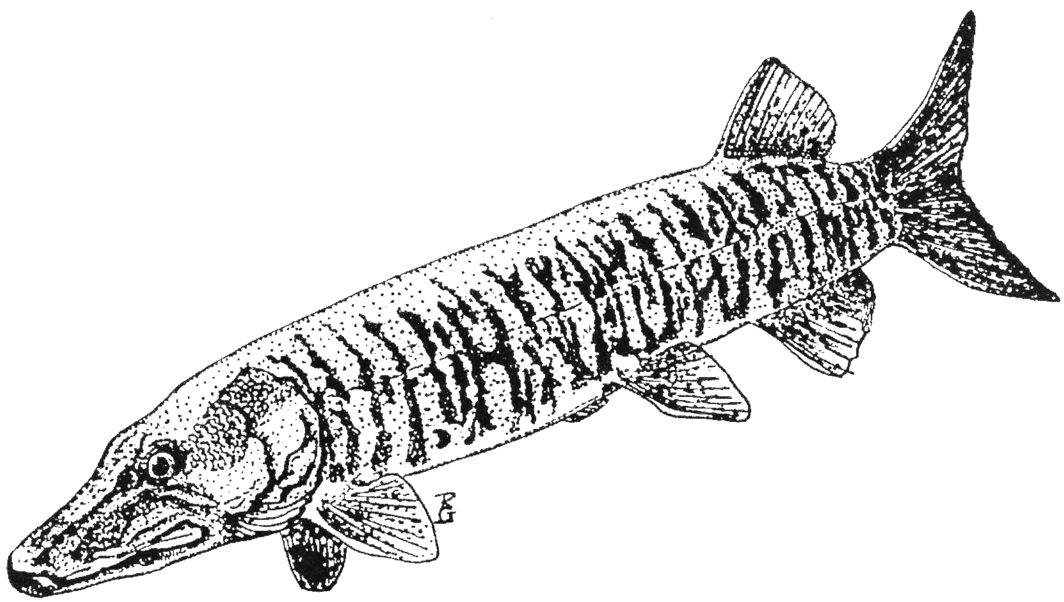
Ontario

Esocid Stocking: An Annotated Bibliography and Literature Review



Esocid Stocking: An Annotated Bibliography and Literature Review

S. J. Kerr and T. A. Lasenby
Fisheries Section
Fish and Wildlife Branch
Ontario Ministry of Natural Resources

March 2001

This publication should be cited as follows: Kerr, S. J. and T. A. Lasenby. 2001. Esocid stocking: An annotated bibliography and literature review. Fish and Wildlife Branch, Ontario Ministry of Natural Resources. Peterborough, Ontario. 138 p. + appendices.

Printed in Ontario, Canada
(0.3 k P. R. 01 31 03)
MNR 51489
ISBN 0-7794-0809-8

Copies of this publication are available from:

Fish and Wildlife Branch
Ontario Ministry of Natural Resources
P. O. Box 7000
300 Water Street, Peterborough
Ontario. K9J 8M5

Cette publication spécialisée n'est disponible qu'en anglais

Cover drawing by Ruth E. Grant, Brockville, Ontario.

Preface

This bibliography and literature review is the seventh in a set of reference documents developed in conjunction with a review of fish stocking policies and guidelines in the Province of Ontario. It has been prepared to summarize information pertaining to the current state of knowledge regarding esocids (northern pike and muskellunge) in a form which can readily be utilized by field staff and stocking proponents.

Material cited in this bibliography includes papers published in scientific journals, magazines and periodicals as well as “gray” literature such as file reports from Ministry of Natural Resources (MNR) field offices. Unpublished literature was obtained by soliciting information (i.e., unpublished data and file reports) from field biologists from across Ontario. Most published information was obtained from a literature search at the MNR corporate library in Peterborough. Twenty-one major fisheries journals were reviewed as part of this exercise. These included Aquaculture (1972-1998), California Fish and Game (1917-2000), Copeia (1913-2000), Environmental Biology of Fishes (1976-2000), Fishery Bulletin (1963-2000), Fisheries Management (1975-1984), Journal of Freshwater Ecology (1981-2000), New York Fish and Game Journal (1954-1985), North American Journal of Fisheries Management (1981-2000), Journal of the Fisheries Research Board of Canada/Canadian Journal of Fisheries and Aquatic Sciences (1950-2000), Progressive Fish Culturist (1940-2000), and Transactions of the American Fisheries Society (1929-2000). Searches were also made of other publications including Proceedings of the Annual Meeting of the Southeastern Association of Fish and Wildlife Agencies, Proceedings of the Annual Meeting of the Western Association of Fish and Wildlife Agencies, Transactions of the North American Fish and Wildlife Conference, Transactions of the Midwest Fish and Wildlife Conference, United States Department of the Interior Fisheries Technical Papers, FAO Fisheries Technical Papers and Circulars, and reports published under the Canadian Technical Report Series of Fisheries and Aquatic Sciences. Some material was obtained by a search on the Fish and Fisheries Worldwide database (1971-2000) via the Internet.

Information from over 370 sources has been assembled. Abstracts from published papers have been included wherever possible. In cases where abstracts were not available, an attempt has been made to extract pertinent material from the document to provide a synopsis of the findings. In some cases, we were unable to obtain a copy of the document but have simply included the citation. Some unpublished data has been included but has not been cited.

Table of Contents

Preface . . . .(i)

Table of Contents . . . .(ii)

History of Esocid Stocking in Ontario 1

Synthesis of Selected Literature 5

Annotated Bibliography 19

Acknowledgements 129

Subject Key 131

Subject Index 133

Appendix 1. Muskellunge stocking in Ontario waters, 1925-2000.

Appendix 2. Muskellunge transfers in Ontario waters.

Appendix 3. Ontario lakes containing introduced muskellunge populations.

History of Esocid Stocking in Ontario Waters

Although muskellunge propagation in Canada dates back to 1877 (MacCrimmon et al. 1974), muskellunge culture and stocking in Ontario was first reported in 1927. Between 1927 and 1937 these early efforts were conducted at a temporary (portable) facility situated on the Pigeon River at Omemee, Ontario (Buie 1960, Tripp 1965). A second temporary facility, situated on the Scugog River at Sturgeon Lake was operated in 1929. In 1934, these efforts were supplemented by a collection of muskellunge eggs from Beaver Creek, Crowe Lake (Hastings County) which were reared at the Belleville fish hatchery.

The Deer Lake fish culture station, a pond station with a surface water supply situated near Havelock, Ontario, was constructed in 1938. This facility was the predominant source of hatchery-reared muskellunge from that point until the facility was closed in 1990.

Muskellunge reared at the Deer Lake facility originated from eggs collected from wild stocks primarily from Stony Lake, Buckhorn Lake (Deer Bay) and the Crowe River. Annual egg collections ranged from 1.80 to 6.26 million eggs (Table 1).

Table 1. Muskellunge egg collections for the Deer Lake fish culture station, 1948-1985.

	Number of Muskellunge Eggs Collected			
Year	Stony Lake	Buckhorn Lake (Deer Bay)	Crowe River	Total Eggs Collected
1948	-	-	-	5,285,000
1949	-	-	-	4,660,000
1950	-	-	-	4,645,000
1951	-	-	-	5,060,000
1952	-	-	-	5,545,000
1953	-	-	-	4,350,000
1954	-	-	-	4,960,000
1955	-	-	-	5,580,000
1956	-	-	-	6,260,000
1957	-	-	-	4,400,000
1958	-	-	-	4,350,000
1959	-	-	-	5,470,000
1960	-	-	-	3,960,000
1961	-	-	-	4,260,000
1962	2,430,000	2,730,000	90,000	5,250,000
1963	2,100,000	1,470,000	190,000	3,760,000
1964	1,770,000	1,230,000	30,000	3,030,000
1965	2,430,000	1,230,000	-	3,660,000
1966	1,830,000	700,000	-	2,530,000
1967	2,400,000	1,920,000	-	4,320,000
1968	2,950,000	1,610,000	-	4,560,000
1969	3,180,000	1,680,000	-	4,860,000
1970	4,080,000	-	-	4,080,000
1971	3,740,000	-	-	3,740,000
1972	4,050,000	-	-	4,050,000
1973	1,800,000	-	-	1,800,000
1974	3,180,000	-	-	3,180,000
1975	3,000,000	-	-	3,000,000
1976	3,282,000	-	-	3,282,000
1977	2,821,500	-	-	2,821,500
1978	2,920,500	-	-	2,920,500
1979	2,983,500	-	-	2,983,500
1980	2,404,800	-	-	2,404,800
1981	2,100,000	-	-	2,100,000
1982	2,481,500	-	-	2,481,500
1983	2,707,500	-	-	2,707,500
1984	2,707,500	-	-	2,707,500
1985	3,477,000	-	-	3,477,000

Muskellunge fingerlings were reared at the Skeleton Lake fish culture station, near Utterson, Ontario, for the first time in 1953. Fry were transferred from the Deer Lake facility and 10,000 were reared to the fingerling stage and stocked.

The annual muskellunge culture program commenced in mid April when several pound nets were set in Stony Lake at water temperatures in the 7º C range. When temperatures neared 10º C muskellunge typically moved toward spawning areas where they were captured and, if mature and ripe, artificially spawned. Fertilized eggs were water hardened on site and subsequently transferred to the Deer Lake facility. Eggs were incubated in upwelling bell jars loaded with approximately 2 liters (~ 100,000) of eggs. Hatching typically occurred in 16 days at water temperatures in the 10-12º C range. At the first signs of hatch, eggs were transferred to pails, in lots of 10,000 per pail, and the small (1º C) increase in temperature ensured a complete hatch. Annual hatching success between 1973 and 1986 averaged 53% (Harris 1987). The hatched fry were transferred to trays and swim-up typically occurred in 1-2 weeks. Most fish were stocked as swim-up fry but a small number (e.g., 250-300,000) were retained for fingerling production. These fish were then transferred to ponds which had been fertilized with soybean meal to promote a zooplankton bloom which would provide a food source for the small fish. Once the fry reached sizes of 2-3 cm, their diet changed to fish and they were initially (first 2-3 days) fed sucker fry and, subsequently, minnow fry. This phase was quite labor intensive as a sufficient quantity of minnows needed to be harvested from nearby lakes (Rice, Pigeon and Buckhorn) and fed to the muskellunge on a daily basis. At Deer Lake, muskellunge grew at the rate of 2 cm per week and by early July they had reached approximately 10-12 cm in length and were stocked at 8-10 weeks of age.

Many problems were encountered in muskellunge propagation. These included predation (by aquatic insects, snakes birds and other fish), cannibalism, starvation (from poor zooplankton production or lack of suitable forage), parasitism and bacterial infection.

Early fish stocking efforts were concentrated in southcentral Ontario particularly in the Kawartha Lakes region (Table 2).

In 1952, transfers of juvenile and adult muskellunge from Nogies Creek, Ontario, were initiated. Between 1952 and 1958 (excluding 1956), a total of 1,533 tagged and 520 untagged muskellunge were transferred to Pigeon and Sturgeon lakes (Muir and Sweet 1964). Subsequent studies were made to evaluate post-release movements and the contributions of these fish to the creel (Dursely and Fry 1961).

In 1958, an attempt was made to transfer muskellunge fry from the Deer Lake station to Vancouver, British Columbia. Fry were shipped on an aircraft in a plexiglass jar. There was no survival after a transport period of approximately 25 hours, however.

An active muskellunge transfer program was conducted in the Sioux Lookout area of northwestern Ontario in the early-mid 1960s. Over 1,000 muskellunge were transferred over a four year period, including introductions to 13 lakes (Armstrong 1963, Semotak and Penney 1966, Penney undated).

Table 2. Some early releases of hatchery-reared muskellunge fry in selected Ontario waters.

Waterbody (County)	First Release of Muskellunge	Number of Fish Planted
Balsam Lake (Victoria)	1930	2,000 fry
Bay of Quinte (Prince Edward)	1934	75,000 fry
Beaver Creek (Hastings)	1934	50,000 fry
Belmont Lake (Peterborough)	1932	5,000 fry
Burnt River (Victoria)	1934	15,000 fry
Cameron Lake (Victoria)	1931	5,000 fry
Chemong Lake (Peterborough)	1932	10,000 fry
Clear Lake (Peterborough)	1934	15,000 fry
Crow Lake (Hastings)	1934	50,000 fry
Indian River (Peterborough)	1934	10,000 fry
Otonabee River (Peterborough)	1934	10,000 fry
Pigeon Lake (Victoria)	1931	10,000 fry
Pigeon River (Victoria)	1927	86,000 fry
Rice Lake (Durham)	1934	75,000 fry
Round Lake (Peterborough)	1934	20,000 fry
Scugog Lake (Durham)	1931	5,000 fry
Scugog River (Victoria)	1928	47,000 fry
Stony Lake (Peterborough)	1930	20,000 fry
St. Lawrence River	1934	35,000 fry
Sturgeon Lake (Victoria)	1930	20,000 fry
Trent River (Northumberland)	1931	10,000 fry
Twin Lake (Hastings)	1934	10,000 fry
Youngs Lake (Victoria)	1930	10,000 fry

The Deer Lake fish culture station was closed in 1990 due to operating expenses, the inability to rear sufficient quantities of large fingerling muskellunge and the recognition that muskellunge stocks should be managed on a self-sustaining basis.

The results of many early stocking projects were successful. Of 302 documented muskellunge lakes in Ontario, seventy-one (23.5%) have been created as the result of an introduction.

No muskellunge were stocked in Ontario between 1990 and 1995. In 1996, a stocking program was initiated in the Spanish River delta area of the North Channel of Lake Huron. This six year program was intended to reintroduce muskellunge to an area where they had been extirpated (LeBeau 1995). The original target for the project was to stock a total of 12,000 fall fingerlings averaging 6 inches (15 cm) in length. Egg collections were carried out in Georgian Bay (MacGregor Bay, Bay of Islands and Serpent Harbour) to ensure a local stock was utilized and fish were reared at a private culture facility in Lindsay, Ontario. Since 1996, a total of 6,514 fall fingerlings and 240 spring yearlings have been released.

Currently, plans are underway to commence restoration efforts to reintroduce muskellunge to Lake Simcoe (Buchanan and LeBeau 2000).

There have been no attempts to artificially rear northern pike in Ontario. There have been some attempts to transfer fish and introduce the species into new habitats, however.

Synthesis of Selected Literature

This section will attempt to summarize and highlight information cited in the annotated bibliography under the following categories:

1. Managed spawning marshes.
2. Survival of stocked esocids.
3. Contributions of stocked esocids to the fishery.
4. Factors influencing stocking success.
5. Impacts of esocid stocking.
6. Best management practices for esocid stocking.
7. Stocking assessment.

Managed Spawning Marshes

As an alternative to the artificial culture of esocids, several jurisdictions have used managed spawning marshes to increase the production of fingerling esocids, particularly northern pike. Generally, this involves spring stocking of broodstock fish at a rate of approximately 20 kg of female fish per hectare in an enclosed and regulated marsh. Usually, 2-3 male fish are stocked for every female fish. Stable water levels are maintained throughout the spawning period and the broodstock are allowed to spawn naturally. An abundant food source, such as zooplankton, is important for young fish. In some cases, forage fish are also released in the marsh. Once spawning, early incubation and hatch have been completed the marsh is slowly drained and the progeny (usually fingerlings) are either captured at an outlet weir or allowed to move out into the recipient waterbody. During the summer, the marsh is kept dry and maintenance activities include removal of undesirable woody vegetation, promotion of grass growth, cleaning of drainage channels, control of beaver and repairs to dams and dykes.

Annual production of fingerling fish varies greatly among managed marshes (Table 3). Factors which can lower production include flooding, cannibalism and predation, unsuitable water temperatures and levels of dissolved oxygen, and a lack of zooplankton as food for young fry.

Table 3. Yields from selected marshes managed for the production of northern pike.

Marsh	Pike Yield	Reference
Kenosee Lake Marsh (Saskatchewan)	1,038-1,570 fish acre^{-1}	Marshall and Johnson (1971)
Pabst Marsh (Wisconsin)	1971 - 681 fish acre^{-1} (276 fish ha^{-1}) 1972 - 1,052 fish acre^{-1} (426 fish ha^{-1})	Fago (1977)
Perry’s Marsh (Wisconsin)	0	Kleinert (1970)

Continued….

Table 3 (cont'd)

Marsh	Pike Yield	Reference
Pleasant Lake Marsh (Wisconsin)	324-3243 fingerlings $acre^{-1}$ (131-1,312 fingerlings ha^{-1})	Fago (1977)
Turtle Marsh (Manitoba)	1,051 fingerlings $acre^{-1}$	Edwards (1979)
Unnamed Marshes (Michigan)	1-13,000 fingerlings $acre^{-1}$ (mean = 2,941)	Williams and Jacob (1971)
Unnamed Marshes (Connecticut)	343-1,282 fingerlings ha^{-1}	Barry (1996)
Unnamed Marsh (Minnesota)	0-93,000 fingerlings (0-10,333 fingerlings $acre^{-1}$)	Groebner (1964)
Ventura Marsh (Iowa)	30,000 fingerlings (50 fingerlings $acre^{-1}$)	Carlander and Erickson (1953)

Survival of Stocked Esocids

Post-stocking survival rates reported in the literature are summarized in Table 4. Based on this information it is obvious that survival rates are related to the age and size of fish at the time of release. Post-stocking mortality is high for younger life stages but the survival of fingerlings is also highly variable. There is also some evidence that female muskellunge have higher survival rates than male fish (Bimber 1982). Belusz (1978) found that the greatest amount of post-stocking mortality was experienced a short time (i.e., within 48 hours) after release.

Table 4. Post-stocking survival rates reported for northern pike and muskellunge.

Species	Life Stage Stocked	Post-stocking Survival Rate	Reference
Muskellunge	Fingerlings (6")	• Annual natural mortality was 54.0%.	Axon (1981)
	Fingerlings	• Survival rates of 0.85 for female fish and 0.69 for male fish.	Bimber (1982)
	Fingerlings	• Survival to age IV varied from 1.0% if released at 2" up to 19% if released at 9".	Colesante (1974)
	Advanced fry	• Survival to first fall was 2.9%.	Farrell (1996)
	Fingerlings	• Survival to first fall was 38.6%.	Farrell (1996)
	Fingerlings	• Survival to first fall ranged from 0.0-45.7% .	Hanson et al. (1986)
	Fingerlings (11-14")	• Short term survival was < 20%.	Margenau and Hanson (1997)
	Fingerlings (8")	• Survival after 32 months was estimated at 45%.	Stroud and Jenkins (1966)

Continued…

Table 4 (cont'd)

Species	Life Stage Stocked	Post-stocking Survival Rate	Reference
Northern pike	Fingerlings	• Mortality from spring to first fall was 0.72.	Beyerle (1972)
	Fry	• Survival rate of 0.75% to first fall (natural and stocked combined).	Carlander and Erickson (1953)
	Fingerlings	• Survival to the anglers creel varied from 15.8-36.3%.	Beyerle (1980)
	Fingerlings (377 mm)	• Average survival of 35%.	Flickinger and Clark (1978)
Hybrids	Fingerlings (9-18 cm)	• Survival rate ranged from 15.1-36.0%.	Beyerle (1981)

Contribution of Stocked Esocids to the Fishery

Contribution of stocked esocids (muskellunge, northern pike and hybrids) to various North American recreational fisheries is summarized in Table 5. Depending on the rate of growth and size limit regulation in place, muskellunge usually enter the fishery at age III-IV. Pike are usually susceptible to angling at an earlier age.

Several factors influence the contribution of stocked fish to the creel. Obviously, post-stocking survival is important. In Escanaba Lake, Wisconsin, Hoff and Serns (1986) reported that two muskellunge stockings with yearling fish were nine times more effective at adding fish to the creel than two fingerling stockings.

There is also evidence that northern pike are more vulnerable to angling than either muskellunge or their hybrid (Weithman and Anderson 1976). Hybrids are believed to be more vulnerable to angling than muskellunge (Hesser 1978, Brege 1984).

Table 5. Returns of stocked esocids to selected recreational fisheries in North America.

Species	Life Stage Stocked	Contribution to Fishery	Reference
Muskellunge	Fry	• 5.8% of number stocked (117 fish of 19,030 stocked).	Erickson (1961)
	Fingerlings	• Six year average return of stocked fish to creel was 39%.	Belusz and Witter (1986)
	Fingerlings	• 11.6% of number stocked.	Brege (1984)
	Fingerlings	• Ten year average of 1.4% of the number stocked.	Margenau and Snow (1984)
	Fingerlings and Yearlings	• < 5% return to the creel over a 25 year period.	Hoff and Serns (1986)
	Yearlings	• 1.7% of number stocked.	Helm (1960)
	Yearlings	• 17% of number stocked.	Helm (1960)
	Yearling	• 44.1% of number stocked.	Wesloh and Olson (1962)
	Subadults	• 30% of fish transplanted.	Spangler (1968)

Continued…

Table 5 (cont'd)

Species	Life Stage Stocked	Contribution to Fishery	Reference
Muskellunge (cont'd)	Unknown	• Two year average of 7% of number stocked.	Snow (1988)
Northern Pike	Fingerlings	• Anglers could expect to harvest 44% of pike stocked in Nebraska farm ponds.	McCarraher (1959)
	Fingerlings	• 65.1% of 1973-75 year classes.	Beyerle (1980)
	Fingerlings	• 3.2% of 93,000 stocked taken by age IV.	Groebner (1964)
	Age-0	• 35.2% of winter rescued fish stocked.	Maloney and Schupp (1977)
	Age-0	• 38.4% of winter rescued fish stocked.	Maloney and Schupp (1977)
	Age-0	• 44.4% of winter rescued fish stocked.	Maloney and Schupp (1977)
	Juvenile/Subadults	• Three year average of 8.7% of winter rescued fish stocked.	Priegel (1968)
	Juvenile/Subadults	• Two year average of 4.3% of winter rescued fish stocked.	Priegel (1968)
Hybrids	Fry	• 0.7% of fish stocked were caught by anglers.	Laarman (1979)
	Fingerlings	• 14.6% of number stocked.	Brege (1984)

Factors Influencing Stocking Success

As with many other stocked species, there are a great number of variables which can ultimately influence the results of a stocking project (Table 6).

Habitat Suitability - Northern pike and muskellunge share may of the same habitat preferences (Table 7). Both species actively seek submersed aquatic vegetation and underwater cover such as fallen trees (Hansen and Margenau 1992). In Nogies Creek, Ontario, McNeil (1979) reported that the presence of a sharp interface between dense areas of aquatic macrophytes and stream channel increased the survival of young-of-the-year muskellunge. As ambush predators, both species of fish are reliant on good water clarity. Weithman (1975) provided evidence that turbidity can have an effect on feeding rate and vulnerability to angling. Both species, particularly northern pike, are relatively tolerant of low levels of dissolved oxygen. Depressed oxygen levels in sites heavily vegetated with *Chara* sp. have been identified as a factor influencing muskellunge stocking success in the St. Lawrence River however (Clapsadl 1993).

The importance of other physical and chemical parameters is less well known. In a Wisconsin study, John (1982) found no relationship between the survival of stocked muskellunge with alkalinity, lake size, amount of shoreline, mean depth or morphoedaphic index (MEI).

Table 6. A summary of potential factors which can influence the success of an esocid stocking project.

Factor	Reference(s)
Poor habitat and/or water quality	Brewer (1968), Royer (1971), Johnson (1972$_b$), Weithman (1975), Stein et al. (1981), European Inland Fisheries Advisory Commission (1982), Mather et al. (1986), Clapsadl (1993), Wahl (1999)
Culture technique (including handling and transportation)	Johnson (1978), Gillen et al. (1981), Klingbiel (1984), Anonymous (1987), Otis et al. (1996)
Genetic strain	Younk and Strand (1992), Margenau and Hanson (1996)
Age/size of fish when stocked	Priegel (1968), Colesante (1974), John (1982), Carline et al. (1986), Hanson et al. (1986), Serns and Andrews (1986), Kinman (1989), Margenau (1992), Larscheid et al. (1997), Wahl (1999)
Fish health and disease	Snow (1974), Sonstegard and Hnath (1978), Colesante et al. (1981), Harvey (1986), Larscheid et al. (1997)
Stocking Technique	
(a) Stocking rate	Snow (1974), Maloney and Schupp (1977), Beyerle (1980), Bry (1980)
(b) Frequency	Steucke (1975), Maloney and Schupp (1977), McNeil (1978)
(c) Release techniques	Johnson (1971), Miles (1974), Belusz (1978)
Predation	Elson (1940), Helm (1960), John (1982), Wahl (1989, 1995, 1999), Wahl and Stein (1989$_a$), Stein et al. (1991), Szendrey and Wahl (1991, 1996), Serns and Andrews (1983, 1986), Beyerle (1984$_a$), Carline et al. (1986), Heidinger (1999)
Cannibalism	MacKay and Werner (1934), McCarraher (1957), Fago (1977), Klupp (1978), Grimm (1981$_b$), Anonymous (1984), Wright and Giles (1987)
Interspecific competition	Oehmcke (1951), Wesloh and Olson (1962), Shipman (1979), Dombeck et al. (1986), Mooradian et al. (1986), Buchanan and LeBeau (2000)
Intraspecific competition	Priegel (1968), Krohn (1969), Craig (1976), McNeil (1978), Grimm (1981$_a$, 1981$_b$, 1983$_a$),
Forage availability	Johnson (1972$_b$), Maloney and Schupp (1977), Flickinger and Clark (1978), Snow (1978), Serns and Andrews (1983), Harris (1988), Johnson et al. (1988), Ratt (1988)
Emigration	Helm (1960), Priegel (1968), Snow (1974)

Table 7. Basic habitat requirements of esocids.

Parameter	Requirement
Waterbody type	• Mesotrophic lakes, rivers and streams.
Aquatic vegetation	• Abundance of submerged vegetation preferred.
Water temperature	• 20-25º C optimal for growth. • 6-12º C for spawning. • 12-24º C preferred.
Underwater cover	• Abundance of underwater structure (fallen trees, boulders, etc.) preferred.
Dissolved oxygen	• > 4 mg L^{-1}
Turbidity	• Relatively good water clarity (> 1-2 m).
pH	• Tolerates 5.0-9.0

Northern pike and muskellunge have some habitat differences. Muskellunge spawn later and at warmer water temperatures than northern pike (8-15º C for muskellunge vs. 5-12º C for northern pike). Generally, large muskellunge seem to prefer warmer water temperatures than northern pike (Bevelhimer et al. 1985, Kerr and Grant 2000). There is also evidence to indicate that muskellunge are more suited to riverine (lotic) habitats while northern pike generally prefer lentic waters.

Culture Technique – With advances in muskellunge culture techniques, practices have shifted from pond rearing, using minnows as a food source, to intensively-reared muskellunge reared on pelleted feeds. In some instances, muskellunge are placed in ponds with minnows as a "finishing" technique prior to their release in the wild. The advantages of intensive culture is that it is cheaper with a more predictable product. There is evidence, however, that minnow-reared muskellunge survive better than fish reared on either pellet diets or a pellet-pond finishing regime (Johnson 1978, Otis et al. 1996). Experiments with tiger muskellunge have shown that, once stocked, pellet-reared fish are slow to convert to forage fish so that survival and growth is affected.

Studies have also shown that esocids suffer physiological stress from traditional capture, handling, marking and transporting techniques (Johnson 1971, 1972_a, 1972_b). Belusz and Witter (1986) believed that delayed mortality resulted from latent stress derived from pathogens associated with transport and handling. Stress is often manifested in terms of elevated blood sugar (Mather et al. 1986) and decreased plasma chloride and liver glycogen (Miles et al. 1973). The greatest physiological stress may originate from the original capture as compared to fin clipping or transport (Miles et al. 1973). There is also evidence that loading density is related to stress levels and ultimate survival (Bean 1986).

Genetic Strain – Although it is generally recognized that muskellunge have evolved to the point where several distinct strains exist, there has been relatively little research done to detect genetic variability and identify important genetic strains. In a Minnesota study involving four different muskellunge strains, Younk and Strand (1992) found that growth, maturation, spawning temperatures, body shape and ultimate growth potential varied among strains. More consideration needs to be given to ensure that valuable muskellunge stocks are protected and that the most appropriate genetic strains are used in fish stocking programs.

Age/Size of Fish Stocked – Muskellunge are stocked at various life stages including eyed eggs, fry, fingerlings, yearlings and juveniles/sub-adults. It is well known that post-stocking mortality is related to the size of muskellunge which are stocked (Porter 1977, John 1982, Johnson and Margenau 1993, Wahl 1997, Wahl and Stein 1993).

Fry stocking is still common although success may be limited particularly in waters having an abundance of predators. In a review of northern pike stocking and transfers in Saskatchewan, releases of fingerlings and adults were more successful than plantings of eggs and fry (Marshall and Johnson 1971). Based on a review of pike stocking in Indiana, Shipman (1979) observed that introductions of fry and small fingerlings were largely unsuccessful. Forney (1968) found that few northern pike, less than 65 mm in length, survived after emigrating from a managed spawning marsh. John (1982) recommended that the practice of stocking 2-3 inch muskellunge be discontinued.

Probably the most common life stage of stocked esocid, particularly muskellunge, is the fingerling. With fingerlings, size is crucial. Serns and Andrews (1983) concluded that larger fingerling muskellunge should be stocked in waters having the greatest density of predators. The survival of large muskellunge fingerlings has been shown to be 2-3 times that of small and medium-size fingerlings (Szendrey and Wahl 1996). After stocking various sizes of muskellunge fingerlings, Kinman (1989) found that a fishery did not develop until annual stockings of fish greater than nine inches in length were initiated. Axon (1981) also recommended that fingerlings be stocked at a length of nine inches.

Stocking projects involving yearlings and older fish are relatively few although there have been several initiatives which have involved the transfer of juveniles and subadults. In one project involving yearling muskellunge, Margenau (1992) found that fish stocked as spring yearlings survived better to the age of 18 months (19% survival) than those released as fall fingerlings (4% survival).

Fish Health and Disease – Fish health should be a concern in any stocking endeavour. Fish pathogens have been identified as a source of mortality in muskellunge culture facilities (Colesante et al. 1981, Harvey 1986). Sonstegard and Hnath (1978) recommended that esocids known to be infected with lymposarcoma, a common and easily transmitted disease of muskellunge and pike, should not be stocked. Parasites were implicated in the mortality of stocked pike in Murphy Flowage, Wisconsin (Snow 1974).

Stocking Technique – Several stocking-related factors, including stocking rate, stocking frequency, stocking site, and release techniques have a large influence on post-stocking success.

Stocking rates vary considerably among various jurisdictions where esocids are stocked (Table 8). In a stocking experiment involving northern pike, Bry (1980) concluded that care should be taken in determining stocking density in order to avoid poor yields from overstocking. Conversely, in a study which involved stocking muskellunge at densities from 4-100 fish ha^{-1} McNeil (1978) found no correlation between stocking density and subsequent contribution to year class strength.

Table 8. Stocking rates utilized in various North American esocid stocking projects.

Species	Waterbody	Stocking Density	Reference
Northern pike	Long Lake (Michigan)	• 40 fingerlings ha^{-1}	Beyerle (1980)
	Murphy Flowage (Wisconsin)	• Maximum of 8 large (10-18") fingerlings $acre^{-1}$	Snow (1974)
	Michigan waters	• 10,000 fry $acre^{-1}$	Borgeson (1987)
	Colorado waters	• 62 fingerlings (50 mm) ha^{-1}	Flickinger and Clark (1978)
	Nebraska ponds	• 111-118 fingerlings/surface acre	McCarraher (1959)
	Minnesota waters	• 1.0-3.0 lbs. winter rescued pike/littoral acre	Maloney and Schupp (1977)
	Finland waters	• 1,000-1,500 fry ha^{-1}	Rasmussen and Geertz-Hansen (1998)
Muskellunge	Cave Run Lake (Kentucky)	• 1.1-3.1 fish ha^{-1}	Axon (1978)
	Cave Run Lake (Kentucky)	• 1 fingerling (9") ha^{-1} recommended	Axon (1981)
	Chautauqua Lake (New York)	• 1.5 fingerlings $acre^{-1}$	Porter (1977)
	Michigan waters	• 2-4 fingerlings (6-9") $acre^{-1}$	Schrouder (1973), Borgeson (1987)
	New York waters	• 2 fingerlings (6-9") $acre^{-1}$	Colesante (1974)
	Pennsylvania waters	• 100-150 fry $acre^{-1}$	Colesante (1974)
	Wisconsin lakes	• 500 fry ha^{-1} • 5 small fingerlings surface $acre^{-1}$ • 2 large fingerlings surface $acre^{-1}$	Wisconsin DNR (1999)
	Four Wisconsin lakes	• 4 fingerlings $acre^{-1}$	Serns and Andrews (1983)
	North American waters	• 0.25-5.0 fingerlings ha^{-1}	Harris (1988)
	Ohio waters	• 1-2 fingerlings (8") $acre^{-1}$	Heybob (2000), Ohio DNR (undated)
	Missouri reservoir	• 2.8 fingerlings (10-12") $acre^{-1}$	Neuswanger (1997)
	Minnesota waters	• 1 young-of-year (3-7/lb.)/ littoral acre	Minnesota DNR (1982)
	Illinois waters	• 100-1,000 fry $acre^{-1}$ • 1-5 fingerlings $acre^{-1}$	Illinois DNR (1990)
	Québec waters	• 1,200 fry or 12 fingerlings ha^{-1} for introductions • 5 fingerlings ha^{-1} for put-grow-take stocking	Québec MLCP (1988)
	Kentucky streams	• 1 fingerling (7-9")/ 2 acres pool habitat	Kornman (1983)
Hybrids	Michigan ponds	• 10 fingerling (6-6.5") surface $acre^{-1}$	Beyerle (1984_a)
	Pennsylvania waters	• 1-2 fingerlings (18-20 cm) ha^{-1} in lakes	Hesser (1978)
		• 250 fry ha^{-1} in lakes	Hesser (1978)

Continued…

Table 8 (cont'd)

Species	Waterbody	Stocking Density	Reference
Hybrids (cont'd)	Pennsylvania waters (cont'd)	• 625 fry km^{-1} for streams < 100m wide	Hesser (1978)
		• 1,000 fry/km for streams > 100 m wide	Hesser (1978)
		• 25 fingerlings/km for streams < 100 m wide	Hesser (1978)
		• 30 fingerlings/km for streams > 100 m wide	Hesser (1978)
	Green River Lake (Kentucky)	• 1 fingerling (6") ha^{-1}	Kinman (1989)

Frequency of stocking also deserves consideration. Generally, it would appear that esocid stocking should not be conducted on an annual basis. Larscheid et al. (1997) recommended an alternate year stocking schedule for Iowa's muskellunge lakes. McNeil (1978) suggested stocking muskellunge every 2-3 years in order to reduce predation by older muskellunge. Weithman (1975) and Maloney and Schupp (1977) recommended that, to prevent overcrowding and maintain consistent fisheries, stocking should be conducted every three years. Steucke (1975) concluded that pike stocking every four years would adequately supplement the resident population of Gordon Lake, North Dakota, at the existing level of angling pressure.

Ideally, stocking densities and the frequency of stocking would be formulated based on the objective of the project, size and life stage of fish being utilized as well as characteristics of the waterbody being stocked.

Release sites and stocking techniques should be developed to maximize post-stocking survival. In terms of stocking site, the release of esocids should be done over shallow (< 2-3 m), moderate-heavily vegetated littoral areas. Ideally, the fish would be distributed along the weedline during the evening when avian predators are less abundant. Generally fish should be dispersed over as large an area as possible. It may be advisable to plant fry in very shallow (15-30 cm) water having an abundance of cover.

Predation and Cannibalism – Predation is a common source of mortality in stocked fish. John (1982) identified the presence of predators as being a major factor influencing the survival of hatchery-reared muskellunge in twenty Wisconsin waters.

Stocked esocids are potential prey for a number of predators (Table 9). Early life stages are particularly vulnerable to predation by other fish. Predation by walleye on stocked muskellunge was identified as one reason for poor stocking success in Fishtrap Lake, Wisconsin (Helm 1960). Walleye predation was attributed as a reason for muskellunge decline in Chautauqua Lake, New York (McKeown et al. 1999). Largemouth bass is another common predator. Mortality caused by largemouth bass predation accounted for 26-45% of the number of muskellunge stocked in two Ohio reservoirs (Stein et al. 1981). Carline et al. (1986) found that predation by largemouth bass on stocked tiger muskellunge was directly related to largemouth bass densities and inversely related to the abundance of prey. Cannibalism is also a source of mortality in esocids.

Table 9. Potential predators of stocked esocids.

Predator	Reference
Aquatic insects	Scott and Crossman (1973)
Frogs	McCarraher (1957)
Turtles	McCarraher (1957)
Birds	McCarraher (1957), Scott and Crossman (1973)
Fish	
Largemouth bass	Stein et al. (1981), Carline et al. (1986), Wahl (1989), Szendrey and Wahl (1991, 1995)
Muskellunge	Scott and Crossman (1973)
Rock bass	Elson (1940), Scott and Crossman (1973)
Walleye	Helm (1960), McKeown et al. (1999)
Yellow perch	Elson (1940), Scott and Crossman (1973)
Northern pike	Scott and Crossman (1973), Grimm (1981_a, 1981_b)

There are differences in susceptibility to predation. Wahl (1989) found that tiger muskellunge were highly susceptible to predation by largemouth bass, muskellunge were the least susceptible and northern pike were intermediate. Muskellunge were also more susceptible to predation by largemouth bass than walleye (Wahl 1985).

Intra- and Interspecific Competition – Esocids are known to compete with other top predators for both food and space. Most notable are interactions between pike and muskellunge as well as competition with largemouth bass and walleye.

Northern pike generally spawn earlier than muskellunge thereby achieving a larger initial size and competitive advantage. Muskellunge spawning success has been found to be inversely correlated with northern pike abundance (Dombeck et al. 1986). In Lake Simcoe, the decline in muskellunge stocks coincided with increases in the abundance of carp and northern pike (Buchanan and LeBeau 2000).

Esocids often coexist in the same waterbody with walleye. Northern pike predation on white sucker may indirectly benefit walleye by reducing competition between white sucker and yellow perch but, in some waters, northern pike may compete directly with walleye by preying on yellow perch (Krishka et al. 1996). Wesloh and Olson (1962) concluded that increased competition with stocked pike increased walleye vulnerability to angling. Conversely, the increased abundance of walleye was correlated with the decline in muskellunge abundance in Chautauqua Lake (Moordian et al. 1986). Krishka et al. (1996) recommended that introductions of northern pike or muskellunge not be considered in walleye waters where they currently did not exist.

Esocids inhabit habitats similar to largemouth bass. In some cases, interspecific interactions have resulted in the decline of largemouth bass (Krishka et al. 1996, Kerr and Grant 2000).

Esocids also compete with members of their own species and this can influence the success of any stocking project in a waterbody containing a resident population of pike (Priegel 1968, Krohn 1969, Grimm 1981_a, 1981_b) or muskellunge (Craig 1976, McNeil 1978). McNeil (1978) reported that success of stocking muskellunge young-of-the-year was inversely related to the strength of the native year class. Similarly, Grimm (1983_a) concluded that pike displayed a density dependent relationship determined through intraspecific competition.

Forage Availability – Esocids are voracious predators and the relative abundance of forage fishes can have a direct influence on the success of a stocking project. Although cylindrical, soft-rayed prey fishes are often preferred, muskellunge and northern pike have a varied diet (Table 10). In Cave Run Lake, Kentucky, Axon (1981) found that yearly fluctuations in a stocked muskellunge population were primarily due to changes in the standing stock of gizzard shad, the primary forage species. Maloney and Schupp (1977) recommended that pike transfers should only be done in lakes having moderate to high populations of yellow perch. The diversity and abundance of forage fish should be a prime consideration when evaluating any stocking program.

Table 10. Food items of stocked esocids.

Food Item	Reference(s)
Invertebrates (including aquatic insects)	Elson (1940), McCarraher (1957), Tennant and Billy (1963), Applegate (1981)
Amphibians	McCarraher (1957), Kerr and Grant (2000)
Fish	
Bluegills	McCarraher (1959), Tomcko (1982), Moody et al. (1983), Tomcko et al. (1984), Headrick (1985)
Black crappie	Hergenrader (1984)
Brook silverside	Wahl and Stein (1991)
Carp	Axon (1978)
Fathead minnow	Jorgensen (1983), Moody et al. (1983), Bevelhimer et al. (1985), Wahl (1989)
Gizzard shad	Jenkins (1973), Axon (1978), Goddard and Redmond (1978), Carline et al. (1986), Johnson et al. (1988), Wahl (1989), Wahl and Stein (1991)
Northern pike	McCarraher (1957)
Panfish (*Lepomis* spp.)	Wahl and Stein (1991)
Squawfish	Tipping (1996)
Suckers	Harris (1988)
Yellow perch	Wesloh and Olson (1962), Gammon and Hasler (1965), Maloney and Schupp (1977), Serns and Andrews (1983), Anderson and Schupp (1986), Harris (1988)

Emigration of Stocked Fish – Poor contribution of stocked esocids to the creel has been attributed to emigration from the point of release (Priegel 1968). Little, if any, significant movement is believed to occur with fish stocked as fry but movements may be extensive with fish stocked at older life stages.

Carlander and Ridenhour (1955) observed that northern pike stocked in Clear Lake, Iowa, dispersed quickly throughout the lake. Similarly, Hanson and Margenau (1992) found that most dispersion of stocked muskellunge occurred within 2 weeks after release. Snow (1974) estimated that 30% or more of the northern pike stocked in Murphy Flowage moved downstream out of the waterbody in which they were released. Maximum movement occurred during the spawning period and was related to population density. Juvenile and adult muskellunge, transplanted from Nogies Creek to Sturgeon Lake, Ontario, moved downstream to Pigeon Lake, a journey involving passage through canal locks or a descent over a dam (Muir and Sweet 1964). In Ohio, only lakes having a low exchange rate are stocked in an effort to ensure stocked fish remain in the lake (Heybob 2000).

Impacts of Esocid Stocking

A general review of potential impacts from stocking northern pike and muskellunge is provided by Kerr and Grant (2000). Basically, impacts involve predation, competition for resources and hybridization.

Probably the greatest impacts relate to the fact that esocids are voracious predators and their presence can alter the composition or abundance of the resident fish community (Flickinger and Clark 1978, European Inland Fisheries Advisory Commission 1982, He and Wright 1992, Margenau 1995, Chapleau et al. 1997, Findlay et al. 2000).

The introduction of pike and muskellunge have been found to alter prey fish communities from small bodied, soft-rayed species to spiny-rayed deep bodied species. Many cyprinid species seem particularly vulnerable to predation. These include creek chub (*Semotilus atromaculatus*), northern redbelly dace (*Phoxinus* eos), blacknose dace (*Rhinichthys atratulus*), common shiner (*Notropis cornutus*), and pearl dace (*Semotilus margarita*). The introduction of northern pike significantly decreased cyprinid densities in two northwestern Ontario lakes (Kidd et al. 1999).

Other species are also vulnerable to esocid predation. Introduced muskellunge dramatically reduced the abundance of yellow perch in George Lake and Corrine Lake, Wisconsin (Gammon 1960). The introduction of muskellunge into two Wisconsin bog lakes resulted in decreases of both yellow perch and largemouth bass (Schmidtz and Hetfeld 1965). In Ireland, the introduction of northern pike has almost eliminated populations of brown trout and salmon (European Inland Fisheries Advisory Commission 1982). In Spain, Elvira (1998) reported that introduced northern pike dramatically reduced the abundance of native prey fish and then switched their diet to crayfish. Introduced northern pike resulted in a dramatic decline of black crappies in two Nebraska ponds (Hergenrader 1984). The transfer of winter-rescued northern pike (mostly yearlings) to supplement a northern pike population in an 885 acre Minnesota lake, substantially reduced the resident yellow perch and walleye population (Scidmore 1964). Pike stocking in Minnesota waters has been observed to reduce the abundance and growth of species including walleye, bass, yellow perch and resident northern pike (Maloney and Schupp 1986). Increased densities of muskellunge in Iron Lake, Michigan, greatly reduced the previously abundant populations of black crappies, common white suckers and golden shiner (Siler and Beyerle 1984). Pike stocking in Murphy Flowage, Wisconsin, had a negative impact on the resident pike population (Snow 1974).

The presence of piscivorous predators, such as northern pike or muskellunge, can alter behavior of prey species. He and Kitchell (1990) found that the introduction of northern pike resulted in significant emigration of prey fish.

Best Management Practices for Esocid Stocking

Based on a review of the information presented, the following best management practices have been developed for esocid stocking in Ontario:

Stocking objective – It is imperative that clearly defined stocking objectives, with quantified measures for determining success, be established before the project begins. Common objectives for esocid stocking programs include restoring degraded populations, re-introducing an extirpated species, producing/maintaining a trophy fishery, diversifying angling opportunities, and controlling non-game and undesirable fish species. Determinations of the age/size of fish to stock and the techniques utilized will be based largely on the stocking objective.

Supplemental stocking – There are many potential impacts and generally poorer stocking success when either pike or muskellunge are stocked over existing populations. Supplemental stocking of either species is generally not recommended in waters having adequate natural reproduction.

Introductions – An environmental assessment must be conducted for any esocid introduction in the Province of Ontario. Careful consideration should be given to all potential impacts. As a general rule, introductions of esocids should not be made into percid communities having walleye as the top predator and where esocids do not currently exist.

Characteristics of stocked waterbody – Physical and chemical characteristics of the recipient waterbody should be determined, normally through an aquatic habitat inventory, to ensure that conditions are favorable for esocids. This includes consideration of other species in the waterbody and the availability of adequate forage. Esocids should only be stocked in waters having suitable water quality and habitat conditions, including spawning areas.

Fish health and disease - Efforts should be taken to ensure that only healthy, disease-free fish are stocked. Muskellunge or northern pike should not be transferred from waters where lymphosarcoma is prevalent in order to prevent the spread of this disease.

Genetic considerations – Genetic variability should be a consideration of every stocking project to ensure that the genetic integrity of valuable stocks is preserved.

Stocking density – Stocking rates should be developed based on a number of factors including the age/size of fish to be stocked and the abundance and diversity of the forage base in the receiving waterbody. As a general rule, stocking rates should be in the order of 1-5,000 fry ha^{-1}, 2-5 small (<8") fingerlings ha^{-1}, and 1-3 large (>8") fingerlings ha^{-1}.

Age/size of fish to stock – The most appropriate age/size of fish to stock will depend on the stocking objective and the fish community in the receiving waterbody. For introductions or stocking in waters having a relatively simple fish community with few other predators, fry may be the most cost effective life stage to stock. In other situations, large fingerlings (> 8-9" in length) has been demonstrated to provide the most success.

Handling and transportation precautions – Handling of muskellunge, between the time of pond harvest and stocking, should be minimized in order to reduce physiological stress. Measures should be initiated (e.g., short transport duration, salt treatments, etc.) to reduce stress during the transport phase.

Stocking methods – Esocids should not be stocked in waters where the temperature differential between the rearing (acclimated) water and site water exceeds 8-10º C. Ideally, fish would be stocked at receiving water temperatures of less than 18-20º C. Fingerling esocids should be stocked at a time when temperatures and availability of food provide a good opportunity for growth before winter. If possible, stocking should take place at night to avoid avian predators. Fish should be well dispersed over littoral areas having extensive submerged vegetation.

Stocking Assessment

The true cost of a stocking project relates to the post-stocking survival of the fish and its subsequent contribution to the anglers creel or natural reproduction. Assessment should be a component of every esocid stocking or transfer project. Stocking activities should be planned in a manner to facilitate subsequent assessment. Stocking assessment programs should be statistically sound, utilize standard sampling protocols and be "low impact" in terms of the number of fish to be lethally sampled. Aging structures, from lethally sampled esocids, should be donated to the Cleithrum project. Assessment criteria should be developed based on the objective of the stocking project. For esocids, the basic stocking objectives are either: (i) introductions and transfers to establish or re-establish a self-sustaining population, and (ii) put-grow-take to supplement and diversify existing angling opportunities.

For introductions and transfers, the assessment criteria should involve measurement of post-stocking survival, growth and maturity and, ultimately, the establishment of a naturally reproducing population.

For stocking projects designed to eventually provide a contribution to the recreational fishery, assessment criteria should involve some estimate of the returns on the number of fish stocked, catch rates from anglers targeting stocked species, angler satisfaction and overall cost effectiveness.

Unfortunately, esocids, particularly muskellunge, are not easily captured by traditional sampling (i.e., index netting) programs. The evaluation of stocked esocids will ultimately depend on the cooperation of local anglers and interest groups who actively seek the species being stocked.

Annotated Bibliography

ADAIR, B. C. 1986. Tiger muskellunge as a trophy species in Iowa lakes. American Fisheries Society Special Publication 15 : 343. (Abstract only)

Approximately 206,000 tiger muskellunge (F_1 hybrid female muskellunge x male northern pike) fingerlings have been stocked into 34 Iowa lakes since 1978 to provide a unique trophy species in lakes dominated by centrarchids and ictalurids. These are mainly impoundments less than 500 surface acres, concentrated in the five southern tiers of Iowa counties. Hatchery production costs for 6-7 inch fingerling tiger muskellunge are currently $129 per 1,000 fish delivered to the lakes. Survival of the stocked hybrids is good in most instances, although sampling difficulty occurs in some lakes. Recruitment to the minimum-legal length (30 inches) typically occurs in age IV fish. The popularity of the tiger muskellunge with the Iowa angler ranges from enthusiasm, to indifference, to dislike.

ALBERTA ENVIRONMENT. 1994. Alberta's fish stocking program. Fish and Wildlife Services Policy. Fisheries and Wildlife Management Division. Edmonton, Alberta.

Fish stocking in Alberta has taken place since the early 1900s. This policy deals with the stocking of reservoirs , lakes, ponds and streams in Alberta with trout, walleye, perch, pike, lake whitefish and Arctic grayling as well as with exotic species. Stocking can add to the fish resources of an area. However, it is the responsibility of the Fish and Wildlife Management Division to ensure that introductions enhance rather than adversely affect existing fish resources or aquatic ecosystems.

Northern pike and perch transplants are authorized to introduce these species into suitable habitat to provide new fishing opportunities.

ANDERSON, D. W. and D. H. SCHUPP. 1986. Fish community responses to northern pike stocking in Horseshoe Lake, Minnesota. Investigational Report 387. Minnesota Department of Natural Resources. St. Paul, Minnesota. 38 p.

The fish community in Horseshoe Lake was drastically influenced for more than 10 years by the stocking of northern pike. Changes in abundance, size distribution and growth rate of walleye, northern pike, yellow perch, and centrarchids following the stocking of northern pike in 1969, 1973 and 1979 were documented. Abundance of perch, walleye, black crappie, largemouth bass and pumpkinseed declined while bluegill abundance increased significantly. Significant changes in growth, mostly negative, were observed for all species except northern pike. The observed changes in growth and abundance were judged to be related primarily to the reduction in abundance of perch. Perch were the most important prey species for pike, bass and walleye. Predation by pike on 5-6 inch perch, which nearly eliminated recruitment of perch to adult sizes, appeared to be the major factor causing a collapse of the perch population. Low abundance and small average size of perch coupled with high abundance and small average size of bluegill may be a symptom of excessive pike predation on perch.

ANONYMOUS. Undated$_a$. Procedures in maskinonge propagation and operation of Deer Lake Hatchery. Ontario Department of Lands and Forests. Lindsay, Ontario. 5 p.

The methodology used in rearing maskinonge from eggs to fingerlings is outlined, including the distribution of the fish. On average, the annual output of post swim-up fry into Ontario lakes is 3,250,000. The fry are carried, 10,000 to a can, to any lake whose water temperature does not exceed 70 degrees Fahrenheit. They may be shipped by rail for up to 48 hours. Fingerling distribution begins at 2 inches and the final fingerlings to leave the hatchery are 6 inches in length, typically by the end of July.

Minnows are transferred with the fish if the trip is to be lengthy and ice may be used to keep water at a desired temperature. Maskinonge fingerlings should be planted into weedy bays, less than six feet deep, which have an ample supply of minnows. The fry should be planted in 6 to 12 inches of water. The fish should be dispersed over as large an area as possible. For transportation in cans the following densities (fish per ten gallon fish can) should be abided by:

- 10,000 swim-up fry
- 300 2-inch fingerlings
- 200 3-inch fingerlings
- 100 4-inch fingerlings
- 50 6-inch fingerlings

ANONYMOUS. Undated$_c$. Muskellunge culture. Ontario Department of Lands and Forests. Lindsay, Ontario. 1 p.

The Deer Lake Fish Culture Station is located near Havelock, Ontario. Annually 10-30,000 advanced muskellunge fingerlings are raised for stocking. Fish are stocked for both research and management purposes. Spawn is collected from Stony Lake adults and the fry are reared at the hatchery. Preparation of the fry ponds must occur at least two weeks prior to stocking. By the beginning of July, at a length of around ten centimetres the fish are ready to be stocked. They are transported to their stocking sites in bags with oxygen and a pinch of buffer from early to late July.

ANONYMOUS. Undated$_d$. Minnesota Chapter of the American Fisheries Society position statement on fish stocking. http://www.fw.umn.edu/mnafs/fishstocking.pdf.

Since the late 1800s fish stocking has been an integral part of fish management in Minnesota. Historically, there occurred many approved and unsanctioned stocking incidents. In order to facilitate the improvement of stocking methods all fish should be marked, explicit stocking goals should be identified, the effects of fish stocking on a specific community should be carefully considered and genetic conservation should remain a priority.

Northern pike have been stocked into Minnesota waters for decades with a variety of results. The majority of pike used for stocking are obtained using traps in shallow, winterkill lakes. These fish have been known to produce significant fisheries. Unfortunately, in some cases, the fish altered the native fish communities by preying upon yellow perch and other species. Because of the threat of negative effects, the stocking of northern pike has been significantly reduced.

For more than 30 years the musky from Shoepack Lake, near the Minnesota-Ontario border were used to stock waters throughout Minnesota. Currently the Mississippi strain from Leech Lake is being used based on its superior growth characteristics.

ANONYMOUS. Undated$_e$. Lindsay District history of fish plantings in the Kawartha lakes. Ontario Department of Lands and Forests. Lindsay, Ontario. 2 p.

Of the ten lakes surveyed (Stony, Balsam, Cameron, Pigeon, Sturgeon, Buckhorn, Clear, Chemong, Katchawanooka and Rice) all were stocked with maskinonge prior to 1937, with Balsam and Stony lakes having received their first plantings in 1930. Plantings have ranged as high as 460,000 for fry and 15,500 for fingerlings. The use of adult fish first began in 1948. Sturgeon and Pigeon lakes have received tagged fish from Nogies Creek continuously since 1952. Stony Lake and Buckhorn Lake have received stock each year because they are the sources of the annual spawn collection.

ANONYMOUS. Undated$_f$. $833 per muskellunge. p. 6. *In* Sport Fishing Institute Bulletin. Washington, D. C.

Coals wastes from a deep mine operation washed into the Little Kanawha River, West Virginia, causing an extensive fish kill last February. Included in the observed fish kill were three muskies over 26 inches in length. The Rochester and Pittsburgh Coal Company offered $2,500 for replacement of the fish but the state fishery chief stated that restocking might not result in improved fishing in the periodically polluted stream.

It was calculated that, to assure three muskie catches equal to the three killed, at least 100 muskies would need to be stocked. At present production prices of one dollar per inch, costs of 100 muskies would require the full $2,500 offered. Instead of restocking, it was proposed that the funds offered be used to intensively survey sources of pollution and the existing fish population of the river.

ANONYMOUS. 1984. Muskie report. South Dakota Game, Fish and Parks Department. St. Pierre, South Dakota. 3 p.

Adult muskies (*Esox masquinongy*) were captured at Amsden Lake near Andover, South Dakota to obtain spawn for intensive culture. The fish were reared in aluminum troughs. It was observed that high fry mortality occurred in both troughs shortly after hatching. Cannibalism, evident at six weeks, was also a cause of mortality. From an original stock of 73,500 fry, only 75 muskie fingerlings, five inches in length, were stocked into inland lakes following 15 weeks of intensive culture at the Blue Dog Lake Fish Hatchery.

ANONYMOUS. 1987. Chautauqua Lake muskellunge. p. 11. *In* 1986-87 Program Report, Division of Fish and Wildlife, New York State Department of Environmental Conservation. Albany, New York.

A decline in the rate of pound net muskellunge captures in Chautauqua Lake prompted the current increased production effort at Chautauqua hatchery. The increased production has been accomplished through reconstruction of the facility and refinement in propagation technique. This includes our recent shift to finishing fingerlings in earthen ponds for one month prior to release. Fingerlings finished in earthen ponds are showing better survival than those finished indoors - eventually this should be reflected in a larger adult population.

APPLEGATE, R. L. 1981. Food selection of muskellunge fry. Progressive Fish Culturist 43(3) : 136-139.

Five genera of invertebrates, collected from a municipal sewage lagoon, were fed to muskellunge (*Esox masquinongy*) fry, which had been placed into tanks, for 23 days. The fry preferred *Moina brachiata* during both day and night (1300 and 2300 hours) and *Cyclops vernalis* at night; they did not prefer *Aspianchna sieboldi*, *Potamocypris* sp., and *Daphnia* sp. Organisms in the foregut of fry collected at 2300 hours were significantly larger, but not more numerous, than those in the foregut of the fry collected at 1300 hours. As the fry grew and the mouth width increased, the size of ingested organisms increased. Fry initially selected the first and second instars of *M. brachiata* and tended to avoid the later instars and adults; by day 23 they selected adults over immature instars. Immature and adult *M. brachiata* appeared to be of adequate size to feed muskellunge fry during alimentary canal development.

ARMSTRONG, A. E. 1963. Tagging and transfer of maskinonge from Maskinonge Lake and Little Vermilion Lake in Sioux Lookout District, 1963. Ontario Department of Lands and Forests. Sioux Lookout, Ontario. 5 p.

A tagging and transfer program was carried out on Maskinonge Lake from May 27 to June 8, 1963. A total of 140 maskinonge were taken by hoop net. Of these, 136 were transferred to Little Vermilion and Minnitaki lakes and released. The fish ranged in length from 21.9 to 40.2 inches, with an average length of 29.3 inches. Age determinations show the growth rate to be slow in comparison with more southerly lakes. This project hoped to improve capture and transfer techniques and to follow up this transfer by studying the survival and growth of these maskinonge in their new environment. The future use of Maskinonge Lake as a rearing pond is discussed.

ARTAMOSHIN, A. S. and L. I. PROKOPENKO. 1980. Role of pike (*Esox lucius*) grown in fish culture ponds in maintenance of a diphyllobothriasis focus. Meditsinskaya Parazitologiya Parazitarnye Bolenzi 49(3) : 51-53.

The possibilities of participation of pike (*Esox lucius*) bred in fish farms in the spread of diphyllobothrial infections caused by *Diphyllobothrium latum* are considered.

AXON, J. R. 1978. An evaluation of the muskellunge fishery in Cave Run Lake, Kentucky. American Fisheries Society Special Publication 11 : 328-333.

Cave Run Lake, 3,347 ha, was impounded in 1974 on the Licking River. The river had a native population of muskellunge but an additional 0.3 fish/ha were stocked above the dam in 1973. Since then, annual stockings of the lake have occurred at the rates of 1.1-3.1 fish/ha; lengths of stocked fish have been 102-356 mm. The largest planting was in 1974: 10,445 fish of 102-305 mm length. Yearly standing crops of muskellunge in coves have ranged between 0 and 0.7 fish (0.04-0.7 kg)/ha. In 1975, anglers took 56 muskellunge (214 kg) of legal size (762 mm minimum length) at a rate of 1 fish/58 hours. In 1976, these statistics improved to 1,029 fish, 4,140 kg, and 1 fish/48 hours. Muskellunge provided 21% by weight of the total angler harvest that year. The 1977 muskellunge take was 478 fish (2,300 kg) at a rate of 1 fish/82 hours. The 1974 year class provided 68% and 78% of the muskellunge harvest in 1976 and 1977, respectively. Muskellunge reach legal length between ages II and IV in Cave Run Lake, compared with ages III-VI in Kentucky streams. Carp and gizzard shad were the only food items identified in stomachs of muskellunge.

AXON, J. R. 1981. Development of a muskellunge fishery at Cave Run Lake, Kentucky, 1874-1979. North American Journal of Fisheries Management 1(2) : 134-143.

The impoundment of Cave Run Lake in 1973-74 eliminated 63 miles of excellent muskellunge (*Esox masquinongy ohioensis*) habitat in Kentucky streams. The formation of this 8,270-acre lake, however, provided an opportunity to create a muskellunge fishery that could more than compensate for the loss of stream habitat by stocking 6 inch fingerlings each year. Investigations were initiated in 1974 to evaluate the success of these stockings. Water quality, fish populations, harvest, and muskellunge age and growth, population size, survival, and exploitation were studied. Cave Run Lake supported a fish population, in the last few years, of 87-151 lb per acre. Yearly fluctuations in biomass were primarily due to standing crops of gizzard shad (*Dorosoma cepedianum*). Muskellunge stocked in 1973 and 1974 grew to 30 inches in total length as early as age II+. After 1976, this length was reached at ages II and IV. The muskellunge fishery developed by late summer of 1975 and, in 1976, anglers creeled 1,029 muskellunge at a rate of one fish per 48 hours of fishing. Although the numbers creeled decreased after 1976, total weight increased. Between 0.61 and 1.15 lb. per acre of muskellunge were harvested annually in 1976-1979. This species also contributed an additional 17-27% to the total pounds of all fish harvested each year during 1976-1979. A management objective of at least a 10% increase over previous yields or a minimum of 1.0 lb of muskellunge harvested per acre was achieved. During 1975-1979, it took an average of 65 hours to harvest a muskellunge. The mean exploitation rate was 23.5% in 1978-1979. Annual natural mortality was 0.54. The estimated population of muskellunge 29.5 inches or longer in 1978 was 2,776 fish. More muskellunge were creeled from the North Fork area than elsewhere in the lake. It was recommended that 9 inch fingerlings be stocked at one fish per acre each year in the tributary arms of the lake.

AXON, J. R. and L. E. KORMAN. 1986. Characteristics of native muskellunge streams in eastern Kentucky. American Fisheries Society Special Publication 15 : 263-272.

The need for more intensive management of the stream fisheries prompted the Kentucky Department of Fish and Wildlife Resources to initiate a muskellunge stream investigation. Fourteen streams were studied from 1980-1983, each during a 1 to 2 year period. Assessments included fish populations, water quality, and morphology for each stream. The mean catch-per-unit-of-effort (CPUE) of muskellunge in the 14 streams was 0.6 fish per hour of electrofishing effort. Highest catches, up to 1.3 fish per hour, were in streams having the most fallen trees. Problems encountered in streams with low or extirpated population of muskellunge were loss of spawning areas due to impoundment, sedimentation, or acidic water conditions. Golden redhorse, longear sunfish, and fallen trees were the most important conditions identified with preferred muskellunge habitat. The supplemental stocking of 6 to 8 inch muskellunge should be continued in streams when benefits to the population and the fishery are evident; streams having suitable muskellunge habitat should be managed for establishment of self-sustaining populations. Present and future concerns for Kentucky muskellunge streams are impacts from oil shale extraction, coal mining, oil-well drilling, clearing of trees in the riparian zone, impoundments and illegal harvest of muskellunge.

BARRY, T. J. 1996. Northern pike spawning marsh management in Connecticut. *In* R. Soderberg [ed.]. 1996 Warmwater Workshop Proceedings – Esocid Management and Culture. Mansfield University. Mansfield, Pennsylvania.

Northern pike are an introduced species in Connecticut and are managed by the production of fingerlings through several spawning marshes. The practice involves selectively stocking pike broodstock into the spawning marsh at a rate of approximately 15 lbs. of female/acre (20.5 kg of female/hectare) and approximately 2-3 males per female. In some cases forage fish are stocked in managed marshes to provide suitable prey for pike fingerlings in an attempt to reduce cannibalism. Water levels are maintained in the marshes until the fingerlings reach the desired size and then the marshes are drained and the fingerlings are collected using weir structures and seines. Fingerling pike are usually given fin clips specific to each marsh and then released directly into weed beds in the recipient lake. Marshes are kept dry from late July to early spring to promote the growth of grassy vegetation and inhibit production of predacious aquatic insects.

Annual production of fingerlings differs greatly between spawning marshes. Estimated egg to fingerling survival also varies between marshes in a given location and year and between years. Between 1990 and 1995, fingerling production (number/ha with an average total length ≥ 100 mm) from all four managed spawning marshes in Connecticut, ranged between 343 and 1,282 fingerlings/ha. Flooding of the marshes is believed to be responsible for the lower survival to fingerling and fingerling production in some years.

Pike stocking rates have varied considerably. Between 1992 and 1995, approximately 900-4,200 pike fingerlings were stocked annually into Bantam Lake. During the same period, between 1,600 and 5,300 fingerlings were stocked annually into Mansfield Hollow Reservoir. Between 1984 and 1995 the number of pike fingerlings stocked annually into the Connecticut River has varied from just 9 fish to over 14,000.

Maintenance of managed spawning marshes includes cutting and removal of undesirable brush and vegetation to maintain the desired grassy vegetation, water level control to keep marshes drained for most of the year, installation of screening devices for beaver control, deepening of drainage channels, raising the level of marsh dikes and repairing access roads.

BARRY, T. and E. MACHOWSKI. 1996. Northern pike (*Esox lucius*) research and management in Connecticut: A preliminary plan for statewide management of northern pike (*Esox lucius*) in Connecticut. Connecticut Department of Environmental Protection. Hartford, Connecticut. 73 p.

The objective is to present a preliminary northern pike management plan including a review of spawning marsh production levels, a literature review and survey to assess other states' and provinces' methods of producing fingerling pike, and an evaluation of the potential for developing additional pike fisheries in Connecticut.

BEAN, Z. 1986. Muskellunge transportation units. American Fisheries Society Special Publication 15 : 344. (Abstract only)

Several fish transportation units were examined and numerically rated by the author for ability to transport muskellunge (*Esox masquinongy*) and hybrid muskellunge (*E. lucius*). Various life support systems including air blowers, bottom draw aerators, surface agitators, and oxygen injection were installed on tanks of varying capacity, construction and locomotion. The factors used in establishing the ranking were practical loading density, initial cost and operation experience. Practical loading density is defined as the ability to maintain the maximum water displacement weight of fish for 4 hours on the primary life support system and 1 hour on any secondary system. Of the factors considered, practical loading density has the greater significance in establishing the numerical rating.

BELL, D. A. 1986. A summary of muskellunge culture techniques used at Chautauqua hatchery in New York State and their application in Ontario. File Report. Ontario Ministry of Natural Resources. Lindsay, Ontario.

The following report documents information collected during a trip to the Chautauqua fish hatchery in New York State and recommends how this information could be used to improve the Deer Lake Fish Culture Station culture program.

The present target size for fingerlings to stock is 15.2 cm (6 inches). This size of fingerling is considered to have sufficient survival to spawning size to contribute to the population. Ontario is presently stocking 7.6-10.2 cm fingerlings. Ontario should continue to evaluate the contribution of these smaller fingerlings and make an effort to raise more larger fingerlings (e.g., 15.2 cm) in the future if an adequate supply of suitable sized minnow can be found. If a larger supply of minnows is not available we should continue to raise as many smaller fingerlings as possible (i.e., 30,000+) until further studies determine if recruitment from the plantings of smaller fingerlings is unacceptable.

The majority of stocked muskellunge are fin clipped. Muskellunge are not anesthetized for clipping. Fingerlings are taken out to the lake and spread along the weed line in the weeds. There appears to be no advantage to stock at night therefore all stocking is done in the daylight.

BELUSZ, L. C. 1975. The use of isolation coves in assessing muskellunge stocking mortality. Proceedings of the Annual Conference of the Southeastern Association of Game and Fish Commissions 29 : 251-253.

A method to determine short-term muskellunge stocking mortality by using isolation coves is discussed. The method allows for free movement and feeding of muskellunge while restricting lakeward movement. Mortality of muskellunge was readily determined with the use of SCUBA. Stocking mortality due to stress of handling and transportation was considered minimal. Observations indicate that future stocking of muskellunge be made in areas of extensive weed cover.

BELUSZ, L. C. 1978. An evaluation of the muskellunge fishery of Lake Pomme de Terre and efforts to improve stocking success. American Fisheries Society Special Publication 11 : 292-297.

Two independent creel census methods (roving and probability) were used to measure fishing pressure and angler success for muskellunge at Lake Pomme de Terre. The two methods provided significant differences in estimated muskellunge harvest and angler effort. The probability method was considered to be more accurate since it utilizes only completed trip information for calculating angler effort. Angler acceptance of muskellunge as a trophy fish has increased since this species was first stocked in 1966. Heavy exploitation of initial releases of muskellunge by anglers in 1972, coupled with limited hatchery production of fingerlings, has resulted in a limited adult population that provides an annual harvest of 100 to 200 muskellunge per year. Stocking mortality of fingerling muskellunge can be very high and delayed releases of muskellunge held in isolation coves showed that the period of greatest mortality occurred within 48 hours. It is suggested that fingerlings be released in areas near aquatic vegetation and that releases be made after dark to reduce stress. Delayed mortality of muskellunge may be caused by latent pathogens under stress conditions associated with transportation and handling.

BELUSZ, L. C. and D. J. WITTER. 1986. Why are they here and how much do they spend? A survey of muskellunge angler characteristics, expenditures and benefits. p. 39-45. *In* G. E. Hall and M. J. Van Den Avyle [eds.]. Reservoir Fisheries Management: Strategies for the 80's. American Fisheries Society. Bethesda, Maryland.

A survey of tournament entrants at the 1981 Pomme de Terre Lake muskellunge tournament was undertaken to identify and evaluate the social and economic benefits associated with the tournament and to estimate the value of the muskellunge fishery to regional and state economies.

On an individual fish basis, the stocking cost per fingerling at Pomme de Terre Lake in 1981 was $17.84 (four year average, 1977-82; range $8.59-$36.97), which includes rearing, distribution and overhead costs. Based on what muskie anglers were willing to spend in 1981, each muskie caught was worth $503 - approximately a 30 fold increase in benefits over cost.

At Pomme de Terre Lake, the average return of stocked muskellunge (through age VII) to the creel from 1966 to 1972 was 39%. More recent estimates show an average return of 31%. Adjusting for survival to harvestable size and using a return of 31% increases production costs to $57.52 per legal fish and reduces benefits from 30:1 to 9:1.

These data indicate that muskellunge stocking programs can provide a high quality, trophy fishing opportunity in spite of characteristically low angler catch rates, and produce substantial economic benefits.

BENDER, T. R. , Jr. Undated. Methods and materials utilized within the Pennsylvania Fish Commission for spawning large esocids. Pennsylvania Fish Commission. Harrisburg, Pennsylvania. 8 p.

Spawning procedures for large esocids are many and varied. To date, a standard spawning protocol has not been established, accepted, and implemented by field personnel. This paper describes techniques and equipment used at Pennsylvania Fish Commission facilities during the esocid spawning season, and attempts to point out the advantages of the procedures, particularly in the areas of egg viability, and human comfort and efficiency. Items discussed include: collection of adults; evaluation of spawning condition; transportation of parent fish to the spawning area; indoor spawning facilities; inclined air bladder spawning rack; spawning, and fertilization of eggs.

BENNETT, G. W. 1974. Management of lakes and ponds. Van Nostrand Reinhold Company. Toronto, Ontario. 375 p.

Numerous stocking combinations involving various species of fish have been studied during the past sixty years, some groupings yielding higher survival rates than others. The northern pike and bluegill combination has been attempted in several central Nebraska ponds 5 acres or larger with positive results. The pike were released as fingerlings and the bluegills as adults so that bluegill offspring would provide forage for the pike.

Muskellunge can also be stocked into ponds; however, the cost of rearing a musky that will survive to 30 inches (to enter the angler's creel) has been estimated at $200. The use of musky, northern pike or walleye to control sunfish populations has been found to be generally unsuccessful.

BERG, L. and D. K. HEPWORTH. 1996. Performance of hybrid striped bass and tiger muskellunge in two southern Utah irrigation reservoirs. Job Completion Report. Publication No. 97-11. Utah Division of Wildlife Research. Salt Lake City, Utah. 19 p.

Tiger muskellunge, hybrid striped bass and forage species were stocked in two irrigation reservoirs (Meadow Reservoir and Forsyth Reservoir) following chemical renovation, to determine survival and growth. Information was also sought on condition and diet of tiger muskellunge and hybrid striped bass.

BEVELHIMER, M. S., R. A. STEIN and R. F. CARLINE. 1985. Assessing significance of physiological differences among three esocids with a bioenergetics model. Canadian Journal of Fisheries and Aquatic Sciences 42(1) : 57-69.

To predict stocking success of esocids in Ohio waters with different thermal regimes, we measured individual food consumption, conversion efficiency, growth, and metabolic rate for Ohio stocks of northern pike (*Esox lucius*), muskellunge (*E. masquinongy*) and their hybrid, tiger muskellunge, in laboratory experiments. The first three parameters were quantified during 2-week experiments of *ad libitum* feeding on fathead minnows (*Pimephales promelas*) at seven constant temperatures (5, 15, 20, 22.5, 25, 27.5, and 30º C). The food consumption and growth data suggest that northern pike should grow faster than muskellunge at cool temperatures (≤20º C), but slower than muskellunge at warm temperatures (>25º C). Latitudinal differences in their natural distributions might explain this observation. Growth data of the hybrid showed no such obvious relationship to either of the parents. Metabolic rates were determined by measuring oxygen consumption in a closed, static respirometer at five constant temperatures (5, 15, 20, 25, and 30º C). We found little difference in metabolic rates among the three taxa. To examine these data further, we used a bioenergetics model that simulated different stocking conditions, both natural (thermal regime and prey availability) and human controlled (stocking size and date). With this model, we predicted growth for 12-15 months after stocking. In general, summer-stocked fish were about 35-90% larger 15 months after stocking than were fall-stocked fish 12 months after stocking. More specifically, the combined effect of ration and temperature permitted hybrids to grow faster than the parents in all simulations. Northern pike grew larger than muskellunge in a cool system, but smaller than muskellunge in a warm system with summer stocking. Based on bioenergetic considerations, tiger muskellunge should outgrow both northern pike and muskellunge in thermal regimes common to Ohio waters.

BEYERLE, G. B. 1971. A study of two northern pike-bluegill populations. Transactions of the American Fisheries Society 100(1) : 69-73.

Northern pike and bluegill populations were established and maintained for 3 years in two small lakes closed to fishing. Growth of pike was slightly less than the average for pike in Michigan; growth of bluegills ranged from 3.6 to 7.4 cm (1.4 to 2.9 inches) below state average. High densities of pike (68 to 78 per ha; 28 to 32 per acre) did not control an abundance of bluegills. Survival of pike from the initial stocking was extremely high (44-60%), whereas survival from subsequent plantings was low (0.8-9.2%).

BEYERLE, G. B. 1972. Contribution of northern pike fingerlings raised in a managed marsh to the pike population of an adjacent lake. Research and Development Report No. 274/Institute for Fisheries Research Report No. 1789. Michigan Department of Natural Resources. Lansing, Michigan.

A yearly average of 4,827 marked fingerling northern pike were stocked from a managed marsh into a 289 acre adjacent lake for 3 consecutive years. Estimated mean yearly survival of these pike through fall of the first year was 1,339 (28%). Estimated mean yearly survival of naturally produced pike was 821, making a total of 2,160 young-of-the-year pike surviving to fall each year. Growth of both stocked and naturally raised pike was well above Michigan state average: after 3 years of growth, stocked pike averaged 3.5 inches longer than state average, and naturally raised pike averaged 2.1 inches longer. This rapid growth would indicate that the stocking rate of pike could be increased substantially with significant benefit to the fishery.

We were unsuccessful in using Bergman-Jefferts magnetic tags to mark fingerling pike for long-term experiments. Although the tagging operation caused no obvious mortality, the inconsistency of response of supposedly tagged pike, when checked on the tag detector, was unexplained.

BEYERLE, G. B. 1973$_a$. Comparative growth, survival and vulnerability to angling of northern pike, muskellunge and the hybrid tiger muskellunge stocked in a small lake. Fisheries Research Report 1799. Michigan Department of Natural Resources. Lansing, Michigan. 11 p.

BEYERLE, G. B. 1973$_b$. Growth and survival of northern pike in two small lakes containing soft-rayed fishes as the principal source of food. Fisheries Research Report No. 1793. Michigan Department of Natural Resources. Lansing, Michigan. 19 p.

Fingerling northern pike were stocked for 3 years in 2 small lakes, one containing only minnows and the other containing minnows and young coho salmon.

BEYERLE, G. B. 1978. Survival, growth and vulnerability of northern pike and walleye stocked as fingerlings in small lakes with bluegills or minnows. American Fisheries Society Special Publication 11 : 135-139.

For northern pike stocked as fingerlings in small lakes with bluegills, survival was high after 3 years for the initial plant but very low for the succeeding two plants. Growth was moderate through age I but slow thereafter, despite an abundance of edible size bluegills. Survival and growth were generally better when northern pike were stocked in lakes with minnows. In one lake, supplementary stocking of young salmonids was necessary to stimulate rapid growth of larger northern pike. In a lake with bluegills, survival of age II and age III walleye was high but growth was slow. In a lake with minnows survival of all three age groups of walleyes was consistently higher and growth was considerably faster than in the lake with bluegills. Northern pike were more vulnerable to angling than walleyes. However, both species were relatively easy to catch. Small lakes offer excellent opportunities to optimize survival, growth, and return to the angler of predator fishes stocked as fingerlings.

BEYERLE, G. B. 1980. Contribution to the anglers creel of marsh-reared northern pike stocked as fingerlings in Long Lake, Barry County, Michigan. Fisheries Research Report 1876. Michigan Department of Natural Resources. Lansing, Michigan. 22 p.

From 1973 to 1975 marsh-reared northern pike were stocked into Long Lake, Barry County, at the average rate of 40 fingerlings per hectare, per year, at a cost of $0.020 each. Survival of these fish to the anglers' creel varied from 15.8 to 36.3% (mean 23.7%). The harvest of each year class was essentially complete 4 years after stocking. Marsh-reared fish provided 65.1% of the total harvest from the 1973-75 year classes of northern pike. The cost to produce the harvested marsh-reared northern pike was $0.87 per fish, or $0.70 per kilogram.

During the study the growth of panfish remained within the anticipated range for southern Michigan lakes. There was no fluctuation in harvest of panfish or largemouth bass that could be related to abundance of northern pike. It was suggested that the stocking rate of northern pike could be increased to 8,000 fingerlings (68.4 per ha) with no detrimental effect on other fish species in Long Lake.

BEYERLE, G. B. 1981. Comparative survival and growth of 8.9 and 17.8 cm (3.5 and 7.0 inch) tiger muskellunge planted in a small lake with forage fishes. Fisheries Research Report 1894. Michigan Department of Natural Resources. Lansing, Michigan.

Fingerlings measuring 8.9 cm in length had a higher survival rate (36%) than 17.8 cm fingerlings (15.1%). No significant difference was found between the size of the two fingerling planting sizes at ages 1 and 2.

BEYERLE. G. B. 1984$_a$. Comparative survival of pellet-reared muskellunge stocked as fingerlings in bluegill ponds with and without largemouth bass. Fisheries Research Report 1920. Michigan Department of Natural Resources. Lansing, Michigan.

For three consecutive years (1980-82), 5.7 to 6.5 inch tiger muskellunge fingerlings were stocked at the rate of 10 per acre in four 3.0 to 4.0 acre ponds at Almena, Van Buren County, Michigan. These ponds contained either forage fish only (mainly bluegills) or forage fish and adult largemouth bass (9.0 inches or larger). The survival of muskellunge was correlated to the density of largemouth bass 12.0 inches and longer; mean survival to fall of tiger muskellunge stocked as 6.0-7.0 inch fingerlings in lakes with known densities of largemouth bass of 12.0 inches and longer was predicted. Data on the number and weight of bluegills and golden shiners collected from the Almena Ponds in the fall of 1982 are provided.

BEYERLE, G. B. 1984$_b$. An evaluation of the tiger muskellunge stocking program in Michigan. Fisheries Research Report No. 1924. Michigan Department of Natural Resources. Lansing, Michigan. 55 p.

In Michigan, the hybrid tiger muskellunge is utilized as a relatively easy to catch, trophy-sized esocid. In 1982, about 16,112 Michigan anglers harvested 13,447 tiger muskellunge, one for every 10 angler days of fishing.

A change from extensive to intensive hatchery rearing techniques in 1976 resulted in a five-fold increase in annual fingerling production and a 50% increase in managed tiger muskellunge lakes, but a considerable decrease in fingerling survival and angling quality. Subsequently, it was found that extensively-reared fingerlings stocked at about 8 inches in early July had 4 to 16 times higher survival than intensively-reared fingerlings stocked at 6 to 7 inches in early August. Attempts to enhance survival of intensively-reared fingerlings by early or late stocking were not successful.

Four factors important to survival of stocked fingerlings were time of stocking, size at stocking, predator density, and density of small soft-rayed forage fishes.

Management recommendations include a return to extensive fingerling rearing techniques. Returns from 30,000 extensively reared fingerlings will equal those from 200,000 intensively-reared fingerlings, at the current program level. But, if intensive rearing techniques continue, fingerling stocking rate should be increased 600% in lakes with good populations of tiger muskellunge. Stocking of tiger muskellunge should cease in lakes with demonstrated poor fingerling survival. The fish populations and angling quality in managed lakes should be monitored more closely. Fishing regulations should be modified to reflect the image of the tiger muskellunge as a trophy fish.

BEYERLE, G. B. 1984$_c$. Survival and growth of early and normal plant tiger muskellunge stocked in a small lake with forage fish and largemouth bass. Fisheries Research Report No. 1923. Michigan Department of Natural Resources. Lansing, Michigan. 12 p.

Survival and growth rates were determined for tiger muskellunge fingerlings stocked for three consecutive years in a 15-acre lake with bluegills, golden shiners and an average population of largemouth bass.

BEYERLE, G. B. and J. E. WILLIAMS. 1973. Contribution of northern pike fingerlings raised in a managed marsh to the pike population of an adjacent lake. Progressive Fish Culturist 35(2) : 99-103.

In summary, an average of 4,827 fingerling pike per year were marked and stocked into Long Lake for 3 consecutive years. An estimated average of 1,339 of these pike-per-year survived to fall of their first year. Together with an estimated yearly recruitment of 821 young-of-the-year pike from natural reproduction, an average of 2,160 young-of-the-year pike existed in Long Lake each fall. Assuming an annual 50% natural mortality beyond the first year and a 25% angling harvest of pike 508 mm (20 inches) and over in length, it can be calculated that during the lifespan of one year class of marked pike, 166 fish (3.4% of fingerlings stocked) will be harvested by anglers. During the same period 84 of the unmarked pike will be harvested, making a total contribution to the fishery of 250 pike of each year class, and a total yearly harvest of 250 pike. After 3 years of growth, marked pike in Long Lake averaged 3.5 inches longer than the State average, and unmarked pike were 2.1 inches longer. This rapid growth plus the calculated yearly harvest of less than one pike per acre would seem to indicate that the stocking rate of fingerling pike in Long Lake could be increased substantially with great benefit to the fishery.

BIMBER, D. L. 1982. Longevity, growth and mortality of muskellunge in Chautauqua Lake, New York. New York Fish and Game Journal 29(2) : 134-141.

Growth and mortality of muskellunge in Chautauqua Lake were estimated from data collected during spring netting of broodstock from 1962 to 1977. Females grew faster and had a higher survival than males. Females usually reached reproductive maturity in their fifth spring at a mean length of 77 cm. Most males matured by age 4 at a mean length of 67 cm. Growth differences between hatchery and native stocks were not significant. Mean condition factors (K) for spawning fish were 0.641 for females and 0.584 for males. Adult muskellunge exhibited a length-weight relationship of log W = -6.70 + 3/51 log total length (TL). Pooled data from seven year classes (1961-1967) indicated survival rates of 0.85 and 0.69 for females and males, respectively.

BONIN, J. D. and J. R. SPOTILLA. 1978. Temperature tolerance of larval muskellunge (*Esox masquinongy*) and F_1 hybrids reared under hatchery conditions. Comparative Biochemistry and Physiology 59A : 245-248.

BORGESON, D. P 1987. Michigan fish stocking guidelines. Fisheries Division, Michigan Department of Natural Resources. Lansing, Michigan. 32 p.

Muskellunge are available for stocking as fry in April-May, 2-4 inch fingerlings in May-June and as 5-10 inch fingerlings in September-October. Muskellunge fingerlings between 3-10 inches may produce good results depending on the availability of forage fish but most situations will demand the larger sizes.

The muskellunge stocking program involves the stocking of strategically-located, sizable lakes on the premise that these large, spectacular fish will add excitement, variety and quality to the state's overall fisheries picture. Planting of muskellunge shall be restricted to lakes which are not scheduled for any type of trout or salmon management or lakes which are not scheduled for routine bluegill thinning operations. Musky fingerlings (8-12 inch) should be stocked annually or biannually at the rate of 2-4 per acre. Smaller muskies (3-6 inches) may be stocked at slightly higher rates. Northern muskellunge fingerlings will be stocked in broodstock lakes to maintain assured sources of eggs for future production.

Northern pike may be reared to 2-4 inches in hatcheries or spawning marshes for release into adjacent lakes. Northern pike fry should be stocked in spawning marsh areas at rates of approximately 10,000 per acre or, if fry are not available, 5 pounds of females may be stocked per acre with sufficient accompanying males for fertilization. If adults are used, care should be taken to assure that they are in excellent spawning condition. To discourage the spread of red sore or lymphosarcoma, northern pike should not be transferred from waters suspected of harboring these diseases.

BRAUN, E. R. and J. PEARSON. 1980. An evaluation of musky stocking in northeast Indiana. File Report. Indiana Department of Natural Resources. Indianapolis, Indiana.

BREGE, D. A. 1984. A comparison of muskellunge and hybrid muskellunge in a southern Wisconsin lake. American Fisheries Society Special Publication 15 : 203-207.

A comparison of age and growth, return to the creel, and harvest size characteristics was made for muskellunge and hybrid muskellunge in Little Green Lake, Wisconsin. Most hybrids reached 30 inches by their fourth summer while most muskies attained that length by their fifth summer. Since 1963, in a voluntary musky registration program, an average of 108 muskellunge and 125 hybrid muskellunge have been recorded annually. Anglers have registered 11.6% of the musky stocked and 14.6% of the hybrid musky stocked; their average size was 33.1 and 31.6 inches, respectively. Total harvest was 2.03 lbs./acre for musky and 1.98 lbs./acre for hybrids. Exploitation rates were 26.6% for musky and 33.3% for hybrid musky. Live bait was used to catch 55.1% of the hybrids while artificial baits accounted for 87.0% of the musky caught. Since 1972, 147 muskellunge and 128 hybrids have been caught and released. Due to the hybrid's greater vulnerability to angling, muskellunge may be the better choice for stocking intensive-fished waters.

BREWER, D. L. 1968. Muskie studies. Federal Aid Project, Job Nos. 1 (A-E), Project Progress Report. Kentucky Department of Fish and Wildlife Resources. Frankfort, Kentucky. 50 p.

The muskellunge (*Esox masquinongy*) is found in 22 Kentucky streams. Four musky streams are located in south-central Kentucky (the Green River system) and the remaining 18 are all in eastern Kentucky. Muskies are also found in the Ohio River.

Pollution from coal mining is threatening a number of musky streams. Musky have become virtually extinct in the North Fork of the Kentucky River as a result of acid and silt pollution. The musky in Goose Creek on the upper South Fork of the Kentucky River is in real danger of extinction. Highway construction along the North Fork of Triplett Creek is posing a serious threat to the morphology of that stream.

Impoundments are also destroying much of the state's natural musky habitat. Impoundment of Buckhorn Reservoir on the Middle Fork of the Kentucky River and Barren River Reservoir has most assuredly seriously restricted spawning and very probably has exterminated the musky upstream from the dam sites. The impoundment of Cave Run Creek Reservoir on the Licking River will destroy 60 miles of natural musky habitat and the proposed Red River Reservoir will cover 15-20 miles of present musky waters.

The Cumberland River supported a musky population prior to its impoundment. Twenty-five thousand (25,000) musky fry were stocked into Cumberland Lake during 1966, but to the present time, none have been recovered. Improving musky populations in Kentucky will depend a great deal on the success of future reservoir stockings.

BROWN, E. H. 1962. Evaluation of muskellunge stocking. Dingell-Johnson Federal Aid Project Report. Ohio Department of Natural Resources. Columbus, Ohio.

BRY, C. 1980. The effect of the initial population density on the survival and growth of pike (*Esox lucius*) stocked as three-month fingerlings. p. 317-323. *In* R. Billard [ed.]. Pond Fish Farming. Symposium on Fish Production in Ponds. Arbonne-la-Foret, France.

The consequences of overstocking pike fingerlings on number and biomass yields were examined. Three 240 m^2 ponds were stocked in June with non-graded pike fingerlings averaging 7 g at 3 densities: 7 fish/100 m^2 (lot BD), 14 fish/100 m^2 (lot MD), 33 fish/100 m^2 (lot HD). During the experiment, food sources were similar in each pond. Nine months after stocking the ponds were drained. The final number of pike was about the same in all the lots: 7-8 pike/100 m^2. Survival rates were 100% (lot BD), 59% (lot MD), 24% (lot HD). The mean weight of the pike recovered was an inverse function of initial density: 160 g (BD), 102 g (MD), 79 g (HD). In all the lots the relative variability of individual weight (the coefficient of variation) exhibited a considerable decrease from the beginning to the end of the experiment. The net pike biomass yielded in 9 months was an inverse function of the initial population density: the lot BD produced 2.7 times more than the lot HD (1,020 g/100 m^2 versus 377 g/100 m^2). These results suggest that stocking density should be carefully chosen in order to avoid poor yields resulting from overstocking.

BRY, C. and Y. SOUCHON. 1982. Production of young northern pike families in small ponds: Natural spawning versus fry stocking. Transactions of the American Fisheries Society 111(4) : 476-480

In small experimental ponds, the stocking of 5-10 fry/m^2 of northern pike (*Esox lucius*) yielded 0.9-2.6 young/m^2 after 50 days in April-May. A similar numerical density of young (0.9-4.0/m^2) was attained by stocking one northern pike female and two males per pond in February and harvesting the fish in May. In the latter case, the stocking rate corresponded to an average egg density of about 60 eggs/m^2. The two methods also provided comparable biomasses of juveniles (41 and 52 kg/hectare averages, respectively). Higher stocking densities might improve production by both methods, but the use of natural spawning may provide a less difficult and expensive – yet equally effective – means of producing young northern pike in small ponds, compared with traditional fry-stocking procedures.

BUCHANAN, I. and B. LeBEAU. 2000. Muskellunge restoration feasibility study, Lake Simcoe, Ontario. Ontario Ministry of Natural Resources. Aurora, Ontario. 73 p.

The stocking of muskellunge into Lake Simcoe occurred between 1931 and 1969 in response to a sharp decline in population numbers. Despite stocking (a total of 1,088,000 fry and fingerlings from the Deer Lake Hatchery), the species disappeared almost completely.

The strain of muskellunge stocked was from the Kawartha Lakes, which is different in its genetic make-up than the Great Lakes strain native to Lake Simcoe. The stocking of the Kawartha Lakes strain caused:

- Increased competition for resources;
- Dilution of the native muskellunge gene pool; and
- Increased muskellunge harvest due to the elevation of angler expectations.

It is thought that the negative impacts occurred at the same time as the increase of carp and northern pike which contributed to the decline.

In order to restore the muskellunge population harsh fishing regulations need to be implemented and site stocking of muskellunge fry and fall stocking of fingerlings must begin.

BUIE, G. D. 1960. Omemee maskinonge hatchery. Ontario Department of Lands and Forests, Weekly Report of the Lindsay District, July 25, 1960. Lindsay, Ontario.

The first known instance of artificial maskinonge propagation in Ontario occurred at Omemee in 1927. In 1927, 1928 and 1929 fish were stripped of eggs and the eggs were sent to a hatchery in Belleville. Young maskinonge were later returned and released into Pigeon Lake and waters of the Kawartha chain. At the Omemee hatchery fry were reared in jars set up in two tents and later released into Pigeon Lake and nearby waters. Between 1930 and 1934 it is estimated that 1.5 to 2 million fry were hatched annually.

BUSS, K. 1960. The muskellunge. Special Purpose Report. Pennsylvania Fish Commission, Benner Spring Fish Research Station. 14 p.

The range of the muskellunge has been shrinking due to northern pike invasion. In Wisconsin there is a trend toward stocking larger muskellunge. In 1950, 188 tagged yearlings were planted into High Lake, Wisconsin, and, three years later, 15 tagged fish were recovered, representing 40% of the total catch. This percentage is high seeing as many of the planted yearlings would not yet have reached legal size.

In an experiment conducted in Ontario, it was discovered that transferred muskies (from sanctuary waters to open waters) resulted in a 30% return, the majority being in the first summer. It was also found in Canada that preopercular tags retarded annual growth by 20 to 80% and increased mortality.

CARLANDER, K. D. 1957. Disturbance of the predator-prey balance as a management technique. Transactions of the American Fisheries Society 87 : 34-38.

Disturbance of the predator-prey relationship may result in increased angler success and may sometimes provide an effective management tool. Exceptional harvest of walleyes (*Stizostedion vitreum*) in Clear Lake, Iowa, in 1951, is perhaps explained by reproductive failure of yellow perch (*Perca flavescens*) in 1950 and by elimination of young bass (*Morone interrupta*) through more than normal predation. Stocking of 5 northern pike (*Esox lucius*) per acre in the fall of 1953 increased the weight of the predator population by about 10%. In the first 6 weeks of the next fishing season, over 20% of the stocked northerns were caught by anglers.

CARLANDER, K. D. and J. G. ERICKSON. 1953. Some population estimates of young northern pike reared in a marsh. Presented at the 15th Midwest Wildlife Conference, December 10, 1953, Chicago, Illinois. 3 p.

Ventura Marsh, which drains into Clear Lake, Iowa, was used this past summer as a rearing pond for northern pike. In March, 100 females and 200 males were transferred from Clear Lake along with 3 million hatchery-reared fry. In August, anglers began to catch small northern pike approximately 11 inches in length. The population in the marsh in October was estimated to be 30,000 young pike (50 per surface acre), which indicates a survival rate of 0.75% from the estimated natural and hatchery propagation combined.

CARLANDER, K. D. and R. RIDENHOUR. 1955. Dispersal of stocked northern pike in Clear Lake, Iowa. Progressive Fish Culturist 17(4) : 186-189.

The results of this tagging experiment indicate that stocked northern pike move to all parts of Clear Lake within 6 months, even if stocked at one end. Although the movement is extensive and general, there is evidence that the fish stocked in some areas do not get to areas at the other end of the lake in quite the same abundance. A longer period of time between stocking and capture of the fish might eliminate even this slight difference in their distribution.

CARLINE, R. F., R. A. STEIN and L. M. RILEY. 1986. Effects of size at stocking season, largemouth bass predation, and forage abundance on survival of tiger muskellunge. American Fisheries Society Special Publication 15 : 151-167.

We conducted studies in the laboratory, experimental ponds (0.8 and 2.0 hectares), and small impoundments (69 and 253 hectares) to define temporal patterns of tiger muskellunge mortality and to identify factors controlling their mortality and growth. Total mortality 50 days after stocking in ponds of impoundments ranged from 5 to 100% and averaged about 70% in 16 trials. Mortality of hybrids due to stresses associated with transport, handling and temperature changes at stocking water were reduced when fish were stocked in early autumn at water temperatures below 20º C. Mortality attributable to predation by largemouth bass ranged from 0-100% (mean 30%) and was related directly to largemouth bass densities and inversely to indices of abundance of largemouth bass prey. Predation on hybrids was most intense when small fish (168-184 mm long) were stocked in summer and was inconsequential when large hybrids (196-225 mm) were stocked in autumn. The presence of aquatic macrophytes did not influence intensity of predation by moderate to high densities of largemouth bass, even though hybrids preferred vegetated areas.

Overwinter survival of hybrids was directly related to their length. Largest hybrids (mean length 225 mm) had highest survival to spring (at least 40%) and to the following autumn (13%). Hybrid diet was related to prey type, density and size. When gizzard shad were present, they were the most common prey, and growth of hybrids was faster in lakes with a gizzard shad-cyprinid forage base than in lakes with only centrarchids. Because hybrid growth was positively related to prey density and hybrid size was directly related to survival, an assessment of available forage should provide guidance on number and size of hybrids to stock in a given lake. By stocking relatively large hybrids in autumn, short-term survival can be enhanced. However, factors affecting overwinter survival need to be identified before appropriate measures can be developed to increase survival to age 1.

CASSELMAN, J. 1978. Monitoring the exploitation of muskellunge and determining the utilization of stocked hatchery muskellunge: A proposed method. Ontario Ministry of Natural Resources. Toronto, Ontario. 4 p.

It is suggested that hatchery fish be injected with a fluorochrome in order to determine from the cleithrum whether or not the fish had been stocked. The use of different colours could be implemented to attribute an individual to a specific stocking. This method would allow the establishment of fish origin even in the field.

CATION, G. 1978. Deer Lake hatchery operations. Presented at the Seminar on Muskellunge Management in Central Ontario, September 26, 1978, Lindsay, Ontario.

Up to seventy-five percent of the fingerlings produced at the Deer Lake Hatchery are stocked into Lindsay District lakes.

CHAPLEAU, C., S. FINDLAY and E. EZENASY. 1997. Impact of piscivorous fish introductions on fish species richness of small lakes in Gatineau Park, Québec. Ecoscience 4(3) : 259-268.

Fish communities of small lakes (<61 ha) of Gatineau Park (Québec, Canada) which originally lacked piscivores were studied to assess the impact of piscivorous fish introductions over the past 85 years. Total species richness was not significantly different between lakes with (N = 15) or without (N = 22) introduced piscivores. However, small-bodied species richness (mainly cyprinid) was significantly lower (nearly half) in lakes with piscivores. Lakes with piscivores (those containing yellow perch, northern pike, largemouth bass or smallmouth bass) showed communities dominated by large or deep-bodied species (mainly Castomidae, Percidae and Centrarchidae) whereas lakes without piscivores contained mostly small-bodied species (mainly Cyprinidae, Umbridae and Gasterosteidae). Few relationships were found between morphometric variables and fish richness variables. Total fish species richness was found to be a positive function of area and a negative function of elevation when all lakes (n = 45) of the park are considered. For the small lakes of the park, small-bodied species (and cyprinid species) richness in lakes without introduced piscivores was inversely related to the elevation of the lake. Such a relationship was not observed for small lakes with introduced piscivores possibly because of the disruptive effect of piscivores on small-bodied species number. These results suggest that piscivory by the introduced species is probably responsible for the local extinction of many small-bodied species. Long-lived large-bodied and deep-bodied species (often with spines) are better able to withstand intense predation pressure due to their large size and the dissuasive effects of spines on fins. Because five native small-bodied species were found only in lakes lacking piscivores, it is predicted that their local extinction would occur if introduced piscivores establish populations in these lakes. Thus, small piscivore-free lakes with high small-bodied fish species diversity should rank high on the conservation priority lists of north temperate parks in order to maintain native fish biodiversity.

CHOLMONDELEY, R., M. ECKERSLEY and L. DEACON. 1989. A feasibility study of stocking muskellunge in the St. Lawrence River. St. Lawrence River Fisheries Management Unit Report 1989-01. Ontario Ministry of Natural Resources. Brockville, Ontario. 36 p.

This working group attempted to determine if stocking was a viable option for rebuilding the St. Lawrence River muskellunge population. This was done by examining historical data on the river's fishery, evaluating the role and potential for success of muskellunge in the St. Lawrence River and other waterbodies, and identifying the collection, rearing and stocking requirements for the river. Extensive culture of muskellunge in Ontario does not appear to provide the quantity of quality-sized fingerlings required for St. Lawrence River stocking. Fry planting is rejected as an option as sufficient quantities of fry could not be obtained to have an impact. With the apparent trend in muskellunge culture moving towards the more cost-effective intensive culture technique to produce higher quality fall fingerlings, the development of a CFIP program based on extensive culture is not a recommended alternative.

CLAPP, D. F. and D. H. WAHL. 1996. Comparison of food consumption, growth, and metabolism among muskellunge: an investigation of population differentiation. Transactions of the American Fisheries Society 125 : 402-410.

We conducted laboratory evaluations of food consumptions, growth, and metabolic rate as functions of water temperature (5-27.5º C) to examine how the young-of-year in six populations of muskellunge (*Esox masquinongy*) (Kentucky, Minnesota, New York, Ohio, St. Lawrence River and Wisconsin) from three drainages might perform under various thermal regimes. Relative food consumption ($g \cdot g^{-1} \cdot d^{-1}$) and growth ($g \cdot g^{-1} \cdot d^{-1}$) were similar among populations at lower temperatures (5 and 10º C), but at higher temperatures (15-27.5º C) fish from Wisconsin and Ohio had higher consumption and faster growth rates than fish from Kentucky and the St. Lawrence River. Metabolic rates increased with temperature from 0.08 mg O_2 $g^{-1} \cdot h^{-1}$ at 5º C to 0.25 mg O_2 $g^{-1} \cdot h^{-1}$ at 25º C, but few differences in metabolic rates were observed among populations at any temperature. Although we found bioenergetic differences among muskellunge from these populations, they could not be explained solely in terms of thermal adaptation or previously defined genetic groupings. Energetic differences among age-0 muskellunge have important implications for conserving existing esocid populations and managing introduced populations.

CLAPSADL, M. D. 1993. An examination of habitat characteristics influencing the survival of stocked muskellunge (*Esox masquinongy*) in four St. Lawrence River embayments. M. Sc. Thesis, New York State College. Syracuse, New York. 72 p.

Habitat characteristics were examined in four St. Lawrence River embayments during 1990 and 1991. Two of the bays are utilized by muskellunge (*Esox masquinongy*) for spawning and two are not. Size, density and species composition of forage fish and aquatic macrophytes were examined. *Chara* sp. effects on dissolved oxygen levels and muskellunge yolk sac larvae survival were also examined. Larval muskellunge were stocked and growth and catch-per-unit-effort were compared between reproductive and non-reproductive sites.

Differences in forage were found between reproductive and non-reproductive sites. Sac fry held in dialysis tubing on substrate covered by *Chara* experienced higher mortality rates (as much as 100%) than on any other substrate. Depressed dissolved oxygen levels below *Chara* are probably the cause of mortality. Vegetation, including *Chara*, was higher and more dense in non-musky sites during the spawning period, appearing to offer less suitable habitat for muskellunge reproduction through lowered sac fry survival.

CLARK, C. F. 1954. Experimental propagation of northern pike at the St. Mary's Fish Farm. *In* Proceedings of the 16th Midwest Fish and Wildlife Conference, St. Louis, Missouri.

CLARK, C. F. 1964. Muskellunge in Ohio and its management. Publication W-329. Division of Wildlife. Ohio Department of Natural Resources. Columbus, Ohio. 18 p.

CLARK, J. H. 1974. Variability of northern pike pond culture production. Colorado State University, Department of Fishery and Wildlife Biology Thesis. Fort Collins, Colorado. 35 p.

CLARK, J. H. 1975. Management evaluation of stocked northern pike in Colorado's small plains reservoirs. Ph. D. Dissertation, Colorado State University. Fort Collins, Colorado. 66 p.

CLARK, T. L. 1984. Muskellunge rearing at Union City Fish Culture Station, Commonwealth of Pennsylvania. Pennsylvania Fish Commission. Harrisburg, Pennsylvania. 4 p.

The rearing of muskellunge fry is documented. On May 15, 1984, the Union City hatchery received 77,000 swim-up fry. On August 10, 2,843 fish were harvested for stocking and the beginning of the stocking of 6 inch fish began on September 11 with the shipment of 18,000 fingerlings. By October 4th, all fish had been stocked from the hatchery, a total of 37,108.

CLAY, C. 1973. 1973 pond emptying. Rice Lake Tourist Association News Letter 15(8) : 1.

On July 11, 1973, the Rice Lake Tourist Association musky rearing pond was emptied of approximately 6,000 fingerlings. These fish were widely distributed around the lake by Association members who had paid their dues. Each paid-up member received 200 fingerlings. It was calculated that the value of the 6,000 fingerlings was $1,306.00 (Canadian).

CLAY, C. 1974. 1974 pond emptying. Rice Lake Tourist Association News Letter 16(7) : 1.

The Association Muskie Rearing Pond activities for this year were a success. On July 17, six thousand fingerling muskie were distributed by 30 resort operators in Rice Lake waters adjacent to their resorts.

COLESANTE, R. T. 1974. A preliminary evaluation of the muskellunge-northern pike hybrid as a game fish for New York State. Federal Aid Project F-9-R. New York State Department of Environmental Conservation. Albany, New York. 26 p. + appendices.

Stocking is only one component of the management of the muskellunge in New York. It has been found that the larger the muskellunge at the time of stocking, the greater are its chances of survival. Percent chance of survival to age IV has been calculated for hatchery-produced muskellunge of various stocking sizes:

- 2 inches (at stocking) equals a 1.0% chance of surviving to age IV;
- 3 inches, a 1.2% chance;
- 4 inches, a 1.5% chance;
- 5 inches, a 2.0% chance;
- 6 inches, a 3.4% chance;
- 7 inches, a 5.5% chance;
- 8 inches, a 9.5% chance; and
- 9 inches, a 19% chance.

It is also acceptable to assume that these figures apply to tiger muskellunge.

Michigan stocks 6-9" muskellunge fingerlings at a rate of 2-4 per acre on an annual or biennial basis, and stocks fry and/or two inch fingerlings after chemical reclamation, provided there are low predator levels. Pennsylvania currently stocks tiger muskellunge fry at the rate of 100-150 per acre and also stock fry in impoundments where the presence of predators is minimal. This state also has evidence that the planting of fry in streams may result in some success. When lakes have been previously stocked, or plantings are done so supplementally, then Pennsylvania stocks tiger muskellunge at a rate of 2-20 fingerlings per acre.

New York stocks muskellunge at a rate of two 6-9" fingerlings per acre, however, availability of fish affects the stocking rate. It is believed that these rates can also be applied to tiger muskellunge.

COLESANTE, R. T., R. ENGSTROM-HEG, N. EHLINGER and N. YOUMANS. 1981. Cause and control of muskellunge fry mortality at Chautauqua Hatchery, New York. Progressive Fish Culturist 43(1) : 17-20.

In 1966-1967, 1970, and 1973-1976, New York State's muskellunge (*Esox masquinongy*) hatchery, located on Chautauqua Lake, sustained total or near total losses of muskellunge fry at or near the swim-up stage of development. Eggs incubated at the Chautauqua hatchery and transferred to other stations resulted in swimming fish, but those held at Chautauqua did not. The chemistry of the lake and well water at the muskellunge hatchery showed no departures from normal. During the production seasons of 1974 through 1976 the hatchery was operated on a controlled, experimental basis in an attempt to determine the cause of the fry losses. Fry die-offs could be correlated with neither the physical or chemical properties of the water nor with the presence of a fish pathogenic virus or pathological tissue changes. Controlled laboratory experiments strongly implicated *Pseudomonas* sp., although *Aeromonas hydrophila* was also indicated; both are well-known fish pathogens. Ultraviolet treatment of lake and well water supplies during incubation and yolk absorption resulted in effective control of fry losses.

COOK, K. D. 1978. Evaluation of non-native fish introductions (northern pike). Fisheries Report F-021-D-13. Oklahoma Department of Wildlife Conservation. Oklahoma City, Oklahoma. 11 p.

COWYX, I. G. 1994. Stocking strategies. Fisheries Management and Ecology 1 : 15-30.

Stocking, transfer and introduction of fish are commonly used to mitigate loss of stocks, enhance recreational or commercial catches, restore fisheries or to create new fisheries. However, many stocking programs are carried out without definition of objectives or evaluation of the potential or actual success of the exercise. Stocking strategies need to account for the suitability of the water being stocked, ecological interactions, source of fish, stocking density, size/age of fish to stock, timing of the stocking event and the mechanism of stocking. The potential genetic, ecological and environmental impacts of stocking are described.

CRAIG, R. E. 1976. The Niagara River maskinonge (*Esox masquinongy*). Ontario Ministry of Natural Resources. Fonthill, Ontario. 7 p.

Within the Niagara district the musky is most abundant in the upper Niagara River. Between 1941 and 1955 New York State stocked Chautauqua Lake musky fry into the Upper Niagara River and presumably this program was discontinued due to a lack of impact on the fishery. Since 1960, the Ontario Department of Lands and Forests has stocked 16,860 fingerlings into the river. Annually, 660 to 3,000 fish were planted, with the exception of the years 1966, 1967 and 1975. On several occasions fish were tagged or clipped. To date no tags have been returned. There is a strong naturally reproducing population in the area and therefore further stocking of this species should be discontinued.

CROSSMAN, E. J. 1956. Growth, mortality and movements of a sanctuary population of maskinonge (*Esox masquinongy*). Journal of the Fisheries Research Board of Canada 13(5) : 599-612.

A Schumacher population estimate based on 995 maskinonge taken by trap nets, between the months of May and October in the years 1951-1953, set the number of maskinonge in Nogies Creek at between 769 and 1,122 in July 1953. The mean standard length of these fish was 53.0 cm. The rate of growth (26.3 cm standard length in the first year) compared favorably with that for maskinonge in other waters. Fish of age-groups II, III, and IV predominated. The small number of fish over four years of age was apparently due to a 70% annual mortality rate at least after the third year of life and perhaps before age III.

Recaptures of tagged maskinonge demonstrated that there was little movement of maskinonge in summer, and what movement there was, was mainly upstream. In the fall there was far more movement of fish, and this was mainly in a downstream direction.

The area supports a fairly large population of maskinonge but the high mortality after three years of age limits its value for raising maskinonge to legal size. The potential for rearing fish to three years of age is such that it may be very advantageous to move hatchery fish here for one or two years before liberation.

DAHLBERG, M. D. and D. C. SCOTT. 1971. Introductions of freshwater fishes in Georgia. Bulletin of the Georgia Academy of Science 29 : 245-252.

The object of the present paper is to clarify, where possible, the source, purpose, and success of known introductions. The muskellunge was introduced over thirty years ago in Lake Blue Ridge by persons unknown to the authors. A few individuals were taken annually in the 1940s and early 1950s but none has been caught there since 1957.

DALEY, S. 1975. Propagation by the millions. The Minnesota Volunteer 38 (220) : 44-50.

The northern pike is a cosmopolitan species and currently its propagation management focuses on the acquisition of the fish and the improvement of potential spawning areas. The Section of Fisheries controls 150 spawning areas throughout the state for the propagation of northern pike fingerlings.

Brood stock are captured and placed into temporary spawning areas (ponds) during the spring. They feed on naturally occurring foods and in early June the fingerlings are harvested by drawing down the water levels of the ponds. Approximately 4 million pike are produced in this manner annually.

Occasionally brood stock is placed into marginal waters for the purpose of harvesting their offspring and transplanting the young to other lakes. Each winter thousands of fish are transferred into waterbodies such as Laura Lake, Roseau River and Rice Lake.

The range of northern pike in Minnesota is extensive and therefore there are few waters suitable for stocking muskellunge, although it does occur to a limited extent. Stocking is typically carried out to enhance naturally-occurring populations, to create a trophy fishery or to extend the range of the species. Rush Lake is only one example of a successful musky introduction outside of its native range. Lakes such as this are now used as donor lakes for artificial fish production. Greater than half of the musky produced in the state artificially originate from Rush Lake.

Musky are hatched in jars and the fry transferred to rearing ponds where they feed on zooplankton and sucker fry. At one inch in total length the fish are then transferred to ponds where they will feed on fathead minnows. The fish are removed from the ponds in the fall, when they are between 8 to 12 inches in length and stocked into lakes and streams.

DAY, R. E. 1988. First year survival and growth of five stocked muskellunge year classes in Clear Fork Reservoir, Ohio. *In* Proceedings of the 50th Midwest Fish and Wildlife Conference. Columbus, Ohio.

DAY, R. E. and F. STEVENSON. 1989. Evaluation of muskellunge management in Clear Fork Reservoir. Dingell-Johnson Project F-29-R-2 to R-28, Study 102, Final Report. Ohio Department of Natural Resources. Columbus, Ohio. 50 p.

Some aspects of the population dynamics of adult muskellunge in Clear Fork Reservoir were examined. Data obtained from spring trap net surveys conducted from 1983-1988 were used to determine population size, age structure, growth rates, and mortality rates. Fish greater than 60 cm were tagged to provide movement, growth, survival, and exploitation information. Growth, survival, and handling mortality were also determined for large (minimum 25 cm) stocked fingerlings 23-27 days post stocking and in the spring (April) following stocking. Creel surveys were conducted from 1983-1985 to determine angling effort, catch data, and angler characteristics. The reservoir tailwater was surveyed to determine the numbers, sizes and ages of emigrating fish, and time of year emigration occurred.

DAY, R. E. and F. STEVENSON. 1991. Survival comparison between trough versus pond cultured muskellunge. Final Report F-029-R-(28-30). Ohio Department of Natural Resources. Columbus, Ohio. 26 p.

The objective was to compare survival and growth rates of pond and trough cultured muskellunge fingerlings stocked in Cowan Lake.

DESJARDINS, M. 1997. The role of genetics in esocid stocking and management. p. 39-43. *In* The Introductory, Maintenance and Restoration Stocking of Esocids. Proceedings of a Workshop Sponsored by the Esocid Technical Committee, American Fisheries Society, LaCrosse, Wisconsin.

Little comparative work has been done to assess the relative effectiveness of various molecular techniques to detect genetic variation among populations. The objective of this study was to investigate the utility of three molecular techniques (allozymes, restriction fragment length polymorphism (RFLP), analysis of mtDNA, and random amplified polymorphic DNA (RAPD) analysis of genomic DNA in assessing genetic variation in two related species, muskellunge (*Esox masquinongy*) and northern pike (*Esox lucius*). Fifteen individuals were collected from each of four muskellunge and four northern pike populations distributed across a wide geographic area. Genetic variation was quantified by assaying the protein loci encoded in 32 enzyme systems, the mtDNA restriction sites generated by 18 restriction enzymes, and the RAPD bands amplified with 20 primers. For both species, a greater percentage of variable characters were revealed with allozymes, followed by RAPD analysis of genomic DNA, and then RFLP analysis of mtDNA. Genetic clustering of populations generated from the allozyme and RAPD analysis were in agreement for both species, indicating potential future use of RAPD's for population genetic analysis. Due to the almost unlimited number of RAPD primers available for population studies, the RAPD technique could be an important tool in the genetic assessment of species characterized by low genetic variability.

DOMBECK, M. P. 1987. Artificial turf incubators for raising muskellunge to swim-up fry. North American Journal of Fisheries Management 7(3) : 425-428.

Muskellunge (*Esox masquinongy*) eggs were incubated in artificial turf incubators in five lakes in Michigan and Wisconsin in 1985. Mean survival of swim-up fry from green eggs was 12% and from eyed eggs was 39%. This technique provides the manager with an economical and rapid method for raising muskellunge in lakes with inadequate spawning habitat.

DOMBECK, M. P., B. W. MENZEL and P. N. HINZ. 1984. Muskellunge spawning habitat and reproductive success. Transactions of the American Fisheries Society 113 : 205-216.

Reproduction of muskellunge (*Esox masquinongy*) has failed in many waters that formerly supported self-sustaining populations. Laboratory experiments were conducted to isolate causes of such failures. Differential mortality occurred among lots of muskellunge eggs incubated in jars of unaerated lake water over substrates of sand, gravel, silt, aquatic macrophytes, wood, tree leaves, polyethylene screen, and bare glass. High and rapid early mortality (days 1-2), attributable to low dissolved oxygen (DO) concentrations (O_2=0.1 mg/liter), occurred among eggs incubated on leaves and macrophytes. After day 3, *Saprolegnia* sp. fungus was implicated in high egg mortalities in jars with inorganic substrates (silt and wood) amidst intermediate DO concentrations (0.4-1.7 mg/liter) and limited fungal infestation. Among eight midwestern lakes and reservoirs, measured DO at the substrate-water interface in four of them was high (means of 6.0-8.4 mg/liter) and showed little microstratification; these lakes contain self-sustaining muskellunge populations. The other four lakes showed extreme DO microstratification and virtual anoxia (means, 0.4-2.4 mg/liter) at the substrate-water interface; muskellunge populations in these lakes are supported almost wholly by stocking. Suitable spawning substrates in these lakes are aerated by annual reservoir drawdown, have inherently low biological oxygen demand, or support dense beds of stonewort *Chara* sp. Reproductive failure is associated with spawning areas having deep accumulations of organic matter and dense macrophyte growth. Improvements of spawning habitat to prevent or alleviate hypoxia are among the options to manage this species.

DOMBECK, M. P., B. W. MENZEL and P. N. HINZ. 1986. Natural muskellunge reproduction in midwestern lakes. American Fisheries Society Special Publication 15 : 122-134.

Throughout the native range of the muskellunge, self-sustaining lake populations of the species are declining. Because little is known of muskellunge reproduction requirements, this study had the objective of statistically identifying ecological variables that may influence natural reproduction in lakes and, further, to develop a procedure for estimating muskellunge reproductive potential in individual lakes by using readily accessible ecological data. The Natural Resources departments of Michigan, Minnesota, and Wisconsin provided file data on 117 selected lakes. Information on water chemistry, hydrology, watershed characteristics, fish communities, and cultural perturbations comprised 94 variables.

Nine variables accounted for 57% of the variability in reproduction. These included northern pike abundance, inflow water source (drainage or seepage lake), conductivity, spring water-level condition, discharge volume, shoreline development factor, cultural development of adjacent lands, and alkalinity. Conditions identified as most strongly promoting reproduction were limited northern pike abundance, rising spring-time water level, high alkalinity, and high shoreline development factor, and drainage-lake systems. Complete data sets for these five variables were available for 89 muskellunge lakes. When organized by discriminant function analysis, 58% of the lakes were classified identically to manager-estimated reproductive level, and 91% were classified within ± 1 reproductive level. Application of the discriminant function produced from this analysis may be useful for determining lake-stocking and habitat-improvement strategies directed toward creating or maintaining self-sustaining muskellunge populations.

DOMINION OF CANADA. 1876. Report of the Commissioner of Fisheries. Supplement No. 4 to the Ninth Annual Report of the Minister of Marine and Fisheries. Ottawa, Ontario.

An experiment on a small scale was entered into at Rice Lake to make a trial for the breeding of maskinonge and bass. A small creek was selected to dam and create a couple of small ponds. The object was not to try the artificial methods of propagation with these fish but to see what would be the result from placing in those ponds a few bass and maskinonge just previous to their time of spawning and closely observe their operations during the laying of their eggs; after they had deposited their ova they were to be put back into the lake which was close at hand. We succeeded in getting a number of maskinonge but from an accident occurring by which the dam gave way the experiment in relation to those fish proved futile.

DURSELY, R. S. and F. E. J. FRY. 1961. A creel census of the maskinonge in Pigeon and Sturgeon lakes. Preliminary Report Series No. 1. Great Lakes Institute, University of Toronto. Toronto, Ontario. 13 p.

For the past nine years, tagged maskinonge, ranging from about twenty inches long to fish well over legal size, have been planted from Nogies Creek into Pigeon and Sturgeon lakes. Contests have been held in order to account for the whereabouts of the tagged fish. The returns of tags in the contest have shown that at least 14% of the lunge planted have been taken in the sport fishery. Unfortunately, maskinonge typically lose their tags after two years and so the number of fish caught by anglers could be much higher. In order to further investigate the contribution of transferred maskinonge to the fishery a creel census was undertaken during the summer of 1961. Six of the 124 fish examined at Pigeon Lake were tagged (i.e., 5% were from Nogies Creek). Only 16 fish were taken from Sturgeon Lake, two of these being tagged. The extent of the contribution of the fish from Nogies Creek to the two fisheries is not yet clear. It is recommended that future plants be fin-clipped as well as tagged for identification purposes. Preferably fin clips would be rotated through the paired fins to identify the various years of release.

EDWARDS, G. A. 1979. Northern pike spawning in the Turtle Marsh, 1976 and 1977. Manuscript Report No. 79-45. Manitoba Department of Mines, Natural Resources and Environment. Winnipeg, Manitoba. 26 p.

An estimated 95,213 northern pike migrated into the 2,143 hectare (5,296 acre) north marsh of the Turtle Marsh, (via the Little Turtle River) during a study concocted in April and May of 1976. Of these fish an estimated production of 1,126.5 million eggs was expected which should produce a minimum of 2,253,115 fingerlings. An estimated 439,051 northern pike migrated into the same north marsh in 1977. The estimated egg production from these fish is 6,114.3 million which could be expected to produce 12.2 million fingerlings. The Turtle River overflowed its banks in most areas adjacent to the marsh in 1976. This provided multiple access routes into the marsh for spawning pike. Consequently, population estimates are minimal. This flooding did not occur in 1977 and the pike were restricted to defined channels.

Substituting fry stocking for natural propagation is not a recommended solution to lack of spawning habitat. A proposal to develop the Turtle Marsh by subdividing the marsh into cells would reduce the amount of available habitat for northern pike. This would adversely affect Dauphin Lake pike production unless intensive marsh management is undertaken. Successful spawning and survival of fingerlings is directly related to the amount of available habitat for each spawning female. A recommended rate of 10 to 12 females per hectare (4 or 5 per acre) should not be exceeded for normal marsh conditions. This rate may be increased only if ideal spawning habitat is made available.

The costs of marsh development and management should include sufficient funds to institute and maintain intensive pike management programs.

ELSON, P. F. 1940. Rearing muskellunge in a protected area. Transactions of the American Fisheries Society 70 : 421-429.

A method of rearing maskinonge to an advanced fingerling stage was investigated. One hundred thousand fry were planted in a natural habitat: a marshy bay normally used by maskinonge as a spawning ground. An attempt was made throughout the summer to remove all possible fish and turtle predators. Altogether 17,334 coarse fish, exclusive of fry of the year, and 563 turtles were removed from the area. Less than one-third of the fish and somewhat more than one-half of the turtles were removed previous to planting the maskinonge fry.

Maskinonge spawn in the spring and the fry remain in the spawning marshes at least until the first of November. The fry show little tendency to range about during this period.

When first commencing to feed, maskinonge fry took plankton crustacea and the cladoceran, *Polyphemus pediculus*, was utilized to a large extent. About one week later they commenced to take very small minnow fry as well as plankton. After they were about 5 weeks old the diet was composed entirely of fish. Cannibalism did not occur when there was an abundant supply of other food.

Maskinonge grew very rapidly under the conditions provided, reaching an average length of nearly 10 inches by the first of November.

A yield of 0.8 advanced fingerlings for each 1,000 fry planted was obtained. However, since the removal of fingerlings was not completed the yield was probably greater. Many predatory fish, notably yellow perch and rock bass, remained in the area throughout a greater portion of the experimental period. There can be little doubt that their predatory activities reduced the yield.

Advantages of raising maskinonge fingerlings under the conditions described are the abundant natural food supply, making possible excellent growth, and the possibility of eliminating predators to a large extent.

ELVIRA, B. 1998. Impact of introduced fish on the native freshwater fish fauna in Spain. Chapter 15. *In* I. G. Cowx [ed.]. Stocking and Introduction of Fish. Fishing News Books. London, United Kingdom.

At least 20 fish species in ten families have been successfully introduced into Spanish freshwaters. Thus, about 38% of the present freshwater fish species are exotic. The introduction of exotic predatory fish species and the dispersion of other non-endemic species which compete with the native fish species have had a marked impact on the survival of the latter. Preliminary data suggest allochthonous fishes such as pike (*Esox lucius*) and largemouth bass (*Micropterus salmoides*) have a negative impact on the native fish fauna.

To ascertain the mechanisms by which the predators eliminate their prey, a study of the diet of fish predators in the lower areas of Ruidera was carried out. The aim was to determine the predator-prey interactions of the large predators, pike and largemouth bass, with native species. Unfortunately, it became clear after the study was started that the native fish species were already on the verge of extinction from this area and another exotic species, the red swamp crayfish (*Procambarus clarkii*) was the most common prey for pike. It was inferred that pike initially fed on the native fish but when these stocks disappeared they switched their diet to crayfish.

ENGLAND, R. H. 1976. Esocid introductions into selected Georgia reservoirs. Georgia Department of Natural Resources. Atlanta, Georgia. 23 p.

Non-uniform probability roving creel surveys during 1974-1975 showed high return of 454 sub-adult northern pike stocked into 337.5 ha Lake Rabun. Fingerling chain pickerel x northern pike hybrids did not appear in significant numbers in a survey on 97.1 ha Lake Seed up to two years after stocking at 10.3/ha. Anglers fished an estimated 6,855 hours on Lake Rabun and creeled 7,701 fish between 18 May and 11 October, 1974. An estimated 9,970 hours were expended to catch 12,649 fish between 24 March and 7 September, 1975. During the same survey periods on Lake Seed anglers fished 3,299 hours for 6,381 fish, and 4,804 hours for 6,297 fish in 1974 and 1975, respectively. On Lake Rabun, 56% of the anglers fished for bass during the 1975 survey, while on Lake Seed 39% and 40% fished for sunfish and bass, respectively. Although few anglers indicated a preference for yellow perch on either reservoir, this species made up a significant portion of the creel on each. The overall catch/hour in each reservoir was roughly the same while harvest/hectare was greater in Lake Seed than in Rabun during both years of the survey.

ERICKSON, J. 1961. Muskellunge stocking evaluation in Deer Creek Reservoir, Stark County, Ohio. Technical Report W-314. Ohio Department of Natural Resources. Columbus, Ohio. 6 p.

Deer Creek Reservoir was stocked with muskellunge fry in the first year of flooding. A large crop of carp and gizzard shad occurred in this same year.

From a total of 19,030 fry stocked in the reservoir, 117 muskellunge from 7 to 42 inches long have been recorded. Length frequency distribution from test-net and angler-caught fish and age-growth data indicate that the crop of muskellunge resulted from the initial stocking of 1955, with only an occasional survival from later plantings. The 117 recorded fish represent a 5.8% survival of the original plant of fry.

Five years after the initial planting of 2,000 muskellunge fry, 21 five year old fish or 1.05% of the plant were taken in test nets. This indicates that liberalized fishing did not result in complete removal of the population, but that a large enough population survived to reproduce.

This data indicates that the first year of stocking, during the year the lake was filled, produced the only practical results from the total of 19,030 fry planted in the lake. This may indicate that increasing the size of the stocked fish after the first year would produce better results. The success in the first year may also have been correlated with the large crop of shad and carp fry or other unknown factors.

ESOCID TECHNICAL COMMITTEE. 1997. The introductory, maintenance and restoration stocking of esocids. North Central Division, American Fisheries Society, LaCrosse, Wisconsin. 58 p.

This publication summarizes information presented at a workshop on the introductory, maintenance and restoration stocking of esocids which was held in LaCrosse Wisconsin on July 24-25, 1996. The workshop was held to bring together esocid managers and researchers from across the midwest to discuss the major goals and objectives of esocid management, stocking strategies employed by state and provincial agencies to meet these goals and consideration and constraints in implementing these strategies. Presentations were made describing esocid management and stocking programs in 14 states and provinces (including Ontario). In addition, a summary of round table discussion is presented and some overall conclusions are drawn.

EUROPEAN INLAND FISHERIES ADVISORY COMMISSION. 1982. Report of the symposium on stock enhancement in the management of freshwater fisheries. EIFAC Technical Paper No. 42. Food and Agriculture Organization of the United Nations. Rome, Italy. 43 p.

Stocks of pike are heavily fished in the Netherlands. The goals for management of pike are, in general, to maximize the populations and to improve the numbers of large fish. These goals are pursued by responsible angling clubs and associations by (i) stocking pike fingerlings (4-6 cm) and occasionally larger pike; and (ii) catch-and-release fishing. The Organization for the Improvement of Inland Fisheries, amongst others responsible for the production of fish for stocking, produced over one million pike fingerlings per year for stocking during the last few years.

Research was started in 1974 to evaluate the value of stocking with fingerlings in two “natural” closed waters. The results of that year raised the question as to whether the stocked fingerlings contributed to the biomass or merely replaced natural recruitment. Moreover, experiments in drainable ponds suggested that the length of vegetated shoreline was of major importance. The total biomass of pike smaller than 54 cm (fork length) is highly dependent on the area of vegetation and corresponds to a maximum of 100 to 120 kg of pike-per-hectare of pike habitat. The biomass of pike smaller than 41 cm is determined by the biomass of pike larger than 41 cm and smaller than 54 cm. Stocking with pike fingerlings and pike up to 23 cm did not increase the pike population.

These results show that maximization of pike populations depends primarily upon the available pike habitat. Therefore, habitat engineering is a better management tool than stocking. These findings are to a certain extent confirmed by experience in Finland where about 18 million pike fry and fingerlings were stocked in 1980 with very little apparent effect on pike catches.

The stocking of northern pike has reduced the survival of many other species through predation. Salmonids are particularly vulnerable and in Ireland where pike are not native, the introduction of this species has almost eliminated populations of the more esteemed salmon and brown trout.

FAGO, D. M. 1977. Northern pike production in managed spawning and rearing marshes. Technical Bulletin 96. Wisconsin Department of Natural Resources. Madison, Wisconsin. 30 p.

From 1969 through 1983, the 3.7-acre (1.5 ha) Pleasant Lake Marsh was stocked each spring with adult northern pike (*Esox lucius*) in an effort to determine the factors that influence the production of fingerlings from managed spawning and rearing marshes. In 1971 and 1972, the 18.5 acre (7.5 ha) Pabst Marsh was also studied. The annual production from the Pleasant Lake Marsh varied from 324 to 3,243 fingerlings-per-acre (131 to 1,312 per ha). The Pabst Marsh produced 681 and 1,052 fish-per-acre (276 and 426 per ha) during the two years it was studied. These fingerlings were produced from an average of 12.1 and 11.0 lbs/acre (13.6 and 12.3 kg/ha) of adult females and males, respectively.

The average production for both marshes at the time of draining was 1,332 fingerlings-per-acre (539 per ha) having an average length of 3.5 inches (88.9 mm), and a length range from 1.5-6.8 inches (38-173 mm). The pounds-per-acre of fingerlings produced varied from 2.2-16.4 (2.5-18.3 kg/ha) with a mean of 10.6 lbs/acre (11.9 kg/ha). Estimated survival from egg deposition until the time of draining varied from 0.15 to 2.69% with an average of 1.09%.

Factors suspected of influencing the production of northern pike from managed marshes were studied. However, sufficient data for making quantitative predictions on the number of northern pike produced from these factors were not obtained. Nevertheless, it was observed that water temperature and dissolved oxygen during the draining of the marsh, cannibalism during the fingerling stage, and zooplankton composition during the fry stage were some of the most important factors influencing the production of northern pike.

A Fortran computer program was developed to handle the analyses of all northern pike stomach, zooplankton, and benthic samples.

FARRELL, J. M. 1996. Natural reproductive success of sympatric esocids and the contribution of stocking to fall age-0 muskellunge abundance in a shared embayment in the upper St. Lawrence River, New York. *In* R. Soderberg [ed.]. 1996 Warmwater Workshop Proceedings – Esocid Management and Culture. Mansfield University. Mansfield, Pennsylvania.

Natural northern pike reproduction was compared to muskellunge from egg collections and habitat assessments during spring spawning to the period just prior to fall emigration of juveniles in a single, shared embayment of the upper St. Lawrence River. Survival of muskellunge from the egg stage to early fall juvenile was compared for three modes or origin including natural reproduction (1994 and 1995), and advanced fry and small fingerling stocking (1994). Natural northern pike egg deposition was estimated over twenty times greater than muskellunge in 1994 and 86 times greater in 1995. Despite this high reproductive effort, survival of northern pike to fall juvenile was estimated to be near zero both years. In comparison, natural muskellunge reproduction contributed 33% to an estimated fall juvenile abundance of 155, 0.087% survival from egg in 1994, and 67 fish, 0.156% survival in 1995. Difference in spawning preferences may explain the variability in natural reproductive success. Both methods of muskellunge stocking contributed to the fall population with post-stocking survival greatest for fingerlings (38.6%). Advanced fry stocking survival was lower at 2.94%, but contributed 56% of the fall juvenile population. We conclude fry stocking can be a cost effective management strategy where survival is sufficient.

FARRELL, J. M. 1997. Abundance, distribution, and survival of age-0 muskellunge in Upper St. Lawrence River nursery embayments. *In* 59th Midwest Fish and Wildlife Conference, December 7-10, 1997, Milwaukee, Wisconsin.

Ten embayments in the Thousand Islands section of the St. Lawrence River were stocked with advanced muskellunge fry (1990-92, 1994, 1996) and small fingerlings (1994, 1996) to examine the distribution of survival among sites, and to evaluate the potential to establish muskellunge spawning populations. Sites were selected based on a 3-year preliminary study of presence-absence of muskellunge. At five of the bays, use as a spawning and nursery area was detected. In the remaining five bays, no previous use by muskellunge was observed. In 1993 and 1995 no stocking occurred, yet naturally reproduced age-0 muskellunge were captured in 9 of the 10 bays, including 4 of 5 with no previous juvenile muskellunge capture. Most age-0 muskellunge within nursery bays were located in shallow habitats (<1.4 m), and success of capture by seining was negatively correlated with increasing depth. A deepwater seining technique (1.5-3.8 m) was used to examine the use of offshore habitats for muskellunge nursery. Muskellunge were captured in water depths up to 3.2 m, but independent studies showed they were spawned in deep habitats and later moved inshore. Two estimators of age-0 muskellunge abundance, a catch-area method by seining technique, and mark-recapture, were compared. The catch-area method was used in abundance and survival analyses. Population density during the nursery period ranged from over 2-42 muskellunge-per-hectare, and no differences in abundance were observed between natural sites and those without previous nursery use. Stocked muskellunge fry were marked using thermal and oxytetracycline treatments to incorporate identifiable patterns in otolith microstructure. The contribution of stocking and natural reproduction to age-0 muskellunge abundance was evaluated at the bays. Survival of stocked fry was very low (0-3%), yet contributed significantly to overall abundance. Survival of small fingerlings was greater at up to 35%, but several unsuccessful stockings occurred. No differences in survival occurred between the two types of bays evaluated, however, important differences in abundance and survival between individual bays were observed.

FARRELL, J. M. and R. G. WERNER. 1995. Contribution of natural reproduction and stocking to fall age-0 esocid abundance in Rose Bay, St. Lawrence River. p. 99-104. In S. J. Kerr and C. H. Olver [eds.]. Managing Muskies in the 90s Workshop Proceedings. Workshop Proceedings WP-007. Southern Region Science and Technology Transfer Unit, Ontario Ministry of Natural Resources. Kemptville, Ontario. 169 p.

Survival of muskellunge (*Esox masquinongy*) from the egg stage to early fall juvenile was compared for three modes of origin: natural reproduction, advanced fry stocking, and small fingerling stocking: Natural reproduction of northern pike (*Esox lucius*) was also compared with muskellunge.

FARRELL, J. M. and R. G. WERNER. 1999. Distribution, abundance and survival of age-0 muskellunge in Upper St. Lawrence River nursery bays. North American Journal of Fisheries Management 19(1) : 309-320.

Distribution, abundance, and survival of age-0 muskellunge (*Esox masquinongy*) were evaluated at 10 bays in the Thousand Islands section of the St. Lawrence River over a 7-year period, 1990-1996. Muskellunge fry (24 mm) identified with thermal or oxytetracycline otolith markers were stocked in 1990-1992, 1994, and 1996, and fin-clipped fingerlings (76 mm) were stocked in the bays in 1994 and 1996. Success of the stockings was evaluated to examine the feasibility of enhancing bays that have natural reproduction (natural) and establishing populations in unused bays (restoration). Most age-0 muskellunge were found in shallow habitats (<1.5 m), and success of capture by seining decreased with increasing water depth. Estimates of age-0 abundance by mark-recapture and catch-area were not significantly different. Population density ranged from 0 to 42 muskellunge/ha of nursery habitat, and no significant differences were observed between natural (18.8 fish/ha) and restoration bays (20.5 fish/ha). For all years combined, 67% of fish in natural bays originated from fry stocking, compared with 74% in restoration bays. No significant difference in contribution to age-0 abundance by origin (fry, fingerling, wild) was observed between natural and restoration bays. No stocking occurred in 1993 and 1995, but wild age-0 muskellunge were captured in 9 of 10 bays. The presence of wild muskellunge in 4 of 5 restoration bays indicated that these bays were incorrectly characterized as lacking natural reproduction. Survival of stocked fry was relatively low (0-3%), compared with survival of fingerlings (0-35%), but stocked fry contributed more to abundance (over 50%)

than wild or fingerling sources. Due to its success, fry stocking should be reconsidered as a useful management tool for enhancing and restoring muskellunge populations.

FINDLAY, C. S., D. G. BERT and L. ZHENG. 2000. Effect of introduced piscivores on native minnow communities in Adirondack lakes. Canadian Journal of Fisheries and Aquatic Sciences 57 : 570-580.

We compared the minnow assemblages of Adirondack lakes with top piscivores to those lakes having similar physiochemical and biotic characteristics but not top piscivores using a subset of data collected from 1984 to 1987 by the Adirondack Survey Corporation. Native minnow richness in lakes with top piscivores was about one third that of lakes without piscivores, with piscivore assemblages dominated by introduced species such as northern pike (*Esox lucius*), largemouth bass (*Micropterus salmoides*), and smallmouth bass (*M. dolomieui*). There was strong evidence that at least four minnow species, including creek chub (*Semotilus atromaculatus*), northern redbelly dace (*Phoxinus eos*), blacknose dace (*Rhinichthys atratulus*), and common shiner (*Luxilus cornutus*), were less likely to occur in lakes with piscivores; for a fifth species – pearl dace (*Margariscus margarita*) – the evidence is suggestive but not as strong. Of 13 minnow species, only for nonnative species (bluntnose minnow, *Pimephales notatus*, and golden shiner, *Notemigonus crysoleucas*) was there strong evidence that their occurrence was unaffected by the presence of introduced piscivores. These results add to the growing body of evidence that the introduction of top piscivores to small temperate lakes puts native minnow communities at high extinction risk.

FLICKINGER, S. A. and J. H. CLARK. 1978. Management evaluation of stocked northern pike in Colorado's small irrigation reservoirs. American Fisheries Society Special Publication 11 : 284-291.

Northern pike of two size groups were stocked into several small irrigation reservoirs in Colorado. Small northern pike approximately 50 mm total length were stocked at an approximate rate of 62/hectare, whereas large northern pike averaging 377 mm total length were stocked at an approximate rate of 25/hectare. Out of 18 introductions of 50 mm pike, nine (50%) resulted in no observable northern pike populations, seven (39%) resulted in northern pike populations of too low a density to interest fishermen, and two (11%) resulted in northern pike populations of a density which would attract fishermen. Survival of 50 mm stocked northern pike was dependent upon large number of small forage fishes. In two instances, when 50 mm fingerlings became established in sufficient numbers to interest fishermen, cost-per-surviving-catchable-sized northern pike averaged $0.16. All four introductions of 377 mm northern pike resulted in northern pike populations of a density which would interest fishermen. Survival of stocked 377 mm northern pike averaged 35% and cost per surviving fish averaged $4.62. Few statistical differences in average size and number of resident fish populations were found within a year after northern pike were introduced into study reservoirs; however the general trend was an increase in average total length and a decrease in number of resident fishes following introduction of northern pike.

FORNEY, J. L. 1965. Utility of a small spawning impoundment for increasing northern pike production. Dingell-Johnson Project F-17-R-9, Job No. II-a. New York Department of Conservation. Albany, New York. 13 p.

Adult northern pike immigrating to spawning areas were netted and stocked in a shallow 7.3 acre impoundment constructed on a tributary to Oneida Lake. Spawning occurred during late March and early April and newly hatched fry were collected in the marsh on April 17. Young emigrating from the marsh to the lake were trapped at the outlet and counted. Emigration began on April 29 and by June 16, 45,099 young had left the marsh. Survival from egg to downstream emigrant was 4.03% based on estimated fecundity and counts of young pike.

FORNEY, J. L. 1968. Production of young northern pike in a regulated marsh. New York Fish and Game Journal 15 : 143-154.

From 1964 to 1967 the production and survival of young northern pike were studied in an experimental marsh at Shackelton Point on Oneida Lake. The number of adults entering the marsh was controlled and their fecundity estimated to determine potential egg deposition. The number of eggs hatching was approximated by determining the density of fry-per-square foot using screen enclosures and young emigrating from the marsh were trapped and enumerated. Mortality between spawning and hatching was 81% and 84% in 1965 and 1966, respectively, and the loss of young between hatching and emigration was 83% in both years. Migrants over 65 millimeters long were fin clipped. Recoveries during subsequent spawning runs suggested that few pike survived that were less than 65 millimeters long when they left the marsh. Maintenance of northern pike populations in many areas may depend primarily on producing large juvenile fish in the nursery areas.

FORNEY, J. L. 1969. Production and behavior of muskellunge in a controlled marsh. Dingell-Johnson Project F-17-R-13, Job No. II-b. New York State Conservation Department. Albany, New York.

Muskellunge obtained from the Chautauqua Hatchery were stocked in a marsh during May 1967 (eyed eggs) and 1968 (sac-fry). Juvenile muskellunge were trapped as they emigrated from the marsh and in July the marsh was drained. Emigration did not begin until late June and was limited to periods of heavy runoff. The yield was low, in both 1967 and 1968, and only part of the population emigrated.

GALL, J. 1973. Ohio muskellunge (*Esox masquinongy ohionensis*) stocking in Piedmont Lake. Progress Report No. 223. Division of Wildlife, Ohio Department of Natural Resources. Columbus, Ohio.

GALLANT, J. 1976. Artificial propagation of maskinonge at the Deer Lake Hatchery and a brief description of the Stony Lake brood stock. Ontario Ministry of Natural Resources. Lindsay, Ontario. 6 p. + tables.

Deer Lake is currently the only fish culture station in Ontario to artificially propagate maskinonge. Young muskies are planted in various areas in order to supplement natural fish populations. Artificial propagation is undertaken for number of reasons:

- To stock waterways which are incapable of producing enough fish naturally to meet angler demand.
- To introduce individuals into previously unpopulated areas with the idea of establishing a stable population.
- To maintain a stable population in a waterbody that has little natural propagation.
- For research purposes which lead to further management implications.

The distribution of the juvenile fish begins at the beginning of July when the fish are approximately 3 inches in length. Shipping continues into August when the musky are 6 to 8 inches. In 1975, a total of 1,486,099 muskellunge were distributed as follows:

- Lindsay district – 693,000 fry and 99 fingerlings
- Bancroft district – 300,000 fry
- Brockville district – 15,000 fry
- Napanee district – 130,000 fry

- Parry Sound district – 16,000 fry
- Huronia district – 32,000 fry
- Hatchery ponds – 300,000 fry

GAMMON, J. R. 1960. The effects of maskinonge stocking on the resident fish populations of two dystrophic lakes. *In* Proceedings of the 22nd Midwest Fish and Wildlife Conference, Toronto, Ontario.

George and Corrine lakes were stocked with yearling muskellunge (*Esox masquinongy immaculatus*) and studied for four years. Populations of bass and perch were estimated before (5 and 3 years, respectively) and after by conventional mark and recapture procedures, using several types of gear as collection devices. Both lakes had brown-stained, soft water with slight bog development.

The adult perch population in George Lake (43 acres) was reduced within a year from about 500 fish-per-acre to a density too low to estimate, and was maintained at this low level throughout the rest of the study. In Corrine Lake (37 acres), three years lapsed before a similar change occurred in a population of 275 perch-per-acre initially. A growth analysis of this species was possible only for the younger age groups because of the extreme scarcity of fish older than three years. Available data indicate an increase in the rate of growth of the younger perch following the reduction in population density. Little change was noted in the length:weight relationship.

About 25% of the yearling muskellunge died shortly after introduction. After this initial loss, a relatively constant annual mortality of 10% to 15% was observed. The rate of growth was below the average for Wisconsin muskellunge in both lakes, and in George Lake very little growth occurred in the last year of the study.

GAMMON, J. R. and A. D. HASLER. 1965. Predation by introduced muskellunge on perch and bass. I : Years 1-5. Transactions of the Wisconsin Academy of Science Arts and Letters 54 : 249-272.

GIBSON, R. J. and E. J. SCHINDLER. 1969. Borrow pits as rearing ponds for muskellunge and walleye. Manuscript Report No. 69. Manitoba Department of Mines and Natural Resources, Fisheries Branch. Winnipeg, Manitoba. 37 p.

GILLEN, A. L., R. A. STEIN and R. F. CARLINE. 1981. Predation by pellet-reared tiger muskellunge on minnows and bluegills in experimental systems. Transactions of the American Fisheries Society 110 : 197-209.

Studies in Wisconsin lakes have shown that stocked tiger muskellunge (F_1 hybrids of female muskellunge, *Esox masquinongy* x male northern pike, *E. lucius*) reared on live food survive better than those reared entirely on dry pellet food. We evaluated the ability of pellet-reared hybrids to convert to a minnow (*Notropis* spp. and *Pimephales promelas*) or bluegill (*Lepomis macrochirus*) diet in laboratory aquaria and hatchery ponds. In aquaria, 86-310 mm (total length) tiger muskellunge selected cyprinids that were about 40% of their own length and bluegills that were about 30% of their length, sizes closely predicted by an optimal foraging construct (time from prey capture to complete prey ingestion ÷ prey dry weight). Using these prey sizes, we tested hybrids (130, 150, and 170 mm long) in conversion experiments in aquaria and ponds. During experiments, prey were maintained at a constant density and predators were sampled periodically to determine the proportion eating fish. Tiger muskellunge converted more slowly to bluegills than to minnows in both aquaria and ponds. In aquaria, 85% of the hybrids converted from pellets to minnows by day 3, whereas only 68% converted to bluegills. By day 5, conversions to minnows and bluegills were 95% and 82%, respectively. In ponds, 73% of the hybrids converted to minnows by day 5 and 89% by day 14. No hybrids had eaten bluegills by day 3 and only 53% converted by day 14. The apparently limited ability of pellet-reared tiger muskellunge to switch to a bluegill diet may influence survival and growth of these predators in reservoirs dominated by a centrarchid forage base.

GODDARD, J. A. and L. C. REDMOND. 1978. Northern pike, tiger muskellunge, and walleye populations in Stockton Lake, Missouri: A management evaluation. American Fisheries Society Special Publication 11 : 313-319.

A three-stage filling of 10,072 ha Stockton Lake coupled with spring releases of walleye and northern pike fry and fingerlings into the flooded terrestrial vegetation in 1970, 1971 and 1972 resulted in good survival, exceptional growth, and a quality fishery. Angler interest in these species was high and accounted for 20% of the fishing trips in 1972. With minimum size limits of 457 mm on walleye and 762 mm on northern pike, harvest reached a high of 1.9 and 1.2 fish-per-ha (2.4 and 4.5 kg-per-ha) in 1972 and averaged 1.0 and 0.4 fish-per-ha (1.5 and 1.5 kg-per-ha). The size limits provided many additional hours of quality angling; in 1971 nearly 31,000 sublegal walleyes and northern pike were caught and released to be caught again (10.3 per ha). In addition, the size limits permitted a very respectable harvest of quality sized fish, averaging 1.4 fish and 3 kg-per-ha. While remaining in the lake, these species effectively preyed on forage fishes, primarily gizzard shad. Tiger muskellunge were released in 1975 to replace the northern pike.

GOEMAN, T. J. and P. D. SPENCER. 1992. Fish community responses to manipulation of northern pike and yellow perch densities in a Minnesota centrarchid lake. Investigational Report 416. Minnesota Department of Natural Resources. Brainerd, Minnesota. 15 p.

Removal of 3,894 small (<600 mm) northern pike (*Esox lucius*), stocking large (≥600 mm) pike, and stocking yellow perch (*Perca flavescens*) over a 6 year period were ineffective in altering pike densities, improving pike growth rates or altering fish community structure in a 156 ha centrarchid lake. Widely dispersed, marginal pike spawning habitat and early, under-ice spawning may have contributed to the largely ineffective removal efforts – less than 15% of the northern pike population was removed during the annual netting. Annual mortality of pike in the study lake exceeded 50%, limiting the potential for improvements in population size structure. Larger stocked pike also exhibited high mortality and had little influence on pike population dynamics or fish community structure. The success of stocking yellow perch to establish a forage base was dependent on size of yellow perch available for stocking. Smaller perch stocked during earlier years of the study did not survive, presumably due to vulnerability to pike predation. Larger perch stocked later in the study were apparently large enough to escape heavy predation by pike, and survived to spawn several times and establish natural year classes. After 6 years of manipulations, desirable changes in fish growth and community structure could not be documented. The potential for managing for larger northern pike may be more promising in larger, deeper lakes having lower pike densities.

GRAFF, D. R. 1978. Intensive culture of esocids – the current state of the art. American Fisheries Society Special Publication 11 : 195-201.

The intensive culture of esocids has been profoundly influenced by the use of artificial diets. Adequate diets have been developed and automatic mechanical feeders have come into wide use. Most culture programs are emphasizing the production of tiger muskellunge (*Esox lucius* x *E. masquinongy*). Hatchery design has changed to reflect increased knowledge of requirements of esocid fishes and to accommodate techniques developed to feed artificial diets. Trends in Michigan and Pennsylvania are to incorporate esocid culture and salmonid culture into an integrated or combination hatchery design. Fiberglass tanks, concrete runways and silos are being used to rear esocids. Techniques and hatchery design have changed dramatically over the past decade; fisheries pathology as related to intensive culture of esocids has not kept pace with this change and basic information is still being developed. Achievements in the art of intensive culture of esocids should serve as an inspiration to culturists working with other difficult-to-rear fishes.

GRAY, C. R. 1977. Deer Lake Hatchery. Unpublished Report. Ontario Ministry of Natural Resources. Lindsay, Ontario. 2 p.

This year, as opposed to other years, no hatchery muskellunge fry will be released at the location where the adults are stripped. This action was taken so that the naturally produced fry may be studied at the spawning areas.

GREEN, D. M. and D. K. SANDFORD. 1995. Comparison of the fishery of Canadarago Lake in the 1970s and 1981-91 following the stocking of walleye and tiger muskellunge. Final Report. New York State Department of Environmental Conservation. Albany, New York. 84 p.

A creel survey was conducted to determine effort, catch and angler characteristics during the 1989-91 period for the purpose of evaluating a fisheries management program involving the stocking of walleye and tiger muskellunge. Results from a diary cooperator program conducted from 1988-89 are compared with a similar survey conducted from 1973-77, a period preceding the management program.

GREGORY, R. W. and T. G. POWELL. 1969. Northern pike introductions. Dingell-Johnson Federal Aid Project. Colorado Department of Game, Fish and Parks. Denver, Colorado.

GRIMM, M. P. 1981a. The composition of northern pike (*Esox lucius*) populations in four shallow waters in the Netherlands, with special reference to factors influencing 0+ pike biomass. Fisheries Management 12(2) : 61-76.

The composition and abundance of northern pike (*Esox lucius*) populations in four shallow waters was monitored during a 4-5 year period, using mark-recapture methods. Pike fingerlings, ranging in size from 4-6 cm fork length were stocked into four lakes between 1974 and 1978. These fish were marked by the removal of a fin, which had no bearing on their mortality or growth. In general the populations were sampled by using a combination of fishing gear but pike that completed their first growing season (0+ pike) were captured quantitatively by electrofishing (3 kw, DC) exclusively.

Within the length range of 0-54 cm fork length, the biomasses of 0+ pike appeared to be negatively correlated with those of larger pike. It is suggested that intraspecific predation is mainly responsible for these relations. The standing stock of <54 cm pike was found to be determined by the amount of aquatic vegetation and more especially so if the different habitat preference of 0+ pike, 0+ < pike < 41 cm ≤ pike < 54 cm was taken into account.

GRIMM, M. P. 1981b. Intraspecific predation as a principal factor controlling the biomass of northern pike (*Esox lucius*). Fisheries Management 12(1) : 77-79.

Intraspecific predation is considered to play a major role in the regulation of numbers of small pike (*Esox lucius*) < 41 cm fork length. In four "natural" waters the biomasses of these pike, especially of the 0+ class, were negatively correlated with those of large pike.

Extensive experiments, originally designed to evaluate artificially propagated pike fingerlings for stocking purposes in fisheries management, have been re-examined in order to elaborate whether these conclusions are not restricted to the pike populations in the above mentioned natural waters.

It was found that the biomasses of the smaller pike (range 0-58 cm fork length) were negatively correlated to those of larger individuals and that no relationship existed between the biomass of the pike and prey fish. It was discovered that there was no relationship between the biomasses of the pike 0-43 cm and ≥50 cm. Vegetation was found to play an important role in the biomass distribution of small pike.

GRIMM, M. P. 1982. The evaluation of the stocking of pike fingerlings. Hydrobiological Bulletin 16 : 285-286.

GRIMM, M. P. 1983$_a$. Regulation of biomasses of small (< 41 cm) northern pike (*Esox lucius*) with special reference to the contribution of individuals stocked as fingerlings (4-6 cm). Fisheries Management 14(3) : 115-134.

The composition and abundance of four northern pike (*Esox lucius*) populations was monitored in the period 1974-82. The biomasses of 0+ pike, pike < 35 cm, and pike < 41 cm were negatively correlated with those of larger individuals following an exponential relationship. It is argued that this density dependent relation is the result of a regulation in which intraspecific predation may play a major role. The standing stock of pike < 54 cm, if related to pike habitat available, was very similar both among sites within years and among years within sites. This stock is tied to a maximum per unit of vegetated area. Within this maximum the biomass of pike < 41 cm is determined by the biomass of larger individuals. Therefore stocked pike did not contribute extra biomass to the population.

GRIMM, M. 1983$_b$. Towards the formulation of guidelines for stocking of fish. European Inland Fisheries Advisory Commission. Food and Agricultural Organization of the United Nations. Rome, Italy.

Stocking of fish is a widespread practice. The results of stocking, however, appear to vary with species, life stages and with locations and management goals. The stocking of fingerlings of predator species to increase population densities appears to be either totally unsuccessful (as in the case of northern pike) or serious doubt about the good results reported seems to be justified. The faith or trust in the beneficial results of stocking might be responsible for the lack of basic evaluation studies on the introductions of many species.

GROEBNER, J. J. 1964. Contribution to fishing harvest from known numbers of northern pike fingerlings. Fisheries Investigational Report No. 280. Minnesota Department of Natural Resources. St. Paul, Minnesota. 24 p.

The contribution to the fishing harvest from known numbers of naturally-produced northern pike fingerlings was investigated in a 456 acre bass-panfish lake during the years 1957 through 1960. The fingerling reproduction from the managed 9 acre natural spawning area had a range from zero in 1959 to 93,000 in 1956. Investigation of other potential spawning sites indicated that during the study period virtually all northern pike fingerlings produced came from the managed spawning area. The best estimates of fingerling production were obtained in 1956 and 1958. Of the 93,000 fingerlings produced in 1956 an estimated 3.2%

were taken by fishermen through age IV and of the 1,000 fingerlings produced in 1958, it was estimated that 5.4% would be returned through age IV. During the four years of investigation northern pike accounted for 39.9% by weight of the total catch of all species.

The range of abundance of northern pike 15 inches and over, in total length, at the beginning of the fishing season (age II and over) was from a low of 3.1 fish/acre in 1960 to a high of 32.2 fish/acre in 1958. These estimates were made during the period 1957 through 1960 using the mark and recapture method. Exploitation rates varied between 11.2 and 21.1% and total mortality between 39% and 89%. The highest natural mortality rate and the poorest condition factor were associated with the greatest population density.

The number of northern pike-per-man hour of summer fishing varied directly with population size as did total harvest although summer angling pressure showed a general decline throughout the period. While total harvest of pike in numbers tended to vary directly with population density, lower population levels produced greater harvest in proportion to their size than did the higher levels. Sex ratios in spawning runs were also determined and are included for informational purposes.

HACKER, V. A. 1967. Soup bowl to fish bowl. Wisconsin Conservation Bulletin 32(4) : 3-4.

In 1955, Little Green Lake was covered with green algae. Chemical treatment in 1956 drastically changed that and today the lake is a sparkling blue. Following a successive summerkill and winterkill Little Green Lake was treated to reduce turbidity and algae growth. In the spring of the following year walleye, largemouth bass and bluegills were restocked. In September of 1957, 300 muskellunge were stocked. During the four summers of 1963 to 1966 fishermen have caught 544 muskellunge, all originating from the planting in 1957. A seine haul conducted in 1966 turned up another 29 musky.

HANSON, D. A. 1993. The muskellunge fishery in nine northern Wisconsin lakes. Research Report No. 159. Wisconsin Department of Natural Resources. Madison, Wisconsin. 18 p.

A comprehensive survey of population characteristics and angler use of muskellunge was conducted for nine Wisconsin lakes to provide baseline information and guidelines for the muskellunge management program. Physical-chemical characteristics, stocking history, predominant fish species, muskellunge population characteristics, fishing pressure, and recommendations for managing the fishery are presented for each lake.

HANSON, D. A., J. R. AXON, J. M. CASSELMAN, R. C. HASS, A. SCHIAVONE and M. R. SMITH. 1986. Improving musky management: A review of management and research needs. American Fisheries Society Special Publication 15 : 335-341.

The muskellunge is currently regarded as a trophy fish for angling in many regions. Reproductive success had declined in many waters, presumably due to deteriorating habitat, excessive angler harvest and increased competition from other species. Consequently, many muskellunge populations are maintained solely through hatchery propagation. The objective of this manuscript is to discuss areas of management and research which limit agencies from managing the species efficiently.

Management agencies need to clearly define their management philosophy. This includes both why they manage muskellunge (to preserve a self-sustaining fishery, to increase angling opportunity, etc.) and setting quantitative management goals (i.e., defining desired population densities, age and size structure, etc.). Simply stating the agency philosophy as trophy management does not provide sufficient guidelines for field managers. Major research needs for improved management include identification of genetic diversity of muskellunge populations, expanded databases on populations obtained from more advanced sampling techniques, better knowledge of muskellunge-northern pike interactions, identification of spawning and nursery habitat requirements and evaluation of propagation and stocking techniques.

The long range well-being of this species is dependent on improved management practices. Intensive muskellunge management often places excessive demands on the resources of the agencies. Private organizations can provide a significant role in obtaining solutions to current problems with their input of money, labor and data.

HANSON, D. A. and T. L. MARGENAU. 1992. Movement, habitat selection and survival of stocked muskellunge. North American Journal of Fisheries Management 12 : 474-483.

High post-stocking mortality of muskellunge (*Esox masquinongy*) has long been an important management problem. This paper documents post-stocking dispersal and subsequent movement, habitat selection, behavior, and survival of fall stocked young-of-the-year muskellunge (12.1-13.1 inches total length) with the objective of providing insights into the mechanism controlling short-term survival. Radio-transmitters were surgically implanted into 27 muskellunge that were then stocked with untagged muskellunge into two northern Wisconsin lakes and monitored for 34 days. Most dispersal from stocking locations occurred within 2 weeks after stocking. Muskellunge selected inshore areas generally less than 10 feet deep. Emersed vegetation, particularly bulrushes (*Scirpus* spp.), submersed vegetation, and the trunks and branches of downed trees were preferred cover. The first day following stocking, muskellunge appeared stressed, failing to demonstrate an escape response when approached. Survival of both transmitter-tagged and untagged muskellunge in these stockings was higher than in previous investigations; presumably this was related to the large size of fish at stocking. Results of this study should aid habitat management and the design of future studies of ways to minimize post-stocking mortality of muskellunge.

HANSON, D. A., M. D. STAGGS, S. L. SERNS, L. D. JOHNSON and L. M. ANDREWS. 1986. Survival of stocked muskellunge eggs, fry and fingerlings in Wisconsin lakes. American Fisheries Society Special Publication 15 : 216-228.

Angler harvests of muskellunge exceeds natural recruitment in most muskellunge waters in Wisconsin; consequently, populations are supplemented by hatchery propagation. This paper summarizes survival estimates from 5 egg, 6 fry and 74 fingerling stockings. Factors influencing survival were examined by comparing estimates of fall fingerling density and two indices of survival to a set of independent factors using simple correlation and stepwise regression.

Stocking fertilized muskellunge eggs on gravel and sand substrate resulted in a measurable year class of muskellunge in two of the five trials, and fall fingerlings were observed from two of six fry stockings. Survival of stocked fingerlings to fall averaged 38.7% and ranged from 0.0% to 95.7%.

In multiple regression analyses of 59 fingerling stockings, a significant positive relationship was found between observed survival to fall and length at stocking. A negative relationship between fall survival and days at large was also identified but this was expected. The geometric mean daily survival was independent of the number of days in the lake and provided a better index for examining the effect of the independent factors on fingerling survival. Mean daily survival was positively correlated with length at stocking and days at large. The fall population density of fingerlings was highly correlated with the initial stocking rates. Tests of the above derived models with nine later stockings found the effect of length at stocking to be variable.

This study suggested that best survival to first fall was achieved by stocking the largest fingerlings, however, similar results may have been achieved by stocking proportionately greater numbers of smaller fingerlings. There was no evidence that high stocking rates adversely affected fingerling survival.

HANSON, H. 1958. Operation fish rescue. Progressive Fish Culturist 20(4) : 186-188.

Many of Minnesota's shallow lakes aren't capable of supporting fish over the winter; so saving thousands of northern pike from winterkill has developed into a large-scale fishery management program. The fish are typically rounded up by creating an area in the lake with a high level of oxygen. This can be accomplished by using portable water pumps to circulate water through artificially created inlet and outlet creeks. This will cause the fish to congregate near the high oxygen concentrations and they can easily be removed in large numbers. It is unknown which channel the fish will be attracted to. During the 1955-56 season at Laura Lake, 80% of the fish came into the inflow channel, while the following season 80% entered the outflow channel. In 1955-56, 52,699 northern pike were removed from Laura Lake. With many more lakes producing large numbers of fish, removal operations have provided an effective means of management stocking.

HARRIS, K. G. 1987. Deer Lake fish culture station muskellunge culture operations assessment report. File Report. Ontario Ministry of Natural Resources. Lindsay, Ontario.

This report was prepared in response to concerns over the performance of the Deer Lake facility in producing both sufficient and consistent annual numbers of good quality muskellunge fingerlings to support enhancement stocking needs. The recommended improvements and measures cited in this report pertain mainly to the ongoing extensive pond culture operations at Deer Lake.

Remaining exclusively with pond culture will, even with the resolution of all the existing problems, still leave the station open to continuing annual inconsistencies or production, very high and increasing operating costs and a very real, persistent doubt as to the long term supply of advanced forage. It is quite evident from reports by both OMNR and angler groups that the need for rehabilitative stocking of other principle muskellunge populations (i.e., St. Lawrence, Eagle-Wabigoon) may shortly be a very necessary management decision. The existence of a much more universally adaptable culture system than pond culture would make such rehabilitation plans much more realistic.

The commencement of developmental intensive culture work at Deer Lake would be most advisable for the long term future of muskellunge production in Ontario;

HARRIS, K. G. 1988. A survey of North American muskellunge culture techniques. File Report. Ontario Ministry of Natural Resources. Lindsay, Ontario.

Muskellunge fingerling stocking is typically carried out from August to October. Six of the surveyed states have minimum stocking sizes of 8 inches (20 cm) or larger, while the remainder set the minimum at 6 inches (15 cm). Only Ontario routinely stocks muskellunge smaller than 5-6 inches (13-15 cm). Commonly expressed views regarding the stocking of fingerlings under 6 inches (15 cm) were that releasing fish that small results in negligible return to the fishery and is essentially a waste of effort in areas of normal predator density. Only Pennsylvania (200,000 for public relations) and Ontario (2.0-3.0 million) continue to stock fry on a regular basis. Production levels of fingerlings range from small programs such as Indiana (5,000/year) to Wisconsin (140,000) and Pennsylvania (100,000). Fin clipping is by far the most common fish marking technique, although there are very few actual assessment programs yielding data on post-stocking survival or capture of hatchery-reared fish.

Fingerling stocking rates vary from 0.25/acre to 5.0/acre but average 1.5-2.0/acre. Most agencies prefer to stock in habitat with high levels of white sucker or perch forage bases. The most common philosophy behind muskellunge stocking among the survey agency was the maintenance of put-grow-take type fisheries (7 states), followed by enhancement oriented stocking (4 agencies). Rehabilitative stocking with the ultimate goal of re-establishing a completely self-sustaining population, is not widely practiced. In light of this information, therefore, it is not surprising that relatively few agencies actively conserve, protect or promote muskellunge spawning habitat.

HARRIS, K. G. 1991. An overview of muskellunge culture techniques in North America. p. 248-252. *In* Proceedings of the North Central Aquaculture Conference, March 18-21, 1991, Kalamazoo, Michigan.

Purebred muskellunge (*Esox masquinongy*) are cultured for stocking purposes by 20 state and provincial agencies. In the last decade, fundamental changes have occurred in the techniques used to produce this prized gamefish species. Extensive pond culture methods on live feeds have largely given way to efforts to rear muskellunge intensively, on dry feeds alone. However, intensive techniques are still far from standardized, and most programs remain in the research and development phase. This paper is a brief overview of the current materials and methods being employed across North America for the intensive culture of muskellunge fry and fingerlings, including discussion of rearing units, water quality, feeds and feeding, density, and disease treatments.

HARVEY, J. E. 1986. Disease incidence and management implications of cultured esocids. American Fisheries Society Symposium 15 : 288-291.

Case histories of disease incidence were reviewed for the five year period (1978-82) at Pennsylvania Fish Commission hatcheries involved in the rearing of esocids. Bacterial columnaris, bacterial hemorrahagic septicemia, gill fungus, bacterial gill disease, external protozoans and monogenetic trematodes were the most prevalent disease agents diagnosed in conjunction with excessive fish mortalities. Gill associated problems were most frequently diagnosed followed by systemic bacterial infections and external skin problems. Various treatments used in controlling esocid diseases are discussed. Cultural practices are considered in their relationship to fish health and the major etiologic agents.

HE, XI. and J. F. KITCHELL. 1990. Direct and indirect effects of predation on a fish community: A whole-lake experiment. Transactions of the American Fisheries Society 119 : 825-835.

We designed an experiment to test the relative importances of direct and indirect effects of piscivorous predation on an assemblage of small fishes in a piscivore-free lake. The direct effect is defined as consumption of prey fishes. Indirect effects include habitat changes associated with predator avoidance behaviour, increases of emigration rates, and changes of composition and size structure of the prey community. After a year of premanipulation study, adult northern pike (*Esox lucius*) (a predator species) were introduced into the lake. Decrease of prey fish biomass due to increased emigration was at least as great as that due to direct consumption by the predators. Significant indirect effects included decreased abundance of dominant species, increases of some rare species, and decreases of mean size for species most vulnerable to predation. Indirect effects occurred rapidly and were most apparent during weeks immediately after northern pike were introduced.

HE, XI and R. A. WRIGHT. 1992. An experimental study of piscivore-planktivore interactions: Population and community responses to predation. Canadian Journal of Fisheries and Aquatic Sciences 49(6) : 1176-1183.

The population dynamics and behavior of an assemblage of fishes in a small bog lake were studied in a succession of whole lake manipulations of piscivores. Total prey fish biomass declined after the addition of northern pike (*Esox lucius*). This decline was the result of emigration by cyprinid prey and consumption by northern pike. The emigration response of the cyprinids was dependent on cyprinid density. At high prey fish biomass, a significant portion of the loss in biomass was the result of emigration; this was not the case at low prey fish biomass. The prey fish community shifted from small bodies soft-rayed species prior to the introduction of northern pike to species with spines or deep bodies after predator stocking. High numerical resolution captured the dynamic short term population responses to predation and suggests unstable community structure.

HEACOX, C. 1946. The Chautauqua Lake muskellunge: Research and management applied to a sport fishery. North American Wildlife Conference 11 : 419-425.

The purpose of this paper is to discuss the decline of the muskellunge population in Chautauqua Lake, the reasons for the decline and the results of the restoration program which is in progress.

The causes of the population decline are suspected to include: the increase in angling pressure, the increase in fishing efficiency and the introduction of the carp (an indirect muskellunge competitor) and the calico bass. In order to combat the decline of muskellunge, a set of strict fishing regulations were implemented and the use of artificially-propagated fish was initiated. In 1904, a hatchery was built for the exclusive culture of muskellunge at the lake. Until recently, the hatchery released large numbers of fry into the lake, but now emphasis is being shifted to fingerling-sized musky. Since 1940 over 30,000 fingerlings (5 to 10 inches in length) have been released into the lake. Unfortunately evaluation of this stocking is not yet possible, however, there are signs that the fishery is improving. In 1944, over 20 tons (3,488 fish in total) of muskellunge were removed from the lake.

HEADRICK, M. R. 1985. Bioenergetic constraints on habitat use by northern pike (*Esox lucius*) in Ohio reservoirs. Ph. D. Dissertation, Ohio State University. Columbus, Ohio. 117 p.

Northern pike (*Esox lucius*) in lakes Logan and Rupert in southeast Ohio were stocked into a temperature regime warmer than that which the species encounters in its natural range. The objectives of this study were to evaluate survival and bioenergetics of northern pike in these habitats. Organismal and population responses to this environment included rapid growth, high juvenile mortality, decreased life span, behavioral thermoregulation and reduced activity. Two stockings in Lake Logan apparently failed, one in Lake Rupert declined to a small portion of its stocked number within one month Northern pike reacted to mid-summer water temperatures by occupying the coolest available water with sufficient dissolved oxygen. They remained at temperatures near 25º C which was the optimum temperature for growth on an *ad libitum* ration for this strain. Adults in Lake Logan grew most rapidly and accumulated most of their weight in spring and summer. Juveniles in Lake Rupert grew rapidly late in summer but most of their weight gain occurred overwinter. Adults in this lake lost weight in early summer, regained some weight in late summer and fall, and accumulated most of their annual biomass increment during winter. Adult diet was almost entirely gizzard shad (*Dorosoma cepedianum*) even though centrarchids were more abundant. Age-0 pike ate mostly bluegill (*Lepomis macrochirus*).

Stocking fingerlings greater than 250 mm total length during the fall may enhance survival by minimizing predation risk and metabolic cost but observations of the species elsewhere along the southern part of its range indicate that densities of 0.5 to 1.9 adults per hectare that I observed in these lakes may be near the maximum attainable.

HEADRICK, M. R., M. S. BEVELHIMER and R. F. CARLINE. 1985. Stocking northern pike in Ohio lakes. Fisheries Report F-057-R-01 to R-06. Cooperative Fisheries Research Unit. Ohio Department of Natural Resources. Columbus, Ohio. 23 p.

HEADRICK, M. R., M. S. BEVELHIMER, R. F. CARLINE and R. A. STEIN. 1982. Evaluation of fish management techniques: Evaluation of stocking northern pike in Ohio lakes. Federal Aid Project F-57-R. Ohio Division of Wildlife. Columbus, Ohio.

HEIDINGER, R. C. 1999. Stocking for sport fisheries enhancement. p. 375-401. *In* C. C. Kohler and W. A. Hubert [eds.]. Inland Fisheries Management in North America. American Fisheries Society. Bethesda, Maryland.

Fish are currently being raised for stocking in sport fisheries by federal and state agencies and by private fish culturists. Including private stocking, I estimate that approximately 2.5 billion sport fishes are stocked annually in the United States and Canada.

An estimated 4,288,000 muskellunge were stocked into inland waters of the United States and Canada during 1995 or 1996. The majority of these fish (99.5%) were stocked in one of seventeen states. Only one Canadian province (Ontario) stocked muskellunge.

Three different life stages were stocked. These included fry (3,714,000), fingerlings (565,000) and fish larger than 203 mm in length (9,000). Stocked muskellunge fry are known to be very vulnerable to predation by other fishes.

HELM, J. M. 1960. Returns from muskellunge stocking. Wisconsin Conservation Bulletin 25(6) : 9-10.

Ten years ago the Wisconsin Department of Natural Resources stocked High Lake and Fishtrap Lake with yearling muskellunge in an attempt to quantify the return of stocked fish to the angler's creel. The cost of production of these yearlings was $1.62 each. At High Lake a 17% return to the angler was observed, whereas that number was only 1.7% at Fishtrap Lake. Possible reasons for the poor return at Fishtrap Lake include escape through an outlet, difficulty in identifying tags, mortality of fish (caused by the tag) or loss of tag or predation by other species such as walleye.

At High Lake is was thought that the stocked muskies helped boost, either directly or indirectly, the natural population by means of spawning or predation on other fish. The walleye fishery has also seen benefits.

HERGENRADER, G. L. 1984. Phytoplankton control and water quality improvement through manipulation of animal communities. Nebraska Water Resources Center. Lincoln, Nebraska. 27 p.

This was a pilot study to demonstrate the feasibility of improving water quality in surface waters by enhancing natural zooplankton grazing on phytoplankton through manipulation of fish communities. Piscivorous northern pike (*Esox lucius*) were introduced to two eutrophic farm ponds in eastern Nebraska containing large populations of planktivorous black crappie in an effort to evaluate the effects of controlled planktivore predation on zooplankton and phytoplankton communities. The stocking of piscivorous northern pike in the study ponds resulted in a marked decline in the immature black crappie densities of both ponds.

HESS, L. J. 1981. Evaluation of esocid stockings in West Virginia. Final Report, Federal Aid Project F-53-R. West Virginia Department of Natural Resources. Charleston, West Virginia.

HESS, L. J. and C. HEARTWELL. 1980. Literature review of large esocids (muskellunge, northern pike, hybrid tiger muskellunge). p. 139-181. *In* Proceedings of the 10th Warmwater Workshop. Montebello, Québec.

A literature review of the larger members of the pike family including the muskellunge (*Esox masquinongy*), northern pike (*E. lucius*), chain pickerel (*E. niger*), redfin pickerel (*E. americanus americanus*), grass pickerel (*E. a. vermiculatus*) and the hybrid musky (*E. lucius* x *E. masquinongy*) was undertaken to gather information to aid in current field research. Distribution, habitat, reproduction, hatchery culture, standing crop, mortality, age and growth, predator-prey relationships, esocid competition, regulations, and generalized management are briefly discussed.

HESSER, R. B. 1978. Management implications of hybrid esocids in Pennsylvania. American Fisheries Society Special Publication 11 : 302-307.

In Pennsylvania, only the sterile muskellunge (northern pike x muskellunge) has been utilized to any great extent among esocid hybrids, and has proven superior to both parents and other hybrids in many hatchery categories. Tiger muskellunge have been planted in 109 waters in Pennsylvania. All new impoundments over 28 hectares are stocked with tiger muskellunge fry at the rate of approximately 250/hectare unless they occur in a parent species' natural range. Following initial introductions of fry, only 18-20 cm fingerlings are stocked subsequently, at the rate of 1 to 2/hectare, usually biennially. Stream stocking rates are 625 fry/km or 20 fingerlings/km for streams less than 100 m wide and 1,000 fry/km or 30 fingerlings/km for wider streams. Fry are stocked in streams only as introductions to rehabilitated waters. Fingerlings are stocked thereafter usually on a biennial basis. Available information indicates the tiger muskellunge is difficult to sample; grows rapidly, particularly in new impoundments; returns better to the angler than the muskellunge; and is readily accepted by a growing segment of anglers as a valued trophy.

HEYBOB, E. 2000. Muskies for the cabin fever crowd. The Journal of Freshwater Fishing 25(2) : 52-62.

Due a large part to stocking, muskie fishing in Ohio lakes during warm winters can be highly successful. Ohio stocks 8-12 inch musky in order to create trophy fisheries in lakes which no longer have self-sustaining muskie populations. Currently, Ohio stocks approximately 22,000 muskies per year, at the rate of 1 to 2 fish-per-acre, in nine high-priority lakes. Lakes which are stocked are those whose water exchange rate is slow, in order to keep the fish in the stocked lake. Exceptionally high survival rates have produced great angling opportunities and, as a consequence, these stocked reservoirs do not require fishing seasons to regulate their populations. Similar stocking programs are also in place in states such as Kentucky, Pennsylvania, Missouri, Indiana and Illinois.

HICKS, D. 1972$_a$. Great northern pike introductions: Introductions. Federal Aid Project F-22-R-5, Job No. 1. Oklahoma Department of Wildlife Conservation. Oklahoma City, Oklahoma. 4 p.

HICKS, D. 1972$_b$. Great northern pike introductions: Fry sampling. Federal Aid Project F-22-R-5, Job No. 2. Oklahoma Department of Wildlife Conservation. Oklahoma City, Oklahoma. 3 p.

HICKS, D. 1972$_c$. Great northern pike introductions: Gonadal inspection. Federal Aid Project F-22-R-5, Job No. 3. Oklahoma Department of Wildlife Conservation. Oklahoma City, Oklahoma. 7 p.

HINER, L. E. 1961. Propagation of northern pike. Transactions of the American Fisheries Society 90(3) : 298-302.

The procedures and techniques involved in the artificial propagation of northern pike (*Esox lucius*) at the Valley City, North Dakota, National Fish Hatchery are discussed. Twenty million to 40 million northern pike eggs are taken from wild fish each spring. The eggs are incubated in Downing-type glass jars and the "swim-up" fry are stocked in the hatchery ponds at the rate of 100,000 per acre. The use of filtered water for incubation purposes increased the percentage of hatch from 20% in 1958 to 78% in 1959. Hatchery ponds are filled with water from the Sheyenne River and fertilized 2 weeks prior to the introduction of free-swimming pike. The fry grow to a length of 2-2.5 inches over a period of 4-6 weeks in the hatchery ponds. Fingerlings are harvested near the end of their plankton-feeding stage to prevent serious losses from cannibalism. Pond yields vary from 0 to 90,000 fingerlings-per-acre with an average of 35,000 during the 1959 and 1960 production years.

HOFF, M. H. and S. L. SERNS. 1986. The muskellunge fishery of Escanaba Lake, Wisconsin, under liberalized angling regulations, 1946-1981. American Fisheries Society Special Publication 15 : 249-256.

The muskellunge population in Escanaba Lake has been unregulated by size, season or bag limits from 1946 to the present. In an attempt to evaluate changes in the population under these liberalized regulations, the harvest and yield and the exploitation of wild and stocked muskellunge was analyzed during the periods 1946-1981 and 1956-1981, respectively. The collection of harvest, yield and exploitation data was facilitated by a compulsory permit-type creel census which was in operation during the entire 36 year period. Harvest (generally ages I and older) has averaged 25 fish annually during this 36 year period. From 1956 to 1981 the estimated population and exploitation rate of muskellunge, generally ages II-III and older, has averaged 47 (0.2/acre) and 0.29, respectively. For muskellunge age IV and older (approximately 30 inches and greater) during this same period the annual harvest averaged 6, yield 70 lb., population estimate 25 and exploitation rate 0.29. Two muskellunge yearling stockings were nine times more effective, on the average, at adding fish to the creel than two fingerling stockings. However, only one stocking contributed more than 5% fish to the creel. Under liberalized regulations 13% of the fish harvested during the present closed season on most Wisconsin waters and only 5% of the muskellunge were part of a bag containing more than one muskellunge. Only 23% of the total muskellunge harvested from 1946 to 1981 were 20.0 inches or greater in total length. The Escanaba Lake muskellunge population did not exhibit reductions in population size or annual harvest during the 36 years of liberalized angling regulations.

HOTTELL, H. E. 1976. Growth rate and food habits of the northern pike (*Esox lucius*) and the chain pickerel x northern pike hybrid (*E. niger* x *E. lucius*) in two north Georgia reservoirs. Georgia Cooperative Fishery Research Unit. M. Sc. Thesis, University of Georgia. Athens, Georgia. 72 p.

HOWARD, H. C. and R. E. THOMAS. 1970. Behavior of northern pike fry as related to pond culture. Progressive Fish Culturist 32(4) : 224-226.

Artificial northern pike propagation has been carried out in the State of Nebraska at the North Platte Hatchery since 1949. Normal procedure requires that 1-2 day old fry be planted into rearing ponds. These fry are scattered in the vegetated areas at the pond perimeter. Little or no movement takes place immediately after stocking. Since mortality of fry is a large problem at many hatcheries, pond-stocking techniques were varied in order to determine the optimal stocking period. Experiments showed increased production from ponds stocked with eyed eggs or a combination of eyed eggs and newly hatched fry, as opposed to ponds stocked with 1-3 day old fry. Success requires the presence of flooded vegetation to which newly hatched fry can attach during the critical period between hatching and swim-up.

HUNER, J. V. and O. V. LINDQUIST. 1983$_a$. How Finland stocks her rivers and lakes. Fish Farming International 10(4) : 10-11.

The production and stocking of fry and fingerlings of high value species is an important part of Finland's fisheries program. Species of particular importance are whitefish (*Coregonus*), northern pike (*Esox lucius*), Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*). Fry and fingerlings are produced both by private interests and government.

HUNER, J. V. and O. V. LINDQUIST. 1983$_b$. Public and private sectors in Finland develop whitefish and trout culture. Aquaculture Magazine 9(2) : 22-24.

Aquaculture in Finland provide fry and fingerlings to support existing sport and commercial fisheries as well as food fish. The fry and fingerlings are very important because factors such as overfishing, pollution and construction of hydroelectric dams have severely impacted natural populations. Fry and fingerlings produced in 1980 included 20 species or strains of fish and a few crayfish. Almost 18 million pike (*Esox lucius*) fry were stocked but less than 2 million one-summer fingerlings were grown.

HUNT, J. M. 1963. The Deer Lake maskinonge hatchery. Ontario Department of Lands and Forests. Lindsay, Ontario. 4 p.

Maskinonge operations at Deer Lake were initiated in 1940 and since this time millions of young muskie have been produced for Ontario waters. Following swim-up, approximately three million fry are placed into waters ranging from Cornwall to Sudbury and Niagara Falls to North Bay. The remaining 300,000 fry are kept for rearing to fingerling size. Distribution of the fingerlings begins at approximately seven weeks of age when the maskinonge have reached four inches in length. The allocation continues until the fish are seven inches in length, or approximately ten weeks old. The fingerling stock amounts to about 30,000 fish which are stocked into Lindsay Forest District lakes.

HUNT, J. M. 1966. Miles 'n miles of musky. Ontario Fish and Wildlife Review 5(3) : 17-18.

Deer Lake Maskinonge Hatchery is located on the Crowe River in Peterborough County. Operations at this hatchery began in 1940 and, since then, millions of fish have been produced for Ontario waters. The hatchery functions to compensate for the egg loss caused by fluctuating water levels and to introduce the species to waters previously uninhabited by the fish.

The musky eggs are cultured in jars and generally planted as 10-day-old fry. Annually 2-3 million fry are placed into Ontario waters. The majority of the stock is placed in the Kawartha-Trent region with those waters supplying the eggs being the most heavily stocked. Three-hundred thousand fry are kept at the hatchery and reared to the fingerling stage in fertilized pounds. Distribution of this stage begins at seven weeks (four inches) and continues until week ten (six inches). The 30,000 fingerlings from the original 300,000 fry are then stocked into 50-60 Ontario lakes.

Between 1948 and 1965, the Deer Lake Fish Hatchery has planted 53,387,000 maskinonge fry and 696,688 fingerlings.

ILLINOIS DEPARTMENT OF NATURAL RESOURCES. 1998. Illinois fish stocking policy. Springfield, Illinois. 8 p.

Suitable new and rehabilitated lakes are stocked with northern pike fry at the rate of 100 to 1,000 per acre depending upon lake fertility and the forage base. Fingerlings are used to establish new populations and augment existing populations in waters that have established fish populations. Fry are available in May; fingerlings in September-October. The stocking rate for fingerlings is 1-5 per acre. State lakes, reservoirs and public lakes are the only types of water areas considered for stocking of northern pike. Stocking of streams, Lake Michigan and non-public waters is not anticipated.

IOWA COOPERATIVE FISHERIES RESEARCH UNIT. 1983. 1982 production of fingerling muskellunge and tiger muskellunge. United States Department of the Interior. Iowa Cooperative Fisheries Research Unit. Ames, Iowa. 3 p.

Between 1974 and 1982, there was a decrease in the production of muskellunge and an increase in that of the tiger muskellunge. Production by state hatcheries of muskellunge in 1982 was 255,437 fingerlings, down 18% from 1974. Fingerling tiger muskellunge increased from 118,000 in 1974 to 714,000 in 1982. Cost estimates are difficult to make, however, the cost range for one muskellunge fingerling was thought to approximate $1-7 ($1.07 in Iowa). Costs per tiger muskellunge fingerling ranged from $0.03 to $0.719.

JENKINS, R. M. 1973. Reservoir management prognosis: Migraines or miracles? Proceedings of the Annual Conference of the Southeastern Fish and Wildlife Agencies 27 : 374-385.

There are about 500 reservoirs, of size greater than 500 acres, totaling 4.3 million acres, in the 14 states of the Southern Division. The steady accumulation of reservoir environmental and biological data during the past quarter century has greatly increased our ability to predict standing crops and angler harvests and to devise management practices based on production potentials. The increasingly successful practice of stocking predators such as striped bass, walleye and northern pike should be thoroughly evaluated in terms of angler harvest and effects on existing fish populations.

Northern pike and muskellunge are large trophy fish that prey on adult gizzard shad. The stocking of pike fry in the south has often resulted in excellent survival, whereas subsequent stockings have had little effect. The fish in the original plant, however, grow up to 4 pounds per year, with a maximum life span of six years. Reproduction of these fry as adults has been largely unsuccessful. The planting of sedges or grasses which allow for egg deposition may aid to sustain northern pike production.

JOHN, L. D. 1982. Factors affecting short term survival of stocked muskellunge fingerlings in Wisconsin. Research Report 117. Wisconsin Department of Natural Resources. Madison, Wisconsin. 24 p.

Factors potentially influencing the short-term survival of stocked muskellunge fingerlings were assessed in a series of releases in 20 Wisconsin waters. Date of stocking, water temperature at time of stocking, and presence of predators appear to be major factors affecting survival. Survival was greater when fish were released late in the season in waters 60-65º F or cooler. Better survival was achieved in four waters with no predators than in sixteen lakes with predators.

Seven to nine inch fish survived about 87% as well as 9-12 inch fish, indicating that hatchery efforts could be reduced by not rearing fingerlings over 9 inches. However, very small fingerlings (2-3 inch average) suffered almost complete mortality after stocking.

Survival of muskellunge fingerlings was not affected by fin clipping, sedation, numbers stocked or in-lake conditioning before release. There was no significant relationship between survival and the biomass of forage fish or between survival and a number of physical-chemical factors.

Recommendations for management include: (1) discontinue stocking muskellunge in the 2-3 inch size range, (2) concentrate on rearing 7-9 inch fish, (3) begin stocking in late August when temperatures are no warmer than 60-65º F, and (4) make any efforts possible to reduce stress from handling and transport of fingerlings.

JOHNSON, B. M. and T. L. MARGENAU. 1993. Growth and size selective mortality of stocked muskellunge: Effects on size distributions. North American Journal of Fisheries Management 13 : 625-629.

Sport fisheries for muskellunge (*Esox masquinongy*) are often sustained by stocking. Size selective mortality has been identified as an important factor affecting stocked muskellunge. However, this mortality is difficult to assess because its effects on the population can be confounded by growth. To partition observed shifts in length frequencies of stocked muskellunge into growth and mortality effects, two lots each of approximately 1,000 hatchery-reared muskellunge fingerlings were sorted into 10 mm size groups, marked with size specific fin clips and stocked into two northwestern Wisconsin lakes. Beginning 30 days after stocking, we used electrofishing to examine length distributions and estimate abundance of stocked fish. Shifts in the length frequency distributions after stocking were found to be caused by size selective mortality and growth. Mortality was highest for the smallest fish. A size-based analysis indicated that growth in fall contributed to changes in length distributions. Our analysis suggests that it may be important to monitor the fate of size classes within cohorts if cohort dynamics are to be fully understood.

JOHNSON, B. M., R. A. STEIN and R. F. CARLINE. 1988. Use of a quadrat rotenone technique and bioenergetics modeling to evaluate prey availability to stocked piscivores. Transactions of the American Fisheries Society 117 : 127-141.

Young-of-the-year gizzard shad (*Dorosoma cepedianum*), the primary prey for piscivores in Ohio impoundments, are difficult to sample by conventional techniques. We developed a technique for sampling littoral zone quadrats with rotenone and compared this method to other gear. To sample, we isolated 0.15 ha shoreline areas (N = 28 quadrats) with a plastic barrier, which confined the rotenone and even small fish, and applied rotenone at concentrations of 2-3 mg L^{-1}. To quantify the densities of dead fish that sank, about 18% of the bottom within the quadrats was covered with netting. These nets eliminated the need for species-specific recovery rates, which typically are highly variable. Tucker trawls and seines provided lower density and size estimates of gizzard shad than did our quadrat method. Despite difficulties associated with the quadrat rotenone technique such as site selection, variability, and personnel requirements, this method provided the best estimate of size structure and density of gizzard shad populations. To determine if prey size or density influenced stocking success of age-0 piscivores, we used our estimates of gizzard shad biomass to calculate total production of prey (71.3 kg/ha) during its first growing season. Five taxa of piscivorous fish (including 3 esocids) were stocked and their growth and survival were monitored in conjunction with regular estimates of gizzard shad. Total consumption of prey by all predators, calculated from observed growth by bioenergetics models, was 14.5 kg/ha, or only about 20% of total young-of-the-year gizzard shad production. Apparently, factors other than summer prey production, such as spatial and temporal overlap of predators and prey, the gizzard shad:predator size ratio at time of stocking, or availability of gizzard shad in winter, limited first year growth and survival of stocked predators.

JOHNSON, F. H. and A. R. PETERSON. 1955. Comparative harvest of northern pike by summer angling and winter darkhouse spearing from Ball Club Lake, Itasca County, Minnesota. Investigational Report No. 164. Bureau of Fisheries. Minnesota Department of Conservation. St. Paul, Minnesota. 11 p. + appendices.

Since 1949, a study has been carried out on the fish population and sport fishing harvest from Ball Club Lake, Itasca County, in north-central Minnesota. This lake of 5,111 acres has a game fish population primarily of northern pike and walleye pike. It is a popular lake for darkhouse spearing of northern pike and also receives light summer angling pressure. Average annual fishing pressure by these two methods over the period 1951-1954 was 0.7 hours-per-acre for spearing and 3.0 hours-per-acre for summer angling.

The sport fishing harvest from Ball Club Lake differs from that of most other Minnesota lakes in that northern pike made up from 75-94% of the summer angling catch and 85-91% of the spearing catch during the census years. The total harvest of northern pike by summer angling and winter spearing combined ranged from 1.9 pounds per acre in 1952 to 3.5 pounds per acre in 1954. These figures may be compared with an average annual total catch of 4.3 pounds per acre of northern pike for 12 lakes under census.

Of 1,255 adult northern pike tagged and released into Ball Club Lake in the spring of 1952, at least 36% were taken by fishermen during the following three years. Of the tagged fish, 23% were taken in Ball Club Lake during the first season after tagging. Some migration of pike to adjacent waters was noted.

Neither angling nor spearing appear to have a detrimental effect on the northern pike population of this lightly-fished lake. It appears that a better harvest from the entire northern pike population was had by a combination of angling and spearing than would have by angling alone. It should be emphasized however, that these conclusions may not hold for other lakes that have heavier fishing pressure for northern pike.

JOHNSON, L. D. 1958. Pond culture of muskellunge in Wisconsin. Wisconsin Conservation Department Technical Fishery Bulletin 17 : 1-54.

JOHNSON, L. D. 1963. The traveling musky. Wisconsin Conservation Bulletin 28(4) : 10-11.

A reliable method for short-term tracking of muskellunge is the use of fishing bobbers. A red and white bobber is attached by 10 feet of sewing thread to a hook which is inserted in the skin of the musky, behind the dorsal fin. Another method, which is mush more expensive involves the use of radio transmitters. Typically, however, muskellunge movements are tracked by marking and recapturing the fish.

Fingerlings can be marked with dyes or by removing a fin prior to leaving the hatchery. This method has helped to establish that 7 to 12 inch muskellunge can travel up to seven miles in one week. Traveling was found to characteristically take place along the shorelines.

JOHNSON, L. D. 1968. Evaluation of muskellunge stocking. Fisheries Report F-083-R-04. Wisconsin Conservation Department. Madison, Wisconsin. 9 p.

JOHNSON, L. D. 1969. Evaluation of muskellunge stocking. Dingell-Johnson Project F-83-R-4, Job No. 11-E, Progress Report. Wisconsin Conservation Department. Madison, Wisconsin.

JOHNSON, L. D. 1971. Development of improved muskellunge stocking procedures. Fisheries Report F-083-R-07. Wisconsin Conservation Department. Madison, Wisconsin. 14 p.

During 1971, a total of 69 lakes were checked for their suitability for further studies relative to development of improved muskellunge stocking procedures. Five lakes were selected for intensive studies primarily because of size (less than 150 acres), ease of access, ease of netting and the effectiveness of alternating current (AC) electrofishing gear. Each lake was netted two weeks, electrofished two weeks, the shoreline was seined for forage fishes, and a general area survey was made of aquatic vegetation. Data obtained in each lake were correlated with survival of stocked muskellunge fingerling.

Our data indicated that the muskellunge fingerlings were stressed from handling encountered during harvest and transport to the lakes. Attempts at conditioning muskellunge in pens did not accomplish complete recovery of the fingerlings before their release in the lakes. Conditioning did not increase survival. Lakes with predators had significantly lower muskellunge survival, compared to survival of fingerlings stocked in Lund Lake, where there were no predators capable of eating the stocked fish. Netting studies in all of the lakes established that predators, as well as other fish species, did not actively seek out the fingerling stocking site. Trends of muskellunge fingerling survival were apparent from data obtained, but correlations were not usually significant at the level of sampling involved. Larger samples may show significance.

JOHNSON, L. D. 1972_a. Musky survival. Wisconsin Conservation Bulletin 37(3) : 8-9.

Wisconsin has been stocking musky since 1955. In a large number of lakes stocked fish make up as much as 80% of the muskellunge population, while others are only composed of 5% stocked fish.

It has been discovered that the stocking of larger muskellunge allows for a higher rate of survival. Experiments have also demonstrated that the survival of fingerlings is highly variable. By electroshocking, survival estimates were found to range from 4 to 90%. Average survival between one to four weeks following stocking ranged between 35 and 50%.

The variability of these survival rates were thought to be caused by the stress the fish experienced prior to planting. It was found that during capture and handling blood sugar levels rose rapidly. The possibility that injured or weaker fish can be more easily spotted by predators and are therefore more susceptible to predation is currently being investigated. Methods of decreasing stress levels during fish handling is also being studied.

JOHNSON, L. D. 1974. Development of improved muskellunge stocking procedures. Dingell-Johnson Project F-83-R-10, Study No. 209. Wisconsin Department of Natural Resources. Madison, Wisconsin. 16 p.

During 1971, a total of 69 lakes were checked for their suitability for further studies relative to development of improved muskellunge stocking procedures. To date, 13 of these lakes have been studied intensively, some of these for periods of two to three years.

Lakes were selected because of size (less than 150 acres), ease of access, ease of netting and the effectiveness of alternating current (AC) electrofishing gear. Each lake was netted two weeks, electrofished two weeks, the shoreline was seined for forage fishes and a general area survey was made of aquatic vegetation.

The four years of data indicated that the muskellunge fingerlings were stressed from handling encountered during harvest and transport to the lakes. Conditioning muskellunge in small nylon pens, compared to a lake pen and to direct release did not increase survival within the lakes. Lakes with predators had significantly lower muskellunge survival, compared to survival of fingerlings stocked in three lakes where there were no predators capable of eating the stocked fish. Netting studies of the lakes established that predators, as well as other fish species, did not reduce survival. Size of stocked fingerlings, within the size ranges available, did not influence survival.

JOHNSON, L. D. 1978. Evaluation of the esocid stocking program in Wisconsin. American Fisheries Society Special Publication 11 : 298-301.

There was great variability in the range of survival of stocked esocids in Wisconsin waters. Generally, muskellunge and northern pike survived in the range of zero to 60% over short-term intervals. Despite high variations, the stocked fingerlings added to the lake populations. There was an overall tendency for hybrids of these two species to survive at higher values, up to 85%. Dry diet-fed hybrids, however, tended toward lower survival than minnow-fed hybrids.

JOHNSON, L. D. 1981. Comparison of muskellunge (*Esox masquinongy*) populations in a stocked lake and unstocked lake in Wisconsin with notes on the occurrence of northern pike (*Esox lucius*). Fisheries Research Report 110. Wisconsin Department of Natural Resources. Madison, Wisconsin. 17 p.

Populations of muskellunge (*Esox masquinongy*) in Sand Lake, which has not been stocked with muskellunge for over 26 years, were compared with populations in Lac Court Oreilles, which has been stocked annually since 1933 with the exception of five experimental non-stocking years, 1966-70. Muskellunge caught in both lakes during the 1972-79 spawning runs were similar in maximum size but Lac Court Oreilles had proportionately more large (over 45 inches) and more old (over age XV) individuals. Sand Lake had two to three times the estimated number of muskellunge/acre but the population density in both lakes was low (1 fish/5-20 acres) as compared to some other Wisconsin lakes.

Stocking appeared necessary for maintenance of the muskellunge population at its present level in Lac Court Oreilles. Naturally reproduced fish did not increase in number during the five year non-stocking period; rather non-stocking produced a “hole” where reduced numbers of fish from these five year classes were recruited to the adult population. Absence of stocking was not the only factor producing weak year classes during the study. Low survival of the stocked 1958-60 year class resulted in a similar “hole” in the population age structure. While it was obvious that stocking increased the numbers of adult muskellunge in Lac Court Oreilles samples, Sand Lake maintained a naturally reproducing population without stocking.

The invasion and subsequent establishment of large populations or northern pike (*Esox lucius*) appeared to be related to the observed decline in the muskellunge population in Lac Court Oreilles. The more recent invasion of northern pike into Sand Lake, however, has not shown a decreased muskellunge population within the period of this study.

JOHNSON, L. D. 1982. Factors affecting short term survival of stocked muskellunge fingerlings in Wisconsin. Research Report 117. Wisconsin Department of Natural Resources. Madison, Wisconsin. 24 p.

JOHNSON, L. D. 1984. Relationship of muskellunge fingerling density and electrofishing catch-per-effort in northern Wisconsin lakes. p. 48. *In* An International Symposium on Managing Muskellunge, April 4-6, 1984, LaCrosse, Wisconsin. (Abstract only)

Historically, evaluation of survival of stocked fingerling muskellunge has involved costly, time consuming, multiple sampling to make population estimates. This paper describes a cost effective method to estimate fingerling muskellunge density with a minimum of effort.

A long-term study (1962-1979) was conducted using multiple electrofishing samples to make population estimates and to evaluate the effectiveness of Wisconsin's muskellunge stocking program. During the 17-year study, 56 population estimates of large (6-12 inch) fingerlings were made in 24 different lakes. The catch-per-mile of shoreline during the first night of sampling, usually one round or circuit of the lake using an alternating current (AC) electrofishing boat, and the estimated fingerling density was used to generate a least-squares linear regression equation.

The equation for describing density (number-per-acre) is: $\text{Log } Y = 0.2469 + 0.7919 \text{ Log } X$ ($R^2 = 51.6\%$), where Y = fingerling density and X = catch per mile of shoreline. This equation can be valuable in an investigation of muskellunge fingerling populations when it is desired to make a preliminary appraisal before more detailed data are available or if further detailed evaluation is not desired.

JOHNSON, L. D. and H. H. LAUGHLIN. 1957. 1957 muskellunge propagation program. Wisconsin Conservation Department, Northwest Area Headquarters. Spooner, Wisconsin. 5 p.

Muskellunge are raised from the egg to fry stage in hatching jars. The weakest/last fish in the hatching jars are either discarded or planted in lakes, while the rest are placed into rearing ponds. Select amounts of muskellunge are harvested at the 1.5 inch size and stocked based on selected lake quota. These fish are then moved to other rearing ponds and any "leftovers" are also stocked into lakes. The final pond drain begins in mid-September with all muskellunge being stocked into lakes. All muskellunge over five inches are marked with a right pelvic fin-clip and dipped in Malachite Green prior to stocking.

JONAS, J. L., C. E. KRAFT AND T. L. MARGENAU. 1996. Assessment of seasonal changes in energy density and condition in age-0 and age-1 muskellunge. Transactions of the American Fisheries Society 125(2) : 203-210.

The objectives of this study were to evaluate seasonal changes in the energy density of age-0 and age-1 muskellunge (*Esox masquinongy*) and to compare energy density to various estimates of condition. Three treatment groups of muskellunge were evaluated to determine temporal changes in energy density (J/g wet weight [ww]), water content, condition factor (K_{TL}; $K = W/L^3$, where W = weight and L = total length in centimeters), and relative weight (W_r; ratio of actual to "standard" weight) through the first year following hatching. Treatment groups were (1) hatchery (muskellunge reared and maintained in hatchery ponds), (2) stocked (hatchery-reared muskellunge stocked in lakes), and (3) natural (muskellunge naturally produced in lakes). Energy levels and relative condition were compared for fish 4 and 11 months old. Differences in energy density were observed between all three treatment groups. An average overwinter reduction of 494 ± 192 J/g ww in energy density was observed over all treatment groups. Natural fish lost less energy (8%) overwinter than either hatchery (12%) or stocked fish (15%). A simple linear model effectively relates energy to indices of condition for muskellunge. A weak positive relation ($P < 0.0001$, $r^2 = 0.39$, 0.40, and 0.43) was observed between dry weight energy density and the three indicators of fish condition (percent water, K, and W_r). Our results show that condition indices may not be the best indicators of seasonal fluctuations in total energy within and between fish populations. Seasonal fluctuations in energetic values for a population can be more accurately determined through assessment of percent water in individual fish.

JONES, A. R. and D. E. STEPHENS. 1984. Muskellunge streams investigation in the South Fork Kentucky River Drainage. Dingell-Johnson F-50-R-(4-6). Kentucky Department of Fish and Wildlife Resources. Frankfort, Kentucky.

In order to determine the present status of the muskellunge populations in streams and to determine the potential for enhancing the muskellunge fisheries, studies of the biological, chemical and physical characteristics were conducted in six streams of the South Fork Kentucky River drainage in 1981 and 1982. The fish population was sampled with an electrofishing unit. Water quality characteristics and the bottom fauna were sampled seasonally. A total of 46 muskellunge were taken from the South Fork Kentucky River drainage during the 2 years of study. Six muskellunge were taken from South Fork Kentucky River, 3 from Sexton Creek, 7 from Redbird River, 18 from Goose Creek, and 12 from Collins Fork. No muskellunge were taken from Little Goose Creek. The catch-per-unit of electrofishing effort was 0.4 muskellunge-per-hour in this drainage. The highest concentrations were in Collins Fork (0.9 muskellunge per hour) and Goose Creek (0.8 muskellunge per hour). Muskellunge grew to a total length of 10.2 inches at age 1, 15.6 inches at age 2, 20.1 inches at age 3, 24.6 inches at age 4, 30.3 inches at age 5 and 31.4 inches at age 6. The fish species most often associated with muskellunge populations was golden redhorse and muskellunge were most often taken in pools where fallen trees were abundant. The strongest year classes of muskellunge were 1978, 1979, and 1980. Stockings of fingerling-size muskellunge evidently strengthened the year class for the year stocked. It is recommended that an annual stocking of muskellunge fingerlings be conducted on streams in the South Fork Kentucky River drainage.

JONES, T. S. 1992. Floodplain distribution of fishes of the Bitterroot River, with emphasis on introduced populations of northern pike. M. Sc. Thesis, University of Montana. Missoula, Montana. 69 p.

JORGENSEN, W.D . 1986. Iowa culture of muskellunge on artificial diet. American Fisheries Society Special Publication 15 : 285-287.

Natural food diets (zooplankton and minnows) and artificial dry diets were compared as a means of increasing fry survival during the intensive culture of muskellunge at the Iowa Spirit Lake Hatchery. Muskellunge fry fed the natural diets had a constant supply of zooplankton available; at about 1.5 inches, fathead minnows were added to their daily diet until stocking occurred. Survival to stocking size (5.3 inches) was 18%. Artificial feeding of muskellunge was initiated on an experimental basis in 1982 and tested on a production scale in 1983. Brine shrimp and Abernathy feed were used for the initial training process, with brine shrimp withdrawn when the fry converted to dry feed. In 1982, only 8.0% of the initial total were reared to stocking size, because a malfunction in the water supply caused the death of 910 fish. In 1983, 53% of the artificially-fed musky survived to a mean stocking size of 5.4 inches, compared with 18%

for those on the minnow diet. Cost comparison to the two rearing methods in 1983 were $1.76/fish for the live-food diet and $0.29/fish for the artificial diet.

KERR, S. J. and R. E. GRANT. 2000. Muskellunge and northern pike. p. 325-355. *In* Ecological Impacts of Fish Introductions: Evaluating the Risk. Fisheries Section, Fish and Wildife Branch. Ontario Ministry of Natural Resources. Peterborough, Ontario. 473 p.

This manual has been prepared as a reference to assist proponents of projects involving fish stocking into new waters (introductions). Potential impacts of introduced esocids are based largely on predation on resident fishes and competition between muskellunge and northern pike. Predation by introduced esocids has been noted to result in a decline of other resident fishes including yellow perch, walleye, largemouth bass, white sucker, salmonids and black crappie. Both species are known to hybridize. Proposals for the introduction of either muskellunge or northern pike should be carefully evaluated.

KIDD, K. A., M. J. PATERSON, R. H. HESSLEIN, D. C. G. MUIR and R. E. HECKY. 1999. Effects of northern pike (*Esox lucius*) additions on pollutant accumulation and food web structure, as determined by δ^{13}C and δ^{15}N, in a eutrophic and an oligotrophic lake. Canadian Journal of Fisheries and Aquatic Sciences 56 : 2193-2202.

In May 1993 and 1994, northern pike (*Esox lucius*) were added to eutrophic Lake 227 and oligotrophic Lake 110 at the Experimental Lakes Area in northwestern Ontario. Both lakes were previously dominated by cyprinids, and northern pike additions significantly decreased cyprinid densities in both lakes. Food web relationships were determined pre- and post-manipulation using stable carbon (δ^{13}C) and nitrogen (δ^{15}N) isotope analyses of zooplankton, benthic invertebrates, and fishes. In Lake 110, fathead minnow (*Pimephales promelas*) shifted from a zooplanktivorous to a zoobenthivorous diet as indicated by a shift in isotopic composition to more depleted δ^{15}N and enriched δ^{13}C values after northern pike additions. It was not possible to direct predator-induced shifts in cyprinid diets in Lake 227. Concentrations of mercury and organochlorines – sum of polychlorinated biphenyls (ΣPCB), dichlorodiphenyltrichloroethane (ΣDDT), and hexachlorocyclohexane (ΣHCH) – in these fish did not change markedly after northern pike introductions despite the shifts in diet for fathead minnow from Lake 110, which is consistent with previous studies. Our results indicate that nutrient availability, rather than short-term changes in food web structure, determined contaminant concentrations in fish and other biota from these lakes.

KINMAN, B. T. 1989. Evaluation of muskellunge introductions in Green River Lake. Fisheries Bulletin No. 85. Kentucky Department of Fish and Wildlife Resources. Frankfort, Kentucky. 50 p.

Muskellunge (1977-1978) and tiger muskellunge (1979-1981) were stocked in Green River Lake at approximately 1 fingerling/acre with fish averaging 6 inches in length to establish an additional fishery and replace the loss of the native Green River muskellunge population following impoundment. A fishery did not develop until annual muskellunge stocking with fish > 9.0 inches were initiated in 1982. Beginning in 1982, stockings alternated between 12-14 inch and 8-10 inch muskellunge. There was significantly higher survival of the year classes from 12-14 inches versus 8-10 inches in muskellunge stockings. The year class strength was 4.2 times higher for the larger sized stockings based on CPUE from electrofishing. Growth of muskellunge indicated most year classes recruited into the legal size range (> 30 inches) at age 2+. The harvest objective of increasing the sport fish yield by either a minimum of 10% or 1 lb/acre was achieved in 1987. A total of 2,771 muskellunge were caught, with 1,014 of this total being harvested; 75% of the legal size muskellunge in the catch were harvested. The total biomass of muskellunge harvested was 10,047 lb.

(1.22 lb./acre), a 9.6% addition to the fish yield. Muskellunge anglers accounted for 8.7% of the fishing trips on the lake and harvested muskellunge at a rate of 0.02 fish/hour. Negative public reaction to the muskellunge introduction prompted an angler attitude survey in 1987 which revealed only 26% of all anglers opposed the stocking program. Annual muskellunge stockings will be continued and evaluated with annual stockings of 1,864 and 3,449 12 inch fish on alternate years.

KINMAN, B. T. 1995. Use of cultured fish for put-grow-and-take fisheries in Kentucky impoundments. American Fisheries Symposium 15 : 518-526.

Twenty large (340-160,300 acres) impoundments and 160 small impoundments are important fisheries resources in Kentucky; 55% of Kentucky anglers prefer to fish in these impoundments. Put-grow-and-take stocking programs were established to create recreational angling opportunities that otherwise would not exist in these altered aquatic environments. Progeny of native muskellunge (*Esox masquinongy*) are stocked into three large impoundments that inundated riverine muskellunge habitat. Native walleye (*Stizostedion vitreum*) was extirpated as a result of dam construction, and a lake-spawning strain has been used to reintroduce this species into seven large impoundments. Channel catfish (*Ictalurus punctatus*) is extensively stocked into small impoundments. Striped bass (*Morone saxatilis*) was introduced as a pelagic predator into one large impoundment with available coolwater habitat. Hybrid striped bass (*Morone saxatilis* females x *M. chrysops* males) has been introduced into six large impoundments to create a pelagic fishery. Two warmwater fish hatcheries owned and operated by the Kentucky Department of Fish and Wildlife allocated approximately 90% of their fish production (biomass) for these stockings. Rainbow trout (*Oncorhynchus mykiss*) was introduced into seven impoundments and three large impoundments with coldwater habitats. A federal hatchery in Kentucky dedicates 35% of annual production to provide rainbow trout for these stockings. These put-grow-and-take stocking programs have achieved the annual yield (weight harvested) objective of at least 1 lb/acre or a 10% addition in the total yield for all species except walleye. Maintenance of these fisheries has successfully supplemented and diversified angling opportunities, possibly dispersed fishing effort, and established trophy fisheries for striped bass and muskellunge.

KLEINERT, S. J. 1970. Production of northern pike in a managed marsh, Lake Ripley, Wisconsin. Research Report No. 49. Wisconsin Department of Natural Resources. Madison, Wisconsin. 19 p.

During the years 1964-1966, Perrys Marsh at Lake Ripley, Jefferson County, was the site of a study to assess the production of northern pike in the marsh. Adult pike were stocked in 1964 and 1966, with northern pike fry from the Delafield and Wild Rose hatcheries being stocked in 1965. No spawning activity was subsequently observed. In 1965, one fish, bearing a 1964 pectoral clip, was captured in Lake Ripley.

The number of northern pike produced in Perrys Marsh was too small to significantly improve the northern pike fishery of Lake Ripley. It was concluded that Perrys Marsh was poorly suited as a managed production area for northern pike, probably due at least in part to low zooplankton levels in the marsh.

KLINGBIEL, J. H. 1954. An evaluation of the stockings of yearling muskellunge. *In* Proceedings of the 16th Midwest Fish and Wildlife Conference, St. Louis, Missouri.

KLINGBIEL, J. 1966. An evaluation of stocking large muskellunge fingerlings. Fisheries Management Report 3. Wisconsin Department of Natural Resources. Madison, Wisconsin. 11 p.

KLINGBIEL, J. 1984. Culture of purebred muskellunge. American Fisheries Society Special Publication 15 : 273-278.

The use of conventional pond rearing techniques for purebred muskellunge has given erratic and unpredictable production but the fingerlings turned out are thought to be large enough to maximize survival after stocking in most Wisconsin waters. The more dependable techniques in culture are spawning, incubation and rearing in ponds to provide fish 3 inches to 8 inches or larger. The culture area that needs the most improvement is rearing from swimming fry to approximately 3 inches in length. The ability to control environmental conditions and provide adequate forage is essential to stabilized production.

Intensive culture techniques using pellet feeding has revolutionized the rearing of hybrid muskellunge and northern pike but has not been nearly as successful with purebred muskellunge. Rearing in tanks using live food has been successful but growth is somewhat slow. It is suggested that for some production programs it appears feasible to rear fingerlings to 3 inches in tanks using live forage and then transfer them to ponds to grow to adequate size. Solutions to production problems vary and are dependent upon local conditions and facilities as well as the size of fingerling needed for cost-effective stocking.

KLINGBIEL, J. and L. E. MOREHOUSE. 1954. Does musky stocking pay? Wisconsin Conservation Bulletin 19(10) : 17-19.

For many years Wisconsin has stocked large numbers of muskies of all sizes. In 1953, a total of 1,504,500 were stocked including: 1,300,000 fry (3/4-inch), 200,000 fingerlings (2-6 inches) and 4,500 yearlings (8-15 inches). The hatcheries have gradually been stressing the superiority of larger size to larger numbers of fish being planted.

The majority of fry are stocked into lakes from which muskie spawn is taken, whereas the yearlings are placed into waters with an unusually high level of fishing pressure. In order to evaluate the benefits of stocking muskie two lakes, High and Fishtrap, were stocked with tagged yearlings (488 and 310, in 1950 and 1951, respectively). Thus far, 15 of those in High Lake have been returned, which accounted for more than 40% of the recorded catch.

KLUPP, R. 1978. The production of pike fingerlings in carp ponds. Fischer und Teichwirt 29(8) : 144-148.

The possibility of using pike fingerlings as the second species in carp farming ponds is discussed. Various aspects of pike behaviour (including cannibalism) must be considered. Indications of stocking and stock density are given.

KOPPLEMAN, J. B. and D. P. PHILIPP. 1986. Genetic applications in muskellunge management. American Fisheries Society Special Publication 15 : 111-121.

Past and current management practices have included hatchery propagation and subsequent stocking programs as an integral part of an attempt to meet increased demands for this species of sportfish. These types of programs may bring mixed blessings. Several subspecies of muskellunge have, at one time, been recognized as distinct by biologists. Although these distinctions have been based on morphological and geographic distributional differences, they do indicate a potential for significant genetic variation among populations of muskellunge throughout the natural range. This suggests it is probable, at least initially, that different genetic stocks existed which, through natural selection, had been genetically tailored to specific environments. If this were true, a certain amount of stock integrity would undoubtedly still exist. Hatchery propagation and stocking programs, intending to improve muskellunge fisheries, need to seriously evaluate their potential impact to preserve the genetic integrity of valuable genetic stocks. Currently this is quite difficult to do, since little genetic variation data is available on a species-wide basis.

The purpose of the study was to assess the level of genetic variability existing among muskellunge populations from a variety of regions within this species' range. To accomplish this, up to 20 individuals were collected from eight different geographic areas and genetically analyzed using vertical starch gel electrophoresis coupled with histochemical staining procedures. Specifically, liver, eye and white skeletal muscle extracts were used to determine the genotype at 45 loci for each individual. The resulting allele frequencies were used to assess the levels of genetic variability existing within populations, among populations and within the species as a whole.

The level of genetic variability observed in this study has clear implications for future muskellunge research and management programs. Once distinct genetic stocks of muskellunge have been identified, their corresponding characteristics and the interrelationships of these characteristics with the biotic and abiotic surroundings must be understood. Future muskellunge management programs need this information if they are to be truly effective. All species of sportfish, including the muskellunge, need to be managed by programs following these genetic stock concepts so that the genetic resources of the species can be safeguarded.

KORNMAN, L. E. 1983. Muskellunge streams investigation at Kinniconick and Tygarts creeks. Fisheries Bulletin No. 68. Kentucky Department of Fish and Wildlife Resources. Frankfort, Kentucky. 64 p.

Biological, chemical, and physical characteristics were determined at two native muskellunge (*Esox masquinongy*) streams, Kinniconick Creek and Tygarts Creek, in 1980-81. This study was carried out to determine the management potential of developing the muskellunge fisheries in streams and evaluate the impact of stocking fingerling muskellunge in 1973, 1976, and 1979. The fish population structure was determined by sampling with a boat-type electrofishing unit. Water quality conditions were recorded and benthic macroinvertebrates were sampled seasonally. Thirty-five muskellunge were captured at Kinniconick Creek and 59 muskellunge were taken from Tygarts Creek during the two-year study. The mean catch rates for muskellunge at Kinniconick Creek were 0.5 fish per hour and 2.9 fish per mile. Muskellunge grew to a total length of 11.4 inches at age I, 17.6 inches at age II, 22.2 inches at age III, 26.3 inches at age IV, 30.1 inches at age V, and 33.1 inches at age VI in Kinniconick Creek. The total lengths for muskellunge from Tygarts Creek were 11.3, 17.9, 22.7, 27.0, 30.8 and 35.8 inches at ages I-VI, respectively. The mean annual exploitation rate on tagged muskellunge was 15% at the Kinniconick Creek and 21% at Tygarts Creek. There were more muskellunge captured from year classes belonging to 2 of the 3 years of stocking at each stream than from unstocked years at both streams, except for the 1975 year class at Kinniconick Creek and the 1980 year class at Tygarts Creek. In order to maintain a more consistent recruitment from each year class of muskellunge in these two streams, an annual supplemental stocking of one 7-9 inch muskellunge per 2 acres of muskellunge pool habitat is recommended. Future muskellunge habitat in the form of fallen trees should be ensured by the protection of trees within the riparian zone near the shoreline of each stream.

KORNMAN, L. E. 1985. Muskellunge streams investigation in Red River, Station Camp Creek and Sturgeon Creek. Fisheries Bulletin No. 77. Kentucky Department of Fish and Wildlife Resources. Frankfort, Kentucky. 68 p.

Three muskellunge streams (Red River, Station Camp Creek, and Sturgeon Creek) were studied during 1982 and 1983, primarily to determine the existing muskellunge population, what management potential exists that may enhance the muskellunge fishery, and evaluate past stockings of muskellunge fingerlings. Additional data was gathered regarding associated fish species. Bottom fauna and selected chemical characteristics were gathered seasonally, and pertinent physical features were recorded at each study pool. Eight muskellunge were collected from Red River during the 2 years of sampling for an overall catch rate of

0.3 muskellunge-per-hour. Mean annual growth of muskellunge at Red River was 10.8, 17.2, 23.1 and 28.0 inches long at ages 1-4, respectively. Muskellunge were better represented by year classes from years that muskellunge were stocked, as reported through the mail-in survey, than based on muskellunge collected during this study. A total of 11 muskellunge were collected in Station Camp Creek for a catch rate of 0.8 muskellunge-per-hour. Age groups 1-4 muskellunge had a mean length of 11.4, 18.0, 23.2 and 27.9 inches based on back-calculated lengths. Five of the 11 muskellunge were from the 1979 year class, a year in which muskellunge were stocked. Only one muskellunge was collected from Sturgeon Creek for a catch rate of 0.2 fish-per-hour. The fish was from the 1979 year class, a year in which muskellunge were stocked, and was 30.0 inches long and 6.78 pounds in weight. This fish was harvested from the same pool 25 months later. The known Red River fish fauna is represented by 85 species, including those species of fish collected during this study. A total of 55 species are now recorded from Station Camp Creek and 56 species are now known from Sturgeon Creek. Ten species from these streams have been given conservation status. Golden redhorse were the most abundant fish taken by electrofishing from each of the streams. Spotted bass was the most abundant black bass species collected from Red River and Sturgeon Creek, but spotted bass and largemouth bass were taken with equal frequency from Station Camp Creek. Except in isolated cases, chemical parameters and benthos sampling indicated the presence of good water quality at all three streams. All three streams should be protected from any degradation that would alter habitat or water quality. Red River from mile 30 to the downstream junction of the Wild and Scenic portion and Station Camp Creek above the junction of Red Lick Creek should be protected as Outstanding Resource Waters. Sturgeon Creek should be closely monitored so that no further degradation occurs as a result of strip mining. Muskellunge fingerlings should be stocked annually into the Red River from mile 20-60 (every other year from mile 0-20), that portion of Station Camp Creek above Middle Fork Creek every other year, and the lower 10 miles of Sturgeon Creek every year.

KORNMAN, L. E. 1989. Muskellunge fishery investigation in the Licking River. Fisheries Bulletin No. 87. Kentucky Department of Fish and Wildlife Resources. Frankfort, Kentucky. 96 p.

The main stem of the Licking River, below Cave Run Lake, was part of a muskellunge streams investigation study from 1983-86. In 1983, a fish population survey was conducted at two stations in the Licking River tailwater below Cave Run Reservoir. In 1984-1986, the Licking River downstream of the tailwater station was investigated, primarily to determine the range and population status of the muskellunge, the success of past muskellunge stockings, and management needs for the muskellunge fishery. Data was gathered from selected species and attempts were made to document all fish species present within the study sites. Bottom fauna and selected chemical characteristics were gathered seasonally, and pertinent physical features and relative observations were recorded at each study pool. Thirty-nine miles of the Licking River were electrofished at least once during this study (18 pool electrofishing stations and 16 riffle-seine sites). In all, 62.8 hours were spent electrofishing 66.8 miles of the river. During this time, only 12 muskellunge were captured and 9 were observed that escaped capture; a hybrid muskellunge was also collected. The catch rate was 0.2 muskellunge-per-hour. However, when only the upper section was sampled in 1985, the catch rate was 0.7 muskellunge-per-hour. Hatchery broodstock acquisition from the Cave Run Reservoir tailwater area of Licking River during the spring of 1983-1988 resulted in an average of 191.53 lbs. of muskellunge removed (and subsequently an equivalent number was restocked) annually. Muskellunge primarily range from Licking River mile 110.0-173.4, although a muskellunge was reportedly harvested at river mile 40. Scale analysis of angler harvested muskellunge from mail-in survey returns in 1983-1987 identified muskellunge from the following year classes: 1976 (3), 1977 (1), 1978 (2), 1979 (7), 1980 (5), 1981 (7), 1982 (2), 1983 (1). Back calculated lengths (inches) from these same fish at each age were: I – 12.0, II – 17.7, III – 22.7, IV – 27.4, V – 30.8, VI – 34.1, VII – 37.2, VIII – 40.6, and IX – 41.8.

Chemical parameters and benthic macroinvertebrate samples indicated characteristics of good water quality in the Licking River to support a diverse, viable community of warmwater fishes and aquatic macroinvertebrates. Every effort should be taken to protect the Licking River below Cave Run Reservoir from any man-made or natural intrusions which may impact these communities. Several threats exist, which if realized, could drastically impact this system. They are the proposed Falmouth Lake Dam and the potential for the development of the oil shale industry within this region. Sedimentation, as in most streams within Kentucky, remains a concern; better land use practices are needed. Riparian habitats should be protected in order to assure bank stabilization, canopy, and a future supply of fallen tree habitat to create instream cover. Annual supplemental muskellunge stockings should continue within the Licking River.

KRISHKA, B. A., R. F CHOLMONDELEY, A. J. DEXTRASE and P. J. COLBY. 1996. Impacts of introductions and removals on Ontario percid communities. Report of the Introductions and Removals Working Group, Percid Community Synthesis. Ontario Ministry of Natural Resources. Peterborough, Ontario. 111 p.

Although northern pike are highly piscivorous predators that may compete with and prey upon walleye, they normally coexist well with walleye populations in Ontario. Nevertheless, the potential exists for negative impacts on walleye populations when northern pike are introduced into walleye lakes. Northern pike predation on white sucker may indirectly benefit walleye by reducing competition between white sucker and yellow perch. However in some lakes northern pike may compete directly with walleye by preying on yellow perch. Interactions between walleye and northern pike may be intensified in smaller waters. The introduction of northern pike into a percid community can therefore have direct, negative impacts on both walleye and its forage base due to predation. Such changes are most likely to occur in clear, shallow, well-vegetated lakes that favour northern pike. Even though northern pike and walleye exist harmoniously in many Ontario lakes, we recommend that northern pike not be introduced into percid waterbodies that do not have northern pike.

Although no studies have examined the impact of introduced muskellunge populations on percid communities in Ontario, there is some evidence from Wisconsin studies that muskellunge can reduce populations of walleye. In recent years, the number of muskellunge in Wisconsin waters has increased substantially due to restrictive size and bag limits, high stocking rates of large fingerlings and high catch-and-release rates of legal-sized fish. The increased numbers of muskellunge have resulted in excellent muskellunge fishing in many Wisconsin waters but moderate to high density muskellunge populations have probably suppressed bass (*Micropterus* spp.) and walleye populations in at least 12 Wisconsin lakes. Although muskellunge coexist well with walleye in many Ontario lakes, the possible risks associated with predation impacts lead us to recommend that caution be exercised with respect to muskellunge introduction into percid waters or connected waterbodies especially in small lakes.

KROHN, D. C. 1969. Summary of northern pike stocking investigations in Wisconsin. Technical Bulletin 44. Wisconsin Department of Natural Resources. Madison, Wisconsin. 35 p.

Information on stockings of northern pike in 19 lakes in Wisconsin, Minnesota and Iowa in past years has been compiled and presented here to evaluate various kinds of stocking efforts and to present recommendations for future stocking and further evaluation.

The stocking of fingerlings and yearlings, averaging 12-17 inches in total length, into waters containing northern pike can result in a considerable return of the stocked fish and short-term improvement of fishing success and harvest. Generally, when northern pike populations were high, competition appeared to occur as indicated by such factors as increased natural mortality and poor growth of stocked fish.

LAARMAN, P. W. 1979. Evaluation of a chemical reclamation and restocking program on the Huron River in the Detroit metropolitan area. Fisheries Research Report No. 1866. Michigan Department of Natural Resources. Lansing, Michigan. 34 p.

Approximately forty miles of the Huron River, including seven impoundments were treated with 2 ppm of rotenone. This treatment was conducted on three segments between October 1972 and October 1973. More than 17 million desirable fish were stocked following the eradication of more than 1,000 metric tons of unwanted species (95% carp). Species stocked included smallmouth and largemouth bass, rainbow trout (catchables), walleye (fry), northern pike and muskellunge (fry).

The major evaluation was done by post-treatment creel censuses on the three segments (Belleville Lake, Ford Lake and the "upper" section). The benefit to cost ratio over a five year period was calculated for each segment. The ratio for the "upper" segment was found to be 4.1:1, that of Ford Lake 5.7:1 and that of Belleville Lake 25.3:1. Although the number of stocked predators which were harvested by anglers was low, all but muskellunge showed up in the creel. It was estimated that 0.7% of the tiger muskellunge stocked were caught by anglers.

LARSCHEID, J., J. CHRISTIANSON, T. GENGERKE and W. JORGENSEN. 1997. Bringing the muskies back to the Iowa great lakes – Stocking the right kind of fish at the right time of year. p. 373. *In* The 59th Midwest Fish and Wildlife Conference, December 7-10, 1997, Milwaukee, Wisconsin. (Abstract only)

Iowa's muskellunge program was established in 1960 when 40 advanced fingerlings were stocked into West Okoboji Lake and a like number were stocked into Clear Lake. The program was expanded in 1975 when 1,000 advanced fingerling muskellunge were stocked into Spirit Lake. Natural reproduction of muskellunge in these lakes is minimal; therefore, these fisheries are dependent upon stocking advanced fingerlings each fall. Despite these stockings, the density of muskellunge has steadily declined since 1984. In response to these declines, an investigation was initiated to determine the causes of the decline and develop management guidelines that will increase the densities of muskellunge in these lakes. Beginning in 1991, all muskellunge fingerlings were marked with a freeze brand. In addition, all adult muskellunge caught each spring during the annual broodstock collection were individually marked with Visual Implant tags. The decrease in the muskellunge populations was attributed to a substantial decrease in recruitment. In fact, some years there was evidence that none of the stocked fingerlings survived. This decrease in recruitment was due to a shift from rearing muskellunge on a live diet (zooplankton-minnows), to a totally dry pelleted diet. The poor survival of these fish was most likely due to a combination of poor health due to nutritional problems, poor colour, and stocking much smaller fish than what were previously stocked. Fish reared on the pelleted diet were generally in poorer condition, and were much smaller than those reared on natural prey items. Also, the camouflage barring on the pellet-reared fish was muted and virtually nonexistent. Fingerling muskellunge stocked in the spring produced the only significant recruitment observed in these lakes in the last 13 years. In fact, one stocking of only 572 muskellunge more than doubled the population of muskellunge in the Okoboji lakes. Such success with stocking muskellunge in the spring could drastically change stocking strategies; fewer fish may need to be stocked, and management objectives could be met without annual stockings. The benefits of these findings will be a decrease in the number of muskellunge produced and stocked each year, attainment of our management objectives, and a decrease in the stocking frequency. Muskellunge could be stocked every other year and, during the alternate years, hatchery space could be devoted to much needed walleye production.

LARSCHEID, J., J. CHRISTIANSON, T. GENGERKE and W. JORGENSEN. 1999. Survival, growth and abundance of pellet-reared and minnow-reared muskellunge stocked in northwestern Iowa. North American Journal of Fisheries Management 19(1) : 230-237.

Recent advances in artificial feeding techniques have increased the numbers and reliability of fingerling production of muskellunge (*Esox masquinongy*) in Iowa. Most of the muskellunge fingerlings produced in

Iowa since 1984 were raised on dry pelleted feed. We compared the survival of pellet-reared fingerlings with traditional minnow-reared fingerlings stocked into Spirit and West Okoboji lakes in northwest Iowa. Beginning in 1991, all muskellunge fingerlings were marked with freeze brands to differentiate the type and year that fingerlings were stocked. Adult muskellunge were caught each spring with 360 foot, 2.5 inch bar-mesh gill nets. All muskellunge caught were examined for brands, individually marked with visual implant tags, and released into the same lake as captured. Abundance and survival of stocked fingerlings to year-classes were estimated from recaptures of branded and individually marked muskellunge. In most years none of the pellet-reared fingerlings survived. The poor survival of these fish was most likely due to a combination of poor health, poor color (camouflage barring was muted and virtually non-existent), and small size (6-9 in total length, TL). Minnow-reared muskellunge fingerlings were much larger (10-13 in TL), displayed strong camouflage barring and had no apparent nutritional problems, and survived much better than pellet-reared fish. Minnow-fed fingerlings stocked in the spring survived much better than those stocked in the fall. One spring stocking of only 572 fish more than doubled the muskellunge population in West Okoboji Lake. Such success with stocking muskellunge in the spring could drastically change stocking strategies in Iowa; fewer fish may need to be stocked, and management objectives could be met without annual stockings.

LeBEAU, B. 1995. Muskellunge reintroduction feasibility study, Spanish Harbour Area of Concern. p. 11-17. *In* S. J. Kerr and C. H. Olver [eds.]. Managing Muskies in the 90s Workshop Proceedings. Workshop Proceedings WP-007. Southern Region Science and Technology Transfer Unit, Ontario Ministry of Natural Resources. Kemptville, Ontario. 169 p.

The objectives of the muskellunge (*Esox lucius*) reintroduction feasibility study are: (i) to examine historical data on the muskellunge population of the Spanish Harbour area and determine what changes may have occurred which lead to its extirpation; (ii) to examine historical and recent information on environmental conditions as it relates to muskellunge; (iii) from this information establish the most likely hypothesis for the extirpation of the muskellunge population and determine whether or not the likely causes still persist; and (iv) to determine the feasibility of reintroducing muskellunge.

LÉVÊQUE, C. 1998. Fish species introductions in African freshwaters. Chapter 20. *In* I. G. Cowx [ed.]. Stocking and Introduction of Fish. Fishing News Books. London, United Kingdom.

Since the middle of the nineteenth century, many exotic fish species have been introduced in African freshwaters for different purposes including sport fisheries, artisanal fisheries, aquaculture, and vector disease control. Northern pike (*Esox lucius*) were first introduced in Morocco from France in 1935.

LEWIS, C. 1984. Muskellunge in the Lindsay District: A review of existing data. Kawartha Lakes Fisheries Assessment Unit Report 1984-9. Ontario Ministry of Natural Resources. Lindsay, Ontario.

Muskellunge fry and fingerlings are stocked in Lindsay district waters annually. Numbers depend on production at the Deer Lake hatchery. The contribution of stocked fish is unknown. However, fin-clipped adults are beginning to make a substantial contribution to the spring spawning run at Stony Lake.

LEWIS, S. A. 1975. Great northern pike introductions. Fisheries Report F-022-R-06. Oklahoma Department of Wildlife Conservation. Oklahoma City, Oklahoma. 32 p.

Natural reproduction did not occur due to lack of spawning habitat or external stimuli. The study was conducted in lakes Arbuckle, Bluestem, Burtschi, Clayton, Etling, Humphries, Ponca, Vincent and Watonga. Fingerling stockings were more successful than fry or adult stockings.

LOPINOT, A. 1992. Pike in farm ponds. Farm Pond Harvest 26(4) : 20-21.

LORENZEN, K. 2000. Allometry of natural mortality as a basis for assessing optimal release size in fish stocking programmes. Canadian Journal of Fisheries and Aquatic Sciences 57 : 2374-2381.

This study evaluated the use of general mortality-size relationships for the assessment of release size in stocked fisheries. Seven release experiments (including three involving muskellunge) (53 stocking events) are analysed, using a survival model based on allometric mortality and linear length growth, allowing variation between experiments in both the allometric exponent and the level of mortality at reference length or generalizing in one or both of the parameters. Results support the existence of a consistent allometry that applies independently of the overall level of mortality. The best performing model is one in which the length exponent of mortality is set to -1 *a priori*, while mortality at reference length is allowed to vary between experiments (ranging from 0.7 to 33 per year at 15 cm in the present study). Even though the allometry of mortality is constant, the relative survival advantage of stocking large fish increases with the level of mortality at reference length. Using the identified length exponent of mortality of -1, survival models are derived for the linear, exponential, and von Bertalanffy growth equations. The models can be used to assess alternative release sizes, given an estimate of mortality at reference length to facilitate comparative studies and to aid in the design of release experiments.

LYONS, J. and T. MARGENAU. 1986. Population dynamics of stocked adult muskellunge (*Esox masquinongy*) in Lac Court Oreilles, Wisconsin, 1961-1977. Technical Bulletin 160. Wisconsin Department of Natural Resources. Madison, Wisconsin.

We examined the long-term population dynamics of adult stocked muskellunge that occurred with an expanding northern pike population in Lac Court Oreilles, Sawyer County, Wisconsin. Using data collected from 1961 to 1977, we estimated population size, mortality, angler exploitation, and recruitment using POPAN-2 (a multiple mark-recapture model). Accurate estimates of these parameters are necessary if current muskellunge populations are to be maintained and managed effectively.

From 1961 to 1977, muskellunge were marked and recaptured during spring spawning, and these data were supplemented with voluntary tag returns from anglers. We analyzed population parameters for a homogenous subset (stocked adult muskellunge age VI or older) to: (1) compare and contrast the population dynamics of male and female adult muskellunge, (2) examine the influence of angler exploitation on the mortality of adult muskellunge, and (3) determine whether increases in northern pike abundance influenced population parameters of adult muskellunge.

We found that male and female adult stocked muskellunge differ in population size and probably recruitment to age VI and harvest, but not in mortality and exploitation rate. For both sexes combined, annual mortality averaged 34% and showed no trends over time. Angler exploitation is clearly the main source of the mortality of adult stocked muskellunge in Lac Court Oreilles, voluntary tag returns by anglers were positively related to muskellunge population size. Coupled with the constant exploitation rate, this finding suggests that total harvest was positively related to muskellunge abundance.

Recruitment to age VI was highly variable from year to year, and was not significantly related to the number of fish stocked 6 years before. Inaccuracy in recruitment estimates was partially responsible for this lack of relationship between stocking and recruitment.

Adult muskellunge numbers declined over the study period, primarily because stocking was suspended from 1966 through 1970. Apparently the large increases in northern pike population size during the study period did not contribute substantially to this decline. Northern pike population size was not correlated with adult stocked muskellunge mortality or recruitment, and the naturally reproduced component of the muskellunge population did not decline as northern pike numbers increased.

MacCRIMMON, H. R., J. E. STEWART and J. R. BRETT. 1974. Aquaculture in Canada: The practice and promise. Fisheries and Marine Service, Department of the Environment. Ottawa, Ontario.

The first record of maskinonge being propagated in Canada was in 1877.

MacCRIMMON, H. R. and E. SKOBE. 1970. The fisheries of Lake Simcoe. Fish and Wildlife Branch, Ontario Department of Lands and Forests. Toronto, Ontario.

Plantings of maskinonge fry and fingerlings have been made in Lake Simcoe since 1936. Between 1936 and 1969, a total of 1,088,200 muskellunge were stocked in Lake Simcoe. The maskinonge fishing has continued to depreciate, however, until now this fish contributes practically nothing to the sport fishery.

MacKAY, H. H. 1956. The maskinonge. Sylva 12(4) : 25-33.

The natural distribution of the maskinonge is restricted to eastern North American, however due to introductions, its range has been extended. Maskinonge populations may be kept in equilibrium through a transfer program which allows a stock to be thinned in order to donate to a waterbody with a decreasing natural population. The first maskinonge hatchery was located in Omemee, then moved to Deer Lake in 1938. There is evidence that stocking with masquinonge can improve a fishery and hatchery-cultured fish are thought to be of considerable value for restocking areas which are subjected to wide variations in water levels.

MacKAY, H. H. and W. H. R. WERNER. 1934. Some observations on the culture of maskinonge. Transactions of the American Fisheries Society 64 : 313-317.

This paper discusses maskinonge-rearing observations made at the Belleville and Glenora hatcheries on the Bay of Quinte, Lake Ontario, Canada. Some highlights include:

- The handling of fish at the egg-sac stage should be avoided at all costs, otherwise mortality rates will be very high.
- The prevalence of cannibalism among fry is so great that large losses may be incurred if hatchery personnel are not careful in separating the fish.
- Maskinonge fry require no ice while being shipped to their site of release.

MADDEN, K. M. and A. D. LYNCH. 1962. Notes on the first rearing and introduction of *Esox masquinongy* in Iowa waters. Proceedings of the Iowa Academy of Science 69 : 273-277.

MAHER, T. J. and W. G. GILLIES. 1970. Bobs Lake. Unpublished Report. Ontario Department of Lands and Forests. Kemptville, Ontario. 2 p.

In 1956-57, maskinonge were planted in Bobs Lake. Unfortunately, none were ever recovered.

MALONEY, J. and D. H. SCHUPP. 1977. Use of winter rescue northern pike in maintenance stocking. Fisheries Investigational Report 345. Minnesota Department of Natural Resources. St. Paul, Minnesota. 29 p.

The stocking of 0-age northern pike, taken in winter rescue operations in Horseshoe, White Sand and Edward lakes in central Minnesota, resulted in high returns of stocked fish to anglers but the relative contribution to the sport fishery was high only in Horseshoe Lake where the abundance of resident pike was low. Stocking pike at a rate of 1.02 pounds/littoral acre in Lake Edward in 1969 resulted in a return of 35.2% of the fish and 89.1% of the pounds stocked. In two summers and three winters stocked fish made up 12.4% of the harvest by number and 10.4% by weight. Stocking in White Sand Lake at a rate of 2.03 pounds/littoral acre resulted in a return of 38.4% by number and 99.8% by weight. Stocked fish made up 13.2% of the harvest by number and 10.2% by weight. Horseshoe Lake was stocked with 2,874 pike weighing 1,607 pounds (3 pounds/littoral acre) in 1969 and 6,758 pike weighing 1,492 pounds in 1973. After two summers and two winters in the fishery, returns from the 1969 stocking were 44.4% by number and 164% by weight; returns from the 1973 stocking were 27.9% by number and 298% by weight. Stocked fish made up 80% of the harvest in the six years studied. No difference in growth between stocked and resident pike was observed in the study lakes. Stocked and resident pike grew most rapidly in Horseshoe Lake. Annual mortality for the 1973 stocked pike in Horseshoe Lake averaged 0.509 for ages I-III. Rate of exploitation at age II was 0.385 and expectation of death from natural causes was 0.132. Yellow perch were the major prey species in the northern pike diet in Horseshoe Lake. Perch density, as indicated by catches in experimental gill nets, declined concomitantly with northern pike stocking from 40 per lift in the summer of 1969 to 3.1 per lift in the summer of 1976.

The results of this study provide a basis for preliminary guidelines for stocking young-of-year and yearling winter-rescued northern pike. In determining stocking needs consideration must be given not only to the contribution to the sport fishery but also to the effect added predation will have on the forage base and on the effect forage reduction will have on other game species present, particularly walleye. The following criteria should be considered when determining stocking priorities:

- Assessment of northern pike abundance with experimental gill nets, preferably the summer before stocking is planned;
- Lakes with a gill net index of less than 2.5 northern pike per lift are most likely to benefit from stocking;
- An initial stocking rate of 3 pounds per littoral acre;
- The presence of moderate to high populations of yellow perch (gill net index of 15 or more perch per lift);
- Stocking every third year to maintain a consistent sport fishery. Stocking rates should be adjusted upward or downward as the forage base responds;
- Where perch are present at less than 5.0/lift, buildup of resident northern pike populations by stocking may be risky particularly if the lake is also managed for walleye.

These criteria should be considered as a starting point for further refinement of local stocking guidelines. Since fish communities vary in abundance and diversity, it is likely that they will need some modification under different circumstances. Stocking rates (pounds per littoral acre) or the frequency of stocking might be increased where fishing pressure is heavier or northern pike growth rates are more rapid than observed in this study. The stocking rate may be adjusted upward if pike available are relatively small (less than 12 inches on average) or downward if they are larger to compensate for differences in survival rate. If a reduction in perch abundance is the main purpose for stocking, higher stocking rates may be used until the perch population is reduced to the desired level.

MANGAN, B. P. 1998. Long-term retention of a radio transmitter by a muskellunge. Journal of Freshwater Ecology 13(4) : 485-487.

The use of surgically implanted radio transmitters in fish is widespread. There are, however, some questions concerning retention time of transmitters and effects on fish health. In 1984, as part of a pilot study, a 76-cm muskellunge was implanted (in the abdomen) with a cylindrical transmitter, 45 mm long and 17 mm wide. This fish was planted into a nearby 10 ha lake. Unfortunately, the signal was lost and electrofishing surveys failed to recover the fish. On April 8, 1997, a dead muskellunge (122 cm long, weighing 20 kg) was found on the shore of the lake. It was determined that this was the fish released 13 years earlier. A fist-sized mass in the abdomen area was suspected to have grown around the transmitter, although no cause of death could be determined, as the fish appeared disease-free.

MARGENAU, T. L. 1992. Survival and cost-effectiveness of stocked fall fingerling and spring yearling muskellunge in Wisconsin. North American Journal of Fisheries Management 12 : 484-493.

Stocking hatchery-reared muskellunge (*Esox masquinongy*) is important to Wisconsin's muskellunge management program. Typically, large (8-12 inch) fingerlings are stocked in fall; however, these fish have poor short-term (30-60 days) survival. To assess survival and cost-effectiveness (maximizing return-per-dollar invested), both over winter and to age 18 months, I compared success of fish stocked as fall fingerlings (FF) and spring yearlings (SY). Overwinter survival of FF averaged 19% (N = 14; range 2.7-43.3%). Mortality was highest from stocking through late fall, then declined over winter. In three lakes stocked with both FF and SY, SY survived better (19%) than FF (4%) to age 18 months. Cost analysis based on survival over winter revealed no consistent economic advantage in stocking larger, more expensive fingerlings within the 8-12 inch range unless precise information is known about potential predators. Cost comparisons indicated SY were one to four times more cost-effective than FF to age 18 months. Stocking SY should provide a better return to the fishery per hatchery dollar than stocking fall fingerlings.

MARGENAU, T. L. 1993. An evaluation of in-lake enclosures for increasing short-term survival of stocked muskellunge. Fisheries Research Report 158. Wisconsin Department of Natural Resources. Madison, Wisconsin. 12 p.

Objectives were to compare survival of muskellunge stocked and held at low densities in predator-free enclosures for periods longer than 48 hours with survival of muskellunge stocked using standard procedures. Survival of both groups was evaluated 42-71 days after stocking.

MARGENAU, T. L. 1994. Improvement of muskellunge fingerling culture and stocking programs. Final Report F-095-R. Wisconsin Department of Natural Resources. Spooner, Wisconsin. 60 p.

Results were less informative than planned, however, this final report was published to describe the most definitive results. The relation between length of stocking and survival of stocked muskellunge is reported. The analysis of factors affecting hatchery production and results from further development of a stocking model did not yield publishable results but are presented in this report as appendices.

MARGENAU, T. L. 1995. Stunted northern pike: A case history of community manipulations and field transfer. Research Report 169. Wisconsin Department of Natural Resources. Madison, Wisconsin.

Community manipulations were conducted to improve the growth and size structure of a stunted northern pike population in Island Lake, Washburn County. Manipulations included removal of small northern pike, bullhead, and bluegill and stocking of white sucker and walleye. Over a period of 8 years, the northern pike population in Island Lake showed no positive response to manipulations. Lack of response may have been the result of ineffective efforts to remove a large portion of the resident northern pike population. Diet information suggested northern pike may not have had adequate numbers of appropriate size and types of food items. Northern pike transferred from Island Lake to Largon Lake grew well and improved in condition. Indexing of forage in Largon Lake indicated an abundance of potential food items in the 6-8 inch size range. While field transfer of stunted northern pike was successful, management guidelines are recommended for the wise use of this as a management tool.

MARGENAU, T. L. 1996. Muskellunge stocking in Wisconsin: At the crossroads. p. 93-98. *In* S. J. Kerr and C. H. Olver [eds.]. Managing Muskies in the 90s Workshop Proceedings. Workshop Proceedings WP-007, Southern Region Science and Technology Transfer Unit. Ontario Ministry of Natural Resources, Kemptville, Ontario. 169 p.

After nearly a century of muskellunge (*Esox masquinongy*) propagation in Wisconsin, hatchery production is capable of meeting the stocking needs of management. Stocking of fertilized eggs, fry, fingerlings, or yearling age muskellunge can each be used in developing a cost effective stocking strategy if environmental conditions of a specific waterbody are known. While low post-stocking survival rates have been a management problem, stocking efforts still contribute to the sport fishery. However, future stocking strategies need to consider the implications of stocking with regard to natural stocks of muskellunge and other fishes.

MARGENAU, T. L. 1999. Muskellunge stocking strategies in Wisconsin: The first century and beyond. North American Journal of Fisheries Management 19(1) : 223-229.

After nearly a century of muskellunge propagation in Wisconsin, hatchery production is capable of meeting the stocking needs of management. Stocking of fertilized eggs, fry, fingerling, or yearling age muskellunge can each be used in developing a cost-effective stocking strategy if environmental conditions of a specific water are known. While low post-stocking survival rates have been a management problem, stocking efforts still contribute to the sport fishery. However, future stocking strategies need to consider the implications of stocking with regard to natural stocks of muskellunge and other fishes.

MARGENAU, T. L. and D. A. HANSON. 1996. Survival and growth of stocked muskellunge: Effects of genetic and environmental factors. Research Report 172. Wisconsin Department of Natural Resources. Madison, Wisconsin. 10 p.

Paired stocking of muskellunge fingerlings in six Wisconsin lakes were conducted to evaluate differential survival and growth of selected populations. Interpretation of results was difficult because of insufficient replication of stockings in lakes, and low numbers of stocked fish sampled at maturity. Short term (< 60 days) survival of stocked fish was in the range reported for fingerlings in Wisconsin. Survival of Mud-Callahan (M/C) fingerlings was generally higher than Lac Courte Oreilles (LCO) fingerlings. At maturity, M/C muskellunge were also more abundant than LCO muskellunge in Mud-Callahan Lake.

Growth comparisons suggested LCO muskellunge reach larger sizes at age than M/C muskellunge. However, environmental factors seemed to also contribute to muskellunge length. In Mud-Callahan Lake, growth of both M/C and LCO muskellunge was inhibited while in other study lakes growth improved but was still slower for M/C muskellunge. Muskellunge in Mud-Callahan Lake were characterized by a dense slow growing population. Most adult fish were < 30 inches and data from partly known age fish suggests some were as old as 17 years. Growth problems in Mud-Callahan Lake appear to be largely environmental but genetic factors also contribute to the small size of fish.

MARGENAU, T. L. and D. A. HANSON. 1997. Performance of Leech Lake, Minnesota, muskellunge in a Wisconsin lake. Research Report 175. Wisconsin Department of Natural Resources. Madison, Wisconsin. 11 p.

Three stockings (1984, 1987, 1990) of 11 to 14 inch fingerling muskellunge originating from the Leech Lake, Minnesota, population were made into Nancy Lake, Washburn County, to assess survival, growth, and natural reproduction. Short-term survival was low (< 20%) for two of the stockings. No survival estimate was made on the third stocking because of late stocking date (October 25). Growth rate of muskellunge in Nancy Lake was above average compared to Wisconsin growth rates. However, muskellunge in Nancy Lake tended to have a leaner body shape, as reflected by lower relative weight (W_r) indices when compared to muskellunge populations in Wisconsin. Natural reproduction of muskellunge in Nancy Lake occurred in four of six years though fall young-of-the-year densities were lower than average for self-sustaining muskellunge populations. Muskellunge performance in Nancy Lake was difficult to assess because no muskellunge were present prior to this introduction. Hence, there was no evidence to suggest that Leech Lake muskellunge would perform better than Wisconsin muskellunge in Wisconsin waters. Stockings such as this need to be carefully evaluated because of potential genetic risks posed by stock transfers among drainages.

MARGENAU, T. L. and H. SNOW. 1984. An evaluation of muskellunge stocking in Murphy Flowage. Fisheries Research Report 128. Wisconsin Department of Natural Resources. Madison, Wisconsin. 10 p.

The stocking of muskellunge fingerlings in Murphy Flowage for ten years produced a limited sport fishery. Using liberalized regulations and a compulsory creel census, 42 muskellunge averaging 27.1 inches in length were registered from 1956 through 1970. Angler harvest of stocked muskellunge from 11 releases ranged from 0 to 8.0% and averaged 1.4%. The low return was due to poor survival of stocked fingerlings and emigration.

MARSHALL, T. L. and R. P. JOHNSON. 1971. History and results of fish introductions in Saskatchewan, 1900-1969. Fisheries Report No. 8. Fisheries and Wildlife Branch, Saskatchewan Department of Natural Resources. Regina, Saskatchewan. 27 p.

Early attempts were made to discourage the increase of the native and cosmopolitan northern pike "because of its cannibalistic habits and poor game fish qualities." Greater appreciation of the species followed and transfers and propagation increased significantly after 1915. To date, nearly 28 million eggs, fry, fingerlings and adults have been introduced into 85 waters of the central and southern portion of the province.

Introductions have provided fisheries in shallow and previously fish barren waters, supplemented native populations, and, more rarely, increased predation on stunted perch populations. Many waters stocked with pike are borderline for permanent establishment because of periodic winterkills, fluctuating salinities, inadequate spawning facilities or drying of ponds and lowering of reservoirs.

Recent analysis of pike introductions indicate minimal success in 35 waters into which eggs and sac fry were planted. Stocking of fingerlings and adults has proved more successful. In a comparison between production of fingerlings from natural spawning and hatchery stocking in a controlled marsh at Kenosee Lake, natural spawning resulted in 1,038-1,570 progeny per acre over a four year period while hatchery stocking produced less than two fingerlings per acre in two years.

MASON, M. 1999. Stocking Iowa's lakes and streams. Iowa Conservationist May/June (1999) : 40-42.

When considering northern pike, the Mississippi River contains the strain-of-choice for developing a brood stock. For every one million eggs which are needed 60 adult females and 180 adult males need to be collected. The eggs are incubated in jars and nine days following hatching they are placed into water-filled plastic bags with oxygen (50,000 fry per bag) and transported to rearing ponds or are stocked into selected waterbodies. Stocked waters include areas of the Cedar, Iowa, Maquoketa, Shell Rock, Wapsipinicon and Winnebago rivers; and Arrowhead, Badger, Beeds, Blue, Browns, Clear, Crystal, Diamond, George Wyth lakes.

MATHER, M. E., R. A. STEIN and R. F. CARLINE. 1986. Experimental assessment of mortality and hyperglycemia in tiger muskellunge due to stocking stressors. Transactions of the American Fisheries Society 115 : 762-770.

Tiger muskellunge (the F_1 hybrid of female muskellunge, *Esox masquinongy*, and male northern pike, *E. lucius*) have survived poorly when stocked in reservoirs. To understand why, we quantified, in the laboratory, both mortality and plasma glucose responses to three common stocking stressors: dipnet handling, confinement, and temperature increase. No young-of-year hybrids died within 48 hours when the temperature was abruptly increased 10º C and only 5% died when the temperature was increased 12º C, but 98% died within 4 hours when the temperature was increased 15º C. Thus, we concluded that thermal stress is an important determinant of post-stocking mortality. Mortalities in response to three multiple-stressor treatments – (1) handling and temperature increase, (2) handling, confinement at a fish density of 83 g L^{-1}, and temperature increase, and (3) handling, confinement at 135 g L^{-1}, and temperature increase – did not differ from each other or from mortality associated with a temperature increase alone. Thus, handling and moderate density confinement during transport do not necessarily increase post-stocking mortality of tiger muskellunge. Abrupt temperature increases of 12 and 15º C increased peak plasma glucose concentrations significantly. Handling and confinement together caused a significant hyperglycemia both with and without a temperature increase. However, the relative magnitude of the hyperglycemia caused by individual handling and confinement stressors depended on the presence of a thermal stressor. Finally, we found that plasma glucose concentrations and mortality were not correlated. Although glucose is easily measured and sensitive to small changes in stress, it is not a good indicator of reduced survival and should not be used as such in studies intended to quantify stress-induced mortality.

MATHER, M. E. and D. H. WAHL. 1989. Comparative mortality of three esocids due to stocking stressors. Canadian Journal of Fisheries and Aquatic Sciences 46 : 214-217.

For stocked sportfish, stocking stress can cause substantial mortality. We evaluated mortality of three young-of-the-year esocids, northern pike (*Esox lucius*), muskellunge (*Esox masquinongy*), and their F_1 hybrid, the tiger muskellunge, in response to simulated handling, transport, and thermal stressors in the laboratory. In 15º C acclimated esocids, a 10º C rapid temperature increase caused little mortality. A 12º increase killed some fish in all taxa; however mean mortality did not differ significantly among northern pike (mean 30%), tiger muskellunge (mean 23%), and muskellunge (mean 10%). Nearly all 15º C acclimated fish (98%) died in response to a 15º increase. Tempering (0.15º min^{-1}) did not reduce this near complete mortality. Handling (30 seconds with dipnet) and transport confinement (60 gm L^{-1} for 120 minutes) also did not alter mortality when compared to a 12º C temperature increase alone. Field experiments, completed concurrently, confirmed our laboratory finding that healthy esocids, acclimated to 15º C, stocked at lake temperature corresponding to a temperature increase (< 10º C) suffered little mortality. Because mortality did not differ among these two species and their hybrid, differential vulnerability to these stocking stressors need not be considered when deciding which esocid to stock.

McCARRAHER, D. B. 1957. The natural propagation of northern pike in small drainable ponds. Progressive Fish Culturist 19(4) : 185-187.

Pond experiments involving northern pike were conducted at the State Fish Hatchery in Valentine, Nebraska, during 1955 and 1956. The objectives were to determine hatching success and fingerling survival following the planting of a brood stock.

Four ponds in total were stocked and two were fertilized. Forage fish were not added to any of the ponds. Percentage of fingerling survival was determined using an estimated number of eggs produced by the stocked fish approximately 7 weeks following the planting of the mature pike.

The total survival for fingerlings in Pond A (stocked in 1955) was determined to be 3.3% of the estimated number of eggs hatched, while that of Pond C (1955) was calculated to be 0.5%. Ponds B (1955) and D (1956) were fertilized with horse manure. Pond B demonstrated a fingerling survival rate of 3.3%, and that of Pond D was found to be 2.1%.

The feeding habits of the pike were also observed. The adult pike were found to feed on various species of frogs, beetle larvae, Dytiscidae and pike fingerlings. Until reaching 1.2 inches in length pike fed mainly on copepods. Between 1.3 to 2.6 inches they consumed mostly insect larvae such as Odonata and Chironomidae. When greater than 2.6 inches the pike tended to become cannibalistic in addition to feeding on available invertebrates.

Frogs, turtles and piscivorous birds preyed on the young pike, although no definite numbers could be calculated.

McCARRAHER, D. B. 1959. The northern pike-bluegill combination in north-central Nebraska farm ponds. Progressive Fish Culturist 21(4) : 188-189.

In order to evaluate the pike-bluegill combination in small impoundments, 2 ponds were stocked with the fish in 1955. Conclusions drawn from this experiment are as follows:

- Northern pike-bluegill combinations in farm ponds produced quality pike fishing.
- Natural reproduction of the pike occurred in both ponds, a condition which should preclude annual hatchery releases.
- Bluegill spawners released in the spring with pike fingerlings provided abundant forage throughout the year for the pike. No evidence of excessive utilization of young-of-the-year bluegills by pike was observed.
- Demands for irrigation water and a subsequent summer drawdown of 4 to 8 feet did not impair the recruitment of the bluegills nor disturb the feeding habits and growth of the pike.
- Growth rates of farm-pond pike, though averaging less than the growth increment recorded for Nebraska's sandhill lakes, still exceeded bass and catfish growth in similar ponds.
- Some evidence suggested that the majority of the adult pike attempted to spawn in the feeder creek and spring-seep areas of the pond.

- Pike fishermen may expect to harvest approximately 44% of the pike stocked as fingerlings, at a rate of 111 to 118 fish-per-surface acre. It is doubtful that increased stocking of fingerlings will substantially increase the rate of harvest.

McCARRAHER, D. B. 1961. Extension of the range of northern pike (*Esox lucius*). Transactions of the American Fisheries Society 90(2) : 227-228.

A survey done by the author in 1955 demonstrated that 26 states and Canadian provinces had resident northern pike populations. Five years later that range has been expanded through introductions.

Maryland has been somewhat successful in introducing both adults and eggs into the 3,900 acre Deep Creek Lake, whereas attempts by North Carolina to introduce this species to waterbodies on the coast have been unsuccessful. In Deep Creek Lake, northern pike survival has been documented, although spawning has not yet been observed. Montana has been successful in planting pike into large ranch ponds and small reservoirs. Colorado has planted pike into Bonny Reservoir and Skaguay Reservoir, however, their status is unknown. It is expected that as interest in the northern pike as a gamefish grows, so too will its range.

McKEOWN, P. E., S. R. MOORADIAN and J. L. FORNEY. 1996. Relative survival rates of differentially reared muskellunge in Chautauqua Lake, New York. *In* R. Soderberg [ed.]. 1996 Warmwater Workshop Proceedings – Esocid Management and Culture. Mansfield University. Mansfield, Pennsylvania.

The propagation and stocking of muskellunge in Chautauqua Lake has supported an economically valuable sport fishery for over a century. Changes in the physical and biological components of Chautauqua Lake as well as changes in management strategies and rearing techniques have influenced the abundance of adult muskellunge. Early propagation programs focused on the production and stocking of fry. With advances in technology in the late 1930s came an increased emphasis on the production of fingerlings reared in ponds. Subsequent increases in the adult catch of muskellunge in the pound nets inferred the superior survival of these fingerlings. Pond rearing of fingerlings continued to the mid 1970s when the increased survival to stocking of trough reared fingerlings (hereafter referred to as intensive fingerlings) resulted in a change in production to intensive rearing. Progressive declines in the pound net catch of adult muskellunge from the mid 1970s through the 1980s raised concern that survival of fingerlings had declined attributed in part to intensive rearing. Paired stocking of intensive and pond-finished fingerlings (hereafter referred to as extensive fingerlings) indicated superior short- and long-term survival of the extensive fingerlings.

McKEOWN, P. E., J. L. FORNEY and S. R. MOORADIAN. 1999. Effects of stocking size and rearing method on muskellunge survival in Chautauqua Lake, New York. North American Journal of Fisheries Management 19(1) : 249-257.

We examined the effects of rearing method and size at stocking on the survival of muskellunge (*Esox masquinongy*) in Chautauqua Lake, New York. Since 1961, changes in rearing methods have coincided with declining abundance of adult muskellunge. In particular, a change from pond rearing to trough rearing coincided with declining catches of adult muskellunge in pound nets. The decline was only partly reversed by changes from trough rearing to pond finishing of fingerlings. Changes in survival to age 5 from 1961 to 1996 indicated that both rearing method and stocking length significantly affected survival. Greater length at stocking resulted in higher survival rates. After accounting for length at stocking, survival was highest for pond-reared fingerlings, intermediate for pond-finished fingerlings, and lowest for trough-reared fingerlings. A modified Ricker stock-recruitment model indicated that survival of fingerlings declined over time. Increases in the adult stock of walleye (*Stizostedion vitrium*) since the 1960s may have increased predatory pressure on fingerlings and increased the importance of greater length at stocking.

McNEIL, F. 1978. Hatchery contribution to an existing muskellunge population. Presented at the Seminar on Muskellunge Management in Central Ontario, September 26, 1978, Lindsay, Ontario.

Stress responses of salmonids and esocids to fin-clipping and other management practices are quite different. It was found that seining caused more stress than fin-clipping and that transportation should be done in aerated bags, as opposed to pressurized bags. The use of MS222 during fin-clipping did not affect survival, and over the long term the loss of a pectoral fin may reduce feeding efficiency and ability to avoid predators. There was no difference in growth in fish with the pectoral or pelvic fin removed or if MS222 was used. Within one year of marking, most (65%) of clips are not recognizable by experienced field staff and this can lead to unreliable estimates of contribution and survival of hatchery-reared fish.

During this study it was also found that:

- Hatchery fish at Nogies Creek represent 40-50% of any given year class.
- Success of stocked young-of-the-year varied inversely with the strength of the natural year class.
- There is no evidence to show that hatchery fingerlings are displacing naturally-reared fingerlings and survival was found to be greater in larger fingerlings.
- Stocking densities varied from 4 to 100 fish/ha although there was no correlation between stocking density and contribution to a year class.

It was recommended that stocking only be done in those years when natural reproduction is low. Once every 2 to 3 years should suffice and using this method will avoid stocked fish being used as forage by older fish.

McNEIL, F. I. 1979. Survival and contribution of hatchery-reared muskellunge introduced into a naturally reproducing population of muskellunge. M. Sc. Thesis, University of Toronto. Toronto, Ontario.

Removal of any single paired fin was equally detrimental to short term survival. In contrast, considering long-term survival, the removal of a pectoral fin was more detrimental than removal of a pelvic fin. The fin removed did not significantly affect either short-term or long-term growth. The use of an anaesthetic during fin clipping had no affect on either survival or growth of fin clipped fish. Within one year of marking, regeneration of totally clipped fins was such that they were unreliable as marks in the recognition of released hatchery fish by even experienced workers. This unreliability increased with time. After an initial period in the first two months subsequent to stocking, in which the stocked young-of-the-year muskellunge experienced higher mortality than did the resident young-of-the-year, mortality was inferred to be the result of predation. The major predator was muskellunge (total length from 260-540 mm). These larger muskellunge apparently moved in response to the availability of both resident and stocked young-of-the-year muskellunge. Stocked young-of-the-year muskellunge disperse rapidly from the stocking sites. The dispersal is apparently a consequence of competition between stocked and resident young-of-the-year muskellunge. Movement on the part of resident young-of-the-year muskellunge prior to the introduction of stocked individuals was the result of competition amongst themselves. It is likely that this movement of young-of-the-year muskellunge resulted in increased vulnerability to predation. The carrying capacity of at least the portion of Nogies Creek below Watson’s bridge for one year olds is approximately 4.1 fish/hectare. The larger young-of-the-year muskellunge stocked, the greater the survival. However, there was no relationship between size of fish stocked and relative contribution to a year class. As stocking density increased, survival of stocked young-of-the-year muskellunge decreased. In addition, as stocking density increased the contribution to the year class increased. Within the range of stocking densities used (1.0-41.5 fish/ha) contribution leveled off at 35%. The presence of a sharp interface between dense areas of aquatic macrophytes and the channel increase the survival of stocked young-of-the-year muskellunge. It is likely that this is the result of increase available resources in the proximity of the interface. Stocking hatchery-reared muskellunge can be effective in managing muskellunge populations which are unable to maintain sufficient natural recruitment to stabilize population levels.

McNEIL, F. I. and E. J. CROSSMAN. 1979. Fin clips in the evaluation of stocking programs for muskellunge (*Esox masquinongy*). Transactions of the American Fisheries Society 108(4) : 335-343.

During laboratory and field experiments in Ontario, with hatchery muskellunge 90-235 mm in total length, total removal of a fin did not add to the immediate mortality caused by seining the fish from ponds. The use of an anesthetic during surgery (MS-222) did not affect subsequent survival of marked, stocked fish. Removal of any single paired fin was equally detrimental to short-term (3 months) survival. In contrast, over long periods (10 months) the loss of a pectoral fin was more detrimental than the loss of a pelvic fin. Removal of both fins of a pair may cause higher mortality than the removal of one fin. Neither the fin removed nor the anesthetic significantly affected short-term or long-term growth. Within one year of marking, regeneration of amputated fins was such that recognition of marked fish was difficult and the degree of difficulty increased with time. Estimates based on marked 2-year-old or older individuals could result in substantial underestimates of survival.

MERNER, F. H. 1958. Statistical report of the history of stocking of the Nith River. Conservation Officers Projects 1957-1958. Ontario Department of Lands and Forests. Cambridge, Ontario.

Between the years 1928 to 1939 and 1939 to 1957, 65,000 maskinonge fry were stocked into the Nith River. This species has been somewhat successful in the river, being that quite a few have been caught, but they were not very large and many fishermen mistook them for pike. The take in comparison to what was put into the system does not warrant more stocking.

MILES, H. M. 1974. Development of improved muskellunge stocking procedures. Technical Report F-083-R-09. Wisconsin Department of Natural Resources. Madison, Wisconsin. 9 p.

Following previous work on physiological effects of handling juvenile muskellunge, it was of interest to test electroshock as an additional capture method as well as test the effects of salt treatment in actual transportation experiments. From the results of this study the following conclusions were drawn:

- Present seining methods are the most satisfactory of the practical harvest methods tested.
- Treatment with 0.5% Cl for six hours has no effect.
- Holding in the lake for 48 hours before release has no effect.
- Hemoconcentration as a stress response is very rapid.

MILES, H. M., S. M. LEOHNER, D. T. MICHAUD and S. L. SALIVAR. 1973. Physiological response of hatchery-reared muskellunge (*Esox masquinongy*) to handling. Transactions of the American Fisheries Society 103 : 336.

Increases in plasma glucose lactate and glucose concentrations, along with decreases in plasma chloride and liver glycogen concentrations, were observed in muskellunge in response to capture and handling. Holding muskellunge in 0.3% NaCl alleviated some of the physiological symptoms of stress, but holding the fish in the lake for 48 hours before release had no effect. Physiological responses to fin-clipping and transport by truck were slight in comparison to that of original capture. Salt treatment and reduction in duration and frequency of handling is recommended.

MILFORD, J. H. 1974. Stony Lake musky population increases. Lindsay District Weekly Release July 19, 1974. p. 1.

One hundred thousand musky fry (approximately 1 inch in length) were distributed along the marshy shores of Stony Lake on June 1st. On July 10th, 5,000 five to six inch fingerlings were stocked in Pigeon, Buckhorn and Sturgeon lakes.

MINNESOTA DEPARTMENT OF NATURAL RESOURCES. 1982. Lake management planning guide. Fisheries Division Special Publication No. 132. St. Paul, Minnesota. 61 p.

Stocking of winter-rescued northern pike is an effective tool for improving pike populations in lakes with inadequate natural reproduction. However, this procedure should be used with caution and only when the forage base (usually perch) is capable of supporting more pike. If a winterkill lake is also being managed for walleye and forage is scarce, pike should not be stocked until the second year. If brood stock are used they are generally stocked at a lower rate than normal. In cases where there is sufficient natural recruitment, winter-rescued pike should not be stocked simply because they are available.

Stocking young-of-the-year muskellunge (3-7 per pound) should be stocked at a rate of up to 1 fish per littoral acre. Stocking is usually on an annual or biennial basis, but less frequent stocking may be sufficient to develop a trophy muskellunge fishery. There should be periodic blanks established to allow assessment of natural reproduction.

MOESCHKE, R. and H. W. PFEIFFER. 1994. Fishery management as a restoration tool in a recreational lake in Hamburg. Methods for Restoration and Reclamation of Stagnant Waters 8 : 295-308.

Lake Eichbaum, a eutrophic bathing lake southeast of Hamburg, Germany, has been artificially mixed since 1990 in order to improve water quality. Before the circulation unit was put into operation, the habitat for fish, zooplankton and benthos was strongly reduced during thermal stratification in summer. Nevertheless, frequently occurring species of fish (i.e., roach and perch) showed higher growth rates when compared to the average growth rates found from other lakes in northern German. Natural regulation of fishes in the lake should be supported by management in order to prevent increased grazing pressure on zooplankton due to strong recruitment of Cyprinidae and perch through the enlarged habitat in summer. Stocking of pikeperch and northern pike is recommended. The proportion of piscivores in the total fish community should be increased until they are 35% of the total fish community and should be structured in an optimal way.

MONAGHAN, J. P., Jr. and J. C. BORAWA. 1986. Recovery of riverine muskellunge populations in North Carolina. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 40 : 258-265.

The muskellunge (*Esox masquinongy*) population of the French Broad River was sampled to determine relative abundance and growth characteristics and to document muskellunge reproduction. In addition, forage fish availability was also documented. Electrofishing catch-per-unit-of-effort rates were 4.7 fish/hour in the French Broad River. Over one-third of the muskellunge captured were non-stocked fish, indicating reproduction is occurring. Back-calculated total lengths for muskellunge in the French Broad River were 325, 476, 621, 727, 809, 881, 910, 961 and 1,026 mm total length at ages I-IX, respectively. Growth patterns of French Broad River muskellunge are similar to other riverine populations. That is, growth rates are faster at the younger ages (I-III) and slower at the older ages (VII-IX) than lacustrine populations.

MOODY, R. C., J. M. HELLAND and R. A. STEIN. 1983. Escape tactics used by bluegills and fathead minnows to avoid predation by tiger muskellunge. Environmental Biology of Fishes 8(1) : 61-65.

To explain why esocids prefer cylindrical, soft-rayed prey over compressed, spiny-rayed prey, we quantified behavioral interaction between tiger muskellunge (F_1 hybrid of male northern pike, *Esox lucius*, and female muskellunge, *E. masquinongy*) and fathead minnows (*Pimephales promelas*) and bluegills (*Lepomis macrochirus*). Tiger muskellunge required four times as many strikes and longer pursuits to capture bluegills than fathead minnows. Tiger muskellunge attacked each prey species differently; fathead minnows were grasped at midbody and bluegills were attacked in the caudal area. Each prey species exhibited different escape tactics. Fathead minnows remained in open water and consistently schooled; bluegills dispersed throughout the tank and sought cover by moving to corners and edges. Due to their anti-predatory behavior (dispersing, cover seeking, and remaining motionless) and morphology (deep body and spines), bluegills were less susceptible to capture by tiger muskellunge.

MOORADIAN, S. R. 1986. Relative survival in Chautauqua Lake, New York, of hatchery-reared muskellunge reared by two different methods. New York Fish and Game Journal 33(2) : 161-167.

Experimental lots of muskellunge were reared at the hatchery by two different methods in 1984 and 1985. All the fish were held in troughs until the first week of August when part of them were transferred to 1 acre earthern ponds. The differential treatment was continued until early September when the two groups were mixed and stocked as fingerlings in Chautauqua Lake. The fish were marked by fin clipping and sampling by electrofishing was done 30 to 40 days later. In both years, it was found that those that had been transferred to ponds were larger at the time of stocking and exhibited a higher rate of survival at the time of sampling than did those that had been reared entirely in troughs.

MOORADIAN, S. R., J. L. FORNEY and M. D. STAGGS. 1986. Response of muskellunge to establishment of walleye in Chautauqua Lake, New York. American Fisheries Society Special Publication 15 : 168-175.

Muskellunge in Chautauqua Lake have supported a large and economically valuable sport fishery for over a century. Walleye were seldom observed prior to 1962 when the first successful year-class was produced. By the following decade the population had increased to about 28 age-1 and older walleye per hectare. Adult stocks of muskellunge initially increased but by the late 1970s the catch-per-unit-effort in pound nets had fallen to about 60% of the mean catch in pre-walleye years. Lower muskellunge abundance was attributed to decreased survival of stocked fingerlings. As abundance declined, mean weight largely compensated for the decline in numbers and biomass of the stock remained near levels which prevailed before establishment of the walleye.

MOORADIAN, S. R. and W. F. SHEPPARD. 1972. Management of the Chautauqua Lake muskalonge. Presented at the Northeast Division of the American Fisheries Society Fish and Wildlife Conference, May 14-17, 1972, Ellenville, New York.

During the 1930s, the Chautauqua Lake muskalonge fishery began to show a drastic decline due to many accountable factors. A decision was made to protect the remaining population with more restrictive regulations which commenced in 1941. Within a few years the spring netting catch of spawning muskalonge and the angler harvest began to increase.

In addition to the more restrictive regulations, a second major management practice initiated in 1941 was maintenance stocking with fingerling muskalonge along with muskalonge fry. Studies conducted between 1961 and 1971 to evaluate the fingerling stocking program have illustrated the importance of hatchery-stocked muskalonge to the lake fishery. The 1971 data indicates that over one-half of the muskalonge in the lake originate at the Prendergast hatchery.

The conclusion of the data seems to indicate that both restrictive regulations and maintenance stocking with fingerlings is vital to the Chautauqua Lake muskalonge fishery.

MOORADIAN, S. R. and F. W. SHEPERD. 1973. Management of muskellunge in Chautauqua Lake. New York Fish and Game Journal 20 : 152-157.

During the 1930s, the muskellunge fishery in Chautauqua Lake began to show a drastic decline due to many accountable factors. A decision was made to protect the remaining population with more restrictive regulations which commenced in 1941. Within a few years the spring netting catch of spawning muskellunge and the angler harvest began to increase. In addition to the more restrictive regulations, a second major management practice initiated in 1941 was maintenance stocking with fingerling muskellunge along with muskellunge fry. Studies conducted between 1961 and 1971 to evaluate the fingerling stocking program have illustrated the importance of the hatchery-stocked muskellunge to the lake fishery. The 1971 data indicate that over half of the muskellunge in the lake originate at the Prendergast hatchery. Thus, both restrictive regulations and maintenance stocking with fingerlings are vital to this fishery.

MORRIS, J. W. 1972. Survival of northern pike produced in an experimental artificial spawning marsh. Fisheries Report F-004-R-17. Nebraska Game and Parks Commission. Gretna, Nebraska. 4 p.

MOULTON, J. C. 1978. Establishing northern pike in Bantam Lake: Evaluation of northern pike spawning areas (population estimates). Federal Aid Projects F-36-R to F-39-R. Connecticut Department of Environmental Protection. Hartford, Connecticut. 36 p.

A program to establish northern pike in Bantam Lake was implemented during the period 1971 to 1977. Data are provided on the impact of the introduction of northern pike on the white perch population of Bantam Lake, and the ability of northern pike to establish a self-sustaining population. Specific areas of the evaluation include: population estimates of white perch and northern pike; the calculation of age and growth parameters for white perch, calico bass, yellow perch and northern pike; and the operation of an experimental northern pike spawning marsh.

MUIR, B. S. 1960. Comparison of growth rates for native and hatchery-stocked populations of *Esox masquinongy* in Nogies Creek, Ontario. Journal of the Fisheries Research Board of Canada 17(6) : 919-927.

Recent techniques have contributed to a more a accurate determination of age by the scale method and a new growth curve for the maskinonge in Nogies Creek has been constructed. Hatchery fish, planted as fingerlings, show similar growth for 4 summers after which their growth rate rapidly falls away from that for native fish. The hatchery fish require 3 years more than the native fish to reach legal length.

A reduction in the annual growth increment for tagged fish ranges from 25% (age IV) to 30% (age VI) for that attained by untagged fish.

No significant divergence in the length-weight relationship was observed in the slower growing hatchery fish.

MUIR, B. S. and J. G. SWEET. 1964. The survival, growth and movement of *Esox masquinongy* transplanted from Nogies Creek sanctuary to public fishing waters. Canadian Fish Culturist 32 : 31-44.

In 1952, the transplanting of juvenile and adult muskellunge from Nogies Creek sanctuary was begun to determine their value in restocking public lakes. This report deals with the survival, growth and movement until time of recapture of the fish transplanted from the sanctuary. It was hoped to learn whether transplanted juvenile and adult muskellunge would survive to significantly contribute to the existing fishery.

During the month of October in the years 1952 to 1958 (excluding 1956), 1,533 tagged and 520 untagged maskinonge were transplanted from Nogies Creek to Pigeon and Sturgeon lakes. A total of 227 of the tagged fish were reported caught by anglers by the close of the 1960 season, providing recapture rates of 14.7% and 14.9% of the fish planted into Pigeon and Sturgeon lakes respectively. However of the 103 recaptures from fish planted in Sturgeon Lake, 32 (31.1%) had passed down into Pigeon Lake, either through the canal locks or over the dam. Since the apparent survival of fish planted into the two lakes is essentially the same, it was convenient to treat the two lakes as one system in so far as the recapture data were concerned. The low percentage return of fish younger than age group V suggests that, unless an extremely large number of tags are lost during the second year, these sub-adult fish do not survive in sufficient numbers to warrant transplanting.

Anglers were requested to report the length of tagged fish at the time of recapture. It was apparent that the partial growth increment for tagged fish transplanted to the larger lakes was greater than the increment during 1957 for tagged fish returned to the sanctuary but still less than that for untagged fish in the sanctuary.

Of the reports returned by anglers, 144 (from year N + 1) included points of recapture that could be located on the map. With the exclusion of two fish, the average distance travelled increased with age from 1.8 miles for age group III to 2.7 miles for age group VII. The distances moved do not appear unduly great as might be expected if the fish could not find suitable habitat. The distance between point of release and point of recapture gives little indication, however, of the nature of the movement since the time out involved was nearly one year.

NAVARRO, J. E. and D. L. JOHNSON. 1992. Ecology of stocked northern pike in two Lake Erie controlled wetlands. Wetlands 12(3) : 171-177.

NEUSWANGER, D. J. 1997. Experience to statewide program development. *In* 59th Midwest Fish and Wildlife Conference, December 7-10, 1997, Milwaukee, Wisconsin. (Abstract only)

A newly impounded 530 acre water supply reservoir in northeastern Missouri was stocked with 10-12 inch muskellunge at a density of 2.8/acre in 1983 in order to introduce the elements of diversity, mystery and surprise to the fishery. The lake was opened to fishing in April, 1985 with a 42 inch minimum length limit for muskellunge. In the absence of natural recruitment or additional stockings until 1990, we positively identified members of the 1983 year class in spring of 1992 when mean lengths of 39 males and 123 females captured in fyke nets were 36 and 42 inches, respectively, at age 9. A Schnabel population estimate revealed the presence of 413 age-9 male muskellunge. Assuming that half of the original 1,500 fish stocked in 1983 were males, the instantaneous rate of mortality of angled but sublegal male muskellunge was only 7.2% annually from 1984 through 1991. A 1989 creel survey revealed that anglers who fished specifically for muskellunge caught one every seven hours. Hazel Creek Lake anglers participating in a voluntary catch reporting project in 1996 reported catching a muskellunge every 8 hours and encountering a muskellunge (follows, strike, and fish hooked but lost) every four hours. Our experience at Hazel Creek Lake was incorporated into the development of a statewide muskellunge management plan in 1995. Our primary goals are to increase the number and improve the distribution of opportunities for anglers to fish for muskellunge in small impoundments, while maintaining population density and size structure commensurate with angler expectations.

NEVIN, J. 1901. The propagation of muskellunge in Wisconsin. Transactions of the American Fisheries Society 30 : 90-93.

The artificial propagation of muskellunge was first taken up by the Fish Commission of the State of New York some twelve years since and, in 1891, that state made the first successful hatch of this species planting over 1,000,000 fry. Since that time the Fish Commission of New York has planted several millions of fry of this species in Chautauqua Lake and other waters with unqualified success. The Commissioners of Fisheries of Wisconsin began the propagation of muskellunge during the spring of 1899 in connection with the work of collecting walleye ova.

I believe we are justified in claiming that our work in planting muskellunge fry during the past two years has shown results of a substantial nature. In the Minocqua waters, where we planted the fry hatched the first two years, more small muskellunge, weighing from one to three pounds, have been taken during this season than were ever taken before from those waters in the same period in the memory of the oldest guide or resident.

Numerous lakes in northern Wisconsin, the habitat of this fish, afford an extensive field in which to work and when once well stocked, these waters will be a source of abundant revenue to the state for no other freshwater fish is so attractive to the sportsman and summer tourist.

NEWMAN, D. L. and T. W. STORCK. 1986. Angler catch, growth, and hooking mortality of tiger muskellunge in small centrarchid-dominated impoundments. American Fisheries Society Special Publication 15 : 346-351.

Angling vulnerability, growth, and hooking mortality of age I and II tiger muskellunge were examined at Ridge Lake, Illinois. Data were obtained from a complete creel census, supplemented by spring and autumn electrofishing samples. Angler catch rates of yearling tiger muskellunge were highest in the spring. Angler catch of the 1981 year class in 1982 and 1983 (N = 202) exceeded the number of stocked as young-of-the-year fish (N = 151), indicating multiple catches of some fish. Growth of tiger muskellunge was most rapid in spring and autumn and slowest during mid-summer. The majority of tiger muskellunge stocked in Ridge Lake as young-of-the-year fish in 1981 are not expected to reach harvestable size (762 mm) until 1985. Ten percent of sublegal tiger muskellunge caught by anglers and 13% of the number stocked in 1981 died as a result of the hooking experience. Eighty-five percent of this mortality occurred in June, July and August, even though only 33% of the catch occurred during that period.

OATES, D. 1985. Development of a genetic marking technique for use in evaluating stockings of walleye and northern pike into the Missouri-Niobrara system. Final Report F-055-R. Nebraska Game and Parks Commission. Gretna, Nebraska. 4 p.

OEHMCKE, A. A. 1951. Muskellunge yearling culture and its application to lake management. Progressive Fish Culturist 13(2) : 63-70.

The purpose of this paper is to elaborate on the production of larger muskellunge which can be used in conjunction with lake management, and to look at the recent history of esocid stocking.

In 1941, the Fish Management Division discontinued the stocking of northern pike fry and fingerlings in four northeastern Wisconsin counties due to suspicions that they were detrimental to the native muskellunge population. Through pond experiments it was demonstrated that northern pike hatched prior to the muskellunge and developed in the same spawning area which allowed them to easily prey on the smaller, newly hatched muskellunge fry. Over time the pike would overtake that spawning habitat.

With trout, the larger the fish planted the greater its chances at survival. It was assumed that the same reasoning would apply to muskellunge and that the stocking of larger fish would decrease the risk of predation. At Woodruff hatchery the production of muskellunge yearlings in ponds was attempted between 1947 to 1949. In the years 1947 to 1948, there was a 76% survival of the pond-stocked fish from the fingerling to the yearling stage and in 1948-1949 that figure was 67.9%. The production cost for the 1947-48 season was $3.69 per muskie, whereas it was only $1.44 per muskie in 1948-49. The increased production of fingerlings and the provision of additional forage fish resulted in a lower cost of fingerlings produced during experimentation. It is estimated that the cost of $1.50 to $2 per fish would be considered a fair price.

OEHMCKE, A. A. 1969. Muskellunge management in Wisconsin. Management Report No. 19. Bureau of Fisheries. Wisconsin Department of Natural Resources. Madison, Wisconsin. 22 p.

The muskellunge (*Esox masquinongy*) is Wisconsin's most highly regarded sport fish. The artificial propagation of muskellunge in Wisconsin was initiated in 1899 at Woodruff. For over 25 years, little effort was directed to rearing muskellunge beyond the sac fry stage. Nearly all muskellunge were stocked shortly after hatching from eggs incubated in jars. The rearing of muskellunge to fingerling size in ponds was attempted at intervals from 1926 to 1938 with little success.

In 1954, pond rearing goals were shifted to total weight produced rather than the number of muskellunge fingerlings reared. The new production goal forced full realization of supplying the demand for forage minnows to feed young muskellunge for it is still the primary key to successful fingerling production. An analysis of muskellunge pond production records at the Woodruff station shows that 4-5 pounds of minnows are required to produce one pound of muskellunge.

New rearing techniques, namely hatching muskellunge at an earlier date and intensified feeding, has now resulted in the production of large sized muskellunge fingerlings which average greater than 12 inches in length in 4 1/2 months of rearing. In summary, progress in the refinement and techniques of hatching and rearing muskellunge have led to a quality product at a greatly decreased cost in Wisconsin.

Modest numbers of high quality muskellunge fingerlings are stocked in Wisconsin lakes and streams annually. Less than 30% of a total of 312,048 acres of muskellunge waters are stocked annually. Stocking rates vary with management requirements. Large-sized fingerlings, ranging from 8-15 inches, are used in all high priority muskellunge plantings. Considerable care and attention is paid to handling of muskellunge fingerlings during the stocking operation. Although both spot planting and scatter planting have been practiced, present stocking procedures call for scatter planting whenever possible to eliminate concentrations of small fish.

OEHMCKE, A. A., L. D. JOHNSON, J. H. KLINBIEL and C. A. WINSTROM. 1958. The Wisconsin muskellunge, its life history, ecology, and management. Wisconsin Conservation Department Publication 225 : 1-11.

The management of the muskellunge typically involves the removal of their competitor, the northern pike. As a follow-up measure the heavy stocking of fingerlings or yearlings may occur to support a small muskellunge population. The stocking of muskellunge fingerlings or yearlings (or even hybrids) to control populations of stunted forage fish and bass has shown some positive results. The introduction of muskellunge may improve panfish growth rates.

OHIO DEPARTMENT OF NATURAL RESOURCES. Undated. Fish hatcheries tactical plan. Division of Wildlife. Columbus, Ohio. 23 p. + appendices.

Muskellunge fisheries in Ohio are sustained by stocking advanced (i.e., 8 inch) fingerlings. In the past lakes have been identified which appeared to represent the best potential for muskellunge survival and sport fishery utilization. In 1999, muskellunge will be stocked at a rate of 1.0 fish/acre. An additional 1.0 fish/acre may be requested as surplus. Surplus fish (fry - fingerlings < 6 inches in length) will be stocked in order of prioritization.

OLSON, D. E. and P. K. CUNNINGHAM. 1989. Sport-fisheries trends shown by an annual Minnesota fishing contest over a 58-year period. North American Journal of Fisheries Management 9 : 287-297.

Since 1915, Fuller's Tackle Shop at Park Rapids in Minnesota's northwestern lake region has sponsored an annual fishing contest. Contest records were available for 113,845 entries of 10 fish species from 1930 to 1987. Under increased exploitation, declining trends in number of large-sized entries and mean weight of total entries indicated the development of less desirable size structure for most sport-fish species. The number of entries of muskellunge (*Esox masquinongy*) abruptly declined after the 1930s. Stocking and size restrictions have not restored a trophy muskellunge fishery. Under increased exploitation, entries of large northern pike (*E. lucius*) have declined gradually since 1948. Numbers of large walleyes (*Stizostedion vitreum*) and largemouth bass (*Micropterus salmoides*) peaked in 1972 and 1977, respectively, and have since declined. Mean weights of bluegills (*Lepomis macrochirus*) and black crappies (*Pomoxis nigromaculatus*) have declined since the early 1950s. Large black crappies ($\geq$ 1.25 lb) nearly disappeared in the 1980s. Increased entries of rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) reflect successful management efforts for these species.

ONTARIO DEPARTMENT OF LANDS AND FORESTS. 1963. A history of the Lake Simcoe forest district. District History Series No. 7. Toronto, Ontario.

It is interesting to learn our northern pike became established in the east watershed of the Humber River and tributary lakes and streams. Pike were reportedly absent from these waters prior to 1940.

A resort owner on Wilcox Lake had trap nets placed in a ditch running out of the Holland River and during the early hours transported pike in 45 gallon barrels from the trap to Wilcox Lake. The fish established themselves and reproduced rapidly.

The following are other waters affected where pike now predominate: Bond Lake, Haine's Lake, St. George's Lake, Lake Marie, Eaton's Lake, Hackett's Lake, Boy's Lake, Bell's Lake, Hall's Lake, and Humber River East (Wilcox Lake to Woodbridge).

Northern pike were transplanted in Musselman's Lake some years ago from Duffin's Creek during the course of Atlantic salmon studies at the latter point. The lake has no inlet or outlet and the fish are unable to reach other waters in the area. A planting in Bell's Lake in King Township, which also has no inlet or outlet, in 1948, apparently was unsuccessful in establishing a population.

During the past ten years, pike have followed the Holland Canal into the Lloydtown stream and into Hall's Lake and have become the predominant species.

ONTARIO FEDERATION OF ANGLERS AND HUNTERS. Undated. Hatchery propagation. p. 7-8. *In* A Brief on the Management of Muskellunge in Ontario. Peterborough, Ontario.

The majority of the muskellunge cultured in Ontario are stocked in the Kawartha lakes. These lakes have good natural reproduction of muskellunge and good muskellunge populations and the present policy of concentrating stocking on these lakes is questionable.

The present policy of OMNR is to take spawn for culturing directly from the body of water to be stocked. It is believed that fish are genetically adapted to the body of water in which they live. The mixing of gene pools from different areas could lead to fish which are not well suited to their environment.

Several U.S. states are presently stocking pike-muskellunge hybrids. These hybrids are readily cultured on an artificial diet and are much cheaper to raise than muskellunge. Anglers, however, prefer to angle for muskellunge instead of hybrids because muskellunge reach a larger size than the hybrids and present more of an angling challenge. Hybrids do not reproduce.

ONTARIO MINISTRY OF NATURAL RESOURCES. 1987. Atlas of muskellunge lakes in Ontario. Fisheries Branch. Toronto, Ontario. 32 p.

This atlas represents our understanding of the distribution of muskellunge lakes in Ontario as of September, 1987. Origins of various populations were assigned the status of introduced, native or unknown.

There are 302 muskellunge lakes documented in this report. Seventy-one of these populations were established through introductions.

ONTARIO MINISTRY OF NATURAL RESOURCES. 1988. Stocking histories for introduced populations of muskellunge. Draft report. Fisheries Branch. Toronto, Ontario. 76 p.

This report summarizes the stocking history for 71 muskellunge lakes in Ontario. For all of these lakes muskellunge were not native but were introduced either intentionally or accidentally. The purpose of this report is to begin the process of more complete documentation of muskellunge introductions. Since 1970, stocking records have included the hatchery where the fish were raised and the source of the stock (Deer Lake and Stony Lake in all recent stockings). However, this information was not recorded in the years prior to 1970.

OTIS, K. J., S. J. FAJFER and R. R. PIETTE. 1996. Post-stocking survival of northern pike reared on three hatchery diets. *In* R. Soderberg [ed.]. 1996 Warmwater Workshop Proceedings – Esocid Culture and Management.

The objective of this study was to determine if switching pellet fed northern pike (*Esox lucius*) fingerlings to minnow diets four weeks prior to fall stocking would significantly increase survival. A second objective compared survival of these two cohorts to a minnow diet cohort and compared costs of the three cohorts based on hatchery food costs during rearing. Four lakes in central Wisconsin were stocked with fall fingerling northern pike reared on three hatchery diets and cohorts were followed for three years in the wild to determine costs/fish based on numbers of survivors to age 3. Hatchery cohorts included: minnow diet (predominantly fathead minnows (*Pimephales promelas*)); pellet diet; and pellet diet switched to minnows four weeks prior to stocking. Rearing food costs were lowest for pellet, intermediate for switched and highest for minnow diet cohorts. Mean lengths (mm), weights (gm), and cost per fish at fall stocking were 221 mm/63 gm/US $0.15 for pellet diet; 236 mm/79 gm/ US $0.74 for switched diet; and 323 mm/240 gm/US $2.52 for minnow diet for northern pike fingerlings. Minnow diet cohorts had greater mean lengths and weights at stocking and overall higher survival than switched or pellet diet cohorts. Switching from pellets to minnows before stocking did not significantly increase survival over pellet diet northern pike fingerling. Although minnow diet northern pike had the higher survival of the three cohorts they might not be the most advisable hatchery product. Since pellet diet fingerling had some survival in all four lakes, their survival was not significantly different than switched diet fish and rearing food costs were much lower than the other cohorts, they would be the recommended northern pike fingerling for most stocking scenarios.

PALMER, J., M. THOMPSON and E. McINTYRE. 1999. Shawanaga Lake synoptic trap net survey report. File Report. Ontario Ministry of Natural Resources. Parry Sound, Ontario.

A synoptic trap net survey consisting of eleven 8 foot trap nets was conducted on Shawanaga Lake from July 27-31, 1998. Northern pike dominated the nearshore fish community comprising approximately 67% of the total fish biomass caught in the survey. The northern pike population appears very healthy and robust; a clear indication that the 1979 introduction of northern pike has been highly successful.

PARSONS, J. W. 1959. Muskellunge in Tennessee streams. Transactions of the American Fisheries Society 88(2) : 136-140.

Muskellunge (*Esox masquinongy*) are known to inhabit 169 miles of rocky and fast-flowing streams on the Cumberland Plateau in East-Central Tennessee. These waters are usually clear (turbidity less than 5 ppm) and slightly acidic. Muskellunge in Tennessee streams grow an average of 5.8 inches per year but few fish live beyond 6 years of age. Male fish mature when about 22 inches long and three years old; females mature when about 25 inches long and 3 or 4 years old. Muskellunge spawn in April when water temperatures are near 50º F. Young fish are found in only 15% of the total habitat distance. Management of the muskellunge streams in Tennessee appears to be necessary to maintain the presently small muskellunge fishery.

A greatly expanded fishery may best be obtained by a well planned and executed propagation and stocking program. Several thousand young muskellunge have been stocked in Dale Hollow Reservoir in an attempt to establish a new fishery and reduce the abundance of gizzard shad by predation.

PATRICK, B. and R. HAAS. 1971. Fin pulling as a technique for marking muskellunge fingerlings. Progressive Fish Culturist 33(2) : 116-118.

Although fin-pulling is a lengthier process than most fish marking methods it provides a permanent identifying mark when done properly. In 1968, a total of 1,237 muskellunge fingerlings (250 unmarked and 989 marked) were stocked into a hatchery pond. Two months following planting the fish were harvested. Ninety percent of the marked fish were recovered, compared to 94.8% of the unmarked fish, making for a difference of only 4.8%.

PATTERSON, R. R. 1971. Establishment of breeding populations of northern pike in Alamogordo, Ute, Conchas and Elephant Butte reservoirs from fry and fingerling releases. Federal Aid Project F-22-R-12, Job No. 4. New Mexico Department of Game and Fish. Santa Fe, New Mexico. 3 p.

Stocking fry was 100% unsuccessful, while fingerling stocking did appear to have some merit.

PEARSON, J. 1982. Tiger muskellunge fingerling stocking success at Cree and Leon lakes. File Report. Indiana Department of Natural Resources. Indianapolis, Indiana.

PENNEY, L. Undated. Capture and transplanting of adult muskellunge at Sioux Lookout. Unpublished Report. Ontario Department of Lands and Forests. Sioux Lookout, Ontario. 8 p.

On May 25 and May 26, 1967, 60 adult muskellunge (*Esox Masquinongy*) were captured while on their spawning run. The fish were captured in a 4.5 foot hoop net and later sexed, measured and tagged with Atkins tags. The captured fish were then moved 75 air miles from Muskie Lake to Sturgeon Lake in an Otter aircraft.

Comments are made on the length data from this and previous years projects as related to the present minimum size. The validity of the present opening day of the muskie season is also discussed.

PERKINS, P. J. 1974. Head start for the musky. Wisconsin Conservation Bulletin March/April (1974) : 26-27.

Although many Wisconsin lakes have a natural population of musky, these populations occasionally need to be enhanced. Regular stocking occurs on many lakes to maintain the population. Wisconsin annually produces 200,000 to 300,000 musky fingerlings, the majority of which are stocked into Wisconsin waters. Oxygenated tanks are used to transport the fish from the hatcheries to their designated (public) waters throughout the state.

PETRIE, C., B. KNOPS, M. C. MARTIN and B. VAUGHN. 1993. Fishing Wisconsin's top 50 muskie lakes. Fishing Hot Spots, Inc. Rhinelander, Wisconsin. 255 p.

In Wisconsin, the bulk of muskellunge stocking is done by the Department of Natural Resources. These plantings are sometimes supplemented by Muskies Inc. The policy of the DNR states that no more than 2,500 fingerlings shall be stocked per waterbody and that the stocking rate will not exceed that of 2 fish/surface acre. The actual number of fish which are planted either annually or in alternate years depends on the output from the hatcheries. There currently exists approximately 700 lakes and flowages and 48 rivers with fishable muskie populations, where 25% of these are stocked and/or introduced. Introductions of these fish are not always welcomed as muskie have been known to kill resident walleye and perch populations. The following is a table summarizing the stocking done in the top 50 muskie lakes across Wisconsin by the DNR:

Waterbody	Stocking Frequency	Stocking Density (Total Number Stocked)	Size of Fish
North East			
Big Arlor Vital Lake	Annually	0.5/acre (550)	8-12" fingerlings
Big Lake	Annually	0.96/acre (800)	10" + fingerlings
Big St. Germain Lake	Annually	0.81/acre (1300)	10" + fingerlings
Upper and Lower St. Germain Lake	Annually	0.91/acre (450) 1/acre (350)	Large fingerlings
Crab Lake	Alternate years	1.05/acre (1,000)	Large fingerlings
Crescent Lake	Annually	0.5/acre (300)	Large fingerlings
Eagle River Chain	Annually	Unknown	Large fingerlings
Gile Flowage	Annually	0.74/acre (2,500)	Fingerlings
Flambeau Lake	Unknown	Unknown	Fingerlings
Big Crawling Stone Lake	Annually	2-2.7/acre (3-4,000)	9-12" fingerlings
Lac Vieux Desert	Annually	0.6/acre (2,500)	Large fingerlings
Little Arbor Vitae	Annually	1/acre (~534)	Large (catchable)
Manitowish Chain	Annually	0.5/acre (in half the lakes)	Large fingerlings
Lakes Minocqua and Kawaguesaga	Annually	1/acre (~1,575)	10-12" fingerlings plus fry
North and South Twin Lakes	Annually	0.72/acre (2,500)	Large fingerlings
Palmer and Tenderfoot lakes	Alternate years	0.95/acre (600)	Fingerlings
Pelican Lake	Annually	0.7/acre (2,500)	Large fingerlings
Plum Lake	Annually	0.85/acre (900)	10" + fingerlings
Presque Isle Lake	Annually	1/acre (1,280)	Fingerlings
Star Lake	Annually	0.5/acre (600)	Large fingerlings
Three Lakes Chain	Annually	1/acre (in large lakes only)	Large fingerlings
Lake Tomahawk	Alternate years	0.73/acre (2,500)	Fingerlings
Trout Lake	Annually	Unknown	10-12" fingerlings
Turtle-Flambeau Flowage	Annually	0.45/acre (6,000 in flowage only)	Fingerlings
North-West			
Bone Lake	Annually	1.4/acre (2,500)	Large fingerlings
Butternut Lake	Alternate years	2/acre (~2,012)	Fingerlings
Chippewa Flowage	Annually	0.16/acre (2,500)	Fingerlings
Day Lake	Alternate years	1/acre (~625)	Fingerlings
Deer Lake	Annually	1.86/acre (1,500)	Large fingerlings
Eau Clair Chain of Lakes	Alternate years	1/acre	Large fingerlings
Grindstone Lake	Annually	0.8/acre (2,500)	Fingerlings
Holcombe Flowage	Annually	0.64/acre (2,500)	Fingerlings
Lac Courte Oreilles	Alternate years	1/acre (~5,039)	Large fingerlings
Lost and Teal lakes	Annually	1.1/acre (2,500)	Large fingerlings
Lake Namekagon	Annually	0.76/acre (2,500)	Large fingerlings
Shell Lake	Annually	1/acre (~2,510)	8-13" fingerlings
Lake Wissota	Annually	0.4/acre (2,500)	Fingerlings
Yellow Lake	Annually	1-2/acre	Large fingerlings
South			
Little Green Lake	Annually	2-2.6/acre (930-1,200)	Large fingerlings
Lake Monona	Annually	0.76/acre (2,500)	6" fingerlings
Pewaukee Lake	Annually	0.4-1.2/acre (1-3,000)	Fingerlings

PORTER, L. 1977. Review of selected literature on muskellunge life history, ecology, and management. Fisheries Special Publication 119. Minnesota Department of Natural Resources. St. Paul, Minnesota. 81 p.

Occasionally, in Ohio, the direct stocking of muskellunge fry will result in an adult population. However, further stocking attempts may have no discernible impact on the fish population. Pennsylvania has been successful in many projects involving the stocking of fry into rivers and new impoundments, whereas Tennessee has only found positive results with fingerlings 8 inches or greater. In the majority of the states surveyed, fry are only stocked when there is an overabundance of this stage at the hatcheries and that any populations which result from these stockings are simply an added benefit.

It is highly suspected that the larger the fish stocked the greater its chances of survival are. In Piedmont Lake, Ohio, there were high correlations found between the size of fingerlings stocked and the percent return to test nets and anglers. It has been found in this state that a legal (30 inch) return of 1,050 muskellunge is expected for each batch of 30,000 fingerlings planted, which translates into a 3.5% return. Wisconsin data, however, demonstrates that there is little difference between the survival of small versus large stocked fingerlings.

Stocking rates across the states are uniform in theory if not in practice. The following table represents stocking densities in selected states:

State	Life Stage	Waterbody	Density/Number
Pennsylvania	Fry	New lakes, rehabilitated waters and reclaimed waters	100/acre
		Rivers less than 100 yards wide	1000/mile
		Rivers greater than 100 yards wide	1750/mile
	Fingerlings	Lakes	2-5/acre
		Rivers less than 100 yards wide	25/mile
		Rivers greater than 100 yards wide	40/mile
New York	Fingerlings	Chautauqua Lake	~1.5/acre (20,000 total)
Wisconsin	Fingerlings	Lakes	2/acre

POWELL, T. G. 1972$_a$. The northern pike in Colorado. Fishery Information Leaflet No. 19. Division of Game, Fish and Parks. Colorado Department of Natural Resources. Denver, Colorado. 2 p.

The northern pike is a recent addition to the fish fauna of Colorado, having first been introduced in Bonny and Sterling reservoirs in 1956. Since this time they have been stocked into many of the reservoirs on the Eastern Slope and in scattered locations on the Western Slope.

Northern pike can be used as a management tool. A recent study has demonstrated that stocking with northern pike can drastically reduce an overabundant population of sunfish or crappie. In order to achieve this, a minimum of 25 pike must be stocked per surface acre over a two-year period. Higher stocking rates will bring results more quickly. In this study 200 fish per surface acre, measuring 8 to 12 inches, were planted for three years. This resulted in a 65% decrease in the sunfish population, while growth increased by 20%. With higher stocking rates, such as that used in the study, a reduced rate of growth of the pike is expected.

POWELL, T. G. 1972$_b$. Northern pike introductions. Fisheries Research Report, Colorado Division of Game, Fish and Parks. Denver, Colorado. 7 : 25-28.

POWELL, T. G. 1973. Effect of northern pike introductions on an overabundant crappie population. Special Report No. 31. Colorado Division of Wildlife. Denver, Colorado. 6 p.

A cyclic pattern of abundance was found in the white crappie population of Carbody Reservoir, Colorado, in 1955. Establishment of a viable northern pike population in this water was not accomplished until large numbers of subadults (8-10 inches) and fingerlings (2 inches) were planted in 1969. Ensuring northern pike predation resulted in an increased average size in age group III crappie and a leveling of the abundance cycle. At the conclusion of the study, however, the cycle still appeared to be in existence. Stocking recommendations are given for the sizes of fish used, along with a recommendation for the size of northern pike effective in panfish population reduction. Other predation studies with this species are underway.

PRIEGEL, G. R. 1968. Movement and harvest of tagged northern pike released in Lake Poygan and Big Lake Butte des Morts. Research Report No. 29. Wisconsin Department of Natural Resources. Madison, Wisconsin. 7 p.

Northern pike were captured in Rush Lake during the winter rescue operations and released into waters containing excellent natural northern pike reproduction. Rush Lake itself is stocked every spring with northern pike and walleye fry. The lakes which received the rescued fish were: Winnebago, Big Lake Butte des Morts and Poygan and Winneconne.

Over a three-year period anglers returned 8.7% of the fish stocked in Lake Poygan, whereas only 4.3% were angled on Big Lake Butte des Morts during a period of two years. Low returns in these cases are not a major concern since the lakes already have healthy pike populations. Possible reasons for the poor contribution to the anglers' catch may include: competition from the native pike, migration of the planted fish or size of fish at stocking.

PRIEGEL, G. R. 1969. Factors influencing success of northern pike reproduction in natural and artificial spawning areas. Federal Aid Project F-83-R-5, Job No. 15, Final Report. Wisconsin Conservation Department. Madison, Wisconsin. 4 p.

QUÉBEC MINISTÈRE DU LOISIR, DE LA CHASSE ET DE LA PÊCHE. 1988. Stocking guidelines for fish species other than anadromous Atlantic salmon. Direction de la Gestion des Espèces et des Habitats. Québec City, P. Q.

Muskellunge are stocked for both put-grow-take and introduction purposes. Introducing this species where a population of northern pike exists as well as in lakes with a surface area smaller than 1,000 hectares is not recommended.

For introductions the following guidelines apply:

- In lakes and watercourses, fry should be stocked at the rate of 1,200 per hectare and small fingerlings should be stocked at the rate of 12 per hectare. These rates apply to the area of suitable habitat namely a submerged vegetation zone were water depth varies from 0-4 meters.
- Fish size should vary between 5 and 10 cm long.
- For all plantings, a minimum quantity corresponding to 75% of these rates is mandatory while not exceeding 100,000 fry or 5,000 small fry per project.
- Stocking frequency is every other year with a project duration involving up to two or three stockings.
- Fish should be stocked in the summer.
- Fry should be released in lots over areas of submerged vegetation. Small fry should be released in lots of 10-15 fish in areas of submerged vegetation.
- Preferably, stocking should be done at night.

For put-grow-take muskellunge stocking the following guidelines apply:

- In lakes and watercourses, fry should be stocked at the rate of 5 per hectare. The maximum quantity is 5,000 fry per project. These rates apply to the area of suitable habitat, namely a submerged vegetation zone where water depth varies from 0-4 meters.
- Fish size must be greater than 15 cm long.
- Stocking frequency is every other year with a project duration of two years.

- Fish should be stocked in the autumn consistent with the size of fish to be stocked.
- Fry should be released in lots of 10-15 fish over submerged vegetation. Preferably, stocking would be conducted at night.
- The success of this type of stocking must be assessed every five years.
- Put-and-take stocking is not recommended for muskellunge.

RAHEL, F. J., R. A. STEIN and R. F. CARLINE. 1985. Evaluating relationships among stocking size, survival and hatchery costs for tiger muskellunge stocked in Ohio reservoirs. American Fisheries Society Annual Meeting 115 : 109. (Abstract only)

RAINE, G. 1972. White Lake. File Report. Ontario Department of Lands and Forests. Kemptville, Ontario. 2 p.

In 1968, it was recommended that 15,000 musky fry be stocked into White Lake following the discontinuation of walleye planting. The musky were stocked for five years, with the annual number varying from 15-60,000 before an assessment was to be conducted.

RASMUSSEN, G. and P. GEERTZ-HANSEN. 1998. Stocking of fish in Denmark. Chapter 2. *In* I. G. Cowx [ed.]. Stocking and Introduction of Fish. Fishing News Books. London, United Kingdom.

Stocking of fish and crayfish in fresh and salt water has taken place in Denmark for more than 100 years but with varying degrees of success. The first pike (*Esox lucius*) hatchery was constructed in 1892. Between 1987 and 1995, 130,639 northern pike fry were released in Denmark waters.

Fry of pike are fed with zooplankton in intensive commercial units and liberated (at about 3 cm in length) into lakes and some fjords in the spring. The number of stocked pike has increased considerably in recent years and is expected to increase further because of biomanipulation activities and catch purposes. The pike are stocked in densities of 1,000-1,500 fish ha^{-1} and, because they are cannibalistic, they regulate their own number to the carrying capacity of the lake during the season.

RATT, A. J. P. 1988. Synopsis of biological data on the northern pike. Fisheries Synopsis No. 30. Food and Agriculture Organization of the United Nations. Rome, Italy. 178 p.

Stocking of northern pike is a management measure in many countries. Several researchers feel that the reduction of breeding grounds cannot be compensated by stocking northern pike because the stocked individuals are affected by the same factors that have caused the decrease of the natural population. The results of many studies of stocked northern pike are biased by methodological problems. There is a positive influence of the availability of prey fish on the survival of pike stocked in ponds without predators. The survival of stocked pike to the anglers creel can vary from 15.8-36.6%. Stockings of northern pike in new reservoirs in the mid-south of the United States have often resulted in excellent survival with growth rates of 4 lb. per year and maximum longevity of 6 years. Stocking of brood fish or larvae in new waterbodies or in waters where the fish population has been removed or drastically reduced are generally successful. Generally, stocked northern pike have the tendency to move and return to their catch site when transferred over a distance of several kilometers. Stocking of summer pike and winter rescue pike can result in considerable return and short term improvement of fishing success and harvest.

REID, J. 1988. Stony Lake muskellunge spawning study. File Report. Ontario Ministry of Natural Resources. Lindsay, Ontario. 18 p.

The purpose of this report is to investigate the characteristics of spawning muskellunge in Stony Lake such as size composition, yearly abundance, incidence of lymphosarcoma and contribution of stocked muskellunge.

Between 1979 and 1985, 11,005 muskellunge were stocked into Stony Lake, each year class bearing alternating fin clips. The returns of stocked fish were small and included only two 1982 year class fish, one 1981 year class fish and four 1980 year class fish. All these specimens were males and comprised only 1.7% of the total catch.

ROBERTS, K. R. 1964. Evaluation of muskellunge stocking. Fisheries Report F-029-R-03, Job No. 3. Ohio Division of Wildlife. Columbus, Ohio. 42 p.

ROYER, L. M. 1971. Comparative production of pike fingerlings from adult spawners and from fry planted in a controlled spawning marsh. Progressive Fish Culturist 33(3) : 153-155.

An experimental northern pike spawning marsh adjacent to Kenosec Lake in southeastern Saskatchewan was operated annually from 1964 to 1970. This study was initiated after a biological survey of Kenosec Lake revealed a dense population of stunted perch and a small population of the predatory northern pike. Natural spawning areas for pike were limited as a result of recreational developments and receding water levels. The objective of this project was to test and compare two methods of producing pike fingerlings by: (1) stocking adult spawners, and (2) stocking hatchery-reared fry.

From the comparison of two methods of producing pike fingerlings in a managed marsh, the use of adult spawners appears to offer a much more reliable and economical means of propagating fingerling pike than the stocking of hatchery fry. Although the poor survival of hatchery fry is not readily explainable, experiments carried out in 1967 did indicate that the fry suffered high post-stocking mortality. Samples of the fry being planted in 1967 were placed in wire baskets containing grass and held overnight in the shallow water near shore. Average mortality of these fish was 40% after 18 hours. The majority of fry settled into the bottom materials of the marsh where hydrogen sulfide or low dissolved oxygen levels may have been encountered.

SANDERSON, C. Undated. Results of feeding *Daphnia* to muskellunge over a prolonged period. Pennsylvania Fish Commission. Harrisburg, Pennsylvania. 4 p.

Results show that it is possible to feed a diet of one hundred percent *Daphnia* to muskellunge for at least five months (May 18 to October 18) with no significant mortality. The survival is very good but the growth is significantly retarded. After a length of 5 cm is attained the *Daphnia* diet does not appear adequate. The fish lose their normal aggressive feeding behaviour and become thin and appear to be in generally poor physical condition.

A diet of *Daphnia* over a prolonged period does not seem to permanently affect the muskellunge. When the diet is changed to minnows growth rate increases rapidly and within a few days vigor is restored and physical appearance is much better.

It is possible that it would be beneficial to hold muskellunge on a diet of *Daphnia* somewhat longer than is now the practice. This would allow sufficient time for spawning of minnows and insure an ample supply of forage fish for use in tank culture.

SANDERSON, C. H. 1974. Artificial diets for esocids and walleye culture. Pennsylvania Fish Commission. Harrisburg, Pennsylvania. 6 p.

During the past several years Pennsylvania has been conducting dry diet testing programs in co-operation with other state and federal fishery agencies. The results from these tests provided enough favorable information to encourage us to initiate full production programs on artificial diets. Programs designed to produce maximum numbers of tiger muskellunge, walleye and northern pike were initiated in 1974. The results of the 1973 diet testing program indicated that we could expect good results with tiger muskellunge on dry feed and moderate success with walleye and northern pike. The results with pure muskellunge revealed limited success and should be continued on an experimental basis only in 1974.

SCHLOEMER, C. L. 1936. The growth of the muskellunge (*Esox masquinongy immaculatus*) in various lakes and drainage areas of northern Wisconsin. Copeia 1936(4) : 185-193.

This study of the growth of muskellunge from 12 Wisconsin lakes shows that those from Lost Land Lake and Grindstone Lake had the most rapid average growth; they reached a legal length of 30 inches during the fourth summer. Those from Chippewa, Teal, Court Oreilles, Sand, and High lakes attained this length during the fifth summer; those from Moose, Ghost, Clear, and Spider lakes during the sixth summer; and those from Island Lake not until the seventh summer. The Island Lake specimens, therefore, had the slowest rate of growth.

With respect to a successful muskellunge stocking policy for these 12 lakes, the results suggest that best returns are to be expected in Lost Island and Grindstone lakes and better than average returns in Chippewa, Teal, Court Oreilles, Sand and High lakes. The other 5 lakes would yield appreciably poorer returns, with Island Lake giving the minimum.

SCHMIDTZ, W. R. and R. E. HETFIELD. 1965. Predation by introduced muskellunge on perch and bass II: Years 8-9. Transactions of the Wisconsin Academy of Science Arts and Letters 54 : 274-282.

Measurements of population changes were made eight and nine years after the introduction of age 0 muskellunge into lakes containing perch and bass. There was a recovery in numbers of age II perch and older. However little recruitment into size classes of either prey fish over 150 mm in total length occurred. The growth rate of age I and II perch was significantly greater after the severe reduction of perch that occurred in the fifth year. The annual survival rate for the predator in two lakes was 0.8. Marked decreases in the growth rate of the muskellunge bore a temporal relation to the reduction in numbers of the prey species. The type of predation and intraspecific competition manifested are discussed.

SCHROUDER, J. D. 1973. Muskellunge management in Michigan. Technical Report 73-31. Michigan Department of Natural Resources. Lansing, Michigan. 21 p.

Muskellunge catch and effort data for 1971 and 1972 was reviewed to evaluate program costs and effectiveness. On a statewide basis, approximately one-half of the state's total harvest (15,000-20,000) were Great Lakes muskellunge from Lake St. Clair. Harvest rates for inland waters having Great Lakes musky were relatively low. Most of the inland harvest and 40% of the statewide annual harvest of muskellunge, was comprised of tiger or hybrid muskies.

Currently, Michigan's management policy involves the stocking of strategically located lakes with muskie or hybrids to add variety, excitement and quality to the fishery. A winter spearing ban has been imposed on most lakes stocked with muskellunge.

Typically waters are stocked annually or biennially with 6-9-inch fingerlings at a rate of 2-4 per acre. This number is based on a predicted survival rate to age 4 (catchable size) of 20%. Fry, 3/4 inch long, or 2 inch fingerlings may be stocked following chemical reclamation or in waters with low predator numbers. Northern muskellunge fingerlings are stocked primarily in lakes designated as brood stock lakes to establish egg sources for future production. It is hoped that habitat protection and regulations will preclude the need to stock Lake St. Clair with muskellunge.

The hatchery costs of producing legal-sized (age 4) purebred or tiger muskellunge are approximately equal. The tiger muskellunge is suited to a wider variety of waters and is highly vulnerable to angling, in contrast to the purebred. For these reasons Michigan will continue to promote the propagation of tiger muskellunge for stocking in selected waters.

SCIDMORE, W. J. 1964. Use of yearling northern pike in the management of Minnesota lakes. Fisheries Investigational Report No. 277. Minnesota Department of Natural Resources. St. Paul, Minnesota. 10 p.

In Minnesota, sizeable quantities of northern pike, mostly yearlings, are available from winter fish rescue operations for stocking purposes. These fish are used primarily to provide fishing where natural reproduction is inadequate. Two examples are described which illustrate variations which may be expected in the response of these stocked fish to a new environment and to fishing pressure.

In an 885 acre lake containing a dense perch and better-than-average walleye population, 5.2 pounds-per-acre of stocked yearling pike were added to the estimated 4.7 pounds-per-acre of resident pike present prior to the opening of the fishing season in mid May. The number of pike present was increased about five times. In two complete fishing seasons, 44.1% of the original number were recovered by fishermen. Total poundage harvested was 1.6 times that stocked. It is estimated that, with no natural reproduction, pike population density would have been reduced to the pre-stocking level by about the end of the third summer season following stocking. The average weight of the fish stocked increased from 0.9 pounds at time of introduction to 3.7 pounds by the second winter season following introduction. Subsequent test netting data indicate that a high northern pike population maintained by stocking has substantially reduced the perch and, perhaps, the walleye populations.

In the second lake, a 78 acre bass-panfish lake with a large population of low growing bluegills and a low northern pike population, 17.7 yearling northern pike per acre were added to the existing population. This was an increment in weight of 21.2 pounds per acre. During the following summer fishing season, 64.1% of these fish and 76.5% of the original poundage were recovered by anglers. In contrast to the first lake these stocked fish showed very little increase in average weight or length while resident fish grew normally throughout the summer. The stocked fish had almost disappeared by the following spring with little apparent effect on populations of other species present.

SCOTT, W. B. and E. J. CROSSMAN. 1973. Muskellunge. p. 363-370. *In* Freshwater Fishes of Canada, Bulletin 184. Fisheries Research Board of Canada. Ottawa, Ontario. 966 p.

Many species of fishes prey on the very young, nearly immobile muskellunge and these include northern pike, yellow perch, basses (*Micropterus* spp.), rock bass, and sunfishes. In hatchery situations, and possibly in nature as well, diving beetles, electric light bugs and the large larvae of some aquatic insects are significant predators on newly hatched muskellunge. In situations where earlier hatching northern pike and muskellunge co-habit and utilize the same spawning areas, predation of muskellunge hatchlings by pike fingerlings is considered to be a major reason for the failure of the muskellunge to survive this contact. Larger muskellunge are nearly free of predation except possibly by large birds of prey and bears.

SEELBACH, P. W. 1988. Considerations regarding the introduction of muskellunge into southern Michigan rivers. Fisheries Technical Report No. 88-5. Michigan Department of Natural Resources. Lansing, Michigan. 16 p.

Literature on the biology and management of riverine muskellunge is reviewed. Three steps in a protocol developed by the American Fisheries Society for introductions of muskellunge are outlined; the potential for it successful introduction is assessed; and a course of action for introduction and evaluation is suggested.

SEMOTAK, M. J. and L. PENNEY. 1966. Operation musky. Ontario Fish and Wildlife Review 5(4) : 17-18.

The maskinonge has a wide, but irregularly spaced distribution in Ontario. During the 1930s a few of the more popular lakes near Sioux Lookout were closed to musky fishing out of concern that the species could be eliminated in the near future. It was originally thought that the fishing closure would allow the present population to grow and for the musky to spread to connecting lakes. When this was found to not be the case a transplant program began. Between 1963 and 1966 adult musky were captured during their spawning runs using impounding gear. The fish were examined and tagged and placed in a nylon retainer in the lake until a sufficient number of fish were caught. These fish were then transported to other lakes.

Transportation for periods of less than twenty minutes in duration did not require aeration of the water supply. With aeration, transport times were extended up to two-and-one-half-hours. These fish were moved by truck or by aircraft.

Considerable success has already been achieved and close to 1,000 fish have been transplanted in the last four years, including introductions to thirteen new lakes. Natural reproduction has been confirmed at three of these sites. Transferring the musky was also found to benefit overcrowded donor lakes.

SERNS, S. L. and L. M. ANDREWS. 1983. Survival and growth of muskellunge fingerlings stocked in four Vilas County, Wisconsin, lakes. Fisheries Management Report 116. Wisconsin Department of Natural Resources. Madison, Wisconsin. 15 p.

The survival and growth of four, eight, and twelve inch muskellunge fingerlings stocked at the rate of 4/acre in four Vilas County lakes in 1976 and 1977 was investigated. This research was suggested by both fish managers and hatchery personnel to provide more information on the survival and growth of muskellunge fingerlings of various sizes. Fish from six separate stockings were given a distinctive fin-clip and data on the survival and growth were obtained in subsequent electrofishing and fyke netting collections.

Short- and long-term survival of all three size groups was similar in Arrowhead Lake for fish stocked in 1976 while short- and long-term survival for muskellunge fingerlings stocked in Arrowhead Lake in 1977 was highest for stocked 12 inch fingerlings. Survival was also highest for the 12 inch fingerlings stocked in Brandy and Johnson lakes in both 1976 and 1977 while survival of all three size groups in Sparkling Lake was negligible both years. Growth of the muskellunge fingerlings stocked in Arrowhead Lake was better than the growth of fingerlings in hatchery rearing ponds. The satisfactory survival and growth of fingerlings stocked in Arrowhead Lake can probably be attributed to the low density of northern pike and other potential predators and an abundant supply of young-of-the-year yellow perch in 1976 and 1977. The yellow perch probably provided a food source for the stocked muskellunge and served as a buffer from would-be predators.

This study indicated that small muskellunge fingerlings (approximately 4 inches) can contribute to a sport fishery when stocked in a lake with a low density of predators and a good supply of suitable forage. It is recommended that only large (12 inches or larger) fingerlings be stocked where there is a moderate to large northern pike (predator) population.

SERNS, S. L. and L. M. ANDREWS. 1986. Comparative survival and growth of three sizes of muskellunge fingerlings stocked in four northern Wisconsin lakes. American Fisheries Society Special Publication 15 : 229-237.

The survival and growth of 4, 8 and 12 inch muskellunge fingerlings stocked at the rate of 4/acre in four northern Wisconsin lakes in 1976 and 1977 were investigated. Fish from the six separate stockings were given a distinctive fin clip and data on survival and growth were obtained in subsequent electrofishing and fyke netting collections.

In Arrowhead Lake, in all three size groups, survival was similar for fish stocked in 1976 but for those stocked in 1977 survival was highest for 12 inch fingerlings. Survival was also highest for the 12 inch fingerlings stocked in Brandy and Johnson lakes in both years but in Sparkling Lake survival was negligible both years for all stocked fingerlings. Growth in Arrowhead lake was better than growth of fingerlings in hatchery rearing ponds. The good survival and growth of fingerlings stocked in Arrowhead Lake may be attributed to the low density of northern pike and other predators and an abundant supply of young-of-year yellow perch, a good potential food source.

Small muskellunge fingerlings (4 inches) can contribute to a sport fishery when stocked in a lake with a low density of predators and a good supply of suitable forage. Where moderate to large northern pike populations exist it is recommended that only larger (12+ inches) fingerlings be planted.

SHIPMAN, S. T. 1979. Observations on the distribution, life history, and stocking strategy for northern pike (*Esox lucius*) in Indiana. Indiana Department of Natural Resources. Indianapolis, Indiana. 32 p.

This paper summarizes distributional and abundance data for northern pike in Indiana. Relevant life history parameters including age and growth, and weight per length were computed for endemic pike populations. These data were then combined with similar data from other studies to construct a potential yield model.

Indiana's northern pike stocking case histories were reviewed and summarized. In general, introductions of pike have been most successful in new or recently renovated lakes. Introductions of advanced fingerlings (6 to 12 inches total length) to adults have been mostly successful, while introduction of fry to small fingerlings have been mostly unsuccessful.

SHUPP, B. D. 1978a. Muskellunge management in New York. Presented at the Seminar on Muskellunge Management in Central Ontario, September 26, 1978, Lindsay, Ontario.

In the State of New York, muskellunge rates ninth for fishing pressure and successful introductions of this fish have occurred in non-muskie lakes.

SHUPP, B. D. 1978$_b$. Chautauqua muskellunge: Most valuable in the world? New York Conservationist March/April(1978) : 32-36.

The population of Chautauqua Lake muskellunge are not as a result of natural reproduction. This lake has been stocked with artificially-reared muskies. In 1977, the Bureau of Fisheries stocked 46,000 six to nine inch fingerlings in 16 experimental lakes, Chautauqua being one of these.

In 1904, a Conservation Department fish hatchery was established on the lake at Bemus Point where fertilized eggs were hatched and the fry reared until just prior to the active feeding stage, and then released into the lake. In the 1940s, experiments began on rearing muskellunge to larger sizes since there appeared to be no evidence that fry stocking was having any effect on the declining population. Between 1940 and 1946 approximately 30,000 fingerlings, ranging in size from five to ten inches, were stocked and from 1941 to 1946 6,000 adult fish were tagged and released. Musky recruitment improved due to the stocking of larger fish and a new hatchery with 21 ponds (as opposed to one at the Bemus Point Hatchery) was constructed. Unfortunately rearing problems caused the state government to buy fish from Pennsylvania, which in turn made up the majority of fingerlings stocked into the lake for a few years. By 1973 the proportion of marked fish in spring netting has topped 75% with natural reproduction contributing little to the fishery.

SILER, D. H. and G. B. BEYERLE. 1984. Introduction and management of northern muskellunge in Iron Lake, Michigan. American Fisheries Society Special Publication 15 : 257-262.

As part of a management plan to expand the range of the northern, or Wisconsin, variation of the muskellunge in Michigan, northern muskellunge were successfully introduced into 396 acre Iron Lake, Iron County, by a number of annual fingerling plants beginning in 1962. By 1966-68 high survival of initial stocks had produced a substantial population of adult (harvestable) muskellunge.

In 1968, Iron Lake was designated a muskellunge brood stock lake. The normal angler harvest of muskellunge was severely restricted when the Department of Natural Resources closed Iron Lake to all winter angling (1968) and imposed an artificial lures only, 36 inch minimum size limit restriction on muskellunge taken by summer anglers (1972). The resulting abnormally high population density of 30 inch and larger muskellunge (0.84 per acre) directly or indirectly severely depressed the previously substantial populations of black crappies, common suckers, and possibly golden shiners. In addition some muskellunge emigrated into two popular brook trout streams. By 1978, public displeasure with the Iron Lake fishery stimulated the Department of Natural Resources to net and remove adult male muskellunge (1978 and 1979), move the muskellunge egg collection operation elsewhere and liberalize angling regulations (1980).

By the spring of 1982, a minimum of 381 muskellunge (0.96 per acre) had been removed from Iron Lake and the capture rate (0.96 per acre) of muskellunge by the Department of Natural Resources netting crews (0.5 per net night) was 93% less than the average capture rate for the three years previous to 1978. Mean annual growth of adult muskellunge during 1981 was 0.98 inches greater than during 1979 and survival of young, naturally produced muskellunge was up sharply.

The fish management experience at Iron Lake stresses the importance of carefully considering beforehand all the possible consequences of any drastic change imposed on a fish population and of intensely monitoring a fish population being subjected to untested management techniques.

SIMONSON, T. D. and S. W. HEWETT. 1999. Trends in Wisconsin's muskellunge fishery. North American Journal of Fisheries Management 19(1) : 291-299.

Wisconsin's populations of muskellunge (*Esox masquinongy*) provide an important recreational fishery. Our objectives were to (1) evaluate progress of the Wisconsin Department of Natural Resources muskellunge management plan, (2) examine subsequent changes in the fishery, and (3) evaluate Wisconsin's muskellunge waters classification system. With the goal of maintaining viable populations and a trophy fishery, the 1979 plan endorsed more restrictive harvest regulations, an increased supply of muskellunge fishing opportunities, and increased data collection. Since the 1980s, muskellunge fishing opportunities have increased 75% in terms of lake acres and 51% in terms of stream miles. Hatchery production and stocking efficacy have improved to the point where the department needs to re-evaluate current stocking practices. With the establishment of a shorter season, a higher statewide minimum length limit, and an increased use of special regulations, harvest regulations have become progressively more restrictive. Concurrently, muskellunge-specific fishing effort increased from the 1980s to 1990s. Harvest of muskellunge declined even though catch remained unchanged. Reducing the season length and increasing the overall availability of muskellunge angling opportunities did not reduce fishing effort on premier muskellunge lakes, but rather compressed effort into a shorter time period on increasingly popular waters. The reduction in harvest was associated with more restrictive regulations and voluntary changes in angler behavior (i.e., increased release of legal-sized muskellunge). Without voluntary release, it is likely that angler harvest would have exceeded levels needed to sustain the fishery. The muskellunge waters classification system, based originally on professional judgment, proved useful in distinguishing the fishery potential of lakes. Preliminary evidence suggests that voluntary constraints on harvest have not improved the size-structure of Wisconsin muskellunge populations because of continued harvest of nontrophy-sized fish. If our goal remains to provide a trophy fishery, more restrictive size-specific restrictions on harvest may be needed.

SMITH, N. W. 1996. Muskellunge stocking: Is it a viable management option? p. 155-158. *In* S. J. Kerr and C. H. Olver [eds.]. Managing Muskies in the 90s. Workshop Proceedings WP-007, Southern Region Science and Technology Transfer Unit. Ontario Ministry of Natural Resources. Kemptville, Ontario. 170 p.

The success and usefulness of muskellunge stocking was discussed at the Managing Muskies in the 90s workshop. The positive and negative aspects of stocking this species were brought into debate and certain questions were discussed by the group. Points which were made during discussions include:

- The possibility of utilizing tiger muskellunge for a put-and-take fishery.
- Fish culture and stocking should be used to rehabilitate a muskellunge fishery and as a means of introducing muskellunge to carefully selected areas.
- Stocking should not be used to supplement existing populations.
- Stocking and fish culture should be used for refugia purposes as long as genetic integrity is taken into consideration.

SMITH, P. 1978. Muskellunge stocking, management and assessment in the Lindsay District. Presented at the Seminar on Muskellunge Management in Central Ontario, September 26, 1978, Lindsay, Ontario.

Muskellunge are seen as an integral part of the Kawartha Lakes fish community. Components of muskellunge management include: habitat protection, enforcement of regulations and the stocking of fingerlings and fry. A number of questions need to be addressed concerning stocking:

- How important is stocking? What is the survival of stocked hatchery fish to catchable size?
- How should hatchery stock be allocated, both among districts and among waterbodies within a district?
- Should fry or fingerlings be stocked at a single site or scattered among many?
  How should an assessment of the impact of stocking be conducted?

In the following discussion period it was recommended that fingerlings should be stocked at night in order to maximize their survival.

SNOW, H. E. 1968. Stocking of muskellunge and walleye as a panfish control practice in Clear Lake, Sawyer County. Fisheries Research Report 38. Wisconsin Department of Natural Resources. Madison, Wisconsin. 18 p.

SNOW, H. E. 1974. Effects of stocking northern pike in Murphy Flowage. Technical Report No. 79. Wisconsin Department of Natural Resources. Madison, Wisconsin. 20 p.

Monitoring of fish populations in Murphy Flowage, a 180 acre flowage in northwestern Wisconsin, between 1955 and 1960 indicated the development of an overabundant, slow-growing population of bluegills (*Lepomis macrochirus*). In 1960 and 1961, attempts to improve bluegill growth by mechanical thinning failed apparently because only the larger bluegills were removed. Since the flowage already had a good northern pike population (*Esox lucius*), it was suggested that increasing this predator population might result in controlling of bluegill numbers and, hence, improving growth. To test this hypothesis, the flowage was stocked in late December, 1963, with 8,534 northern pike fingerlings ranging in size from 10.4 to 22.8 inches in total length. On an area basis, this stocking was equal to 47 fish/acre or 40.3 lbs/acre which met the intent of approximately doubling the northern pike population in the flowage. Complete angling records were obtained by a compulsory permit system throughout the entire study from 30 April 1955 through 31 May 1970.

Population density of stocked northern pike declined drastically following stocking from 47.0 pike or 40.3 lbs./acre in 1963 to 0.2 pike or 0.6 lbs./acre by 1968. By the spring of 1966, the stocked and native northern pike population was at its lowest level since 1960. In addition, the number of fish 26.0 inches and larger declined 76% between the 1955-1963 and 1964-1966 periods.

Within 5 years after stocking, anglers caught only 6.6% of the stocked fish, comprising 9.1% of the pounds stocked. Ninety percent of the total number and 78% of the total pounds caught were taken the first year after stocking. In addition the harvest of native pike declined drastically after stocking.

Sampling in downstream areas indicated that possibly 30% or more of the total number of pike stocked in Murphy Flowage had moved out of the flowage by the spring of 1965. Maximum downstream movement appeared to occur during the spawning period, involved largely stocked fish and was significantly related to population density.

In addition to harvest and emigration, pike were also lost as a result of observed natural mortality caused by a parasite, *Myxobolus*, believed to have been introduced at the time of stocking. Total observed mortality was significantly related to population density, and mortality or larger native pike was greater than that of smaller native pike.

Mortality from all causes averaged 60% for 9 years prior to stocking, while the first year after stocking, total mortality was 90% for both stocked and native pike. Total mortality remained higher than the prestocking average for 3 years.

Stocking of northern pike had no discernible impact on the bluegill population. After stocking, numbers of bluegills, particularly small ones, continued to increase while their growth continued to decline.

Impact of stocked pike on the native pike population and angler harvest was also unfavourable. By 1965, the second year after stocking, harvest of native pike had declined to the lowest level during the 9 preceding 6 year periods.

The decision to stock northern pike in a given body of water should be carefully considered if a lake is to be stocked to either establish, maintain, or increase a northern pike population. It is suggested that the total density after the stocking of large fingerlings (10-18 inches) not exceed 8 pike/acre. If the lake to be stocked already contains a native northern pike population, the fish populations should ideally be monitored prior to stocking in order to determine whether the lake can support more pike and to avoid the problems caused when the carrying capacity is exceeded.

SNOW, H. E. 1978. Responses of northern pike to exploitation in Murphy Flowage, Wisconsin. American Fisheries Society Special Publication 11 : 320-327.

The harvest and population dynamics of the fish populations in Murphy Flowage were studied for 15 years. A complete creel census and annual population estimates were utilized to describe the relationship between exploitation and other selected statistics of the northern pike, which was the major predator present. The entire study was conducted under liberalized fishing conditions (no bag, season, or size limits). Annual densities of native northern pike over 356 mm ranged from 5.8 to 40.6/hectare (mean = 20.8) and the biomass averaged 14.7 kg/hectare. The addition of stocked northern pike (117.2/ha) in December of the ninth year of the study temporarily increased the standing stock to 121.6/ha the following spring. The annual harvest of northern pike averaged 6.9 fish/ha (6.7 kg/ha) and they were caught at an average annual rate of 3.8/100 hours of angling. Annual exploitation rate (u) averaged 26%; natural mortality rate (v), 40%; and total mortality rate (A), 66%. Total mortality was not density dependent within the range of population density observed for native northern pike but became density dependent only when the numbers of fish were increased to high levels by stocking. I conclude that except when their densities were artificially high, the most important determinant of northern pike population density in Murphy Flowage was the availability of suitable forage (small bluegills). The results suggest that forage may contribute to predator abundance only above some threshold density of prey. Conversely, at lower forage levels predators may control the abundance of forage species.

SNOW, H. E. 1988. Effects of the introduction of muskellunge and walleye on bluegill and other species in Clear Lake, Sawyer County, Wisconsin, 1959-1984. Research Report 147. Wisconsin Department of Natural Resources. Madison, Wisconsin. 20 p.

Repeated stocking of muskellunge (*Esox masquinongy*) and walleye (*Stizostedion vitreum*) in Clear Lake from 1959-84 did not improve growth or size structure of the overabundant bluegill population. This study evaluated the effects of these stockings on the other species present especially the most abundant species – bluegill. Minimum harvest of muskellunge through 1967 as determined from voluntary registration at the only local resort, was 7% of the number stocked in 1960 and 1961. The stocking of muskellunge and walleye provided additional angling opportunities for Clear Lake.

SONSTEGARD, R. A. and J. G. HNATH. 1978. Lymphosarcoma in muskellunge and northern pike: Guidelines for disease control. American Fisheries Society Special Publication 11 : 235-237.

Epizootics of a malignant blood cancer (lymphosarcoma) affect populations of northern pike and muskellunge. Overall frequencies of occurrence of the disease in northern pike and muskellunge as high as 20.9% and 16.0%, respectively, were found. The disease in feral muskellunge causes high mortalities while in northern pike spontaneous regressions are common. The disease is transmitted percutaneously during the act of spawning. The disease does not seem to be transmitted to progeny via the egg. These species should be stocked as eggs or fry, not as adults, if the spread of lymphosarcoma is to be restricted.

SORENSON, L. 1968. Survey of experimental stocking of muskellunge in Union City Reservoir. Mimeo. Pennsylvania Fish Commission. Harrisburg, Pennsylvania. 4 p.

SORENSON, L., K. BUSS and A. D. BRADFORD. 1966. The artificial propagation of esocid fishes in Pennsylvania. Progressive Fish Culturist 28(3) : 133-141.

The hatchery propagation of esocids, especially the muskellunge, dates as far back as 1890 in New York and 1899 in Wisconsin. Low hatchability of esocid eggs and survival of fingerlings in rearing ponds can plague a hatchery. The timing of the harvest of fingerlings from rearing ponds is crucial to avoid cannibalism, as is the number of fish planted in the pond. A series of experiments demonstrated that increasing the size of the muskellunge from $^3/4$ inch to $1^1/8$ inches before they are planted into ponds can increase the harvest from below 10% to an excess of 60%. By stocking the correct number of fish, harvests can be increased from less than 5% to more than 70%. The best results were obtained when ponds four feet in depth were planted with one fish for each 8 square feet of water. If this rate is exceeded cannibalism will likely occur.

Surplus fry should be stocked immediately following swim-up. The most economical method to transport this size of fish is to place 2,000 fry into an 8 by 12 inch plastic bag, where the ratio is one part fish to ten parts water. The bag is then inflated with pure oxygen and sealed. The fish will survive for at least 10 to 12 hours.

SOUCHON, Y. 1980. The effect of initial population density on the survival and growth of young pike (*Esox lucius*) reared as 45-day fingerlings. p. 309-316. *In* R. Billard [ed.]. Pond Fish Farming. Symposium on fish production in ponds, Arbonne-la-Foret, France.

Just before the end of yolk-sac resorption, the pike larvae were stocked in three similar 400 m^2 ponds, according to the following numerical densities: 2.25 fish/m^2 (batch A), 3.75 fish/ m^2 (batch B), 5 fish/ m^2 (batch C) and kept for 45 days. They were only fed the organisms which developed naturally in each pond. The survival rate was identical in the 3 ponds: 22.8% (A), 23.7% (B), 24.8% (C). Fingerling mean length was the same: 9.7 cm (A), 9.7 cm (B), 9.3 cm (C). In the three populations, the relative variability of individual length was low (coefficient of variation: 8-12%). The total biomass of pike fingerlings was a direct function of the initial number of pike stocked. The results suggest that pike number and biomass can be augmented by increasing the initial population density. This study also shows that good yields can be obtained with pond invertebrates as the sole food source.

SPANGLER, G. R. 1968. Angler harvest and mortality of *Esox masquinongy* in Pigeon and Sturgeon lakes, Ontario. Journal of the Fisheries Research Board of Canada 25(6) : 1145-1154.

In 1961, a creel census was begun on Pigeon Lake in south-central Ontario to assess the contribution to the fishery of maskinonge transplanted from nearby Nogies Creek Fish Sanctuary. A correction being made for a tag loss of 58%, it was estimated that 30% of the transplanted fish had appeared in the anglers' catch. The mean catch of maskinonge from Pigeon Lake for the seasons of 1961-65 was estimated to be 1,318 fish-per-year. About 4% of the annual catch from Pigeon Lake was attributed directly to fish transplanted from Nogies Creek.

From a catch curve, the rate of total mortality of Pigeon Lake maskinonge age V or older was estimated to be 43% per year. Partitioning this into mortality due to fishing and mortality from other causes yielded estimates of 24.5% for each of these components.

STEIN, R. A., R. F. CARLINE and R. S. HAYWARD. 1981. Largemouth bass predation on stocked tiger muskellunge. Transactions of the American Fisheries Society 110(6) : 604-612.

To better understand why stocked esocids survive poorly, we estimated mortality rates of tiger muskellunge (F_1 hybrid of female muskellunge, *Esox masquinongy*, x male northern pike, *E. lucius*) that were placed into two Ohio reservoirs (mean fish total length, 171 and 179 mm; 62 fish per ha). Because pond experiments showed that hybrids stocked at night experienced mortality rates as high as those released during the day, we stocked tiger muskellunge into lakes during the day. Mortality of stocked hybrids (estimated by catch per effort of electrofishing) exceeded 95% within 40 days in both lakes. Population estimates of largemouth bass (*Micropterus salmoides*) coupled with stomach-content data revealed that these predators accounted for 26 and 45% of the numbers stocked in the two lakes. In addition, some hybrids died from thermal stress. Improved survival of tiger muskellunge should result if they are stocked at lengths greater than 250 mm to reduce predation losses, and late in fall when thermal stress is reduced.

STEIN, R. A., R. F. CARLINE and R. S. HAYWARD. 1982$_a$ Evaluation of fish management techniques: Evaluation of stocking tiger muskies into Ohio lakes. Federal Aid Project F-57-R. Ohio Division of Wildlife. Columbus, Ohio.

STEIN, R. A., R. F. CARLINE and R. S. HAYWARD. 1982$_b$. Evaluation of stocking tiger muskies into Ohio lakes. Dingell-Johnson Federal Aid Project. Ohio Department of Natural Resources. Columbus, Ohio.

STEIN, R. A., R. F. CARLINE, F. J. RAHEL and M. E. MATHER. 1985. Evaluation of tiger muskellunge for stocking Ohio lakes. Fisheries Report F-057-R-01-R-07. Ohio Department of Natural Resources. Columbus, Ohio. 127 p.

STEIN, R. A., F. J. RAHEL and M. E. MATHER. 1984. Evaluation of tiger muskellunge for stocking into Ohio lakes. Fisheries Report F-057-R-06. Ohio Department of Natural Resources. Columbus, Ohio. 85 p.

STEUCKE, E. W. 1975. Survival of hatchery-stocked fish in two North Dakota lakes. *In* Proceedings of the 1975 Interstate Musky Workshop, September 30-October 1, 1975, LaCrosse, Wisconsin.

Jarvis Lake and Gordon Lake were stocked over a number of years with walleye and northern pike fingerlings. It was found that in Jarvis Lake the age-0 year class consisted only of stocked fish. Gordon Lake has a small amount of natural reproduction because fish from the 1968, 1970 and 1971 age-0 year classes were recovered. For this lake it is likely that northern pike stocking every four years will adequately supplement the population with the present amount of fishing pressure.

Generally, for both lakes and others in North Dakota, the growth of the hatchery-stocked fish and the native population is identical, although hatchery fish indicate a higher survival rate by establishing stronger year classes. As with the rest of the Turtle mountain lakes, Jarvis and Gordon must rely on stocking to support a fishery.

STORCK, T. W. and D. L. NEWMAN. 1986. Evaluation of the introduction of tiger muskellunge into impoundments dominated by the bass-bluegill combination, evaluation of a partial creel, and size-specific survival of stocked channel catfish. Federal Aid Project F-40-R, Final Report. Illinois Natural History Survey. Champaign, Illinois.

STORCK, T. W. and D. L. NEWMAN. 1992. Contribution of tiger muskellunge to the sport fishery of a small, centrarchid dominated impoundment. North American Journal of Fisheries Management 12(1) : 213-221.

We used creel and draining censuses to measure angling catch, harvest, and hooking mortality of tiger muskellunge (female muskellunge, *Esox masquinongy*, x male northern pike, *E. lucius*) in a 6.1 ha Illinois impoundment dominated by largemouth bass (*Micropterus salmoides*) and bluegill (*Lepomis macrochirus*). The vulnerability of tiger muskellunge to angling produced a substantial catch-and-release fishery: 226 hybrids stocked in 1981 and 1982 were caught 388 times (1.7 times per fish) during four fishing seasons, and 27 others were recovered in the draining census in 1985. Only four legal fish (≥ 762 mm in total length) were harvested, but this number might have increased to 29 (13% of the number stocked) if the minimum length limit had been reduced to 710 mm. Strict enforcement of a 762-mm minimum-length limit failed to generate a productive and cost-effective trophy fishery, because growth was slow and many hybrids died from natural or hooking mortality before they reached legal size. The cost of each trophy fish harvested at Ridge Lake, Illinois, was prohibitively high (US $100); a more reasonable investment of $1.00 was required for each fish that contributed to the catch-and-release fishery. More than 40% of the hybrids stocked in 1981 and 1982 survived the first winter, and at least 19% were alive in April 1985. Twelve percent of the tiger muskellunge caught by anglers died within 24 hours of capture. Hooking mortality increased as water temperatures increased and was greater in the last year of the study (22%) than in the previous 3 years (8-10%). Hooking mortality was not affected by the type of bait (live or artificial) or size of fish. Predation by tiger muskellunge on bluegill did not reduce bluegill density and hence had no apparent effect on growth, size structure, or angling catch of bluegill.

STROUD, R. H. 1958. Two hundred dollar muskies. p. 1-2. *In* Sport Fisheries Institute Bulletin 84. Washington, D. C.

STROUD, R. H. and R. M. JENKINS. 1962. Predator stocking ineffective. p. 6. *In* Sport Fisheries Institute Bulletin 123. Washington, D. C.

STROUD, R. H. and R. M. JENKINS. 1966. Rehabilitated muskellunge. Sport Fisheries Institute Bulletin 180. p. 3.

Little Green Lake, Wisconsin, is a perfect example of a successful renovation of a waterbody using chemical treatment. After removal of coarse species in 1956, yellow perch, bluegills, largemouth bass, smallmouth bass, walleyes and muskellunge were restocked. Muskellunge had not been present in the lake prior to chemical treatment. They were stocked several times to establish succeeding year classes. Success was poor except when 8-inch fingerlings were used. Mark and recapture methods were implemented to determine survival of those fish introduced in 1969, following 32 months in the lake. The study revealed that survival of this stocking was approximately 45%. This amounted to 667 fish between 21.5 and 28.4 inches in length. It is assumed there were also additional survivors from the 1957 and 1961 plantings.

SZENDREY, T. A. 1992. Effect of feeding experience on vulnerability to predation, growth and survival of esocids. M. Sc. Thesis, University of Illinois. Springfield, Illinois.

SZENDREY, T. A., D. F. CLAPP and D. H. WAHL. 1993. Evaluation of muskellunge and tiger muskellunge stocking program. Dingell-Johnson Project F-113-R, Report 93/11. Illinois Department of Conservation. Springfield, Illinois.

SZENDREY, T. A. and D. H. WAHL. 1991. Effects of rearing technique on survival of stocked esocids. p. 50. *In* The 53rd Midwest Fish and Wildlife Conference, November 30-December 4, 1991, Des Moines, Iowa. (Abstract only)

We compared survival, growth and susceptibility to predation of pellet and minnow-reared esocids in reservoir, pond and laboratory experiments. Previous work with northern pike and muskellunge reared on live forage has found higher survival and lower vulnerability to predation than tiger muskellunge reared on pelleted diets. These differences may be innate or may be due to different rearing techniques. To evaluate these two hypotheses, we stocked equal numbers (17/ha) and similar sizes (200 mm) of minnow and pellet reared muskellunge and tiger muskellunge into two reservoirs for each taxa. Predation by largemouth bass was twice as high on pellet reared esocids of both taxa. Survival of tiger muskellunge through fall was higher for minnow reared fish (mean = 17%) than for pelleted fish (mean = 4%), whereas survival of pellet and minnow reared muskellunge was similar. Growth rates of tiger muskellunge after one year were also higher for minnow reared fish. In ten pond experiments (0.04 ha), tiger muskellunge reared on pellets were more vulnerable to predation by largemouth bass than those reared on minnows, whereas vulnerability of pellet and minnow reared muskellunge was similar. Laboratory experiments indicate survival and vulnerability to predation among fish reared by habitat selection. Our results suggest that rearing technique should be considered in development of escocid stocking strategies.

SZENDREY, T. A. and D. H. WAHL. 1995. Effect of feeding experience on growth, vulnerability to predation, and survival of esocids. North American Journal of Fisheries Management 15 : 610-620.

We evaluated direct and indirect effects of feeding experience on growth, food consumption, susceptibility to predation, and survival of esocids. We conducted five experimental stockings of equal numbers and similar sizes (200 mm) of experienced (minnow-fed) and naïve (pellet-fed) muskellunge (*Esox masquinongy*) (two stockings) and tiger muskellunge (muskellunge x northern pike *E. lucius*; three stockings) in reservoirs. Feeding experience had no direct influence on prey consumption and growth. Food consumption was similar in laboratory pool experiments. In contrast, experienced esocids exhibited higher fall survival than naïve fish of both taxa. Feeding experience indirectly affected survival, because predation by largemouth bass (*Micropterus salmoides*) was higher on naïve esocids. Examination of potential mechanisms in field and laboratory experiments suggested predation vulnerability was not affected by differences in habitat selection, foraging behavior, antipredatory behavior, or dispersal. Color pattern between minnow- and pellet-fed fish differed in both absolute color and contrast between light and dark markings, which may influence susceptibility to predation. Our results suggest that feeding experience can affect survival of introduced fish.

SZENDREY, T. A. and D. H. WAHL. 1996. Size specific growth of stocked muskellunge: Effects of predation and prey availability. North American Journal of Fisheries Management 16(2) : 395-402.

We examined survival, predation mortality, growth, and prey consumption for three sizes of muskellunge (*Esox masquinongy*) after stocking. Small (100 mm total length), medium (200 mm), and large (250 mm) fingerlings were introduced into each of three reservoirs over three years. Fall survival, based on population estimates and electrofishing catch per unit effort, was slowest for small fingerlings and increased with fingerling size. Across all reservoirs, survival of large fingerlings was 2-3 times that of medium fingerlings. Cost-benefit analyses showed large fingerlings to have the lowest cost-per-survivor. Predation by largemouth bass (*Micropterus salmoides*) decreased with fingerling size at stocking. Both foraging success and growth of stocked fingerlings were correlated with prey density. In contrast, prey species composition did not appear to influence foraging success or growth. Because they were stocked earlier, medium fingerlings achieved a greater size than did large fingerlings through the first fall when prey density was high but not when prey density was low. To maximize survival, growth, and cost-effectiveness, we recommend stocking large muskellunge fingerlings in systems with high prey and low largemouth bass densities.

TENNANT, D. L. and G. BILLY. 1963. Artificial hybridization of the muskellunge and grass pickerel in Ohio. Progressive Fish Culturist 25(1) : 68-70.

A male muskellunge (*Esox masquinongy*) and a female grass pickerel (*E. americanus vermiculatus*) were successfully crossed and 75% of their eggs hatched. Fifteen days following hatching 120 had survived and were planted into a newly constructed pond. The following day 1,000 fathead minnows (*Pimephales promelas*) were stocked into the pond. When the fish were 6 months in age the pond was seined and ten fish were captured. Their average length was 11.25 inches and weighed 5.5 ounces. The hybrids were heavier bodied than either of the parent species. A stomach analysis revealed that the fish had been feeding on large quantities of dragonfly nymphs was well as other invertebrates. Approximately 1.5 years following stocking the pond was opened to public fishing.

THREINEN, C. W. and A. OEHMKE. 1950. The northern invades the musky's domain. Wisconsin Conservation Bulletin 15(9) : 10-12.

In the last 15 years northern pike have been taking over muskellunge territory and effectively displacing the other species. Many management measures are being taken to enhance muskellunge populations depleted by the northern pike invasion. Hatcheries are currently concentrating on raising musky to fingerling or yearling size to improve stocking returns. There is an ongoing study being conducted on Pike Lake, Price County, with the purpose of controlling the northern pike and simultaneously stocking muskellunge to boost their numbers. Results of this study are yet to be determined but there is hope that drastic measures will aid the musky population.

THREINEN, C. W., C. WISTRON, B. APELGREN and H. SNOW. 1966. The northern pike, its life history, ecology and management. Wisconsin Conservation Department Publication 235. Madison, Wisconsin. 16 p.

The techniques involved in rearing and stocking northern pike are currently being improved. Ideally, the stocking of northern pike would strengthen weak year classes and therefore provide more stable fishing.

TIMMERMAN, G. A. 1979. Culture of fry and fingerling pike (*Esox lucius*). European Inland Fisheries Advisory Commission (EIFAC) Technical Paper 35 (Supplement 1) : 177-183.

TIPPETT, R. W. 1975. Trap netting of fish, Doe Lake, Armour/Ryerson Township, and transfer of adult pike from Doe Lake to Owl Lake, Armour Township. Memorandum. Ontario Ministry of Natural Resources. Huntsville, Ontario. 2 p.

Two trap nets were operated on Doe Lake between June 24th and June 28th, 1975, for a total of 103 hours. Species caught included smallmouth bass, yellow pickerel, white suckers, yellow perch, pumpkinseed, brown bullhead and pike. Fifteen northern pike in total were captured. Four of these died in the net. Nine fish were transferred to and planted into Owl Lake (one fish died in transit). The pike were marked with a right pectoral fin clip and were dipped in malachite green prior to release. It is anticipated that the pike will help in controlling the large population of coarse fish in Owl Lake.

TIPPING, J. M. 1996. A case history of the tiger muskie program in Mayfield Lake, Washington. *In* R. Soderberg [ed.]. 1996 Warmwater Workshop Proceedings – Esocid Culture and Management. Mansfield University, Mansfield, Pennsylvania.

Tiger muskies were introduced in Mayfield Lake, Washington, to control northern squawfish (*Ptychocheilus oregonensis*) an undesired juvenile salmonid predator and to create angling opportunities for a trophy fish. Results have shown a doubling of angler effort on the lake, rapid growth of tiger muskies, a preference of tiger muskies for squawfish as prey, and a reduction of 30+ cm squawfish. Sport harvest has averaged about 12 muskies-per-year although another 100-200 fish-per-year are caught and released. However, squawfish remain abundant and survival of rainbow trout fingerlings remains poor, the latter probably due to high winter flows. Information gathered on movements of six ultrasonic tagged tiger muskies tracked for 15-34 months indicated they had winter/spring and summer/fall home ranges.

TIPPING, J. M. and J. R. HEINRICHER. 1993. Use of magnetic wire tags to mark tiger muskellunge. North American Journal of Fisheries Management 13 : 190-193.

Tiger muskellunge (*Esox masquinongy* x *E. lucius*) were marked with magnetic wire tags in the cheek musculature, dorsal fin, and anal fin and later examined with a magnet wire wand detector in an effort to determine the viability of using tag location was a means of identifying groups of fish. Tag retention was 88.3% in the dorsal fin after 185 days, 99.4% in the cheek after 185 days, and 99.0% in the anal fin after 72 days. Varying tag location appears to be a useful way to identify groups of tiger muskellunge.

TOMCKO, C. M. 1982. Use of bluegill forage by tiger muskellunge: Effects of predator experience, vegetation and prey density. M. Sc. Thesis, Ohio State University. Columbus, Ohio. 47 p.

TOMCKO, C. M., R. A. STEIN and R. F. CARLINE. 1984. Predation by tiger muskellunge on bluegill: Effects of predator experience, vegetation, and prey density. Transactions of the American Fisheries Society 113 : 588-594.

Many pellet-reared tiger muskellunge (F_1 hybrid of female muskellunge, *Esox masquinongy*, and male northern pike, *E. lucius*) do not survive stocking in reservoirs dominated by bluegill (*Lepomis macrochirus*) prey. Poor survival may occur because few hybrids capture bluegills. In a previous study done in hatchery ponds, only 10% of naïve hybrids (those never before exposed to live prey) captured bluegills during 15 days. In similar ponds, we tested the effects of predator experience (using hybrids previously exposed to bluegill prey), vegetative cover, and bluegill density on the number of hybrids capturing prey. Few experienced or naïve hybrids captured bluegills at low prey density, regardless of the presence or absence of vegetation. When bluegill density was increased from 1 to 5 prey/m^2 in ponds to 40/m^2 in aquaria, many hybrids captured bluegills. Our pond study suggests that most hybrids will not fare well when stocked in lakes where only bluegill forage is available.

TRIPP, S. 1965. The Pigeon River muskie hatchery. The Outdoorsman. p. 58-64.

The hatchery on Pigeon River was considered "portable" due to the fact that the hatchery buildings were no more than tents. It was in operation from 1927 to 1932 and produced thousands of muskie fry which were then shipped elsewhere for rearing, if not placed immediately into surrounding waters.

VASEY, F. W. 1968. Evaluation of introductions of northern pike. Dingell-Johnson Project F-1-R-17, Work Plan No. 24, Job No. 2. Missouri Department of Conservation. Jefferson City, Missouri. 13 p.

VASEY, F. W. 1974. Life history of introduced northern pike in Thomas Hill Reservoir. Fisheries Report F-001-R-23. Missouri Department of Conservation. Jefferson City, Missouri. 25 p.

WACHELKA, H. Undated. Hybrid stocking - Is it a viable option? *In* The Release Journal. Muskies Canada Inc. Toronto, Ontario.

It was 1991 when the Province of Ontario closed the Deer Lake muskellunge hatchery and since then the muskellunge populations within Ontario have not received stocking support. I think most anglers now understand that stocking is not a cure all for our native/wild stocks. In the past it has contributed to genetic dilution, disease introduction and a perception that underlying fishery problems need not be addressed.

With that said, I would like to propose a program initiative to stock hybrid muskellunge in Ontario. I believe that the act of stocking tigers will lead to a more vibrant provincial fishery and divert some fishing pressure from natural musky to hybrids.

Rearing tigers artificially has proved to be slightly easier than for muskellunge but is still expensive (around $10 US) to get a stockable tiger in the range of 10-12 inches. They grow fast in their early years and angling wise are considered easier to catch than true muskellunge. In some states such as Colorado and Minnesota, tiger stocking has proved to be popular with anglers especially as some stocked fish are reaching past the thirty pound mark.

I think this can also be looked at as an opportunity to further protect the "wild" muskellunge resource by offsetting some fishing pressure onto stocked fish that can provide a "trophy" fishery especially near urban centers. A tiger musky is a strangely beautiful creature, one that in my view should be seen more often in our waters.

WAHL, D. H. 1989. The population ecology of two species of esocids and their hybrid. Dissertation Abstracts International 50(1) : 163 p.

I assessed the roles of competition (via resource partitioning), predation and abiotic factors in determining survival and growth of three stocked esocids. In the laboratory, I documented differential vulnerability of fathead minnow, gizzard shad and bluegill to predation by muskellunge, northern pike and their hybrid, tiger muskellunge. Capture ability did not differ among esocids however mean captures-per-strike were higher for fathead minnow (0.67) and gizzard shad (9.78) than for bluegill (0.14). Morphology and anti-predator behavior, unique to each prey, contributed to this differential vulnerability. In reservoirs esocids ate fewer prey and grew more slowly with centrarchids than with gizzard shad, strongly preferring shad over bluegill. To maximize growth and survival, esocids should be stocked in systems with soft-rayed or fusiform prey such as cyprinids or shad, rather than in centrarchid dominated systems.

I compared vulnerability among esocids to predation by largemouth bass in a series of reservoir, pond and laboratory experiments. In five reservoir stockings, tiger muskellunge were significantly more susceptible to predation than muskellunge with northern pike intermediate. Pond experiments provided similar results. However, in pool experiments, susceptibility to predation did not differ among taxa. Differential habitat selection may partially explain susceptibility to predation as tiger muskellunge spent more time in open than vegetated habitats in both pond and pool experiments than either of its parents. For all taxa, stocking lengths greater than or equal to 205 mm in fall will increase survival by reducing predatory losses.

I used a bioenergetics model to assess the combined effects of temperature and ration in determining esocid growth. Northern pike and tiger muskellunge grew faster than muskellunge through the first year; food consumption followed similar patterns but was highest for tiger muskellunge. Growth and ration were highest immediately after stocking, declining through fall to their lowest levels in December and spring. The bioenergetics model underestimated final mass by a factor of two to three for all esocids.

WAHL, D. H. 1995. Effect of habitat selection and behavior on vulnerability to predation of introduced fish. Canadian Journal of Fisheries and Aquatic Sciences 52(12) : 2312-2319.

Losses from resident predators can be an important source of mortality for introduced fish, but may vary among species. I compared vulnerability between muskellunge (*Esox masquinongy*) and walleye (*Stizostedion vitreum*) to predation by largemouth bass (*Micropterus salmoides*). In pool experiments (N = 51) with simulated vegetation, muskellunge were more susceptible to predation than walleye. Habitat selection explained some of these differences as walleyes spent more time in the simulated vegetation and associated with the substrate more than muskellunge. Expectations from pool experiments were confirmed in reservoirs stocked with two size groups of walleye (N = 8 introductions) and esocids (N = 20). Walleye were less susceptible to largemouth bass predation for both small (mean 14% of stocked fish) and large (mean 0%) size groups than were small (mean 36%) and large (mean 21%) esocids of three taxa. For muskellunge only, walleye were less vulnerable to predation for large size groups, but not for small ones. Predation from largemouth bass should be a more important source of poststocking mortality for esocids than for walleye in lakes and reservoirs. Largemouth bass population demographics, specific to each system and year, should be considered more carefully in determining where esocids should be introduced than for percids.

WAHL, D. H. 1999. An ecological context for evaluating the factors influencing muskellunge stocking success. North American Journal of Fisheries Management 19(1) : 238-248.

From an ecological perspective, predation, competition or resource partitioning, and abiotic factors interact to affect species distribution and abundance. To make management recommendations, I review research dealing with the relative influence of these factors in determining stocking success of muskellunge (*Esox masquinongy*). Survival of stocked muskellunge is affected by losses to resident predators. Prey preference and composition are also important, and better in centrarchid-dominated systems. However, potential for competition with resident fishes has not been carefully considered. Abiotic factors, particularly temperature, can influence stocking mortality and subsequent growth. Survival increases with size and is maximized with large muskellunge fingerlings (>240 mm), but cost-effectiveness can vary substantially with predator and prey populations. Hatchery rearing techniques can also affect muskellunge stocking success. Pellet-reared fish have lower survival than minnow-reared fish because predation mortality is higher, but both groups exhibit similar food consumption and growth. The parental population can affect survival and growth because temperature-related differences in bioenergetic variables occur among muskellunge populations. In addition to compromising genetic integrity, the mixing of populations with different physiological characteristics may have negative consequences for native populations. Thermal regimes of recipient waters should be considered in choosing the most appropriate population for stocking outside the native range. Muskellunge stocking should be pursued within an ecological context that integrates the relative importance of predation, competition, and abiotic factors. This framework provides a guide for making management decisions concerning populations, hatchery rearing techniques, sizes, and timing of muskellunge introductions into systems with specific characteristics.

WAHL, D. H., L. M. EINFALT, T. A. SZENDREY and D. F. CLAPP. 1997. Evaluation of muskellunge and tiger muskellunge stocking program. Final Technical Report 97/12. Illinois Natural History Survey Aquatic Ecology. Champaign, Illinois. 188 p.

Five jobs related to muskellunge and tiger muskellunge stocking evaluations were conducted: (1) Size specific survival of muskellunge and tiger muskellunge; (2) Effect of rearing techniques on esocid survival; (3) Laboratory and pond experiments evaluating mechanisms influencing esocid growth and survival; (4) Growth and food habits of muskellunge and tiger muskellunge; and (5) Assessment of different genetic stocks of muskellunge.

WAHL, D. H. and R. A. STEIN. 1984. Evaluation of stocking northern pike, muskellunge and tiger muskellunge into Ohio lakes: A comparative approach. Federal Aid Project F-57-R-6. Ohio Department of Natural Resources. Columbus, Ohio. 35 p.

Susceptibility of tiger muskellunge, muskellunge, and northern pike to largemouth bass predation in a 0.05 ha hatchery pond was compared. Survival, growth, and food habits of these esocids were also compared following stocking in North Reservoir, with primarily gizzard shad forage, and in Worthington Pond, a centrarchid dominated system.

WAHL, D. H. and R. A. STEIN. 1989$_a$. Comparative vulnerability of three esocids to largemouth bass (*Micropterus salmoides*) predation. Canadian Journal of Fisheries and Aquatic Sciences 46(12) : 2095-2103.

We compared vulnerability among tiger muskellunge (*Esox masquinongy* x *E. lucius*) (TM), northern pike (*E. lucius*) (NP), and muskellunge (*E. masquinongy*) (M) to predation by largemouth bass (*Micropterus salmoides*). Equal numbers (about 25/ha) and sizes (either 145, 180 or 205 mm) of each esocid taxa were stocked into three reservoirs (40-89 ha) during 3 years (5 stockings in total). Tiger muskellunge were significantly more susceptible to predation (mean = 30%, range 1-53% mortality) than muskellunge (mean = 12%, range 2-26%); northern pike were intermediate in susceptibility (mean = 19%, range 2-35%). Esocid size influenced predation rates for all taxa; losses to predation by largemouth bass decreased from an average of 31% at 145 mm to 2% at 205 mm. Pond experiments (N = 7) provided results similar to reservoirs: TM>NP>M. In laboratory pools with simulated vegetation (N = 106 experiments), susceptibility to predation among esocids did not differ. Dispersal rates by esocids were similar in reservoirs and all taxa preferred vegetated habitats. However, differential habitat selection may partially explain why tiger muskellunge are more vulnerable to largemouth bass predation, as they spent more time in open than vegetated habitats in both pond and pool experiments than either of the parent species. For all taxa, stocking lengths ≥ 205 mm in the fall will increase survival by reducing predatory losses.

WAHL, D. H. and R. A. STEIN. 1989$_b$. Evaluation of stocking northern pike, muskellunge and tiger muskellunge into Ohio lakes: A comparative approach. Final Report. Ohio Department of Natural Resources. Columbus, Ohio. 216 p.

The following five manuscripts constitute this final report: (1) Comparative vulnerability of three esocids to largemouth bass predation; (2) The application of liquid oxytetracycline in formulated feeds to mark and treat tiger muskellunge; (3) Field testing an esocid bioenergetics model; (4) Selective predation by three esocids: The role of prey behavior and morphology; and (5) Comparative mortality of three esocids due to stocking stressors.

WAHL, D. H. and R. A. STEIN. 1991. Food consumption and growth of three esocids: Field tests of a bioenergetic model. Transactions of the American Fisheries Society 120(2) : 230-246.

We quantified diet and compared field estimates of growth and daily ration with predictions from a bioenergetic model for young-of-year muskellunge (*Esox masquinongy*), northern pike (*E. lucius*) and tiger muskellunge (*E. masquinongy* x *E. lucius*) introduced into five Ohio reservoirs. Gizzard shad (*Dorosoma cepedianum*) dominated esocid diets (77-97% by weight) through autumn but were absent by spring. Diets in late autumn and spring included sunfishes (*Lepomis* spp.) and brook silversides (*Labidesthes sicculus*). Northern pike and tiger muskellunge grew faster than muskellunge through the first year. Food consumption was highest for tiger muskellunge followed by northern pike, then muskellunge. Growth rates and rations were highest immediately after stocking, declining through autumn to their lowest levels in December and spring. A bioenergetic model underestimated final mass by a factor of two to three for all esocids; predictions for food consumption were better than those for growth but still overestimated observed values by 39-52%. Neither behavioral thermoregulation nor incorporation of seasonal energetic content of prey altered predictions (maximum of 2% increase). In contrast, adjustments in metabolic rates to account for differences in season and temperature substantially improved model predictions. Size-selective mortality did not account for the inaccuracies in model predictions. Conversion efficiencies (39-63%) exceeded those previously measured for esocids fed maximum rations, suggesting that model variables should be determined for a range of ration levels. Though used extensively, the predictions of bioenergetic models should not be accepted until the models have been subjected to additional field verification.

WAHL, D. H. and R. A. STEIN. 1993. Comparative population characteristics of muskellunge (*Esox masquinongy*), northern pike (*E. lucius*), and their hybrid (*E. masquinongy* x *E. lucius*). Canadian Journal of Fisheries and Aquatic Sciences 50 : 1961-1968.

We compared growth, survival, diet, and angler catch of muskellunge (*Esox masquinongy*), northern pike (*E. lucius*) and tiger muskellunge (*E. masquinongy* x *E. lucius*) through 5 years after their introduction into three Ohio reservoirs. Muskellunge grew slower than northern pike and tiger muskellunge through the first year but faster than northern pike in subsequent years. Large, stocked esocids (180-205 mm) survived better than small ones (145 mm). Survival patterns established through the first fall were maintained through age 5; northern pike survived best, followed by muskellunge and tiger muskellunge. Angler catch reflected differences in survival as well as catchability among taxa. Northern pike were caught at smaller sizes and younger ages than other taxa. Gizzard shad (*Dorosoma cepedianum*) dominated esocid diets for all taxa and age classes, followed by centrarchids and cyprinids. Prey length consumed increased linearly with esocid length; northern pike selected larger gizzard shad than either muskellunge or tiger muskellunge. These differences in population characteristics among esocids should influence management and stocking programs. Whereas northern pike maximize angling opportunities, muskellunge probably will provide trophy fisheries. Although tiger muskellunge can be reared inexpensively, they appear to provide little recreational fishing in return.

WAHL, J. R. and R. L. APPLEGATE. 1981. Growth of muskellunge in a power plant cooling reservoir. Progressive Fish Culturist 43(1) : 15-16.

In order to create a brood stock for South Dakota muskellunge, fingerlings were introduced into the heated water of a power plant cooling reservoir. Fingerlings were stocked on three occasions: 704 on August 11, 1978 (203 mm mean total length), 15,500 on June 10, 1979 (36 mm mean TL) and 290 on August 2, 1979 (137 mm mean TL). In February and March of 1980, fish were collected from the heated water discharge area with a gill net. Eight of the fish stocked in August 1978 were age 22 to 23 months and had a mean length of 753 mm. Nineteen of the fish stocked in June and August 1979 were recaptured at the age of 10 to 11 months and were an average of 465 mm long. The growth of the fingerlings during the first two years exceeded that of other North American waters. The fast growth and presence of muskellunge near the optimum feeding temperature of 20º C indicated that growth occurred during the winter as well as in other seasons.

WAHL, R. M. 1958. First muskie stocking. West Virginia Conservation November (1958) : 18-19.

WEBSTER, B. O. 1929. Propagation of muskellunge. Transactions of the American Fisheries Society 59 : 202-203.

Three years ago, experiments were initiated to rear muskellunge beyond the fry stage for stocking purposes. During the first year of trying to raise muskellunge to fingerling size 20,000 fry were planted into five ponds, which had crustacea food supplies from nearby lakes. The fish were placed in the ponds in the middle of May and harvested for stocking in the middle of October. Only 110 8-10 inch fish were harvested from the ponds. During the second season the survival rate was 17,000 of the 20,000 originally planted and this past year only five to six hundred fingerlings were distributed. It does not appear that rearing to the fingerling stage has any real advantage.

WEITHMAN, A. S. 1975. Survival, growth, efficiency, preference and vulnerability to angling of esocidae. M. Sc. Thesis, University of Missouri. Columbia, Missouri. 71 p.

The goal of this study was to determine if there exists a biological advantage for stocking northern pike, muskellunge, or their F_1 hybrid, the tiger muskellunge. Esocid stocking can satisfy two purposes: (1)

Predation on underused forage species such as gizzard shad and (2) Lower the adult densities of prey species in order to increase availability of young-of-year to other predators. Based on experimental results management recommendations are made.

Some of the findings of this study include:

- Turbidity can have an effect on feeding rate and vulnerability to angling.
- In one pond only 5% of the original number (N=75) of esocid fingerlings, stocked with adult largemouth bass and limited prey, survived.
- Fingerling tiger muskellunge had a higher survival rate than the northern pike and muskie in this study.
- Muskie do not survive as well when stocked in conjunction with other esocids.
- Given a choice, esocids will feed selectively.
- Northern pike are extremely vulnerable to angling when compared to muskie (4.2 times) and tiger muskie (3.2 times).

A summary of management recommendations is as follows:

- Esocids should not be stocked into waters with a Secchi disk < 25 cm.
- Esocids should be stocked into large bodies of water > 400 ha.
- Fingerlings should be stocked in large reservoirs when prey such as young gizzard shad are abundant.
- To prevent overcrowding, when stocking esocids only one year class should be established every three years (i.e., stock once every three years).
- Overstocking should be avoided. Fingerlings should be stocked at a rate of 0.8 per ha.
- When trophy fish are needed, the northern pike is undesirable, since the ease with which it is caught does not allow it to grow very large.

WEITHMAN, A. S. and R. O. ANDERSON. 1976. Angling vulnerability of esocidae. Proceedings of the Conference of the Southeastern Association of Fish and Wildlife Agencies 30 : 99-107.

Five yearling northern pike (*Esox lucius*), muskellunge (*E. masquinongy*), or their F_1 hybrid (“tiger muskie”) were stocked in duplicate 0.2 ha ponds in April, 1974. Two additional ponds were stocked with a combination of five fish of each of the three forms. In 58 hours of angling from April to September, northern pike were 3.1 and 4.2 more times more vulnerable than tiger muskies and muskellunge, respectively. No fish were caught in 18 hours of fishing from June 15 to August 13. Repeat catch accounted for 35.6% of the total catch; hooking mortality was negligible (1.7%).

WEITHMAN, A. S. and R. O. ANDERSON. 1977. Survival, growth, and prey of esocidae in experimental systems. Transactions of the American Fisheries Society 106(5) : 424-430.

Survival (July to November) of young-of-the-year esocids stocked in 0.2 ha experimental ponds in Missouri was: muskellunge (*Esox masquinongy*), 24%; northern pike (*E. lucius*), 58%; and the F_1 hybrid of these two species (tiger muskie), 74%. Survival of yearlings from April to September was: muskellunge, 80%; northern pike, 90%; and hybrids, 85%. Growth rate of yearlings of all three forms was rapid in late spring, declined to a seasonal low in July, and then increased until the ponds were drained in September. Average weight gain of the hybrids (719 g) during their second year of life in ponds was significantly greater than that of northern pike (617 g) or muskellunge (615 g). Maintenance diets (grams of food per gram of fish) calculated for fish in tanks (1.2 x 4.8 x 1.1 m) for 28 day periods were as follows: northern pike, 0.23; muskellunge, 0.51; and hybrids, 0.62. Food conversion efficiencies in tanks were: northern pike, 29.0%; muskellunge, 25.0%; and hybrids, 22.0%. Non-game species were more vulnerable than game fishes to esocid predation in tanks. As esocid can be stocked in addition to or as an alternative to largemouth bass (*Micropterus salmoides*), walleye (*Stizostedion v. vitreum*), or striped bass (*Morone saxatilis*) because of a faster rate of growth. The hybrids may be the most desirable form of the three esocids because of rapid growth rate, intermediate angling vulnerability, and ease of rearing in a hatchery compared to either parent species.

WESLOH, M. L. and D. E. OLSON. 1962. The growth and harvest of stocked yearling northern pike (*Esox lucius*) in a Minnesota lake. Fisheries Investigational Report 242. Minnesota Department of Natural Resources. St. Paul, Minnesota. 9 p.

The contribution of stocked yearling northern pike to the sport fishery of an 885 acre walleye lake was evaluated through the return of marked fish in a creel of the angler's catch. Of 5,133 pike stocked in December 1958, 2,265 (44.1%) were harvested in the course of two complete angling seasons. The two year catch of stocked pike weighed 6,618 ponds which was 1.6 times the total weight of the yearling fish when stocked. Summer anglers harvested 51.8% of the total catch of stocked pike, winter spearers 31.2% and winter anglers 17.0%. When stocked, the yearling pike averaged 14.8 inches in length and 0.8 pounds in weight. With abundant perch forage they reached an average length of 24.8 inches and average weight of 3.8 pounds two years after stocking. The total catch of walleyes in 1960 (4,796 weighing 2,102 pounds) was about twice as great as the average walleye catch for the three preceding years. It is suggested that added competition from the stocked northern pike may have increased walleye vulnerability to angling.

WHITE, M. O. and R. E. GEHRES. 1962. Muskellunge stocking evaluation and age-growth studies in Piedmont Lake. Ohio Division of Wildlife. Columbus, Ohio. 6 p.

WILLIAMS, J. E. 1959. The muskellunge in Michigan. Fish Division Pamphlet No. 30. Michigan Department of Conservation. Lansing, Michigan.

Most of the muskellunge caught in Michigan originate in Lake St. Clair, however there exist populations in many smaller lakes. In 1955, Michigan began a three year program to deal with the experimental introduction of northern muskellunge into lakes in the Lower Peninsula. Eggs originated from lakes in Gogebic County and the fish were planted when they reached fingerling size. Criteria for selected lakes included the absence of northern pike. In 1955, Bass Lake, Budd Lake, Valley Lake and Wildwood Lake each received a few thousand musky fingerlings. In 1956, Spider Lake was stocked and in 1957, Bass Lake was restocked. Since 1958, Budd Lake has been the source of many legal-sized musky and it was reported that over 100 spearing shanties were located on the lake in the winter of 1959.

One small introductory plant of Great Lake muskellunge was carried out on Gun Lake, yet the status of these fish is as of yet unknown.

WILLIAMS, J. E. 1963. Evaluation of reproduction of northern pike in controlled marshes. 1963 Annual Program Report. Michigan Department of Conservation. Lansing, Michigan. 8 p.

WILLIAMS, J. E. 1966. Evaluation of introductory and maintenance stocking of muskellunge. Dingell-Johnson Federal aid Project Report. Michigan Department of Natural Resources. Lansing, Michigan.

WILLIAMS, J. E. 1968. Evaluation of maintenance stocking of muskellunge. Dingell-Johnson Federal Aid Project Report. Michigan Department of Natural Resources. Lansing, Michigan.

WILLIAMS, J. E. and B. L. JACOB. 1971. Management of spawning marshes for northern pike. Research Report 242. Michigan Department of Natural Resources. Ann Arbor, Michigan. 22 p.

The northern pike is a favored game fish. Also, it appears to serve as an important predator in keeping yellow perch populations under control, but it has little effect on bluegill populations. Pike populations are at low levels in most lakes because of heavy angling pressure and because of the loss of spawning marshes. Management of spawning marshes increases and stabilizes recruitment.

Marsh management gives better returns than natural spawning marshes by: (1) Maintaining high water levels, (2) Controlling stocking rate, (3) Eliminating fish predators and competitors, and (4) Getting better growth and survival through fertilization. However, production of fingerling pike, after 1-3 months in the marsh, is highly variable; for 12 marshes in Michigan it ranged from 1 to 13,000 but averaged 2,941 two inch fingerlings per acre per year. Nevertheless, intensive marsh management on 25 lakes increased the populations of adult pike in the lakes from 1.1 to 5.3 per acre. Loss of pike spawners in marshes appears to be high; hence stocking pike fry in artificial marshes is being evaluated. Hatching pike fry in troughs appears to be another promising approach.

WILSON, D. R. 1958. Maskinonge – White River District. Ontario Department of Lands and Forests. 1 p.

It is likely that approximately 1,000 3-4 inch fingerling lunge will be available for stocking in the Mishibishu chain of lakes between the end of June and the beginning of July, 1958. The fish should be planted along the edge of weed beds where there is an abundance of forage fish. It is recommended that the fingerlings not be dropped from aircraft. The ideal shipping water temperature is no more than 65-75º F and 5 gallon polythene containers should be used.

WINGATE, P. J. 1986. Philosophy of muskellunge management. American Fisheries `Society Special Publication 15 : 199-202.

Major areas of past, present, and future muskellunge management philosophy are briefly described with suggested directions for future management. Most muskellunge management has been to maintain or produce a trophy fishery, to protect or restore an endemic fishery, to diversify angling opportunity and/or to control nongame fish populations. These goals have been attained through various techniques which include: regulations, special stamps, stocking, and promoting natural reproduction, various genetic strains and hybrid muskellunge. Future management needs include more reliable estimates of harvest, pressure and economic values of the muskellunge fishery, much of which could be voluntarily supplied by anglers. Muskellunge genetics and the role each available strain might have in management plans may well be the single most important area in future muskellunge management.

WISCONSIN DEPARTMENT OF NATURAL RESOURCES. Undated$_a$. Woodruff hatchery. Pamphlet. Wisconsin Department of Natural Resources. Madison, Wisconsin.

The Woodruff Hatchery was established in 1900 and has since produced millions of muskellunge, northern pike and walleye for stocking. Once eggs have hatched and fry have reached the swim-up stage the fish are either shipped to other areas for rearing or stocked into district rearing ponds. Fry are shipped in plastic bags which contain oxygen instead of air. The fish stocked into rearing ponds are fed zooplankton until they are large enough to consume minnows. Once ready to be stocked in public waters, rearing ponds are drawn down and the fish removed. The last fish to be stocked is usually 14 inches in length. Factors used in determining the number of fish to stock into a waterbody include: availability of forage, condition of the native fishery and angling pressure on the lake.

WISCONSIN DEPARTMENT OF NATURAL RESOURCES. Undated$_b$. Spooner hatchery. Wisconsin Department of Natural Resources. Madison, Wisconsin. Pamphlet.

Muskellunge, northern pike and walleye are reared at the Spooner Hatchery. In the early years of operation all fish were released immediately following hatching but now fish are raised to a much larger size prior to stocking in area waters.

WISCONSIN DEPARTMENT OF NATURAL RESOURCES. 1999. An evaluation of stocking strategies in Wisconsin with an analysis of projected stocking needs. Report prepared for the Joint Legislative Audit Committee. Madison, Wisconsin. 37 p.

In Wisconsin, two major muskellunge hatcheries went into full production by about 1950. The shift to raising larger fingerlings (8-15 inches) occurred in 1954, when 2-6 inch fish were cropped off and remaining fish were reared to a larger size and stocked by October. By about 1970, approximately 30% of muskellunge waters were stocked annually with large fingerlings. Refinements in stocking procedures resulted in targeted plantings in critical problem waters. These specialized stocking situations included waters faced with heavy depletion by angling, excessive competition with northern pike, loss of spawning areas, natural catastrophes and stocking waters that had been reclaimed with toxicants. Since 1970, an average of 128,747 large fingerlings have been stocked annually. In the last four years, since the renovation of the two major muskellunge hatcheries, an average of about 72,000 muskellunge have been stocked annually. At present, approximately 216 waters (27% of Wisconsin's 804 muskellunge waters) are regularly stocked with muskellunge to maintain the fishery.

The costs to produce and stock muskellunge increases considerably with size from about $1.36/1,000 fry to about $5.20/spring yearling. Cost effectiveness is measured as the cost per stocked fish that is recruited to the fishery (i.e., catchable size). In general, stocking fewer large fish has been shown to be more cost effective than stocking many small fish. For example, with muskellunge fry stocking, the costs are relatively low but the survival of fry is highly variable and the likelihood of any muskellunge surviving at all in any given year is low.

Guidelines for rehabilitation stocking of muskellunge are:

- Winter kill lakes should not be stocked if serious mortality occurs more frequently than once in 15 years.
- Either fry or small fingerlings (4-6 inches) should be stocked in the first year followed by large fingerlings (> 7 inches) or adult transfers in subsequent years.
- Fry should be stocked at the rate of 500/acre; small fingerlings at the rate of up to 5/acre; and large fingerlings at the rate of up to 2/acre. If production is unable to meet all quota requests, a maximum of 100,000 fry, 5,000 small fingerlings or 2,500 large fingerlings will be stocked per water.
- Fry or small fingerlings should be stocked in the first year with large fingerlings during the next four years.

- If natural reproduction is not established after ten years from the onset of stocking, discontinue stocking until action is take to identify and correct the reason for poor natural recruitment.

Guidelines for stocking muskellunge for remediation or recreation purposes are:

- We recommend no stocking occur in waters with adequate natural reproduction in order to minimize the potential negative impact of stocked fish on naturally reproducing populations.
- Either small fingerlings (4-6 inches) or large fingerlings (> 7 inches) should be stocked depending on the abundance of existing predators.
- Stocking rates should be 5 small fingerlings/acre and 2 large fingerlings/acre. If production is unable to meet all quota requests, a maximum of 5,000 small fingerlings or 2,500 large fingerlings will be stocked per water.
- Fish can be stocked on either an annual of alternate year basis.
- If the fishery objective is not met after ten years, discontinue stocking until action is taken to identify the reason(s) for poor survival.

The overall goal of northern pike management in Wisconsin is to link the diversity of lakes and their pike populations to pike anglers' diverse attitudes and preferences. Northern pike stocking and transfers are conducted for one of four objectives: rehabilitation, biomanipulation, remediation and to provide recreational pike fisheries. Associated stocking guidelines to meet these objectives may be summarized as follows:

Rehabilitation (highest priority):

- For projects involving complete chemical treatment of a water, stock 1,000 fry/acre of habitat. Fingerling stocking may be conducted the following year if desired.
- Fingerling stocking rates can be determined using the equation: (total number of habitat acres) (desired density of fall young-of-year) / estimated proportion of fish surviving to fall young-of-year where survival is size dependent.
- Winterkill waters should only be stocked once after a mortality but a second stocking is permitted if the first survives poorly.
- Stocking adults (i.e., field transfers) to reproduce is also acceptable.

Biomanipulation:

- No stocking will be done specifically for panfish control unless special regulations are imposed to reduce northern pike harvest.
- Fingerlings are the recommended size for stocking.
- Fingerling stocking rates outlined above.
- Fry can be stocked at the rate of 1,000/acre of habitat.

Remediation:

- Stocking is recommended in conjunction with other management actions.
- All remediation stocking should be done for put-grow-take and not put-and-take.
- Catchable sized fish may be stocked for maintenance purposes but only if fish become available as a byproduct of another operation through field transfer.

Recreational Fisheries:

- All stocking should be conducted for put-grow-take and not put-and-take.
- Fingerling stockings are recommended using the formula previously outlined.

WOJCIESZAK, D. B. 1995. Effects of predator acclimation and artificial vegetation on growth and survival of muskellunge and tiger muskellunge. M. Sc. Thesis, University of Illinois. Urbana, Illinois.

WRIGHT, R. M. and N. GILES. 1987. The survival, growth and diet of pike fry (*Esox lucius*) stocked at different densities in experimental ponds. Journal of Fish Biology 30 : 617-629.

Yolk sac pike fry were stocked at densities of 0.74-81.4 m^{-2} in two ponds each divided into eight sectors (mean area 155.8 m^2). Growth and survival were recorded from May to December 1985. The growth rates were variable within each sector. The size range of sampled fish increased throughout the years but showed no significant correlation with density. Fry survival was initially density independent but switched by late June-July to density dependence, ranging from 0.5 to 43.6% of initial stocking numbers. The highest mean daily mortality rates occurred during May-July. The final survival in December ranged between sectors from 0.059 to 11.25% of the starting stock densities. The final biomass-per-unit-area of pike surviving in December was not related to initial stocking density. In Pond 1 the mean biomass produced was 2.21 gm m^{-2} and in Pond 2 was 3.49 gm m^{-2}. Pike fry (< 30 mm) fed only on invertebrates; those 30-100 mm took a wide range of invertebrates, cyprinids, sticklebacks and other pike. Cannibalism occurred at most densities between 5.45 and 81.4 fish m^{-2}. Where attempts are made to increase pike production in managed populations by releasing small fry, an upper stock density of 5 fry m^{-2} is advised if large, density dependent, mortalities are to be avoided.

YOUNK, J. A. and R. F. STRAND. 1992. Performance evaluation of four muskellunge (*Esox masquinongy*) strains in two Minnesota lakes. Fisheries Investigational Report 418. Minnesota Department of Natural Resources. St. Paul, Minnesota. 22 p.

Historically, some of Minnesota's native muskellunge (*Esox masquinongy*) populations have undergone a period of declining abundance (1930-1959). Restoration, introduction, and maintenance stocking programs relied on the Shoepack strain muskellunge for over 30 years. Genetic variation between 2 native self-sustaining populations of Minnesota muskellunge, Mississippi (Leech Lake) and Shoepack (Shoepack Lake) strains, was detected, but the impact of these differences were not defined. Performance of 4 muskellunge strains (Court Oreilles and Minocqua [Wisconsin strains], Mississippi, and Shoepack) was evaluated in 2 Minnesota lakes. Growth, color patterns, and reproductive characteristics are compared among these 4 strains. Shoepack strain matured earlier and at a smaller size than the Mississippi strain. Although temporal spawning periods tended to overlap, Mississippi strain spawned at significantly higher water temperatures that the Shoepack strain. After 6 growing seasons, Mississippi-strain fish were longer and heavier than the other strains. Weight-length relationships were significantly different, with Shoepack and Wisconsin strains exhibiting a more robust body shape. Ultimate growth potential was greatest for the Mississippi strain followed by the Wisconsin and Shoepack strains. The superior growth performance of the Mississippi strain suggests that its use in Minnesota's muskellunge culture program should be promoted.

ZORN, S. A., T. L. MARGENAU, J. S. DIANA and C. J. EDWARDS. 1998. The influence of spawning habitat on natural reproduction of muskellunge in Wisconsin. Transactions of the American Fisheries Society 127 : 995-1005.

Many of Wisconsin's native populations of muskellunge (*Esox masquinongy*) exhibit declining reproductive success and failing natural recruitment. As a result, self-sustaining populations of muskellunge are diminishing. This study focused on spawning habitat factors that influence egg development and survival and, consequently, the reproductive success of muskellunge. Muskellunge spawning habitat characteristics in lakes with self-sustaining populations were compared with spawning habitat characteristics in lakes that were once self-sustaining but are now maintained by stocking. The hatching success of artificially fertilized eggs was assessed under natural lake conditions. Spawning sites were typically marshy areas in waters less than 1 m deep. Characteristics of the spawning habitat influenced successful reproduction. Spawning areas in stocked lakes had low dissolved oxygen (DO; 1.2-5.4 mg/L) at the substrate-water interface, whereas self-sustaining lakes had more viable DO (0.5-9.6 mg/L) with some microhabitats having high DO. Organic carbon content, texture of spawning substrate, and water temperature at the substrate did not differ between self-sustaining lakes and lakes supported by stocking. Fallen logs, stumps, and other wood in spawning areas may increase egg survival. Muskellunge egg survival over natural substrate was low (0.0-1.3%), even in lakes with self-sustaining populations. Collections of eggs and observations of fry indicated that major mortality occurred after egg deposition but before fry reached nursery habitats several weeks after hatching.

Acknowledgements

We are grateful to MNR field staff and colleagues from other administrative jurisdictions who responded to our request for esocid stocking information. MNR library staff Margaret Wells and Elizabeth Gustafsson were extremely helpful. Wendy Stott and Wayne Selinger provided muskellunge stocking information.

Subject Key

1.0 General References

1.1 Stocking policies and objectives
1.2 Esocid culture and production
1.3 Managed spawning marshes
1.4 Reports of stocking activities
1.5 Esocid transfers
1.6 Introductions
1.7 Tiger muskellunge

2.0 Stocking Guidelines

2.1 General
2.2 Stocking frequency
2.3 Time of stocking
2.4 Stocking rates
2.5 Genetic strain
2.6 Age/size of fish
2.7 Marking techniques
2.8 Diseased fish
2.9 Fish community in stocked waters
2.10 Transport and release techniques
2.11 Stocking site
2.12 Physical/chemical requirements of stocked waters

3.0 Stocking Assessment

3.1 General
3.2 Assessment projects
3.3 Post-stocking survival
3.4 Returns to fishery
3.5 Physiology of stocked fish
3.6 Behavior of stocked fish
3.7 Growth of stocked fish
3.8 Movements of stocked fish
3.9 Food habits of stocked fish
3.10 Maturation of stocked fish
3.11 Reproduction of stocked fish
3.12 Hybridization of stocked fish
3.13 Impacts of stocked fish
3.14 Susceptibility to predation
3.15 Stocking economics

Subject Index

1.0 General References

1.1 Stocking Policies and Objectives

Bennett (1974)
Cholmondeley et al. (1989)
Clark (1964)
Cowyx (1994)
Esocid Technical Committee (1997)
Gray (1977)
Hanson et al. (1986)
Hess and Heartwell (1980)
Illinois Department of Natural Resources (1998)
Margenau (1999)
McKeown et al. (1996)
Minnesota Department of Natural Resources (1982)
Mooradian and Sheppard (1972)
Neuswanger (1997)
Oehmcke (1969)
Ohio Department of Natural Resources (Undated)
Ontario Federation of Anglers and Hunters (Undated)
Québec Ministère du Loisir, de la Chasse et de la Pêche (1988)
Schrouder (1973)
Scidmore (1964)
Shupp (1978$_a$)
Simonson and Hewett (1999)
Smith (1978)
Threinen et al. (1966)
Wingate (1986)
Wisconsin Department of Natural Resources (1999)

1.2 Esocid Culture and Production

Anonymous (1984) (1987) (Undated$_a$)
Bell (1986)
Bender (Undated)
Bonin and Spotilla (1978)
Buie (1960)
Clark, C. (1954)
Clark, J. (1974)
Clark, T. (1984)
Daley (1975)
Dombeck (1987)
Gibson and Schindler (1969)
Graff (1978)
Harris (1987) (1988) (1991)
Hiner (1961)
Iowa Cooperative Fisheries Research Unit (1983)
Johnson (1958)
Jorgensen (1986)
Klingbiel (1984)
Klupp (1978)
MacCrimmon et al. (1974)
McKay and Werner (1934)
Nevin (1901)
Sanderson (Undated) (1974)
Sorenson et al. (1966)
Timmerman (1979)
Tripp (1965)
Webster (1929)
Wisconsin Department of Natural Resources (Undated$_b$)

1.2 Managed Spawning Marshes

Barry (1996)
Barry and Machowski (1996)
Beyerle (1972) (1980)
Beyerle and Williams (1973)
Bry and Souchon (1982)
Carlander and Erickson (1953)
Crossman (1956)
Dominion of Canada (1876)
Edwards (1979)
Elson (1940)
Fago (1977)
Forney (1965) (1968) (1969)
Kleinert (1970)
Marshall and Johnson (1971)
McCarraher (1957)
Morris (1972)
Moulton (1978)
Preigel (1969)
Royer (1971)
Williams (1963)
Williams and Jacob (1971)

1.4 Reports of Stocking Activities

Brewer (1968)
Cation (1978)
Clay (1973) (1974)
Craig (1976)
Gall (1973)
Gallant (1976)
Hanson (1993)
Heacox (1946)

Reports of Stocking Activities (cont'd)

Headrick et al. (1985)
Heidinger (1999)
Huner and Lindquist (1983$_a$) (1983$_b$)
Hunt (1963) (1966)
Johnson and Laughlin (1957) Kinman (1995)
MacCrimmon and Skobe (1970)
Maher and Gillies (1970)
Mason (1999)
Merner (1958)
Milford (1974)
Nevin (1901)
Parsons (1959)
Perkins (1974)
Petrie et al. (1993)
Raine (1972)
Rasmussen and Geertz-Hansen (1998)
Shupp (1978$_b$)
Snow (1968)
Wahl (1958)

1.5 Esocid Transfers

Alberta Environment (1994)
Armstrong (1963)
Buss (1960)
Hanson (1958)
Maloney and Schupp (1977)
Minnesota Department of Natural Resources (1982)
Penney (Undated)
Preigel (1968)
Tippett (1975)

1.6 Introductions

Buchanan and LeBeau (2000)
Cook (1978)
Dahlberg and Scott (1971)
England (1976)
Gregory and Powell (1969)
Hergenrader (1984)
Hicks (1972$_a$) (1972$_b$) (1972$_c$)
Jones (1992)
Kinman (1989)
LeBeau (1995)
Levesque (1998)
Lewis (1975)
Madden and Lynch (1962)
Marshall and Johnson (1971)
McCarraher (1961)
Ontario Department of Lands and Forests (1963)
Ontario Ministry of Natural Resources (1987) (1988)
Palmer et al. (1999)
Powell (1972$_a$) (1072$_b$) (1973)
Seelbach (1988)
Semotak and Penney (1966)
Shipman (1979)
Siler and Beyerle (1984)
Snow (1988)
Storck and Newman (1986)
Vasey (1968) (1974)
Williams (1959)

1.6 Tiger Muskellunge

Adair (1986)
Berg and Hepworth
Beyerle (1981) (1984$_a$) (1984$_b$) (1984$_c$)
Brege (1984)
Carline et al. (1986)
Goddard and Redmond (1978)
Green and Sandford (1995)
Hesser (1978)
Moody et al. (1983)
Pearson (1982)
Schrouder (1973)
Stein et al. (1982$_a$) (1982$_b$) (1984) (1985)
Storck and Newman (1986) (1992)
Tipping (1996)
Tipping and Heinricher (1993)
Tomcko (1982)
Tomcko et al. (1984)
Wachelka (Undated)
Wahl and Stein (1993)

2.0 Stocking Guidelines

2.1 General

Borgeson (1987)
Dent (1986)
Grimm (1983$_b$)
Lopinot (1992)
Margenau (1994)
Smith (1996)
Wahl (1999)

2.2 Stocking Frequency

Borgeson (1987)
Hesser (1978)
Jones and Stephens (1984)
Kornman (1985) (1989)
Larscheid et al. (1997)

Stocking Frequency (cont'd)
Maloney and Schupp (1977)
McNeil (1978)
Petrie et al. (1993)
Québec Ministère du Loisir, de la Chasse et de la Pêche (1988)
Steucke (1975)
Wisconsin Department of Natural Resources (1999)

2.3 Time of Stocking
Beyerle (1984$_b$)
John (1982)
Larscheid et al. (1999)
Québec Ministère du Loisir de la Chasse et de la Pêche (1988)

2.4 Stocking Rates
Axon (1978) (1981)
Beyerle (1980)
Borgeson (1987)
Bry (1980)
Flickinger and Clark (1978)
Hesser (1978)
Heybob (2000)
Illinois Department of Natural Resources (1998)
Kornman (1983)
Maloney and Schupp (1977)
McNeil (1978)
Minnesota Department of Natural Resources (1982)
Ohio Department of Natural Resources (Undated)
Petrie et al. (1993)
Porter (1977)
Québec Ministère du Loisir et de la Chasse et de la Pêche (1988)
Schrouder (1973)
Snow (1974)
Wisconsin Department of Natural Resources (1999)

2.5 Genetic Strain
Desjardins (1997)
Koppelman and Philipp (1986)
Margenau and Hanson (1996)
Younk and Strand (1992)

2.6 Age/Size of Fish
Beyerle (1981)
Carline et al. (1986)
Colesante (1974)
Farrell (1996)
Hoff and Serns (1986)
Johnson and Margenau (1993)
Kinman (1989)
Klingbiel (1966)
Lorenzen (2000)
Margenau (1992)
McKeown et al. (1999)
Petrie et al. (1993)
Porter (1977)
Québec Ministère du Loisir, de la Chasse et de la Pêche (1988)
Rahel et al. (1985)
Serns and Andrews (1983) (1986)
Wahl (1999)
Wisconsin Department of Natural Resources (1999)

2.7 Marking Techniques
Buss (1960)
Casselman (1978)
Dursely and Fry (1961)
Grimm (1981$_a$)
Johnson (1963)
Johnson and Laughlin (1957)
Mangan (1998)
McNeil (1978) (1979)
McNeil and Crossman (1979)
Patrick and Haas (1971)
Tipping and Heinricher (1993)

2.8 Diseased Fish
Artamoshin and Prokopenko (1980)
Colesante et al. (1981)
Harvey (1986)
Sonstegard and Hnath (1978)

2.9 Fish Community in Stocked Waters
Beyerle (1984$_a$)
Carline et al. (1986)
Craig (1976)
Dombeck et al. (1986)
John (1982)
Krohn (1969)
Ratt (1988)
Weithman (1975)

2.10 Transport and Release Techniques

Anonymous (Undated$_a$) (Undated$_c$)
Bean (1986)
Bell (1986)
Johnson (1971)
Miles (1974)
Miles et al. (1973)
Québec Ministère du Loisir et de la Chasse et de la Pêche (1988)
Wilson (1958)

2.11 Stocking Site

Bell (1986)
Belusz (1975)
Québec Ministère du Loisir, de la Chasse et de la Pêche (1988)
Wilson (1958)

2.12 Physical/Chemical Requirements of Stocked Waters

Axon and Korman (1986)
Clapsadl (1993)
Dombeck et al. (1984) (1986)
European Inland Fisheries Advisory Commission (1982)
Grimm (1981$_a$)
Headrick (1985)
McNeil (1979)
Weithman (1975)
Wojcieszak (1995)
Zorn et al. (1998)

3.0 Stocking Assessment

3.1 General

Braun and Pearson (1980)
Brown (1962)
Bry and Souchon (1982)
Clark (1975)
Grimm (1982) (1983$_a$)
Headrick et al. (1982)
Johnson (1963) (1968) (1978) (1981) (1982)
Klingbiel (1954)
Krohn (1969)
Larscheid et al. (1997)
Lewis (1984)
Margenau (1996)
Navarro and Johnson (1992)
Roberts (1964)
Sorenson (1968)
Szendrey et al. (1993)
Wahl (1989)
Wahl et al. (1997)
Wahl and Stein (1984) (1989$_b$)
Williams (1959) (1966) (1968)

3.2 Assessment Projects

Hess (1981)
Johnson (1984)
Kidd et al. (1999)
Kormman (1979)
Lyons and Margenau (1986)
Margenau (1993)
Margenau and Snow (1984)
Monaghan and Borawa (1986)
Mooradian et al. (1986)
Olson and Cunningham (1989)
Patterson (1971)
Pearson (1982)
Stroud and Jenkins (1962)
Threinen and Oehmke (1950)
White and Gehres (1962)

3.3 Post-Stocking Survival

Belusz (1975)
Beyerle (1971) (1973$_a$) (1973$_b$) (1978) (1984$_a$) (1984$_c$)
Bimber (1982)
Day (1988)
Day and Stevenson (1989) (1991)
Erickson (1961)
Farrell (1996) (1997)
Farrell and Werner (1995) (1999)
Gammon (1960)
Hanson and Margenau (1992)
Hanson et al. (1986)
Jenkins (1973)
Johnson (1972$_a$)
Margenau (1992)
Margenau and Hanson (1997)
Mooradian (1986)
Otis et al. (1996)
Serns and Andrews (1983) (1986)
Souchon (1980)
Stuecke (1975)
Stroud and Jenkins (1966)
Weithman and Anderson (1977)

3.4 Returns to Fishery
Axon (1978) (1981)
Belusz (1978)
Beyerle (1980)
Brege (1984)
Carlander (1957)
Goddard and Redmond (1978)
Groebner (1964)
Hacker (1967)
Helm (1960)
Johnson and Peterson (1955)
Klingbiel and Moreehouse (1954)
Laarman (1979)
McCarraher (1959)
Ratt (1988)
Snow (1978)
Spangler (1968)
Storck and Newman (1992)
Wesloh and Olson (1962)

3.5 Physiology of Stocked Fish
Bevelhimer et al. (1985)
Clapp and Wahl (1996)
Johnson (1972_a) (1974)
Jonas et al. (1996)
Mather et al. (1986)
Mather and Wahl (1989)
Miles et al. (1973)

3.6 Behavior of Stocked Fish
Howard and Thomas (1970)

3.7 Growth of Stocked Fish
Axon (1981)
Beyerle (1972) (1973_a) (1973_b) (1978) (1984_c)
Clapp and Wahl (1996)
Day (1988)
Hottell (1976)
Kornman (1983)
Muir (1960)
Muir and Sweet (1964)
Schloemer (1936)
Serns and Andrews (1983) (1986)
Szendrey and Wahl (1996)
Wahl and Stein (1991)
Wahl and Applegate (1981)
Weithman and Anderson (1977)

3.8 Movements of Stocked Fish
Carlander and Ridenhour (1955)
Hanson and Margenau (1992)
Howard and Thomas (1970)
Muir and Sweet (1964)
Priegel (1968)
Snow (1974)

3.9 Food Habits of Stocked Fish
Applegate (1981)
Axon (1978)
Elson (1940)
Gillen et al. (1981)
Hottell (1976)
Jenkins (1973)
Johnson et al. (1988)
Kerr and Grant (2000)
McCarraher (1957)
Moody et al. (1983)
Sanderson (Undated)
Tennant and Billy (1963)
Tomcko (1982)
Tomcko et al. (1984)
Wahl and Stein (1991) (1993)
Weithman and Anderson (1977)
Wright and Giles (1987)

3.10 Maturation of Stocked Fish
Bimber (1982)

3.11 Reproduction of Stocked Fish
Margenau and Hanson (1997)
Reid (1988)
Semotak and Penney (1966)

3.12 Hybridization of Stocked Fish
Hottell (1976)
Tennant and Billy (1963)

3.13 Impacts of Stocked Fish
Anderson and Schupp (1986)
Anonymous ($Undated_d$)
Chapleau et al. (1997)
Elvira (1998)
European Inland Fisheries Advisory Commission (1982)
Findlay et al. (2000)
Gammon (1960)
Gammon and Hasler (1965)
Goeman and Spencer (1992)
He and Kitchell (1990) (1992)
Hergenrader (1984)
Kerr and Grant (2000)
Krishka et al. (1996)

Impacts of Stocked Fish (cont'd)

Moulton (1978)
Powell (1973)
Schmidtz and Hetfield (1965)
Snow (1974) (1988)

3.14 Susceptibility to Predation

Grimm (1981_b)
Johnson (1971)
McKeown et al. (1999)
McNeil (1979)
Scott and Crossman (1973)
Stein et al. (1981)
Szendrey (1992)
Szendrey and Wahl (1991) (1995)
Wahl (1995)
Wahl and Stein (1989_a)
Weithman (1975)
Weithman and Anderson (1976)
Wojcieszak (1995)

3.15 Stocking Economics

Adair (1986)
Anonymous (Undated_f)
Belusz and Witter (1986)
Bennett (1974)
Flickinger and Clark (1978)
Laarman (1979)
Margenau (1992)
Stroud (1958)

Appendix 1. Muskellunge stocking in Ontario waters, 1925-2000.

Year	Eggs	Fry	Fingerlings	Yearlings	Adults	Total
1925	-	-	-	-	-	-
1926	-	-	-	-	-	-
1927	-	86,000	-	-	-	86,000
1928	-	53,000	-	-	-	53,000
1929	-	20,000	-	-	-	20,000
1930	-	70,000	-	-	-	70,000
1931	-	65,000	-	-	-	65,000
1932	-	115,000	-	-	-	115,000
1933	-	-	-	-	-	-
1934	-	909,500	-	-	-	909,500
1935	-	465,000	-	-	-	465,000
1936	-	274,000	-	-	-	274,000
1937	-	420,700	-	-	-	420,700
1938	-	2,005,000	-	-	-	2,005,000
1939	-	2,795,000	1,300	-	-	2,796,300
1940	-	2,345,000	2,333	-	-	2,347,333
1941	-	2,100,000	1,494	-	-	2,101,494
1942	-	1,575,000	705	-	-	1,575,705
1943	-	1,165,000	2,100	-	-	1,167,100
1944	-	2,705,000	2,952	-	-	2,707,952
1945	-	2,030,000	200	-	-	2,030,200
1946	-	1,150,000	6,875	-	-	1,156,875
1947	-	2,790,000	11,540	-	127	2,801,540
1948	-	3,135,000	24,600	-	195	3,159,600
1949	-	2,770,000	38,000	-	-	2,808,000
1950	-	3,350,000	29,700	-	-	3,379,700
1951	-	2,360,000	21,940	-	-	2,381,940
1952	-	3,750,000	62,257	-	156	3,812,413
1953	-	2,740,000	42,966	-	143	2,783,109
1954	-	3,550,000	39,563	-	-	3,589,563
1955	-	3,711,500	50,900	-	-	3,762,400
1956	-	3,610,000	73,524	-	86	3,683,610
1957	-	2,430,000	38,575	-	923	2,469,498
1958	-	2,940,000	17,512	-	501	2,958,013
1959	-	4,220,000	50,450	-	-	4,270,450
1960	-	3,390,000	51,405	-	-	3,441,405
1961	-	2,832,500	74,500	-	-	2,907,000
1962	-	2,970,000	23,550	-	-	2,993,550
1963	-	1,870,000	27,150	-	-	1,897,150
1964	-	1,530,000	26,300	-	-	1,556,300
1965	-	1,850,000	24,600	15	-	1,874,615
1966	-	1,303,112	-	-	-	1,303,112
1967	-	2,650,000	12,000	-	195	2,662,195
1968	-	2,400,000	26,600	-	-	2,426,600
1969	-	2,957,600	33,350	-	-	2,990,950
1970	-	2,700,000	27,350	-	-	2,727,350
1971	-	1,865,000	22,250	-	-	1,887,250
1972	-	2,665,000	17,900	-	-	2,682,900
1973	-	620,000	50,550	-	-	679,550
1974	-	1,253,200	38,010	-	-	1,291,210
1975	-	1,186,000	99	-	-	1,186,099

Year	Eggs	Fry	Fingerlings	Yearlings	Adults	Total
1976	-	1,360,100	33,111	-	-	1,393,211
1977	-	949,493	19,785	-	-	960,767
1978	-	1,271,274	11,274	-	-	1,282,548
1979	-	1,510,000	30,303	-	-	1,540,303
1980	-	1,219,898	19,898	-	-	1,239,796
1981	-	860,000	32,345	-	-	892,345
1982	-	1,230,000	16,014	-	-	1,246,014
1983	-	980,000	22,503	-	-	1,002,503
1984	-	1,370,000	20,435	-	-	1,390,435
1985	-	1,646,500	55,586	-	-	1,702,086
1986	-	1,161,000	-	-	-	1,161,000
1987	-	804,000	-	-	-	804,000
1988	-	171,000	-	-	-	171,000
1989	-	926,000	-	-	-	926,000
1990	-	-	-	-	-	-
1991	-	-	-	-	-	-
1992	-	-	-	-	-	-
1993	-	-	-	-	-	-
1994	-	-	-	-	-	-
1995	-	-	-	-	-	-
1996	-	-	500	-	-	500
1997	-	4,000	1,850	-	-	5,850
1998	-	-	2,570	-	-	2,570
1999	-	-	606	140	-	746
2000	-	-	2,388	100	-	2,488

Appendix 2. Muskellunge transfers in Ontario waters.

Year	Donor Waterbody	Recipient Waterbody	# Fish Transferred	Age/Size of Fish Transferred
1947	Unknown	Cameron Lake	8	Juvenile/Adult
		Four Mile Lake	12	Adult
		Pigeon Lake	73	Juvenile/Adult
		Sturgeon Lake	34	Juvenile/Adult
1948	Unknown	Bald Lake	18	Juvenile/Adult
		Balsam Lake	10	Juvenile/Adult
		Cameron Lake	13	Juvenile/Adult
		Four Mile Lake	5	Adult
		Pigeon Lake	14	Juvenile/Adult
1949	Nogies Creek	Cordova Lake	14	Juvenile/Adult
1952	Unknown	Bald Lake	25	Juvenile/Adult
		Sturgeon Lake	55	Juvenile/Adult
1953	Unknown	Sturgeon Lake	34	Juvenile/Adult
1955	Unknown	Sturgeon Lake	159	Juvenile/Adult
1956	Unknown	Dore Lake	50	Juvenile/Adult
		Rice Bay	25	Juvenile/Adult
		Dogtooth Lake	34	Juvenile/Adult
		Rainy Lake	27	Juvenile/Adult
1957	Nogies Creek	Sturgeon Lake	159	Juvenile/Adult
1958	Nogies Creek	Pigeon Lake	262	Juvenile/Adult
1961	Nogies Creek	Pigeon Lake	212	Juvenile/Adult
	Nogies Creek	Sturgeon Lake	213	Juvenile/Adult
1962	Nogies Creek	Pigeon Lake	297	Juvenile/Adult
	Nogies Creek	Sturgeon Lake	500	Juvenile/Adult
1963	Maskinonge Lake	Sandy Beach Creek	17	Juvenile/Adult
	Maskinonge Lake	Maskinonge Lake	66	Juvenile/Adult
	Minnitaki Lake	Little Vermillion Lake	72	Juvenile/Adult
1964	Unknown	Sandy Beach Creek	77	Juvenile/Adult
		Abram Lake	42	Juvenile/Adult
		Big Vermillion Lake	88	Juvenile/Adult
		Little Vermillion Lake	11	Juvenile/Adult
		Minnitaki Lake	110	Juvenile/Adult

Year	Donor Waterbody	Recipient Waterbody	# Fish Transferred	Age/Size of Fish Transferred
1965	Unknown	Dore Lake	13	Juvenile/Adult
		Sandy Beach Creek	49	Juvenile/Adult
		Mameigwess Lake	39	Juvenile/Adult
		Longbow Lake	54	Juvenile/Adult
		Dion Lake	13	Juvenile/Adult
		Misfit Lake	33	Juvenile/Adult
		Zarn Lake	23	Juvenile/Adult
1966	Unknown	Abram Lake	76	Juvenile/Adult
		Minnitaki Lake	74	Juvenile/Adult
		Pakwash Lake	41	Juvenile/Adult
		Pigeon Lake	74	Juvenile/Adult
		Red Lake	36	Juvenile/Adult
		Sturgeon Lake	123	Juvenile/Adult
1967	Unknown	Maskinonge Lake	60	Juvenile/Adult
		Niagara River	165	Juvenile/Adult
		Rice Lake	31	Juvenile/Adult
		Sturgeon Lake	60	Juvenile/Adult
1968	Unknown	Little Pine Lake	31	Juvenile/Adult
		Maskinonge Lake	47	Juvenile/Adult
		Minnitaki Lake	21	Juvenile/Adult
		Sturgeon Lake	26	Juvenile/Adult
		Wigwam Lake	49	Juvenile/Adult
1987	Unknown	Pelican Lake (Vemillion River)	84	Subadults

Appendix 3. Ontario lakes containing introduced muskellunge populations. Year of introduction is based on the first stocking record in the provincial fish stocking database (OFIS).

Lake	Latitude	Longitude	Year of Introduction	Reference(s)
Apsley	44º 46'	78º 04'	1971	MNR (1988)
Baptiste	45º 07'	78º 03'	1958	MNR (1988)
Beech	45º 05'	78º 42'	-	MNR (1988)
Benoir	45º 11'	78º 09'	1974	MNR (1988)
Big Cedar	44º 36'	78º 10'	1973	MNR (1988)
Black	45º 02'	78º 25'	1976	MNR (1988)
Blackstone	45º 14'	79º 53'	1953	MNR (1988)
Brady	45º 03'	78º 50'	1969	MNR (1988)
Bruno	44º 34'	77º 08'	1950	MNR (1988)
Bull	44º 41'	76º 58'	1963	MNR (1988)
Canning	44º 56'	78º 38'	-	MNR (1988)
Carafel (NL)	46º 45'	80º 31'	-	MNR (1988)
Collins	44º 21'	76º 27'	1957	MNR (1988)
Contau	44º 53'	78º 26'	1963	MNR (1988)
Coon	44º 37'	78º 12'	1957	MNR (1988)
Cranberry	45º 07'	78º 34'	1963	MNR (1988)
Crane	45º 13'	79º 57'	1954	MNR (1988)
Crego	44º 47'	78º 42'	1972	MNR (1988)
Dore	45º 37'	77º 07'	1968	MNR (1988)
Duck	44º 40'	78º 58'	1980	MNR (1988)
Elephant	45º 08'	78º 08'	1950	MNR (1988)
Fishog (Fish Hawk)	44º 47'	78º 53'	1966	MNR (1988)
Fortescue (Black)	44º 50'	78º 26'	-	MNR (1988)
Galloway (Deer)	44º 48'	78º 23'	1963	MNR (1988)
Golden	45º 34'	77º 21'	-	MNR (1988)
Grant	49º 11'	93º 05'	-	MNR (1988)
Grass	45º 02'	78º 33'	1969	MNR (1988)
Grassy	46º 02'	77º 33'	1962	MNR (1988)
Green	45º 07'	78º 37'	1963	MNR (1988)
Greens	44º 47'	78º 23'	-	MNR (1988)
Haas (Paradise)	45º 02'	78º 27'	1965	MNR (1988)
Head	45º 03'	78º 31'	1968	MNR (1988)
Insect	46º 41'	80º 30'	-	MNR (1988)
Jack	44º 42'	78º 02'	1946	MNR (1988)
Jimbeef (NL)	45º 04'	78º 32'	-	MNR (1988)
Julien	44º 36'	78º 09'	1966	MNR (1988)
Kashagawigamog	44º 59'	78º 36'	-	MNR (1988)
Kasshabog (Kosh)	44º 38'	77º 58'	1946	MNR (1988)
Little Long	44º 41'	78º 09'	1970	MNR (1988)
Long	44º 34'	77º 59'	-	MNR (1988)
Long	44º 48'	79º 29'	-	MNR (1988)
Loon (Dudman)	45º 01'	78º 23'	1972	MNR (1988)
Maple (Ninatigo)	45º 06'	78º 40'	-	MNR (1988)
Maskinonge	46º 47'	80º 27'	1952	MNR (1988)
Methuen (Clear)	44º 43'	77º 55'	1956	MNR (1988)
Mitten	44º 35'	77º 07'	1950	MNR (1988)
Morrison	44º 53'	79º 27'	-	MNR (1988)
Muskosung	46º 29'	80º 03'	1946	MNR (1988)

Lake	Latitude	Longitude	Year of Introduction	Reference(s)
Nepawassi	46º 22'	80º 38'	1954	MNR (1988)
Pakwash	50º 45'	93º 30'	1966	MNR (1988)
Pine	45º 07'	78º 35'	1963	MNR (1988)
Pinus (Big Pine)	49º 84'	93º 53'	-	MNR (1988)
Potts (Little Pine)	48º 54'	93º 55'	-	MNR (1988)
Red	51º 03'	93º 49'	1966	MNR (1988)
Rosseau	45º 10'	79º 35'	-	MNR (1988)
Rustyshoe (NL)	44º 52'	78º 24'	-	MNR (1988)
Salerno (Devil's)	44º 51'	78º 29'	1968	MNR (1988)
Sandy	44º 41'	77º 54'	1946	MNR (1988)
Schistose	49º 10'	93º 37'	-	MNR (1988)
Shirtcliff	44º 35'	77º 08'	1950	MNR (1988)
South	44º 35'	77º 56'	1946	MNR (1988)
South Little Mink	45º 12'	78º 08'	-	MNR (1988)
South Portage	45º 03'	78º 24'	1969	MNR (1988)
St. Croix	44º 46'	78º 26'	1970	MNR (1988)
Stump (NL)	45º 02'	78º 24'	1972	MNR (1988)
Sugarbush	44º 44'	77º 57'	-	MNR (1988)
Trout	46º 13'	80º 35'	1969	MNR (1988)
West Twin	44º 39'	77º 54'	1946	MNR (1988)
White	44º 50'	78º 29'	1947	MNR (1988)
Whitewater	46º 32'	81º 09'	1972	MNR (1988)
Wolf	44º 44'	78º 11'	1969	MNR (1988)

NL - not listed in the Gazateer of Canada

MNR 51489
(0.3 k P. R. 01 31 03)
ISBN 0-7794-0809-8