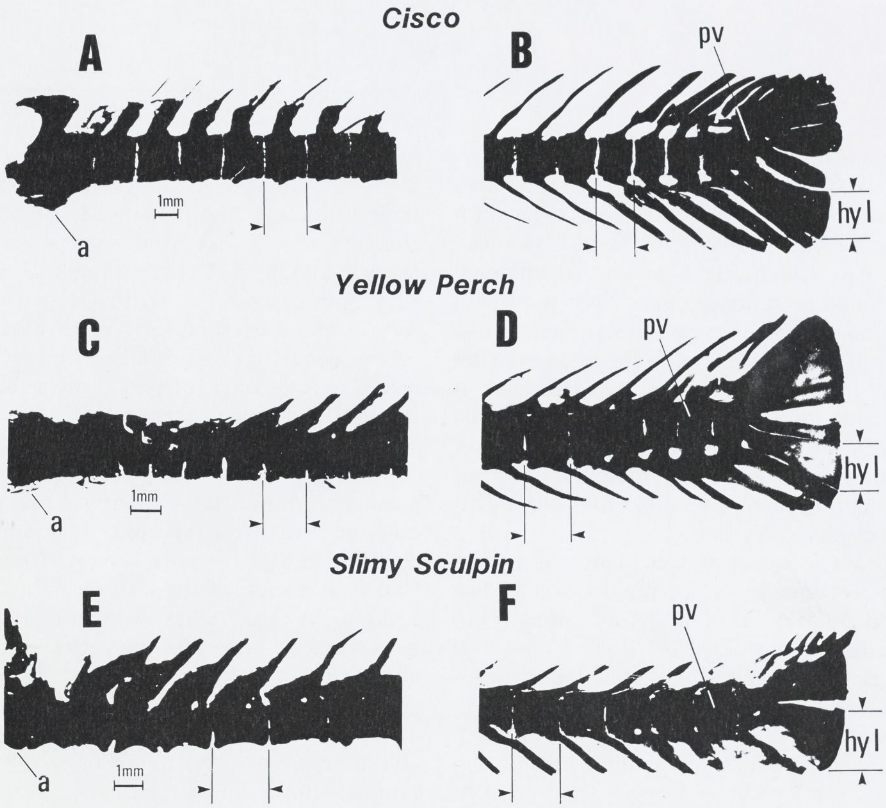

FIGURE 1.—Axial skeletal sections of three forage species from Burnt Island Lake. a = atlas; pv = posterior vertebra; hyI = hypural I. Length of fifth vertebra is indicated by arrows in A, C, and E. Lengths of the fifth-last vertebra of the axial skeleton and of the posterior margin of hypural I are indicated by arrows in B, D, and F.

TABLE 1.—Simple linear regression equations ($Y = \beta_0 + \beta_1 X_1$) between fresh fork length (Y) and length of several morphometric characteristics (X_1) of ciscoes, yellow perch, and slimy sculpins from two Ontario lakes (Y represents fresh total length for slimy sculpins). N = 50 for cisco and yellow perch and 25 for slimy sculpin. All relationships were significant at P = 0.0001; CI = confidence interval.

Predictor variable (X_1)	Slope (β_1) ±95% CI	Intercept (β_0) ±95% CI	r^2	F-value
Cisco				
Fork length (preserved)	1.015±0.018	−1.421±3.090	0.998	5,786.9
Standard length	1.096±0.036	−0.182±5.866	0.990	2,284.5
Snout to posterior margin of last vertebra	1.117±0.038	−0.334±5.958	0.990	2,218.0
Axial skeleton	1.243±0.056	11.227±7.650	0.981	1,183.1
Fifth vertebra	62.044±7.496	46.810±15.988	0.886	175.2
Fifth-last vertebra	79.029±12.348	42.186±21.298	0.826	106.9
Hypural I (posterior edge)	52.143±6.742	50.058±16.700	0.871	151.2
Yellow perch				
Fork length (preserved)	1.061±0.028	−4.916±2.990	0.998	11,807.3
Standard length	1.153±0.020	−1.053±0.488	0.997	6,924.7
Snout to posterior margin of last vertebra	1.172±0.022	−0.236±1.836	0.997	6,464.5
Axial skeleton	1.542±0.050	−2.764±3.240	0.989	2,178.4
Fifth vertebra	57.665±4.426	10.929±6.798	0.941	376.7
Fifth-last vertebra	67.068±4.850	−0.017±7.152	0.948	424.1
Hypural I (posterior edge)	57.449±5.864	19.491±8.200	0.901	214.0
Slimy sculpin				
Total length (preserved)	1.019±0.035	−0.699±3.362	0.995	3,501.3
Standard length	1.123±0.064	5.785±4.568	0.983	1,309.3
Snout to posterior margin of last vertebra	1.166±0.070	5.775±4.874	0.980	1,150.3
Axial skeleton	1.288±0.085	18.294±4.440	0.978	1,000.5
Fifth vertebra	45.926±10.039	16.861±15.152	0.795	89.1
Fifth-last vertebra	48.719±7.065	19.985±9.934	0.898	202.6
Hypural I (posterior edge)	23.494±4.345	36.791±9.589	0.844	124.6

Prediction of the original size of ingested organisms is commonly performed by back calculation with regression equations that relate fish length to the size of specific undigested stomach remains (e.g., Knight et al. 1984). To this end, otoliths found in stomachs have been used with considerable success for marine mammalian piscivores whose stomachs have been frozen after capture (Jobling and Breiby 1986). However, if stomach contents are preserved in a formaldehyde solution, as is often done during field operations, dissolution of otoliths occurs (McMahon and Tash 1979) rendering them unreliable for back calculation to original prey size.

The purpose of our study was to provide a series of regression equations that predict size of fish consumed by lake trout *Salvelinus namaycush* from the dimensions of various body and skeletal parts of prey recovered from the predators' formaldehyde-preserved stomachs. Prey species examined were cisco *Coregonus artedii,* yellow perch *Perca flavescens,* and slimy sculpin *Cottus cognatus.*

Methods

Lake trout, ciscoes, yellow perch, and slimy sculpins were captured from Loch Erne (48°37′N, 90°21′W) and Burnt Island Lake (48°47′N, 90°51′W), Ontario, in gill nets and wire minnow traps from July 5 to August 28, 1986. Stomach contents of each lake trout were preserved separately in a 4% formaldehyde solution. Total lengths TL (±1 mm), and fork lengths FL (±1 mm) were recorded for fresh samples (N = 25) of ciscoes and yellow perch from each lake. Similar measurements were recorded for 25 slimy sculpins from Burnt Island Lake, except fork lengths were not measured because this species has a rounded caudal fin. All fish were then preserved in a 4% formaldehyde solution for 4 months, after which the measurements were repeated. At this time, standard length SL (±1 mm), distance from snout to posterior margin of the last vertebra (±1 mm), and lengths of the axial skeleton (±1 mm), fifth vertebra (±0.1 mm), fifth-last vertebra (±0.1 mm), and posterior margin of hypural I (±0.1 mm) were also measured (Figure 1). A dissecting scope with an ocular micrometer was used to measure skeletal dimensions to 0.1 mm. For each population sample, simple linear regression equations were calculated (SAS 1985, subroutine REG) between fork or total length of fresh specimens and size of the aforementioned body and skeletal parts. Analysis of covariance (ANCOVA; SAS 1985, subrou-