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THE ROLE OF RESEARCH IN MINNESOTA FISHERIES MANAGEMENT: AN UPDATE

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Abstract.--Fisheries research plays several important roles in the management of the fisheries resource in Minnesota. These roles include the development of sampling tools and management techniques, the evaluation of management programs and practices, the promotion of scientific fisheries management, and the prediction of and preparation for future problems. The Investigational Report Series, initiated in 1938, details the past contributions from fisheries research in Minnesota. To date, 407 reports have been published in 11 major categories which include most Minnesota fisheries management activities. Creel surveys have had the most extensive reporting followed by resource assessment, procedure and technique development, walleye propagation, walleye stocking, walleye management and associated species, lake rehabilitation, salmonid propagation, salmonid stocking, winter rescue of northern pike, and investigation of pollution related problems. The role of fisheries research in developing current management techniques is discussed.

Introduction

Research is a fundamentally important tool in the management of fisheries resources. Careful and innovative research can improve the efficiency and success of fisheries management. The changing expectations, needs and values of the angling public in combination with increasing numbers of anglers equipped with better fishing skills and technology have made fisheries management more complex than ever before. Fisheries research can measure these changes and allow for the redirection of management efforts to meet the changing demand. Traditional fisheries management programs and practices need to be continually evaluated within the context of these changes. New management techniques and programs must be developed when traditional methods are no longer effective. Fisheries research can develop and refine many of these new techniques and programs. With some foresight, fisheries research can address anticipated problems before controversial, no-win situations arise. Fisheries research can also play an important role in protecting the aquatic environment by identifying ecologically detrimental factors and influences. This report discusses the role and contributions of the Minnesota Department of Natural Resources Section of Fisheries Research Unit to the management of fisheries in the state.

Significant fisheries research has already been accomplished by the Fisheries Research

Unit. This contribution can be detailed within the Fisheries Investigational Report Series, initiated in 1938 (Table 1). Davis (1985a) divided the subject matter of the reports into 11 categories covering basic Minnesota fisheries management activities. Some titles were included in more than one category when equal emphasis was placed on more than one subject area. This report is an update of Davis' 1985 Investigational Report on the role of fisheries research in Minnesota fisheries management. Much of the text remains the same. Additional information obtained from fisheries research studies completed since the publication of Davis (1985a) has been added.

Results

The Fisheries Research Unit has investigated many areas of concern to fisheries managers since the 1930's. To date, 407 Investigational Reports have been published. Table 1 illustrates the frequency distribution of types of studies addressed by Investigational Reports from 1938 through 1991.

The most frequent activity of Investigational Reports was the creel survey, including the studies which led to the development of current creel survey techniques (Table 1). These methods have been refined and expanded into one of fisheries management's primary tools and provide the manager essential information about his clientele and their effects on the resource. The quantitative creel survey of sport fisheries was begun in 1951 to measure angling pressure and harvest on representative lakes. Moyle and Franklin (1955) described the methods used and results obtained for the early years of creel surveys, and Schupp (1964) adapted those methods to large lake fisheries. A recent example of the importance of creel surveys is Thorn's (1984) documentation of the lack of adverse effects of the controversial continuous season on Mississippi River walleye and sauger populations. Another example is the creel survey program on Lake of the Woods (Payer et al. 1987) that has provided information on the recreational fishery effects of eliminating a commercial fishery. Creel survey techniques are now routinely used by fisheries managers.

The second most extensively examined category was assessment of the resource. This includes lake survey and population assessment work that provided basic information on the status of a species or fish community. This information enabled managers to inventory aquatic resources and provided them with a scientific basis for management. Through the early 1950's, lake surveys were developed and conducted almost exclusively by research personnel, and the first lake survey guide was developed by Fisheries Research. Examples of Investigational Reports of this type include Johnson (1968), Johnson and Johnson (1971), and Schupp (1972). Comprehensive descriptions of the status and dynamics of some of Minnesota's major naturally reproducing walleye populations, plus recommendations concerning potential future management strategies were presented. Strand's (1984) report identified spawning areas and seasonal movements of Leech Lake muskellunge, and allowed for the collection of muskellunge eggs of the strain that now provides the foundation of Minnesota's muskellunge rearing program. In another important report, Olson and Cunningham (1990) presented evidence of a significant decline in the production of trophy fish in northwestern Minnesota, and attributed the decline to increased fishing pressure.

Another category receiving substantial attention from the Research Unit has been the development of procedures and techniques used to collect and analyze basic population data. This includes field and statistical comparisons of net types and materials (Scidmore 1955a; Scidmore and Scheftel 1957; Bonde 1965; Davis and Schupp 1987), and the development of specialized sampling methods such as pulsed direct current electrofishing gear (Newburg 1973), shoreline seining for young of the year largemouth bass (Newburg and Schupp 1986), a stomach pump for sampling the food of live fish (Seaburg 1957), fluorescent

Table 1. Minnesota Department of Natural Resources, Section of Fisheries Investigational Reports tabulated by 11 major categories (updated from Davis (1985a)). Some reports were included in more than one category.

Category	Number of reports
Creel census	92
Survey and assessment	58
Sampling methods	41
Walleye propagation	18
Walleye stocking	9
Walleye management and associated species	15
Lake rehabilitation	14
Salmonid propagation	13
Salmonid stocking and management	23
Winter rescue	11
Pollution investigation, aquatic nuisance control, parasites and diseases	30

pigment marking techniques (Bandow 1988; Negus et al. 1990), and oxytetracycline marking of walleye fry (Younk and Cook 1991). Considerable research effort has also been devoted to the development of procedures for determining fish age and growth. Pioneering work was done in this area by Carlander (1939, 1944), Eddy and Carlander (1940, 1941), and Franklin (1951). More recent work has reexamined and refined some of these assumptions and techniques (Olson 1980).

The walleye is Minnesota's number one fish in terms of angler preference (Leitch and Baltezore 1987) and management effort. Considerable research effort has been devoted to its propagation. Eighteen Investigational Reports dealt with conditions in and operations of walleye rearing ponds, especially with work done by John Dobie in the 1940's and 1950's. This research has benefitted not only Minnesota's walleye rearing program, but many other state, federal and private walleye aquaculture programs. Research effort in recent years has refined hatchery techniques to increase egg fertilization rates (Olson 1971), and more effectively coordinate walleye fry emergence with available natural food (Olson 1974). Olson (1981) developed a new technique of hatching fish eggs in a moist air or low water environment with a compact portable incubator. These incubators perform the same function as large, energy-consuming hatching batteries requiring more than 100 times as much water. Eiler (in press) investigated factors that affect sex ratios of walleye fingerlings raised in rearing ponds.

Other aspects of walleye management have also been examined and refined by the Research Unit. Walleye fry and fingerling stockings were originally based on the premise that more is better. Research investigations in the late 1950's, early 1960's, and 1970's examined walleye fingerling stocking and evaluated survival in subsequent years (Maloney 1956; Johnson 1957; Groebner 1959; Olson and Wesloh 1962; Johnson 1971). These studies led to the development of specific stocking guidelines to fit different management situations and objectives. Other studies have gathered considerable life history data on the walleye and its relationships with other species (Maloney and John-

son 1956; Wesloh and Olson 1962; Dobie 1966; Johnson 1975).

More recent studies have focused on the dynamics of walleye populations and fisheries. Osborn and Schupp (1985) illustrated how increased fishing pressure on Lake Winnibigoshish has caused the average size of walleye in the angler's catch to decline. Payer et al. (1987a) reviewed the status of the Lake of the Woods walleye fishery and developed a simulation model of the population. The important question of hooking mortality of walleye was addressed by Payer et al. (1987b). They found that hooking mortality rates of walleye may be low enough to allow for further experimentation with size limit regulations, and voluntary catch and release programs. The success of live-release walleye tournaments has also been evaluated (Goeman, in press).

Research at the fish community level has increased in recent years. Goeman et al. (1990) investigated the response of some fish communities to yellow perch and walleye stocking. Schupp (in press) examined lake surveys from across the entire state, and classified lakes based on limnological characteristics. This new lake classification system will provide managers with a powerful tool in analyzing future lake survey results, and in developing management plans. This system will also provide the cornerstone for future management at the fish community level.

Another important management activity refined by Fisheries Research is lake rehabilitation. Investigations of chemical reclamation methods for warmwater and coldwater species began in the 1940's (Dobie and Moyle 1945; Appleget 1949). In the 1950's and 1960's, basic principles were developed regarding water chemistry parameters, target species, and concentrations necessary for eradication (Johnson 1954; Scidmore 1955b; Johnson 1959; Johnson and Micklus 1965). Studies in the 1970's examined the effects of lake reclamations on the entire lake ecosystem (Bandow 1980), and the selective use of toxicants to achieve partial eradication of some species while leaving others unharmed (Davis 1979). The distribution of toxicants under the ice using winter lake aeration equipment was investigated by Bandow (1989). Lake reclamation is now an accepted management tool.

Field managers and hatchery personnel in Minnesota have benefitted considerably from research on trout and other salmonids. Thirteen Investigational Reports have dealt with hatchery techniques and procedures, concentrating primarily on diet and treatment of disease (Schumacher 1950, 1953, 1957, Economon 1962, Thorn 1974; and others). Other studies have examined techniques for enhancing reproduction (Anderson 1983) and developing new hatchery strains (Scidmore 1966; Anderson and Woods 1979).

Twenty-six Investigational Reports have evaluated trout and salmonid stocks in lakes and streams, including forage and predator species introductions. Conclusions and recommendations from many of these reports have been incorporated into *The Management of Lakes for Stream Trout and Salmon* (Johnson 1978), which has become the definitive manual for managing lakes for salmonids. Research on salmonid management in inland lakes continued with a strain evaluation of rainbow trout (Close et al. 1985). Lake trout in inland lakes have become the focus of more recent research with a strain evaluation conducted by Siesennop (in press). Scientific management of Lake Superior has only recently become a high priority. Early research included endemic and exotic species interactions. Contemporary research has provided the necessary evaluation of exotic salmonid introductions (Hassinger 1974; Close and Hassinger 1981; Close et al. 1984). Studies have continued assessing the juvenile life stage dynamics prior to smoltification to Lake Superior (Close et al. 1989). Considerable research effort has been made towards understanding stream habitat needs and improvements (Hale and Jarvenpa 1950; Hale 1966; Hale 1967; Hale 1969; Thorn 1988a, 1988b), and special regulations and angling

quality in southeastern Minnesota trout streams (Thorn 1990; Wiechman 1990).

The rescue of northern pike from potential winterkill situations was an extensive management practice in Minnesota. Hundreds of thousands of pounds of northern pike were removed and stocked into other lakes with adequate conditions for overwinter survival. Early research contributed significantly to the development of this activity. Scidmore (1964) and Groebner (1964) described the potential uses and contributions of rescued fingerling and yearling northern pike, and Johnson and Moyle (1969) summarized the procedures. Maloney and Schupp (1977) proposed guidelines and recommendations for its use. Recent research has suggested that this technique may actually be detrimental for some lakes. Anderson and Schupp (1986) measured a dramatic decline in the yellow perch population in Horseshoe Lake after the stocking of northern pike. The collapse of the perch population had major detrimental consequences for the fish community in the lake such as a large increase in the population of small bluegill and a significant decline in walleye abundance. The winter northern pike rescue program has been greatly reduced because of these findings. The most recent research has investigated reversing these negative effects by removing small northern pike from bass-panfish lakes (Goeman and Spencer, in press).

Investigations of pollution problems have been conducted by the Fisheries Research Unit since the 1940's, when a study examined the physical and chemical properties of taconite tailings and their effects on Lake Superior fish (Moyle 1947). Other studies have dealt with environmental manipulation and management of enriched lakes. The increasing environmental awareness of the 1970's fostered the water quality and mercury monitoring programs which eventually were placed under the responsibility of the Ecological Services Section. Recent concern with acid precipitation has inspired a cooperative venture with the Minnesota Pollution Control Agency to monitor a representative sample of lakes that are potentially vulnerable to acidification.

There have been several other important research efforts that are not covered by the above categories. Davis (1985b) described the use of flathead catfish as a predator for controlling overabundant panfish and bullhead populations. Cross et al. (in press) investigated the effects of macrophyte removal on bluegill and largemouth bass populations. Bandow (1986) evaluated the effectiveness and cost of several winter lake aeration techniques which is now an important part of fisheries management in southern Minnesota. Cross et al. (1991) described how channel catfish can be used to create a fishery in an urbanized area. Pierce and Tomcko (1989) provided some of the first data on the physical, chemical and biological characteristics of mine pit lakes in northeastern Minnesota. Aadland et al. (1991) collected stream fish habitat use information that will be important in developing guidelines for stream flow management and regulation. Cunningham and Anderson (in press) analyzed the results of a statewide angler survey which measured the attitudes, beliefs, motivations, preferences and knowledge of Minnesota anglers. Also, an economic survey of anglers is being completed that will measure, not only the economic impact of fishing in Minnesota, but will also develop a model that measures the economic ramifications of changes in specific fisheries management programs.

Discussion

The Fisheries Research Unit has contributed significantly to the progress of fisheries management in Minnesota. While a number of other organizations conduct basic fisheries research, such as universities and several federal agencies, the focus of the Section of Fisheries Research unit is applied research. As illustrated by the Investigational Report series, the Research Unit conducts research for the direct benefit of fisheries management. Fisheries management is becoming increasingly capable of solving many prob-

lems by conducting small, well designed studies. The research unit fills the role of conducting the larger, more complex studies that fisheries management does not have the time, manpower, or expertise to do. Fisheries managers periodically identify research project needs and ideas. Research projects are then developed and designed to answer the fisheries manager's specific questions. The applied approach of fisheries research directly compliments the efforts of fisheries management.

The Fisheries Research Unit has developed many of the methods now used by fisheries managers to sample fish populations and survey anglers. The unit has also developed and refined management tools such as fish propagation, stocking methods, strain evaluations, habitat improvement, special regulations, and lake rehabilitation techniques. The development of these tools has allowed the Section of Fisheries to broaden the scope, efficiency, and effectiveness of its fisheries management program.

Another important role of fisheries research is to evaluate current fisheries management programs and practices. This evaluation consists of measuring the efficiency and cost effectiveness of the program or practice. There are many instances where fisheries research has improved the efficiency or cost effectiveness of management programs. For example, one activity that consumed considerable management funding and effort was the removal of roughfish by state-employed crews. Scidmore and Woods (1961) examined the effects of roughfish removal on four southern Minnesota lakes and concluded there was no particular benefit to game fish. These findings have helped fisheries management divert their manpower and resources into more productive endeavors, and to transfer the harvesting of carp and bullhead to commercial operators.

Another important role of research is to promote the scientific management of the fisheries resource. For many years, fish populations were managed with little or no life history information. Little was known of the basic biological requirements of popular fish species. Stocking was based more on availability of the fish than on actual need as determined by assessment or management plan. Numerous species were often stocked with no concern for the lake's suitability for a particular species or its compatibility with other species already present. An example was the stocking of chinook salmon into Lake Minniebelle in Meeker County, prior to 1942 (Hutchinson Area Fisheries files). Many stockings of largemouth bass fingerlings were made into lakes that already supported abundant, self-sustaining bass populations. Now, the Section of Fisheries develops detailed management plans for each managed body of water. These scientifically based plans contain specific goals and objectives, recommended management procedures, and a schedule for the evaluation of the progress and success of the plans.

Related to the promotion of scientific fisheries management is the ability of the Research Unit to provide technical expertise to fisheries managers. Many of the biologists in the Research Unit have expertise in mathematics, statistics, computers, population dynamics, limnology, chemistry, and technical writing. Biologists can assist fisheries managers with the design of creel surveys and sampling programs, computer software and hardware, laboratory techniques, editing of reports, and a host of other special procedures that managers do not normally use on a daily basis.

The final role of fisheries research to be discussed is the use of fisheries research to foresee and predict future problems. Fisheries management is becoming progressively difficult as pressures on the resource increase. These pressures include increasing numbers of anglers, improvements in fishing technology and knowledge, declining habitat quality, and an increasing diversity of angler motivations and needs. The recent research efforts in the socio-economic dimensions of fisheries management are important for meeting this demand from the increasingly diverse angling public. Fisheries research can play a role in anticipating problems related to the increasing demand, and sug-

gesting solutions and alternatives for these problems before they become major crises.

The Research Unit is currently conducting over 20 different studies. These studies include warmwater research on special regulations, population dynamics, walleye stocking, aquatic vegetation removal, and research on warmwater streams including river muskellunge populations. Panfish research is taking a higher priority with projects on developing better crappie assessment techniques, investigating the role of largemouth bass in affecting the size structure of bluegill, and studying how bluegill reproductive behavior plays a role in shaping bluegill populations. Coldwater research includes continued studies on the relationship between habitat and trout (including large trout) in southeastern Minnesota, lake trout-smallmouth bass relationships, effects of stocking size of rainbow trout, bioenergetics of salmonids in Lake Superior, and a study of the survival of steelhead parr in North Shore streams.

Future research efforts will shift from species-centered projects to community-based approaches. Nearly all management efforts directed at individual species have community-wide consequences. A greater understanding of these community effects is required to adequately assess management techniques such as stocking, fish removal, special regulations, and habitat management. Ultimately, lakes and streams will be managed using a community-based ecosystem approach rather than a single species approach. Research will continue to play an important role in the management of Minnesota's fisheries.

References

Aadland, L.P., C.M. Cook, M.T. Negus, H.G. Drewes, and C.S. Anderson. 1991. Microhabitat preferences of selected stream fishes and a community-oriented approach to instream flow assessments. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 406, St. Paul.

Anderson, D.W. 1983. Factors affecting brown trout reproduction in southeastern Minnesota streams. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 376, St. Paul.

Anderson, D.W., and D.H. Schupp. 1986. Fish community responses to northern pike stocking in Horseshoe Lake, Minnesota. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 387, St. Paul.

Anderson, D.W., and D. Woods. 1979. Evaluation of intensive inbreeding for selection of trout broodstock. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 364, St. Paul.

Appleget, J.G. 1949. Elimination of a roughfish population from Surprise Lake, Itasca Co., Minnesota, and an estimate of the total population. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 89, St. Paul.

Bandow, F. 1980. Effects of winterkill and chemical eradication of fish on a lake ecosystem. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 369, St. Paul.

Bandow, F. 1986. Evaluation of winter lake aeration techniques in Minnesota. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 386, St. Paul.

Bandow, F. 1988. Fluorescent pigment marking of seven Minnesota fish species. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 393, St. Paul.

Bandow, F. 1989. Under-ice distribution of rotenone with lake aeration equipment. Minnesota Department of Natural Re-

sources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 397, St. Paul.

Bonde, T.J.H. 1965. Comparison of two types of gillnets used for lake survey purposes in Minnesota-Ontario boundary waters. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 285, St. Paul.

Carlander, K.D. 1939. Coefficients for converting total lengths of fish to standard lengths and vice versa. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 12, St. Paul.

Carlander, K.D. 1944. Relationship be tween scale radius and body-length of walleye pike, *Stizostedion vitreum* (Mitchell). Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 15, St. Paul.

Close, T., D. Belford, S. Colvin, and C. Anderson. 1989. The role of low flow habitat and interspecific competition in limiting anadromous parr abundance in north shore streams. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 398, St. Paul.

Close, T., and R. Hassinger. 1981. Evaluation of Madison, Donaldson and Kamloops strains of rainbow trout *(Salmo gairdneri)* in Lake Superior, Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 372, St. Paul.

Close, T., S. Colvin, and R. Hassinger. 1984. Chinook salmon in the Minnesota sport fishery of Lake Superior. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 380, St. Paul.

Close, T., S. Colvin, and R. Hassinger. 1985. Kamloops, Madison and Donaldson Strains of Rainbow Trout in an Oligotrophic Lake. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 385, St. Paul.

Cross, T., M. McInerny, and R. Davis. (in press). Macrophyte removal to enhance bluegill, largemouth bass and northern pike populations. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report, St. Paul.

Cross, T., T. Polomis, and R. Davis. 1991. Use of channel catfish to create an urban fishery in Lion's Lake, Mankato, Minnesota. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 407.

Cunningham, P.C., and C.S. Anderson. (in press). Angler opinions on fishing motivation, fish management, and agency policy: Comparisons of resident anglers, nonresident anglers, fishing club members and fishery professionals. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report, St. Paul.

Davis, R.A. 1979. The use of antimycin to reduce stunted sunfish populations in hardwater lakes. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 363, St. Paul.

Davis, R.A. 1985a. The role of research in Minnesota fisheries management. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 383, St. Paul.

Davis, R.A. 1985b. Evaluation of flathead catfish as a predator in a Minnesota lake. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 384, St. Paul.

Davis, R.A., and D.H. Schupp. 1987. Comparisons of catches by standard lake survey nets with catches by modified nets. Minnesota Department of Natural

Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 391, St. Paul.

Dobie, J. 1966. Food and feeding habits of the walleye, *Stizostedion v. vitreum*, and associated game and forage fishes in Lake Vermillion, Minnesota, with special reference to the tullibee, *Coregonus (Leucicthys) artedi*. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 293, St. Paul.

Dobie, J., and J.B. Moyle. 1945. Report on the effects of cube root (rotenone) on fish and fish food organisms of Dew Lake (16-414), St. Louis County. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 64, St. Paul.

Economon, P.P. 1962. Experimental treatment of infectious pancreatic necrosis of brook trout with polyvinlpyrrolidone-iodine. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 251, St. Paul.

Eddy, S., and K.D. Carlander. 1940. The problem of annual increments in fish growth studies. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 13, St. Paul.

Eddy, S., and K.D. Carlander. 1941. Growth rate studies of Minnesota fishes. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 28, St. Paul.

Eiler, P. (in press). Sex ratios of young-of-the-year walleye from rearing ponds and lakes in Minnesota. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report, St. Paul.

Franklin, D.R. 1951. Notes on the use of median growth indices for comparisons of fish growth. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 117, St. Paul.

Goeman, T.J. (in press). Live release wall eye tournaments. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report, St. Paul.

Goeman, T.J., D. Anderson, and D.H. Schupp. 1990. Fish community responses to manipulation of yellow perch and walleye abundance. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 404, St. Paul.

Goeman, T.J., and P. Spencer. (in press). Fish community responses to manipulating northern pike and yellow perch densities in a Minnesota centrarchid lake. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report, St. Paul.

Groebner, J.F. 1959. A three-year creel census of Lake Mazaska, Rice County, with evaluation of the harvest of stocked year-classes of walleye. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 212, St. Paul.

Groebner, J.F. 1964. Contributions to fishing harvest from known numbers of northern pike fingerlings. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 280, St. Paul.

Hale, J.G. 1966. The influence of beaver on trout streams with special reference to streams of the Minnesota North Shore of Lake Superior. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 244, St. Paul.

Hale, J.G. 1967. The effects of habitat alterations of trout streams with special reference to streams of Minnesota's North Shore of Lake Superior. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of

Fisheries, Investigational Report 296A, St. Paul.

Hale, J.G. 1969. An evaluation of trout stream habitat improvement in a North Shore tributary of Lake Superior. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 296B, St. Paul.

Hale, J.G., and O. Jarvenpa. 1950. Beaver-trout relations of the North Shore of Lake Superior watershed. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 143, St. Paul.

Hassinger, R.L. 1974. Evaluation of coho salmon *(Oncorhyncus kisutch)* as a sport fish in Minnesota. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 328, St. Paul.

Hassinger, R.L., and T.L. Close. 1984. Interaction of lake trout and rainbow smelt in two northeastern Minnesota lakes. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 379, St. Paul.

Johnson, F.H. 1954. Rainbow trout mortality and carrying capacity of a rehabilitated trout lake in Minnesota. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 152, St. Paul.

Johnson, F.H. 1957. Survival of stocked walleye fingerlings in Moose Lake, Itasca County, Minnesota. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 215, St. Paul.

Johnson, F.H. 1968. Status of the fish population of Lake Vermillion in 1968 with special emphasis on the walleye, *Stizostedion vitreum*. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 300, St. Paul.

Johnson, F.H. 1971. Survival of stocked walleye fingerlings in northern Minnesota lakes as estimated from the age-composition of experimental gillnet catches. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 314, St. Paul.

Johnson, F.H. 1975. Interspecific relation ships of walleye, white sucker and associated species in a northeastern Minnesota lake with an evaluation of white sucker removal for increased walleye yield. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 338, St. Paul.

Johnson, F.H., and M. Johnson. 1971. Characteristics of the 1957-1958 and 1939 sport fishery of Lake Winnibigoshish and connecting waters with special emphasis on the walleye population and catch. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 312, St. Paul.

Johnson, F.H. and J.B. Moyle. 1969. Management of a large shallow winterkill lake in Minnesota for the production of pike *(Esox lucius)*. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 304, St. Paul.

Johnson, M. 1959. The effectiveness of toxaphene at low temperatures. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 197, St. Paul.

Johnson, M. 1978. The management of lakes for stream trout and salmon. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 125, St. Paul.

Johnson, M., and R. Micklus. 1965. An evaluation of the management of reclaimed trout lakes. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 287, St. Paul.

Leitch, J., and J. Baltezore. 1987. Attitudes of Minnesota anglers. Final Project Report to the Minnesota Department of Natural Resources, Division of Fish and Wildlife, St. Paul.

Maloney, J.E. 1956. Development of an introduced fish population in a small northern Minnesota lake with notes on survival of stocked walleye pike young-of-the-year. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 172, St. Paul.

Maloney, J.E., and F.H. Johnson. 1956. Life histories and interrelationships of yellow walleye and yellow perch, especially during their first summer, in two Minnesota lakes. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 173, St. Paul.

Maloney, J.E., and D.H. Schupp. 1977. Use of winter-rescued northern pike in maintenance stocking. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 345, St. Paul.

Moyle, J.B. 1947. Physical and chemical properties of taconite tailings and the effect of their disposition on the fishes of Lake Superior. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 75, St. Paul.

Moyle, J.B., and D.R. Franklin. 1955. Creel census of 12 Minnesota lakes, 1 December 1953 to 1 December 1954. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 159, St. Paul.

Negus, M., D. Belford, and S. Colvin. 1990. Long-term retention of fluorescent pigment marking of chinook salmon. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 402, St. Paul.

Newburg, H. 1973. Evaluation of potential use of pulsed direct current electrofishing gear in some fish management activities. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 321, St. Paul.

Newburg, H., and D.H. Schupp. 1986. Shoreline seining for young-of-the-year largemouth bass as a method of predicting recruitment to the anglers catch. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 388, St. Paul.

Olson, D.E. 1971. Improvement of artificial fertilization methods at a walleye hatchery. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 310, St. Paul.

Olson, D.E. 1974. Effects of elevated temperatures and fry density on initiation of feeding by walleye fry. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 327, St. Paul.

Olson, D.E. 1980. Comparison of marks on scales and dorsal spine sections as indicators of walleye age. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 371, St. Paul.

Olson, D.E. 1981. Experimental incubation of fish eggs in a moist-air environment. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 373, St. Paul.

Olson, D.E. and P.C. Cunningham. 1990. Sport-fisheries trends shown by an annual Minnesota fishing contest over a 58 year period. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 400, St. Paul.

Olson, D.E. and M. Wesloh. 1962. A record of six years of angling on Many Point Lake, Becker County, Minnesota, with special reference to the effect of walleye fingerling stocking. Minnesota

Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 247, St. Paul.

Osborn T., and D.H. Schupp. 1985. Long-term changes in the Lake Winnibigoshish walleye sport fishery. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 381, St. Paul.

Payer, R., R. Pierce, D. Pereira. 1987b. Hooking mortality of walleye caught on live and artificial baits. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 390, St. Paul.

Payer, R., D. Pereira, M. Larson, J. Younk, R. Frie, D. Schupp, and T. Osborn. 1987a. Status and simulation model of Lake of the Woods, Minnesota, walleye fishery. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 389, St. Paul.

Pierce R., and C. Tomcko. 1989. Limnological characteristics of mine pit lakes in northeast Minnesota. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 399, St. Paul.

Schumacher, R.E. 1950. Comparison of red-gil with standard feeds in Minnesota trout hatcheries. Recommendations for increasing trout hatchery operating efficiency. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 92, St. Paul.

Schumacher, R.E. 1953. Results of fortifying standard Minnesota hatchery diet with aureomycin and thiamin hydrochloride on the growth of brown trout. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 142, St. Paul.

Schumacher, R.E. 1957. Experimental feeding of pelleted trout food to large fingerling and yearling trout 1955-56. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 181, St. Paul.

Schupp, D.H. 1964. A method of creel census applicable to large lakes. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 174, St. Paul.

Schupp, D.H. 1972. The walleye fishery of Leech Lake, Minnesota. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 317, St. Paul.

Schupp, D.H. (in press). A limnological classification of Minnesota lakes with associated fish communities. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report, St. Paul.

Scidmore, W.J. 1955a. Notes on trapnet catches in two ponds and their relationship to the fish populations present. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 166, St. Paul.

Scidmore, W.J. 1955b. Field observation on the use and cost of application of powdered rotenone. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 167, St. Paul.

Scidmore, W.J. 1964. Use of yearling northern pike in the management of Minnesota fish lakes. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 276, St. Paul.

Scidmore, W.J. 1966. Preliminary observations on the use of estrone for inducing sex-reversal in rainbow trout. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 290, St. Paul.

Scidmore, W.J., and Z. Scheftel. 1957. A study of the relative efficiency and selec-

tivity of linen and nylon experimental gillnets. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 182, St. Paul.

Scidmore, W.J., and D.E. Woods. 1961. The effects of roughfish removal on four southern Minnesota lakes. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 238, St. Paul.

Seaburg, K. 1957. A stomach sampler for live fish. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 193, St. Paul.

Siesennop, G.D. (in press). Evaluation of various lake trout strains in inland lakes in northeastern Minnesota. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report, St. Paul.

Strand, R.F. 1984. Identification of principal spawning areas and seasonal distribution and movements of muskellunge. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 377, St. Paul.

Thorn, W.C. 1974. Evaluation of diets, water quality and disease problems in chinook salmon culture in a Minnesota hatchery. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 330, St. Paul.

Thorn, W.C. 1984. Effects of continuous fishing on the walleye and sauger population in Pool 4, Mississippi River. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 378, St. Paul.

Thorn, W.C. 1988a. Evaluation of habitat improvement for brown trout in agriculturally damaged streams of southeastern Minnesota. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 394, St. Paul.

Thorn, W.C. 1988b. Brown trout habitat use in southeastern Minnesota and it's relationship to habitat improvement. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 395, St. Paul.

Thorn, W.C. 1990. Evaluation of special regulations for trout in southeast Minnesota streams. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 401, St. Paul.

Wesloh, M., and D.E. Olson. 1962. The growth and harvest of stocked yearling northern pike, *Esox lucius* Linnaeus, in a Minnesota walleye lake. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 242, St. Paul.

Wiechman, J. 1990. Evaluation of fishing quality indices and sizes of brown trout preferred by anglers in southeast Minnesota. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 403, St. Paul.

Younk, J.A., and M.F. Cook. 1991. Fluorescent chemical marking of walleye larvae with a selected literature review of similar investigations. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Investigational Report 408, St. Paul.

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