The Burbot Fishery in Lake of the Woods

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INTRODUCTION

Burbot, *Lota lota* (Linnaeus), is the single surviving freshwater species of the codfish family, Gadidae. Various subspecies are designated throughout its circumpolar range. The North American forms have been called *Lota lota leptura* or *Lota lota maculosa* (Wynne-Edwards, 1952; Speirs, 1952). Lindsey (1956) states that evidence did not warrant subspecies designation and suggests that future reference be *Lota lota* (Linnaeus). This nomenclature has been adopted by the American Fisheries Society (1960).

Walters (1955) describes the origins of the present burbot distribution in North America. He believes the species radiated outward from refugia in the Yukon Valley and the Mississippi Valley after the ice sheets receded or from Siberia after the land bridge connecting Asia and North America collapsed some 11,000 years ago. Rostlund's (1952) distributional boundaries include the Atlantic coast from the Chesapeake Bay northward to Newfoundland; westward along the Arctic Sea coast to the Bering Sea; southward along the eastern slope of the Pacific coastal mountains to the Columbia River Drainage; and eastward including the Missouri River drainage, upper Mississippi River drainage, and along the southern shores of the Great Lakes.

Although the distributional range of burbot is wide and it is abundant in most waters where it is found, knowledge of the species is limited. Its lack of commercial value and the limited demand for it as a sport fish have relegated the species to a position of minor importance. Clemens (1951a and b) reports one of the most authoritative studies of the species in North America. A few papers on feeding (Van Oosten and Deason, 1938; Bjorn, 1940; Beeton, 1956; Bonde and Maloney, 1960), spawning (Cahn, 1936; Hewson, 1955; McCrimmon, 1959), and growth (Martin, 1941; McCrimmon and Devitt, 1954) provide additional information about burbot. More recently, Miller (1970a and b) and Bailey (1972) studied the life history and population dynamics of burbot and added substantially to the knowledge of the species.

The objectives of the present study are 1) to determine potential commercial production of burbot in Lake of the Woods, 2) to determine the relationship of burbot to production of other species, and 3) to determine life history data necessary for management of the species. In a large ecosystem such as Lake of the Woods, where the fish species complex is large and where commercial and sport fisheries operate simultaneously, management policies must be based on the above types of information. The present study was conducted to gather this information. Potential burbot production estimates were the first concern of the study; data on age, growth, mortality, and reproductive potential characteristics of the burbot population were collected. These data together with commercial catch statistics were used to achieve the first study objective. The next phase of the study was to examine interspecies relationships and to determine specifically if burbot are significant predators or competitors for food resources with other species in the lake. Finally information about general ecology and the life history of burbot was collected to add to the general knowledge of the species.

The study was conducted on Lake of the Woods, located on the United States-Canada border. The total surface area of 1,485 square miles is divided with two-thirds being provincial waters of Manitoba and Ontario and one-third (470 square miles) Minnesota waters (figure 1).

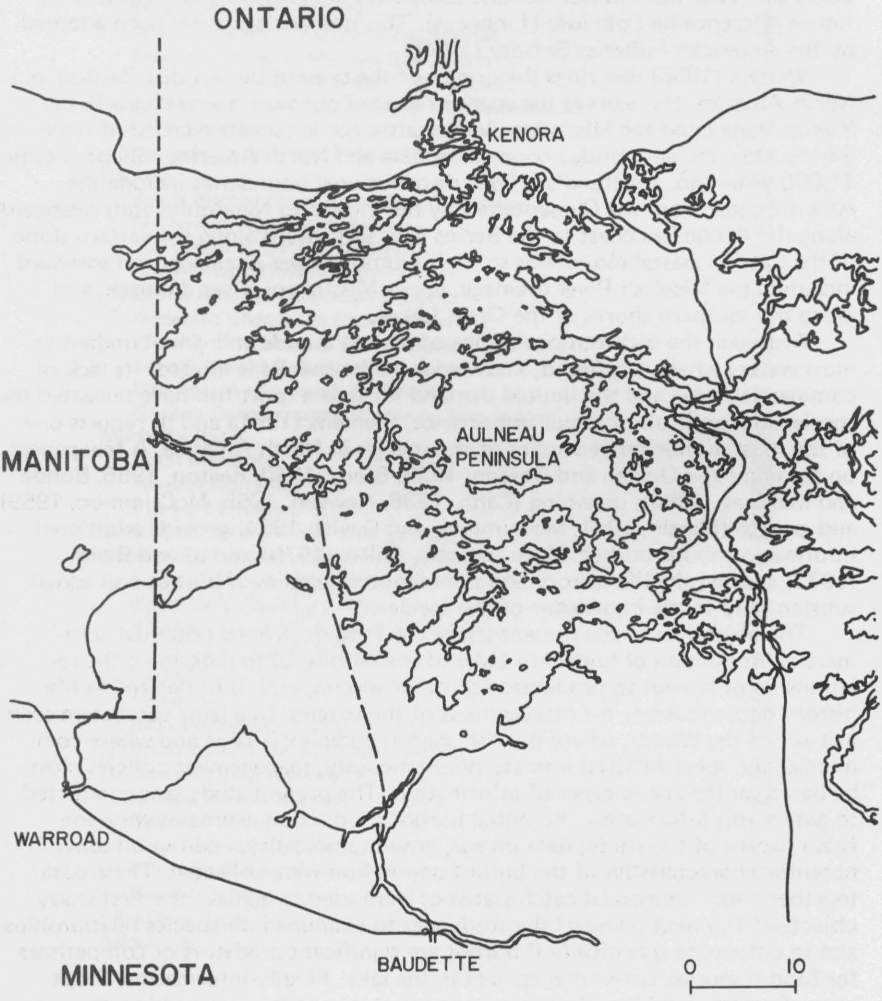

Figure 1. Lake of the Woods.

Schwartz and Thiel (1954) state that Lake of the Woods is a remnant occupying a deeper area of the basin of former glacial Lake Agassiz. Carlander (1942) reviewed the geological features of the area. Although the Canadian and Minnesota segments of the lake are broadly connected, the characteristics of the areas are distinctly different and could be considered as separate lakes. Much of the Canadian water is oligotrophic with depths of 15 meters or more. Approximately 1400 islands are in this part of the lake and form numerous bays and channels typically bordered by steep rocky shores. In contrast, Minnesota waters are eutrophic in nature. Depths in this part of the lake usually do not exceed 11 meters, and approximately one-fourth of the area has depths less than 5 meters. The U.S. portion of the lake is a broad, open expanse (figure 2) with only a few islands in the northern extremity of the Minnesota waters.

Carlander (1942) reports that the water supply for Lake of the Woods is derived from a drainage area of 26,750 square miles that is divided about equally between Canada and the United States. Rainy River, flowing out of Rainy Lake, is the principal tributary to Lake of the Woods and provides about 78 percent of the inflowing water. Entering the lake are numerous smaller tributary streams including Bostig Creek, Zippel Creek, Elm Creek, Swift Ditch, Stoney Creek, and the Warroad River, but their relative contributions to the lake's total water budget are minor.

The outlet of Lake of the Woods is the Winnipeg River located at the extreme northern side at Kenora, Ontario. Several dams have been constructed there to generate hydroelectric power and control the fluctuations of water levels in the lake. However, the Winnipeg River outlet is not the only factor in water level fluctuations and the dams have only moderated the natural conditions. Water loss from evaporation can be significant during certain periods of the year and, together with the effects of seiches caused by wind on the broad water expanse of the Big Traverse, can result in pronounced water level fluctuations on a localized and day-to-day basis.

Shoreline along the Minnesota segment of the lake is distinctly different from the rocky shoreline typical of much of the Canadian area. Proceeding westward from the Rainy River along the south shore, the beaches are windswept and predominantly sand and gravel until the rocky outcropping at Long Point. The remainder of the southern shoreline and much of the western shoreline is protected from wind action by sandbars in the shallow water permitting growth of weed beds over large areas behind the bars. These blend into floating muskeg and bogs. The northern shorelines of Minnesota waters are sandy beaches in areas unsheltered from wave action.

Bottom substrates in the lake's shallow waters generally consist of sand subject to wave action with progressively increasing amounts of silt as depths increase to about 5 to 8 meters. Substrates in depths greater than 8 meters are predominantly muck with 10 to 15 percent organic matter (Carlander, 1942). Sheltered shallow bays frequently have large quantities of decomposing plant materials on the bottom.

Water analysis was not systematically conducted during this project but Carlander's data (1942) indicate that the water is moderately soft with total alkalinity between 45 and 68 ppm calcium carbonate, total dissolved solids between 114 and 227 ppm, and pH ranging from 7.0 to 8.3. Secchi disc readings ranged from 1/2 to 1-1/2 meters and light readings indicated a penetration of 1 percent of the surface light intensity to depths of 2 to 4 meters at different times of the year. Dark staining of the water contributed by the surrounding bog areas and the turbidity generated by wave action causes the changes in secchi disc and light penetration.

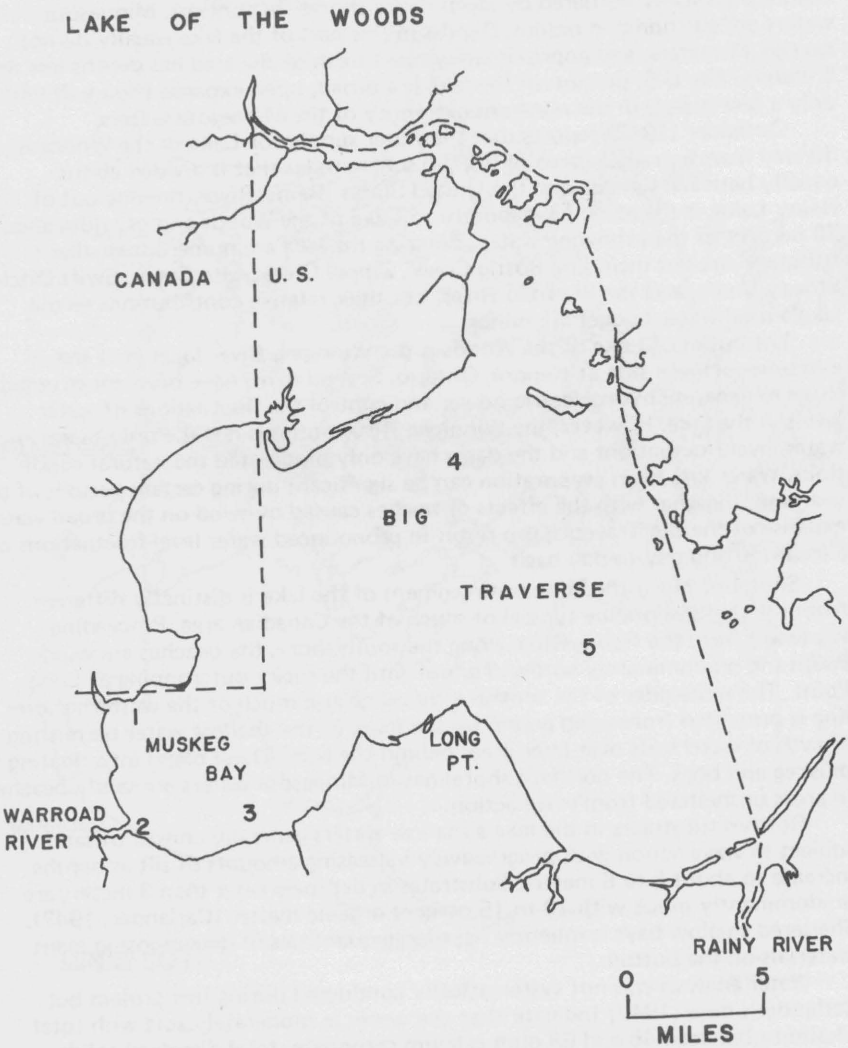

Figure 2. Sampling areas in American waters of Lake of the Woods.

Minnesota waters seldom stratify because of their shallowness and the mixing effects of the wind. Oxygen levels vary between 4.2 and 9.6 ppm with near saturation at all depths. Water temperatures are cool and average, about 14°C during the May-June period. Rapid warming occurs about mid-July to levels as high as 22°C. Rapid cooling begins in mid- or late September followed by freeze-up from November to the following April. Carlander's thermal and chemical data for the lake do not vary greatly from some of the values reported by the Advisory Board on Water Pollution, Rainy River and Lake of the Woods (1963) for sampling stations outside the direct influence of paper pulp pollution or from random analysis conducted during this project.

Pollution effects from the paper mill at International Falls on the total water volume of the lake are not known. A detailed study of domestic and industrial pollution has been conducted primarily on the Rainy River and to a lesser degree on the southeastern area of the lake known as Four Mile Bay where the Rainy River enters the lake (Advisory Board on Water Pollution, Rainy River and Lake of the Woods, 1963). Adverse effects on the water chemistry and the biota in the area have been documented. However, most of the solid pollutants have settled out before the river water mass departs from Four Mile Bay, and dissolved pollutants become diluted in the main body of the lake. Generally, water quality in Lake of the Woods is considered to be good.

The study of burbot in Lake of the Woods was begun in 1968 in conjunction with a major study of the commercial and sport fisheries on the lake. This study terminated in 1970 but burbot investigations continued until the completion of field work in October 1972.

Sampling during the field seasons included fish taken every month except April, but most samples were collected during the ice-free period of June through October. Winter samples were collected from December through March during 1970, 1971, and 1972, but most were taken in February during the spawning periods.

Sampling gear included all of the commercial fishing gear described in the following section. Sampling from the commercial catch occurred either when the catches were brought into the fishery at Warroad, Minn. or when project personnel helped the fishermen lift their nets. No record of the number of gear lifts that provided burbot samples could be tabulated. This was not a problem in the case of the commercial trawl. This gear was fished under state experimental permit from 1968 to 1970, and project personnel had to accompany the gear during every day of operation. Hauls normally took 60 minutes, and 487 hauls were made during the 3 years of operation. Burbot samples were obtained from 249 of these hauls.

Burbot samples were obtained also by project personnel independently of commercial fishery operations. Most of these samples consisted of juvenile and young burbot that were not large enough to be captured by commercial gear. The samples were taken with an ecological semi-balloon trawl with a 26-foot headrope, a 1-1/2-inch stretch mesh body and codend, and a 1/2-inch stretch mesh nylon inner liner in the codend. Standard hauls with this gear normally took 10 minutes and covered an estimated area of 400 to 500 square meters. Approximately 600 hauls were made during the project.

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THE COMMERCIAL FISHERY

History of the Fishery

Commercial fishing on Lake of the Woods started about 1885 when commercial pound nets were fished for the first time. Expansion of the fishery was rapid, and by 1896 more than 300 pound nets were being fished in Canadian and Minnesota waters. The Minnesota Board of Game and Fish Commissioners recognized the need to protect the industry. Their recommendations to the state legislature in 1894 resulted in the adoption of fishing regulations in 1895. The regulations specified the season length, number of nets permitted each license holder, net sizes and mesh sizes, and areas in the lake that were open to commercial fishing. Provisions were made for recording the annual catches.

Changes in the fish populations occurred as the commercial fishing pressure increased on the lake. The population of lake sturgeon, *Acipenser fulvescens* Rafinesque, declined to commercial extinction by 1920 followed by the lake whitefish, *Coregonus clupeaformis* (Mitchill), in the late 1930's. As these declines became evident, more restrictive regulations were adopted.

Commercial fishing regulations stabilized by 1941 and have not been changed significantly since then. Size limits for sauger, walleye, northern pike, and whitefish were established. Sturgeon, muskellunge, bass, and crappies were excluded from commercial catches. Commercial license holders were restricted to fishing six pound nets, 10 fyke nets, or 4,000 feet of gill nets. Fishermen's helpers must be licensed. The commercial fishing season opening was set at June 1. Finally, certain areas of the lake were closed to commercial fishing to avoid conflicts with sport fishing.

Operation of the Fishery

Most commercial fishermen on Lake of the Woods are individuals with a family tradition in fishing experience. Knowledge of fishing grounds and lake conditions along with fishing methods have been passed down through the generations.

Fishing craft are of three general types. Outboard motor boats up to 17 feet long are used most frequently by the gill net and fyke net fishermen. Larger boats (20 to 25 feet) with inboard engines are used by the pound net and trap net fishermen. Steel hull vessels up to 43 feet long were used briefly for commercial trawling in 1961 and 1962 and again under experimental fishing permits during the 1968 to 1970 period of the current study. However, trawling is not an authorized fishing method on the lake and the vessels no longer are used.

Fishing gear used by the commercial fishermen includes gill nets, fyke nets, trap nets, pound nets, and commercial trawls. The gill nets are the most common type of gear because they are relatively inexpensive, can be fished by a single individual with a minimum amount of accessory equipment, and can be moved readily from area to area as the fishing success changes. The gill nets are essentially a curtain of monofilament mesh hung vertically in the water between a horizontal float line and a lead line. Minimum net size is 4-inch stretched mesh with net depth not to exceed 30 meshes. Nets normally are fished in gangs of 1000 feet and anchored on the lake bottom. This type of passive fishing gear is dependent on fish swimming into the meshes and becoming entangled.

The second most used gear is the pound net. This gear is hung on stakes driven into the lake bottom and consists of a lead, a funnel-shaped heart, and a pot or crib. The lead section is restricted to 600 feet in length of unspecified mesh size and usually about 12 feet in depth. The rectangular crib extends above the water surface with an open top for brailing out the catch. Crib dimensions are unrestricted but normally measure about 20 square feet. Crib mesh size is limited to 2 1/2-inch minimum or 4-inch maximum stretch measured size. This gear is not as popular as the gill net because it requires several men and accessory gear to operate it, is restricted to relatively shallow in-shore fishing areas, and cannot be moved readily. It has the advantage of catching fish without entangling and killing them which means a better condition of the catch and affords the fishermen the opportunity to select fish of the desired sizes and species.

Trap nets are essentially the same as pound nets with greater restrictions on size. Leads cannot exceed 400 feet in length, and crib dimension cannot be greater than 22 feet on any side. Frequently trap nets and pound nets were declared as individual gear types for administrative reasons.

Fyke nets are another passive type of fishing gear. This gear consists of a lead, heart, tunnel, and an enclosed pot end. Sometimes wings are attached to the net on either side of the lead or without a lead. Length of lead is restricted to 300 feet with wing length limited to 100 feet. Mesh of fyke nets cannot be smaller than 2 1/2 inches or greater than 4 inches stretched measure. Hoops in the body of the net cannot exceed 6 feet in diameter. This gear is anchored on the lake bottom for fishing and is used most frequently under the ice during the winter months for catching burbot. It has the same advantages as pound nets: quality of catch is good and unwanted fish species and sizes can be returned to the water unharmed.

The commercial trawl is an active fishing gear and depends on catching fish by being towed along the lake bottom. The trawl consists of a large tapered net bag ending in a tied-off cod end section. The mouth of the net is held open by a trawl door on either side that is rigged to pull outward as the net is towed forward. A lead line along the bottom and a float line along the top also aid in keeping the net mouth open. The use of this gear is no longer permitted, but initial gear requirements included a maximum head rope length of 88 feet and stretched mesh size in the cod end of between 3 1/2 and 4 inches. The disadvantages of this gear are that it requires a large and powerful vessel to operate the net and the fishing areas are restricted to segments of the lake with smooth bottoms.

Thirty-nine fish species inhabit the lake or have been reported at some time (table 1). Not all of these species were collected during the current study but ninespine stickleback, *Pungitius pungitius* (Linnaeus), and mottled sculpin, *Cottus bairdi* Girard, were taken and added to the lists compiled by previous authors (Evermann and Latimer, 1910; Carlander, 1942). Walleye, sauger, burbot, perch, and northern pike are the piscivorous fish taken most frequently by the fishery and by the sampling methods used for this study. Common planktivorous and benthic feeding fish species taken commercially include tullibee and white sucker. Other species have no commercial importance but frequently contribute to the food resources of commercial species.

Annual Catches of Commercial Species

Carlander (1942) summarized the commercial catches in Lake of the Woods that were available from 1888 to 1941. Catch data from 1942 to 1969 are provided by the Minnesota Department of Natural Resources. These values along with the species composition of the catch are averaged over 5-year intervals (figure 3). The early collapse of sturgeon and whitefish is evident. The production peak during the 1960-1964 period is the result of very good tullibee

Table 1. Fish species reported in Lake of the Woods either collected during present study (asterisks) or during previous surveys (Evermann and Latimer, 1910; Carlander, 1942)

Petromyzontidae
*Silver lamprey, *Ichthyomyzon unicuspis* Hubbs and Trautman

Acipenseridae
*Lake sturgeon, *Acipenser fulvescens* Rafinesque

Hiodontidae
*Mooneye, *Hiodon tergisus* LeSueur
Goldeye, *Hiodon alosoides* (Rafinesque)

Salmonidae
*Tullibee, *Coregonus artedii* LeSueur
*Lake whitefish, *Coregonus clupeaformis* (Mitchill)
Lake trout, *Salvelinus namaycush* (Walbaum)

Esocidae
*Northern pike, *Esox lucius* Linnaeus
*Muskellunge, *Esox masquinongy* Mitchill

Catostomidae
*Quillback, *Carpiodes cyprinus* (LeSueur)
*White sucker, *Catostomus commersoni* (Lacépède)
*Longnose sucker, *Catostomus catostomus* (Forster)
*Silver redhorse, *Moxostoma anisurum* (Rafinesque)
*Shorthead redhorse, *Moxostoma macrolepidotum* (LeSueur)
Northern hog sucker, *Hypentelium nigricans* (LeSueur)

Cyprinidae
*Emerald shiner, *Notropis atherinoides* Rafinesque
*Spottail shiner, *Notropis hudsonius* (Clinton)
Common shiner, *Notropis cornutus* (Mitchill)
Redfin shiner, *Notropis umbratilis* (Girard)
River shiner, *Notropis blennius* (Girard)
Rosyface shiner, *Notropis rubellus* (Agassiz)
Blacknose shiner, *Notropis heterolepis* Eigenmann and Eigenmann
Golden shiner, *Notomigonus crysoleucas* (Mitchill)

Ictaluridae
*Black bullhead, *Ictalurus melas* (Rafinesque)
Tadpole madtom, *Noturus gyrinus* (Mitchill)

Percopsidae
*Trout-perch, *Percopsis omiscomaycus* (Walbaum)

Gadidae
*Burbot, *Lota lota* (Linnaeus)

Gasterostidae
*Ninespine stickleback, *Pungitius pungitius* (Linnaeus)

Centrarchidae
*Rockbass, *Ambloplites rupestris* (Rafinesque)
*Black crappie, *Pomoxis nigromaculatus* (LeSueur)
Smallmouth bass, *Micropterus dolomieui* Lacépède

Percidae
*Iowa darter, *Etheostoma exile* (Girard)
*Johnny darter, *Etheostoma nigrum* Rafinesque
*River darter, *Percina shumardi* (Girard)
*Logperch, *Percina caprodes* (Rafinesque)
*Yellow perch, *Perca flavescens* (Mitchill)
*Sauger, *Stizostedion canadense* (Smith)
*Walleye, *Stizostedion vitreum vitreum* (Mitchill)

Cottidae
*Mottled sculpin, *Cottus bairdi* Girard

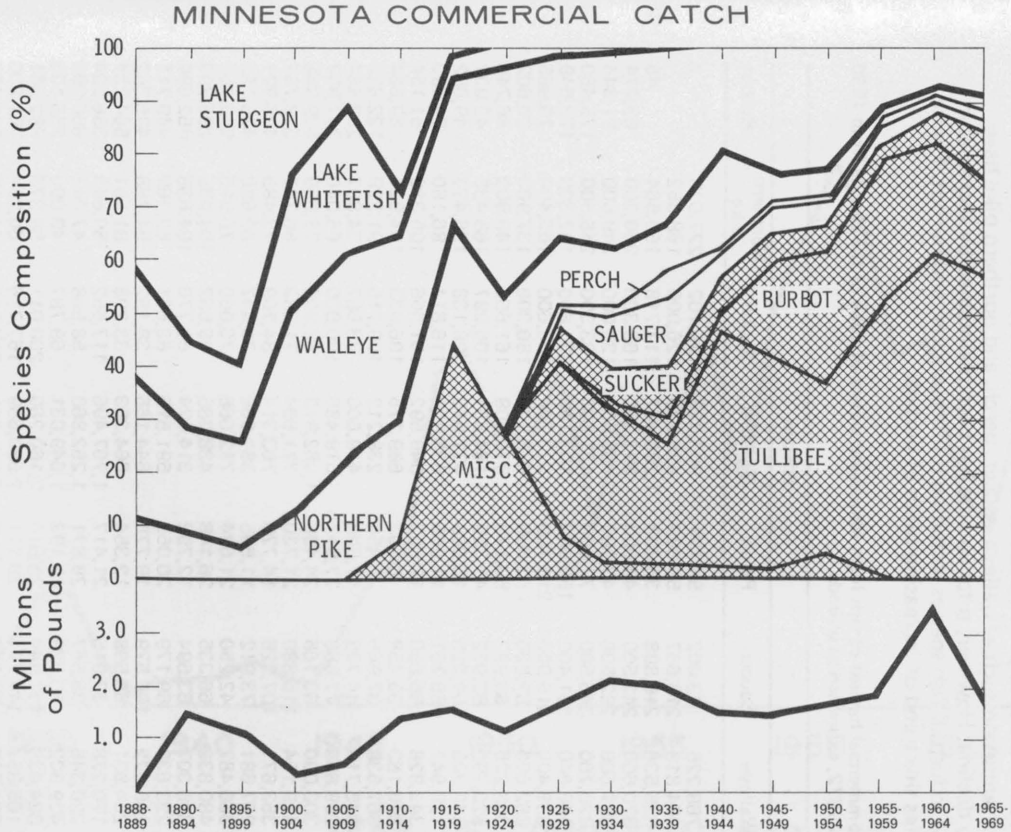

Figure 3. Minnesota commercial fisheries catches from Lake of the Woods averaged over 5-year intervals expressed as percentage species composition and pounds harvested.

and burbot populations and the introduction of commercial trawls which effectively harvested these species. Annual production at other times usually fluctuates between 1 and 2 million pounds taken in United States waters with a similar amount harvested by the Canadian fisheries.

Table 2 shows the annual harvest of the primary commercial species in Minnesota waters from 1930 to 1972. These data show that, although total production has remained relatively stable through the years, a significant change has occurred in the species composition of the catch. Catches of fish used for human consumption such as walleye, sauger, perch, and northern pike have tended to decline. However, total volume has been maintained by increases in catches of industrial fish species including tullibee, sucker, and burbot. Figure 4 illustrates this trend of increasing catch of burbot.

Table 2. Commercial harvest of fish from Minnesota waters of Lake of the Woods from 1930 to 1972, expressed as pounds

Year	Species						
	Walleye	Sauger	Perch	Tullibee	Sucker	Northern pike	Burbot
1930	768,225	73,602	54,721	903,023	125,102	227,628	–
1931	954,818	218,657	55,883	435,225	126,000	168,352	–
1932	625,536	215,898	36,698	1,296,467	117,718	150,564	45
1933	670,600	242,500	40,000	293,300	168,300	260,200	63,974
1934	891,600	282,500	43,700	155,500	120,000	349,500	91,344
1935	1,020,700	346,500	77,800	131,600	183,300	246,500	175,480
1936	846,600	391,400	156,000	103,100	230,600	197,300	178,649
1937	636,400	415,000	218,700	223,300	183,600	163,400	70,965
1938	362,600	87,900	53,600	878,120	180,300	137,900	20,602
1939	332,225	68,987	50,179	910,508	161,666	146,900	46,746
1940	520,790	82,072	41,259	1,184,851	100,297	168,435	42,037
1941	643,209	69,625	16,688	471,513	98,138	126,417	49,082
1942	420,547	55,761	11,965	533,920	118,814	86,150	74,293
1943	343,828	56,850	12,552	549,592	151,566	105,319	51,154
1944	346,183	33,458	8,703	689,175	106,033	104,921	39,634
1945	367,538	37,965	6,456	238,212	109,715	91,229	122,839
1946	345,714	44,798	17,508	419,600	83,687	84,802	203,484
1947	299,855	77,988	27,517	519,480	100,000	66,040	247,807
1948	303,090	63,165	24,498	1,062,913	68,800	73,899	539,985
1949	419,154	116,880	21,720	771,604	71,383	86,747	578,767
1950	353,671	107,725	14,770	763,314	84,709	73,485	436,991
1951	257,681	73,912	11,595	387,866	73,447	80,580	425,753
1952	366,487	42,250	21,624	712,666	76,060	76,919	540,753
1953	480,835	66,335	26,148	438,285	95,582	104,038	296,293
1954	326,307	63,594	12,792	314,474	66,776	104,638	452,690
1955	233,639	69,179	20,055	591,516	63,661	52,969	449,711
1956	245,472	109,579	19,775	644,165	38,152	54,768	496,342
1957	204,531	63,598	12,354	664,353	33,298	81,551	564,234
1958	170,278	37,915	21,417	1,767,496	117,652	59,654	356,024
1959	220,345	36,567	20,871	1,252,860	58,568	47,305	650,092
1960	429,802	59,929	17,192	1,649,031	69,787	49,090	755,106
1961	324,038	117,844	25,614	2,160,260	200,011	58,376	882,561
1962	165,857	144,771	28,271	2,660,669	167,715	60,254	767,830
1963	224,932	84,356	19,505	2,029,785	247,813	74,299	571,675
1964	217,030	68,472	11,554	2,203,501	203,479	76,066	594,582
1965	140,888	42,826	8,414	843,684	282,427	59,926	351,859
1966	305,218	27,286	22,762	921,827	195,814	64,028	285,530
1967	138,180	25,645	28,069	862,810	185,650	33,846	467,288
1968	107,344	16,847	36,053	1,224,334	106,332	51,480	365,625
1969	81,554	13,054	21,343	1,139,707	65,195	66,932	253,516
1970	102,756	17,421	12,703	758,300	111,238	57,816	175,841
1971	129,435	16,638	5,619	618,309	89,467	63,413	262,171
1972	286,922	13,006	10,470	794,715	151,590	66,551	161,478

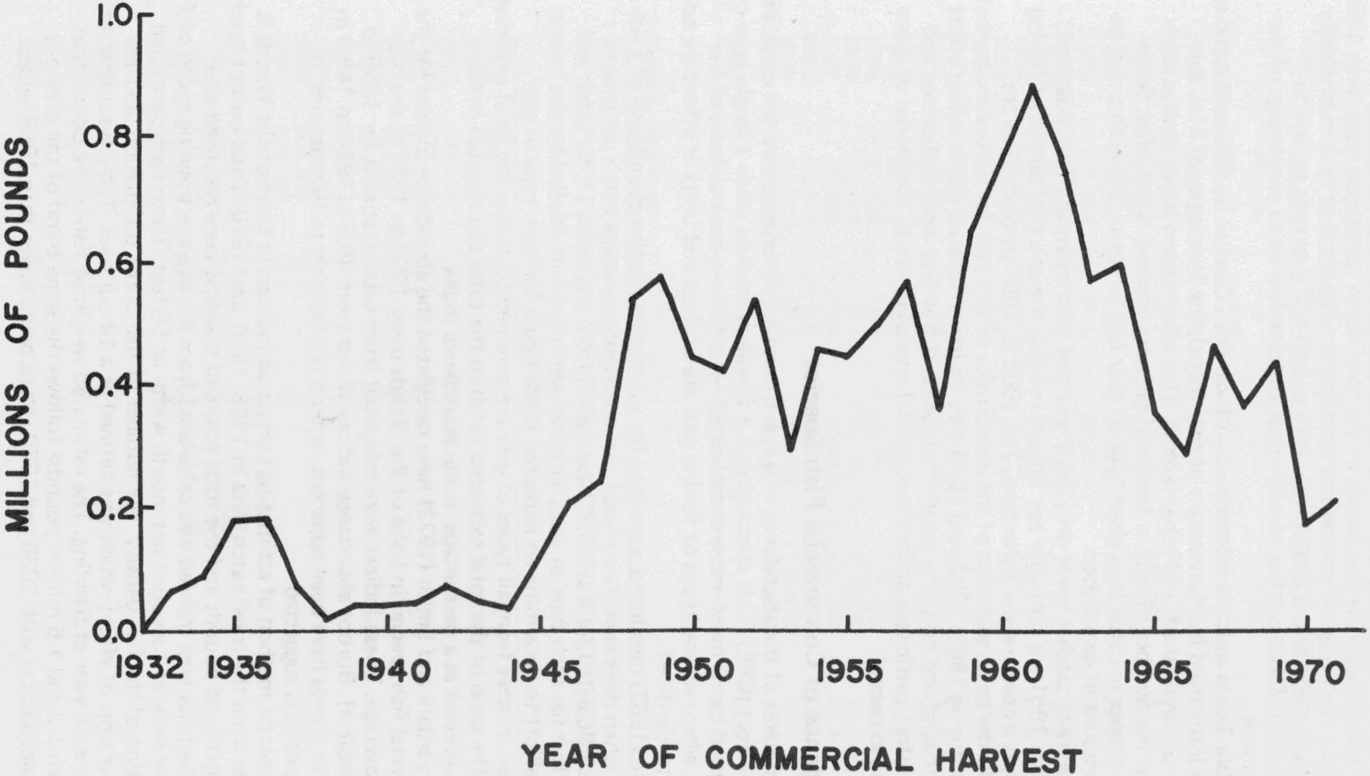

Figure 4. Total commercial harvest of burbot from Lake of the Woods since 1932. Data provided by the Minnesota Department of Natural Resources.

Burbot Catches in Various Gear Types

Table 3 shows the catches of burbot in different types of fishing gear in Lake of the Woods. The percentage of the total catch taken each year from 1950 to 1970 by each type of commercial fishing gear suggests that fyke nets usually contributed the greatest production, with pound and trap nets second in importance. Gill net catches usually constituted only a small percentage of the total amount.

Table 3 data must be interpreted with caution. Catches by different types of gear are influenced by the amount of gear fished, the frequency of lifts, the number of days fished, and other factors. This information is not always available, but the number of nets or length of gill nets licensed is provided. Sometimes a change in catch by a given type of gear can be correlated with a change in the amount of gear fished.

The trawl catches cover only the 7 years of data when this gear was used. Data from 1961 are probably not typical because it was a trial period of fishing by inexperienced trawler fishermen. The 1962 to 1964 trawl catches are probably the best indication of the capabilities of this gear for harvesting burbot. Catches during 1968, 1969, and 1970 may be lower because less trawling effort was expended and only one trawler was used. If trawling were authorized and fishing effort sufficient, an increase in total annual catch of 10 percent or more might be expected.

Abundance of Commercial Fish Species

Estimates of the abundance of a fish species are determined by the catch per unit of effort (CPE). This calculation is a simple procedure when a single type of gear is used but is much more complicated for a fishery, such as Lake of the Woods, where several types of fishing gear are utilized and units of effort are not easily standardized.

Hile (1962) developed a method for estimating relative abundance of a fish species when diverse gears are used. An unweighted average catch per unit of effort is calculated for a selected base period from the known total catch and total effort for each type of gear. This average value is multiplied by the known yearly effort to determine an expected catch figure for each type of gear. Expected catches from all types of gear are summed to obtain the total expected catch. The ratio of the total expected catch to the total actual catch in any year, expressed as a percentage, is the abundance index.

Heyerdahl and Smith (1972) have calculated the abundance indices for the commercial fish species in Lake of the Woods using 1958 to 1967 as the base period average. These indices were tabulated from catch statistics for 1950 to 1970 (table 4). Burbot abundance indices varied from 48.8 in 1950 to 148.9 in 1959. No trends have been apparent, and no relationship to fluctuations in other species is suggested.

A second method of estimating burbot abundance in Lake of the Woods is available from the trawl catch data in 1968, 1969, and 1970. Total burbot catch in numbers and pounds and the total hours of trawling were recorded each year. The total area trawled was calculated from the average trawling speed of 2 miles per hour and an open net mouth width of 50 feet. These data permitted calculation of the fish density, the number of fish in the population, and the catch per unit of effort which was defined as a 1-hour haul. Table 5 summarizes data for each year of trawling. The estimated weight of fish in the population (between 1.3 and 1.6 million pounds) follows the same trend of the previous abundance indices with 1968 and 1970 values being lower than 1969 values.

Table 3. Burbot catches for 1950-1970 by different types of gear expressed as pounds and percentage of total annual catch. Amount of gear is indicated as licensed nets and trawl permits

Year	Gill nets			Pound and trap nets		
	Pounds	Percent of total	Feet of net licensed	Pounds	Percent of total	Number of nets licensed
1950	58,130	13.3	74,500	219,716	50.3	56
1951	86,388	20.3	65,500	252,719	59.4	44
1952	213,311	39.4	70,000	285,147	52.7	39
1953	54,991	18.6	70,000	169,153	57.1	38
1954	65,591	14.5	70,000	134,974	29.8	41
1955	63,354	14.1	67,500	191,676	42.6	41
1956	73,200	14.7	67,500	192,472	38.8	35
1957	38,517	6.8	67,500	184,164	32.6	29
1958	96,032	27.0	68,500	184,461	51.8	36
1959	40,189	6.2	66,000	303,350	46.7	35
1960	81,159	10.7	69,000	300,727	39.8	35
1961	46,733	5.3	69,000	315,570	35.8	44
1962	36,531	4.8	66,000	212,636	27.7	34
1963	21,614	3.8	60,000	62,532	10.9	23
1964	22,690	3.8	57,000	108,259	18.2	23
1965	21,337	6.1	63,000	102,220	29.1	41
1966	23,094	8.1	64,000	33,909	11.9	43
1967	63,264	13.5	60,000	132,757	28.4	42
1968	32,944	9.0	54,000	106,934	29.2	35
1969	33,913	13.4	51,000	188,938	74.5	20
1970	37,093	20.4	45,000	97,210	53.4	12
Mean		13.0	64,047.6		39.0	35.5

Table 3. Continued

Year	Fyke nets			Trawl			Total catch (lbs)
	Pounds	Percent of total	Number of nets licensed	Pounds	Percent of total	Number of trawl permits	
1950	159,145	36.4	53	—	—	—	436,991
1951	86,646	20.3	60	—	—	—	425,753
1952	42,295	7.8	60	—	—	—	540,743
1953	72,149	24.4	59	—	—	—	296,293
1954	252,125	55.7	60	—	—	—	452,690
1955	194,681	43.3	60	—	—	—	449,711
1956	230,670	46.5	43	—	—	—	496,342
1957	341,553	60.5	23	—	—	—	564,234
1958	75,531	21.2	16	—	—	—	356,024
1959	306,553	47.2	15	—	—	—	650,092
1960	373,220	49.4	10	—	—	—	755,106
1961	485,178	55.0	18	35,080	4.0	2	882,561
1962	416,632	54.3	13	102,031	13.3	2	767,830
1963	425,304	74.4	25	62,225	10.9	2	571,675
1964	405,945	68.3	23	57,688	9.7	2	594,582
1965	227,340	64.6	30	—	—	—	351,859
1966	228,527	80.0	33	—	—	—	285,530
1967	271,267	58.1	23	—	—	—	467,288
1968	215,992	59.1	20	9,755	2.7	1	365,625
1969	22,860	9.0	10	7,805	3.1	1	253,516
1970	41,538	22.8	20	6,181	3.4	1	182,022
Mean		45.6	32.0		6.7	1.5	

Table 4. Abundance indices of the commercial fish species in Lake of the Woods as determined by Hile's method and using 1958-1967 catch statistics for the base period averages (Data after Heyerdahl and Smith, 1972)

Year	Percentage of the 1958-67 base period average						
	Walleye	Sauger	Perch	Tullibee	Sucker	Northern pike	Burbot
1950	115.6	155.2	65.3	45.9	39.2	78.6	48.8
1951	76.5	98.6	43.1	21.8	30.4	76.4	55.4
1952	116.1	59.8	77.7	41.7	32.2	85.2	117.8
1953	138.4	87.4	96.9	23.4	37.5	105.2	49.5
1954	102.2	96.1	53.2	18.4	27.7	116.9	62.1
1955	78.4	112.6	92.3	36.8	28.3	61.3	60.9
1956	79.7	177.2	91.9	38.1	15.8	71.5	112.4
1957	11.6	171.5	97.6	65.3	23.3	181.3	138.8
1958	64.7	63.3	110.8	120.6	62.4	83.3	73.9
1959	88.5	72.3	122.8	90.4	30.3	76.6	148.9
1960	195.1	107.1	92.0	108.9	33.3	72.9	148.3
1961	116.1	165.2	103.9	105.2	92.3	86.4	141.4
1962	70.0	178.3	98.3	138.2	96.3	112.2	141.3
1963	86.0	105.0	68.8	92.3	120.8	119.4	55.0
1964	113.2	108.5	50.6	126.9	152.4	174.5	92.7
1965	66.3	94.8	52.3	73.7	178.5	100.3	77.2
1966	139.1	56.2	134.8	76.3	120.9	113.5	25.6
1967	60.8	49.3	165.5	67.3	112.6	60.8	95.6
1968	57.5	39.9	265.1	106.5	76.4	110.0	72.2
1969	57.3	51.5	237.3	143.6	57.8	157.5	103.8
1970	63.8	63.2	119.7	82.6	84.7	125.5	66.6

Table 5. Estimates of burbot density, catch per unit of effort, and abundance as determined from 1968-1970 trawl data. Burbot abundance is estimated for the entire lake (950,400 acres)

	1968	1969	1970
Total trawl time (hrs.)	218.06	153.61	136.26
Total number of burbot caught	3,732	3,199	2,279
C.P.E. (fish/hr.)	17.11	20.84	18.13
Total weight of burbot caught (lbs.)	9,755	7,806	6,181
Fish density			
number/acre	1.41	1.71	1.37
lbs./acre	3.69	4.19	3.74
Fish abundance (density x 950,400)	1,340,064	1,625,184	1,302,048

Estimates of fish abundance from trawl data must be regarded as minimum values for several reasons. Burbot caught in the trawls do not include fish younger than 3 years old, and even 3 year olds may not be sampled in proportion to their abundance. Trawls are not 100 percent efficient, and presumably some unknown number of catchable size burbot in the trawl area are not captured. Finally, although burbot distribution is not uniform throughout the lake, estimates are based on this assumption because density in untrawled areas cannot be determined. Nevertheless, if these factors are the same from year to year, the abundance values should be good population indicators.

Length and Age Frequencies of the Commercial Burbot Catch

Tables 6 and 7 show length and age class characteristics of Lake of the Woods commercially caught burbot. These data were collected from 1968 to 1972. Catches were not separated according to the different types of gear because preliminary examination of the data did not suggest great differences in either age or length of burbot captured. Samples were obtained predominantly from pound nets, fyke nets, and trawls with some samples from gill nets.

The predominant age classes in the catch were IV to VII (82 percent), and the predominant lengths were from 500 to 625 mm (59 percent). The significance of these data will be discussed later.

Table 6. Length frequency distribution of commercially caught burbot from 1968 to 1972

Length interval (mm)	Number of fish	Percent of total sample
326-350	13	0.2
351-375	17	0.3
376-400	25	0.5
401-425	56	1.0
426-450	122	2.2
451-475	256	4.7
476-500	388	7.1
501-525	561	10.3
526-550	626	11.5
551-575	743	13.6
576-600	686	12.6
601-625	599	11.0
626-650	505	9.2
651-675	360	6.6
676-700	221	4.1
701-725	143	2.6
726-750	74	1.4
751-775	43	0.8
776-800	9	0.2
801-825	7	0.1
Total	5,454	100.0

Table 7. Age frequency distribution of commercially caught burbot from 1968 to 1972

Age group	Number of fish	Percent of total sample
III	359	6.5
IV	1,095	20.0
V	1,333	24.5
VI	1,161	21.3
VII	881	16.2
VIII	381	7.0
IX	149	2.8
X	65	1.2
XI	18	0.3
XII	6	0.1
XIII	6	0.1
Total	5,454	100.0

Commercial Use and Value of Burbot

Burbot has never been a popular food fish on the market although they are edible. Their physical appearance has often prevented people from eating them, and the availability of walleye and other popular species has reduced the need for new sources of fish protein.

Initially, some demand for burbot occurred because the liver oil has a vitamin content higher than that in codfish liver oil (Tack *et al*, 1947; Nelson, Tolle, and Jamieson, 1932). However, less costly vitamin sources became available and the utilization of burbot oil ceased.

A second and more important use of burbot is as feed for commercially grown mink. Two factors regulate burbot use by the mink industry. First, the mink industry has declined somewhat in recent years and so the need for burbot as mink food also has declined. Second, burbot contains an enzyme, thiaminase, that at high concentrations is detrimental to mink. Thiaminase can be destroyed by cooking the burbot before feeding it to the mink but this is time consuming and costly. Therefore, uncooked burbot is mixed in small quantities with other types of mink feed to minimize the levels of thiaminase while providing inexpensive food for the mink.

This use of burbot has not increased its value. Although burbot ranks second in total volume caught in Lake of the Woods, it is third in average annual value (Stam, 1972). Average price per pound from 1955 to 1969 was 2.8 cents, higher in price than only suckers and redhorse. Annual value of burbot catches in Lake of the Woods from 1940 to 1969 varied from $355 in 1942 to $30,860 in 1961. Table 8 summarizes the values of burbot and the total value of all species. The percentage of the total fishery value attributed to the burbot catch has varied from 0.3 percent in 1942 to 17.9 percent in 1957.

Table 8. Annual value (dollars) of burbot as related to the total value of the commercial fisheries in Minnesota waters of Lake of the Woods, 1940-1969

Year	Total fishery value	Burbot value	Percent of total value
1940	116,340	631	0.5
1941	150,545	738	0.5
1942	123,763	355	0.3
1943	163,134	1,408	0.9
1944	128,095	–	–
1945	159,251	2,393	1.5
1946	133,851	3,492	2.6
1947	125,559	5,324	4.2
1948	204,564	9,143	4.5
1949	155,230	4,590	3.0
1950	148,040	2,785	1.9
1951	151,088	10,733	7.1
1952	147,006	16,300	11.1
1953	128,942	10,377	8.1
1954	114,781	9,055	7.9
1955	90,843	11,243	12.4
1956	94,453	14,751	15.6
1957	84,422	15,122	17.9
1958	74,971	4,421	5.9
1959	109,297	16,057	14.7
1960	182,646	22,696	12.4
1961	176,342	30,860	17.5
1962	156,120	21,190	13.6
1963	132,928	9,525	7.2
1964	141,463	17,547	12.4
1965	100,495	15,855	15.8
1966	161,300	7,000	4.3
1967	80,745	12,322	15.3
1968	85,490	8,015	9.4
1969	85,598	9,212	10.8

GROWTH

In order to provide data on growth rate and structure of the burbot population of Lake of the Woods, samples of fish were taken over a 5-year period. A total of 5,952 fish were examined. Length, weight, age, and sex were determined for 2,617 fish. The remainder which includes 418 fish less than 1 year old were measured.

Adult Burbot Growth and Age Frequency

Table 9 and figure 5 show length-frequency distribution of all samples including young-of-the-year burbot. Table 10 and figure 6 show age-frequency of all fish aged from otolith examination other than young-of-the-year. The sex ratios of these samples did not vary significantly from 50:50 in any of the 5 sample years as concluded by a chi-square test at the .05 level.

Table 9. Length-frequency distribution of aged and measured burbot samples collected during each study year

Length interval (mm)	Years					Interval total
	1968	1969	1970	1971	1972	
0- 25	—	—	—	—	—	
26- 50	—	—	72	2	32	106
51- 75	—	—	54	74	80	208
76-100	1	—	2	10	55	68
101-125	—	—	—	8	31	39
126-150	—	1	4	4	2	11
151-175	—	1	5	1	3	10
176-200	—	2	4	—	7	13
201-225	—	—	2	—	4	6
226-250	—	—	1	3	2	6
251-275	—	—	3	3	2	8
276-300	1	—	7	5	—	13
301-325	1	—	7	—	2	10
326-350	1	—	8	4	—	13
351-375	2	2	11	—	2	17
376-400	6	9	8	—	2	25
401-425	6	15	25	5	5	56
426-450	16	54	32	6	14	122
451-475	16	98	69	14	59	256
476-500	21	130	74	47	116	388
501-525	23	147	118	69	204	561
526-550	19	159	119	83	246	626
551-575	17	204	155	110	257	743
576-600	16	141	152	122	255	686
601-625	16	116	122	119	226	599
626-650	10	87	94	119	195	505
651-675	6	56	70	79	149	360
676-700	5	33	37	61	85	221
701-725	3	27	21	30	62	143
726-750	2	10	15	16	31	74
751-775	2	7	3	6	25	43
776-800	2	2	1	1	3	9
801-825	2	1	1	1	2	7
Yearly totals	194	1,302	1,296	1,002	2,158	
Grand total						5,952

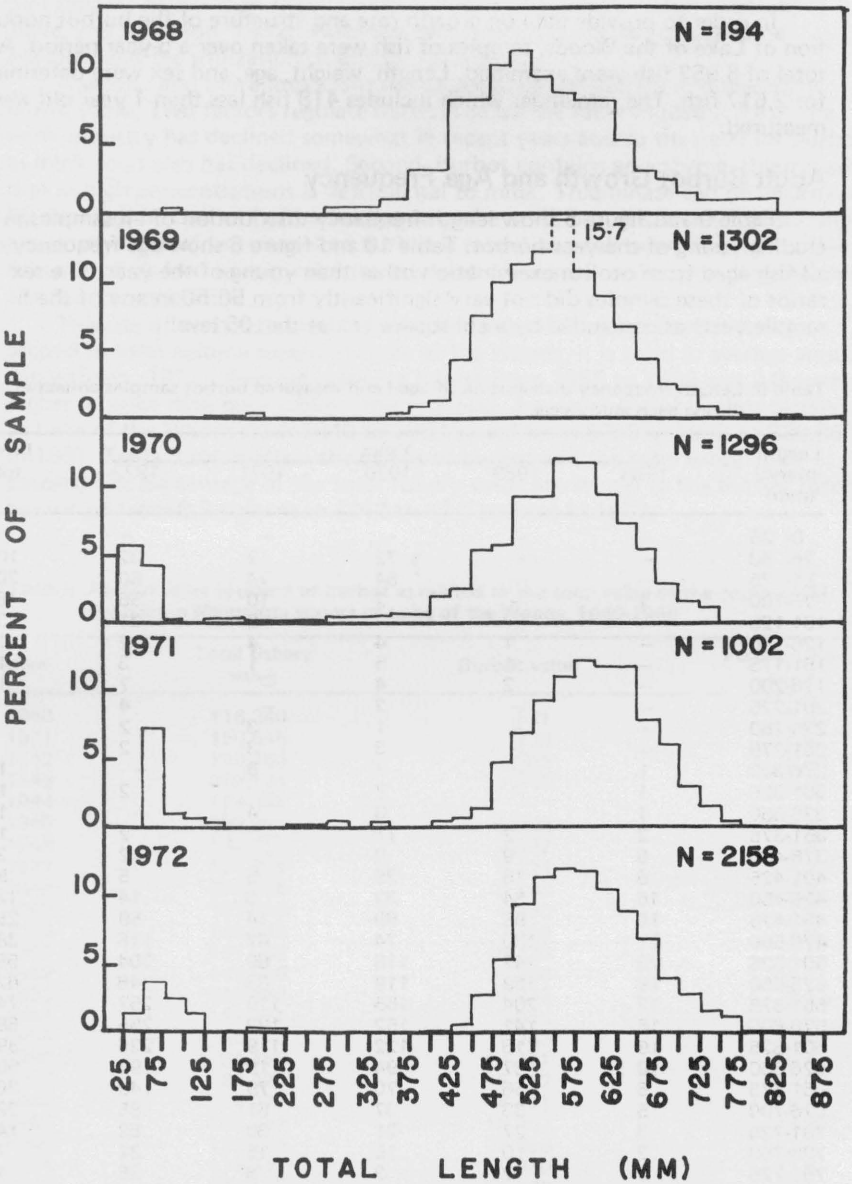

Figure 5. Length-frequency distribution of all burbot collected during each year of the study expressed as the percent of each year's total sample (N) in each 25mm length interval.

Table 10. Age-frequency distribution of samples as determined by reading otoliths collected during each study year (young-of-the-year burbot not included)

Age groups	Years 1968	1969	1970	1971	1972	Group totals
I	—	4	17	7	18	46
II	8	1	36	14	6	65
III	25	30	49	26	42	172
IV	69	85	95	83	192	524
V	43	148	167	140	114	612
VI	20	71	136	179	116	522
VII	12	33	97	128	128	398
VIII	7	11	35	53	65	171
IX	7	2	6	21	30	66
X	2	2	4	7	15	30
XI	—	1	—	2	4	7
XII	—	—	1	2	—	3
XIII	—	—	—	—	1	1
Yearly totals	193	388	643	662	731	
Grand total						2,617

The age-frequency for the entire 5,952 samples was estimated by determining the percentage of each age class that contributed to a given length interval in the aged samples and then applying these percentages to the total number of fish in each length interval. Table 11 shows the final age-frequency estimates for all data collected during the 5 sample years. The size ranges of individual age groups indicate the length variability with age that occurs in the population. Greatest variability is evident in the predominant age groups of IV through VII with 10, 14, 14, and 13 size classes respectively representing these ages. The most frequently occurring size class in the population is the 551 – 575 mm interval typical of 5 annulus fish.

Method of Age Determination

Otoliths for age determination were taken from each specimen from a median incision in the head made by a large pair of tin shears. The largest otoliths are the sagittae. Both sagittae from each fish were extracted with forceps and placed in vials containing a weak tri-sodium phosphate solution.

Otoliths were analyzed with a binocular microscope using 10x magnification and a calibrated ocular micrometer. No preparation before examination was required. Measurements from the focus to each annulus and to the anterior margin were used to calculate body length at time of annulus formation. Each pair of otoliths was aged twice (independently) and the results compared. When readings did not agree, a third examination was made; if no agreement on age was reached, the sample was discarded.

The otoliths of burbot are oval and slightly concave structures consisting primarily of calcium carbonate. Growth of these structures is systematically associated with growth of the fish in length. A central opaque kernel, the focus, is evident and is surrounded by alternating concentric layers of clear and

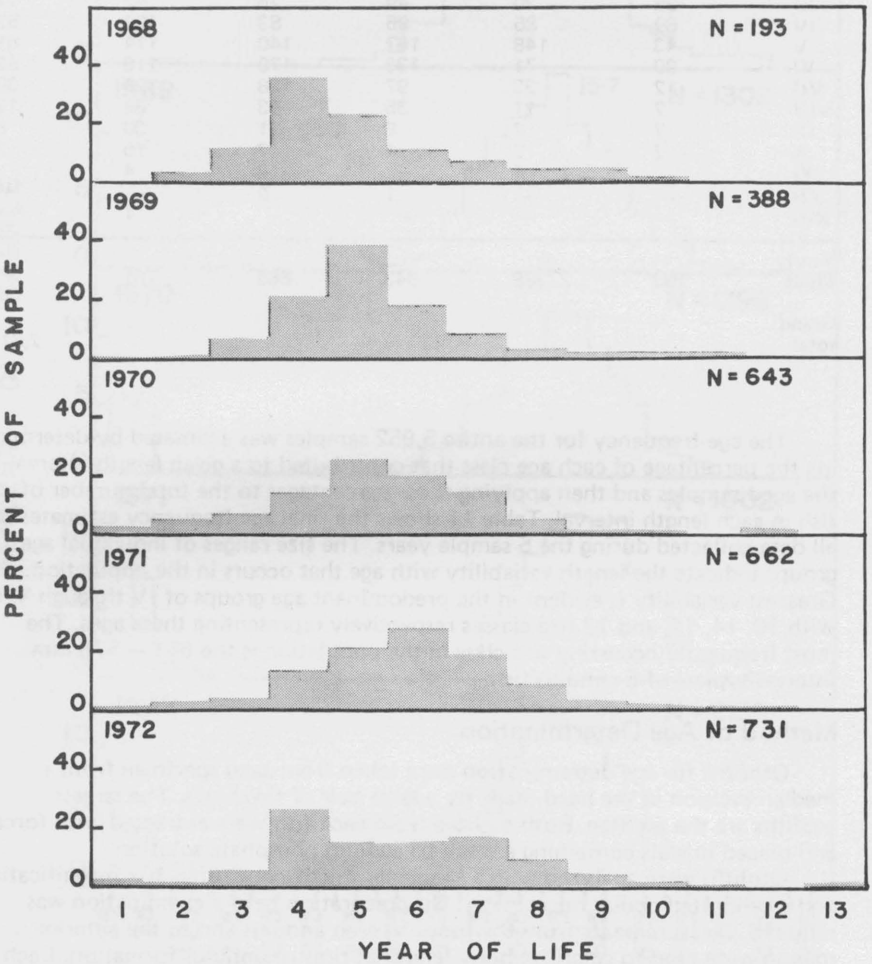

Figure 6. Age-frequency distribution of burbot for fish 1 year or older as determined from otoliths and expressed as the percent of each year's sample (N).

Table 11. Age-frequency in each 25 millimeter interval of the 5952 fish samples

Length interval (mm)	Age groups 0	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	Total
0- 25	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
26- 50	106	–	–	–	–	–	–	–	–	–	–	–	–	–	106
51- 75	208	–	–	–	–	–	–	–	–	–	–	–	–	–	208
76-100	67	1	–	–	–	–	–	–	–	–	–	–	–	–	68
101-125	36	3	–	–	–	–	–	–	–	–	–	–	–	–	39
126-150	1	10	–	–	–	–	–	–	–	–	–	–	–	–	11
151-175	–	10	–	–	–	–	–	–	–	–	–	–	–	–	10
176-200	–	13	–	–	–	–	–	–	–	–	–	–	–	–	13
201-225	–	6	–	–	–	–	–	–	–	–	–	–	–	–	6
226-250	–	3	3	–	–	–	–	–	–	–	–	–	–	–	6
251-275	–	1	7	–	–	–	–	–	–	–	–	–	–	–	8
276-300	–	–	13	–	–	–	–	–	–	–	–	–	–	–	13
301-325	–	–	10	–	–	–	–	–	–	–	–	–	–	–	10
326-350	–	–	9	3	–	1	–	–	–	–	–	–	–	–	13
351-375	–	–	12	4	–	–	1	–	–	–	–	–	–	–	17
376-400	–	–	8	14	3	–	–	–	–	–	–	–	–	–	25
401-425	–	–	7	35	10	4	–	–	–	–	–	–	–	–	56
426-450	–	–	4	60	50	8	–	–	–	–	–	–	–	–	122
451-475	–	–	–	76	133	39	4	4	–	–	–	–	–	–	256
476-500	–	–	–	59	224	85	14	6	–	–	–	–	–	–	388
501-525	–	–	–	46	277	150	65	23	–	–	–	–	–	–	561
526-550	–	–	–	19	212	254	100	32	9	–	–	–	–	–	626
551-575	–	–	–	2	116	308	209	76	28	4	–	–	–	–	743
576-600	–	–	–	2	61	229	227	132	29	2	4	–	–	–	686
601-625	–	–	–	–	7	138	213	166	61	12	2	–	–	–	599
626-650	–	–	–	–	–	90	175	141	83	14	2	–	–	–	505
651-675	–	–	–	–	–	17	108	144	67	17	4	3	–	–	360
676-700	–	–	–	–	–	8	28	96	42	33	14	–	–	–	221
701-725	–	–	–	–	–	5	12	38	36	33	14	5	–	–	143
726-750	–	–	–	–	–	–	4	17	21	17	11	2	2	–	74
751-775	–	–	–	–	–	–	3	6	3	9	11	6	3	2	43
776-800	–	–	–	–	–	–	–	–	–	3	6	–	–	–	9
801-825	–	–	–	–	–	–	–	–	1	3	–	2	1	–	7
Totals	418	47	73	320	1093	1336	1163	881	380	147	68	18	6	2	5952

opaque material. The clear material, or hyaline zone, represents the rapid summer growth and the opaque zone the slow winter growth (Pannella, 1971). Martin (1941), Clemens (1951b), and Bailey (1972) indicate that the hyaline zone formation begins in early summer and continues through about November when opaque zone formation starts. Otoliths used in the present study have a similar pattern with each annual growth increment including a wide hyaline zone and a slightly narrower opaque zone.

Validation of Otolith Analysis

Growth history of a species as determined by back calculation to each annulus assumes that (1) the structure used grows with a definite relationship to the growth of the body length of the fish and (2) a reliable description of this relationship can be determined from accurately aged and measured samples.

The use of otoliths for determining age is an established technique for many fish species including herring, salmonids, smelt, shad, codfish, and sole (Chugunova, 1959; Watson, 1964; Christensen, 1964). Aging burbot from otoliths is the usual method because the species has small imbedded scales that are impractical to collect or read.

Age was determined by examining one or both otoliths from each fish. In most cases annuli could be distinguished easily except in fish older than 8 years which had increased crowding of annuli at the anterior margin of the otolith.

Ages could not be verified by length-frequency distribution because of the overlapping of sizes for each age (figure 5). Consistency of aging was tested by conducting independent readings and comparing results. Two independent readings arrived at the same assigned age for approximately 82 percent of the samples. Another investigator in two independent readings, without consulting the previous readings, arrived at the same assigned age at a similar high percentage. Overall agreement of age assignment by both investigators was approximately 75 percent with most disagreement occurring in the older ages where the differences were usually not greater than 1 year.

Evidence of the accuracy of the age determination in this study included: 1) calculated lengths at the end of each year of life were reasonably close between designated year classes; 2) average empirical lengths at capture represent some growth of each year class because they were collected throughout the growing season and, as would be expected, these values fall between calculated growth of assigned ages; 3) the average body length increased with assigned age of fish; and 4) otolith size generally increased with assigned ages.

Body Length-Otolith Relationship

The relationship of body length to otolith radius was calculated from a randomly selected subsample of aged fish consisting of 318 males and 285 females. Otolith radius from the center of the focus to the anterior margin was measured with an ocular micrometer in the microscope. Separate plots of these values against fish length were made for each sex. The appropriate method in this analysis is to consider the otolith measurement fixed and regress the otolith length on the body length for predictive purposes (Whitney and Carlander, 1956). The data were plotted in this manner, and linear regressions for each sex were calculated. The empirically fitted lines were not very different from the calculated regressions, but the majority of the otolith measurements occurred between 35 and 65 units. Measurements beyond these extremes are not well represented by the equations.

Polynomial equations are derived readily from data sets with the aid of computers, and several of these were attempted with the above data. Hile (1970) criticizes the use of polynomials by suggesting that any set of data can be described with a mathematical equation containing enough terms. However, second degree polynomials with multiple correlation coefficients of .924 and .948 for male and female equations respectively were used to describe the body length-otolith relationships for burbot in Lake of the Woods. These equations are:

Males	$\text{Log } Y = -\ .5094 + 2.7828 \text{ Log } X - .5350\ (\text{Log } X)^2$
Females	$\text{Log } Y = -\ .4717 + 2.7471 \text{ Log } X - .5273\ (\text{Log } X)^2$

Figure 7 shows both linear and polynomial regression curves, and the male and female equations do not differ significantly in either type of curve.

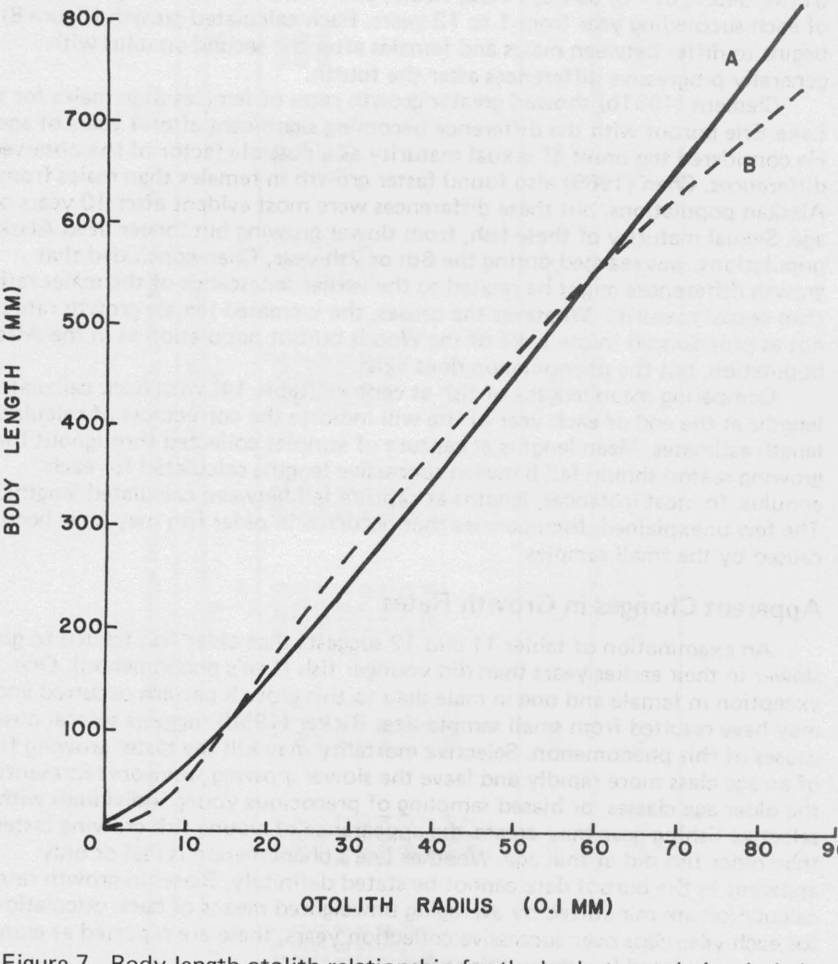

Figure 7. Body length-otolith relationship for the burbot population in Lake of the Woods. The solid line, A, represents the equation log Y = .6831 + 1.1583 log X and the broken line, B, represents the polynomial equation log Y = –.5094 + 2.7828 log X –.5350 $(\log X)^2$.

Grand Average Calculated Lengths

Growth rates of females were determined for year classes 1961 to 1971 (table 12), and male growth rates include the 1959 to 1971 year classes (table 13). Females averaged 129.3, 287.3, 401.2, 484.6, 538.1, 582.1, 619.1, 652.3, 681.4, 699.6, and 725.6 mm in total length at the end of each succeeding year from 1 to 11 years. Males averaged 129.1, 288.8, 399.0, 479.2, 532.3, 576.1, 611.8, 643.7, 671.6, 694.0, 710.2, 726.7, and 745.6 mm total length at the end of each succeeding year from 1 to 13 years. Back calculated growth (figure 8) begins to differ between males and females after the second annulus with generally progressive differences after the fourth.

Clemens (1951b) showed greater growth rates of females than males for the Lake Erie burbot with the difference becoming significant after 4 years of age. He considered the onset of sexual maturity as a possible factor of the observed differences. Chen (1969) also found faster growth in females than males from Alaskan populations, but these differences were most evident after 10 years of age. Sexual maturity of these fish, from slower growing but longer lived Alaskan populations, was reached during the 6th or 7th year; Chen concluded that growth differences might be related to the earlier senescence of the males rather than sexual maturity. Whatever the causes, the increased female growth rate is not as pronounced in the Lake of the Woods burbot population as in the Alaskan population, but the phenomenon does exist.

Comparing mean lengths of fish at capture (table 14) with back calculated lengths at the end of each year of life will indicate the correctness of calculated length estimates. Mean lengths at capture of samples collected throughout the growing season should fall between successive lengths calculated for each annulus. In most instances, lengths at capture fell between calculated lengths. The few unexplained discrepancies that occurred in older fish may have been caused by the small samples.

Apparent Changes in Growth Rates

An examination of tables 11 and 12 suggests that older fish tended to grow slower in their earlier years than did younger fish (Lee's phenomenon). One exception in female and one in male data to this growth pattern occurred and may have resulted from small sample size. Ricker (1958) suggests several possible causes of this phenomenon. Selective mortality may kill the faster growing fish of an age class more rapidly and leave the slower growing survivors representing the older age classes, or biased sampling of precocious young individuals with selective fishing gear may create the appearance of young fish growing faster than older fish did at that age. Whether Lee's phenomenon is real or only apparent in the burbot data cannot be stated definitely. Biases in growth rate calculation are minimized by averaging unweighted means of back calculations for each year class over successive collection years; these are reported as grand average calculated lengths in this study.

Table 12. Average calculated total lengths in millimeters of female burbot from random samples collected from 1970 to 1972

Year class	Number of fish	Length at end of year of life										
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI
1961	3	141.1	301.8	411.0	500.0	553.9	595.8	638.0	667.5	689.7	711.6	725.6
1962	6	123.9	286.6	397.4	482.3	534.6	582.2	616.2	644.0	669.8	687.6	
1963	12	127.5	288.2	413.5	503.3	564.0	606.8	638.2	663.8	684.7		
1964	23	118.6	274.2	396.3	478.8	538.3	579.0	610.7	634.0			
1965	50	125.4	279.5	389.0	470.9	525.7	564.3	592.5				
1966	44	125.8	280.4	390.8	479.8	526.4	564.4					
1967	63	125.9	286.3	397.0	471.9	523.7						
1968	51	143.4	308.7	419.3	489.6							
1969	16	146.2	305.6	396.6								
1970	12	117.6	261.7									
1971	5	127.4										
Number of fish	285	285	280	268	252	201	138	94	44	21	9	3
Grand average calculated length		129.3	287.3	401.2	484.6	538.1	582.1	619.1	652.3	681.4	699.6	725.6

Table 13. Average calculated total lengths in millimeters of male burbot from random samples collected from 1970 to 1972

Year class	Number of fish	Length at end of year of life												
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
1959	1	125.1	298.6	401.3	485.9	534.7	580.5	632.0	672.2	694.8	710.0	724.3	738.1	745.6
1960	1	121.8	291.0	377.4	467.8	520.2	569.3	597.1	633.4	667.4	683.3	699.3	715.3	
1961	3	134.6	295.1	409.2	499.9	564.4	602.1	630.9	653.3	672.4	691.1	707.0		
1962	13	122.5	276.8	403.1	490.1	550.8	595.7	625.5	650.6	672.5	691.6			
1963	19	126.8	283.7	393.8	476.0	531.6	571.2	605.5	629.3	650.8				
1964	30	124.3	276.1	386.9	467.9	523.9	567.6	599.4	623.6					
1965	59	123.5	281.4	391.4	472.2	524.5	563.4	592.1						
1966	73	120.3	275.2	391.0	471.0	524.4	559.2							
1967	58	124.2	286.5	396.9	470.0	516.6								
1968	32	148.2	315.3	325.2	491.0									
1969	13	136.8	305.0	412.8										
1970	11	154.5	280.5											
1971	5	115.2												
Number of fish	318	318	313	302	289	257	199	126	67	37	18	5	2	1
Grand average calculated length		129.1	288.8	399.0	479.2	532.3	576.1	611.8	643.7	671.6	694.0	710.2	726.7	745.6

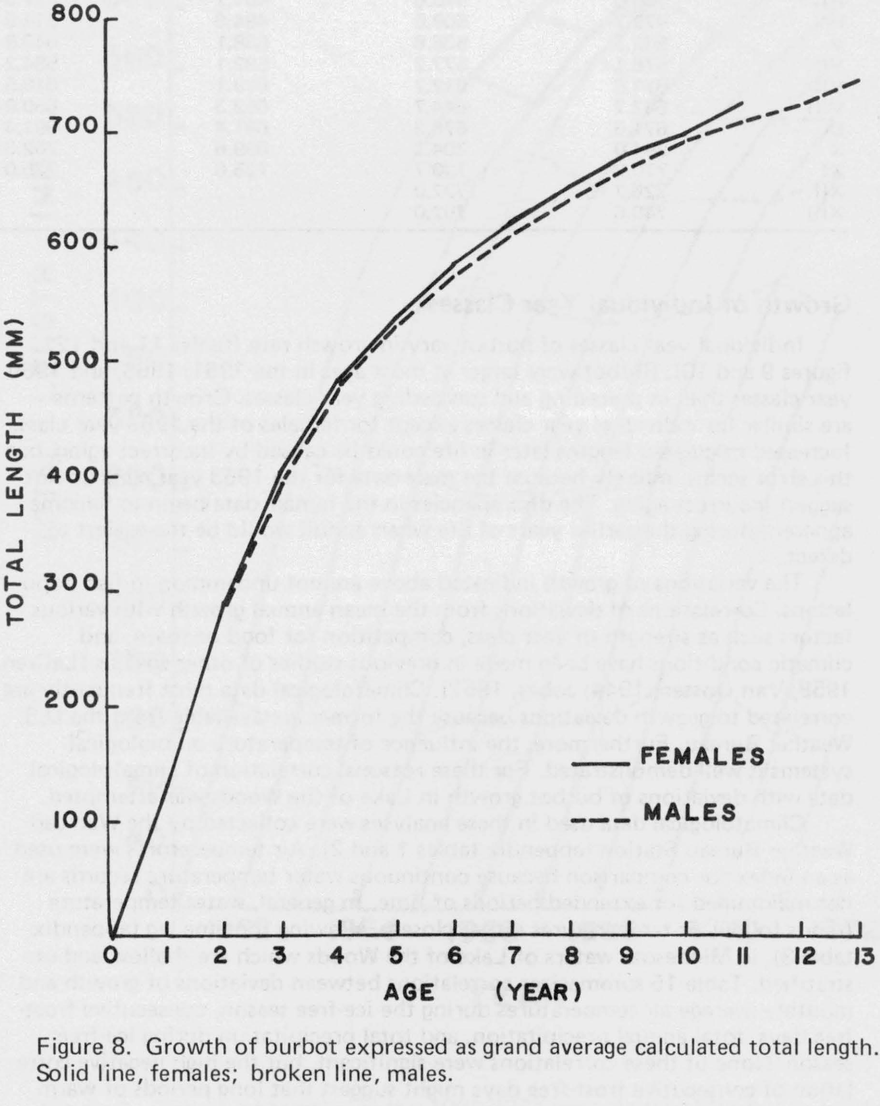

Figure 8. Growth of burbot expressed as grand average calculated total length. Solid line, females; broken line, males.

Table 14. Mean total lengths of burbot at time of capture and at time of annulus formation, expressed as millimeters

Age group	Males		Females	
	Length at annulus	Length at capture	Length at annulus	Length at capture
I	129.1	167.2	129.3	184.4
II	288.8	318.9	287.3	305.7
III	399.0	440.6	401.2	427.6
IV	479.2	509.5	484.6	514.9
V	532.3	535.6	538.1	543.9
VI	576.1	577.2	582.1	584.2
VII	611.8	612.7	619.1	610.5
VIII	643.7	644.7	652.3	650.0
IX	671.6	670.2	681.4	691.4
X	694.0	704.3	699.6	702.3
XI	710.2	720.7	725.6	735.0
XII	726.7	727.0		
XIII	745.6	752.0		

Growth of Individual Year Classes

Individual year classes of burbot vary in growth rate (tables 11 and 12, figures 9 and 10). Burbot were larger at most ages in the 1961, 1968, and 1969 year classes than in preceding and succeeding year classes. Growth patterns are similar for individual year classes except for females of the 1963 year class. Increased calculated lengths later in life could be caused by incorrect aging, but this error seems unlikely because the male data for the 1963 year class do not suggest incorrect aging. The discrepancies in the female data begin to become apparent during the earlier years of life when annuli would be the easiest to detect.

The variations of growth indicated above are not uncommon in fish populations. Correlations of deviations from the mean annual growth with various factors such as strength of year class, competition for food or space, and climatic conditions have been made in previous studies of other species (LeCren, 1958; Van Oosten, 1944; Jobes, 1952). Climatological data most frequently are correlated to growth deviations because the former are available from the U.S. Weather Bureau. Furthermore, the influence of temperature on biological systems is well demonstrated. For these reasons, correlation of climatological data with deviations of burbot growth in Lake of the Woods was attempted.

Climatological data used in these analyses were collected by the Warroad Weather Bureau Station (appendix tables 1 and 2). Air temperatures were used as an index for comparison because continuous water temperature records are not maintained for extended periods of time. In general, water temperature trends follow air temperatures rather closely, allowing for time lag (appendix table 3), in Minnesota waters of Lake of the Woods which are shallow and unstratified. Table 15 summarizes correlations between deviations of growth and monthly average air temperatures during the ice-free season, consecutive frost-free days, total annual precipitation, and total precipitation during ice-free season. None of these correlations were significant, but the high negative correlation of consecutive frost-free days might suggest that long periods of warm temperatures may affect growth adversely.

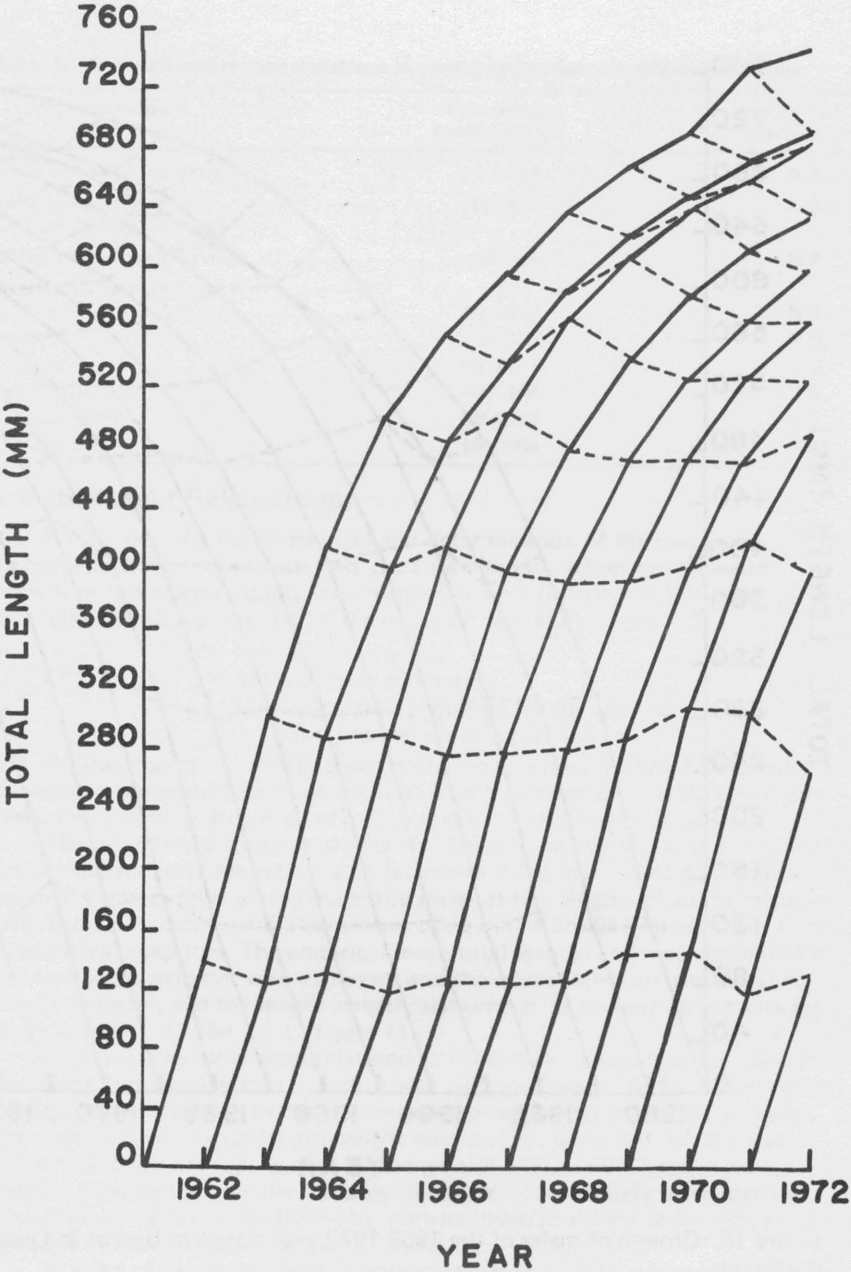

Figure 9. Growth of females of the 1961-1972 year classes of burbot in Lake of the Woods.

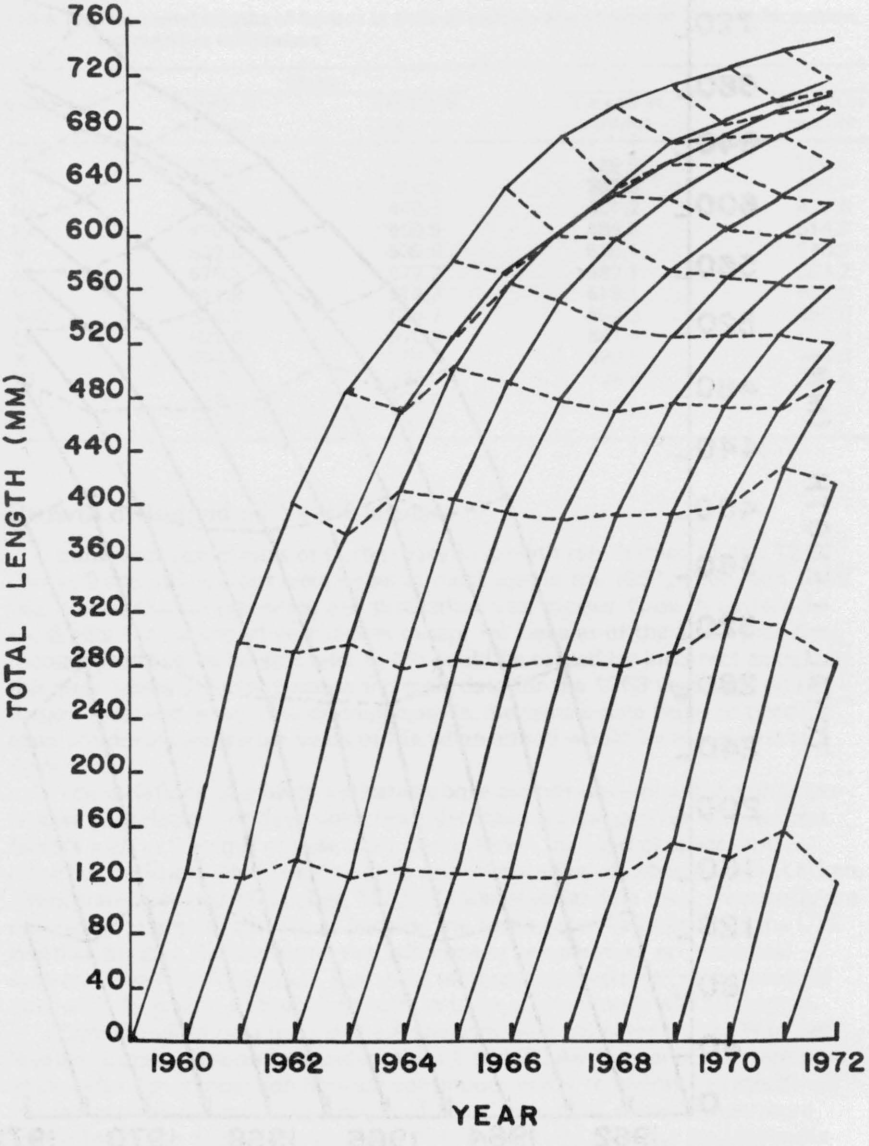

Figure 10. Growth of males of the 1959-1972 year classes of burbot in Lake of the Woods.

Table 15. Correlations between deviations in growth and various climatological factors

Climatological factor	Correlation coefficient (r)	Level of significance
Total annual precipitation	+0.1443	N.S.
Total precipitation – May through October	+0.0470	N.S.
Consecutive frost-free days	−0.5704	N.S.
Average air temperature		
May	+0.3312	N.S.
June	−0.1895	N.S.
July	+0.3927	N.S.
August	−0.1948	N.S.
September	−0.4343	N.S.
October	+0.1069	N.S.

Length-Weight Relationships

Predictions of a potential yield and determination of the proper sizes of fish to harvest for maximum sustained yield are directly related to fish weight. The growth in fish weight usually is considered to be a function of fish length, and this relationship is expressed by the equation $W = aL^b$ where:

W = fish weight in grams
L = fish length in millimeters
a and b = calculated constants for the specific fish population being considered

The log transformation of this equation to $\log W = \log a + b(\log L)$ is a more convenient method of handling the data, and the regression line of the length-weight relationship is computed by the method of least squares.

The length-weight relationship of the Lake of the Woods burbot was calculated independently for each sex to determine if any significant differences existed. Samples represented the entire range of fish lengths of adults including data from all sample years. Regressions using data from 856 females and 1,056 males were computed. The empirical mean total lengths and mean weights for the two sexes were not very different, and the regressions were similar. Data were combined, and the length-weight relationship for the population was $\log W = -4.4684 + 2.7484 \log L$ (figure 11).

Estimating length-weight relationship for fish in a population has several problems associated with it (Tesch, 1968; Hile and Jobes, 1941). Some species go through several distinct developmental stanzas during their lives, and each stanza may have its own length-weight relationship. Some old fish are slow-growing and are not represented by the general relationship. Length-weight relationships vary seasonally, notably during and immediately after spawning. Total fish weights may be biased by stomach content weight depending on the amount of food ingested just before weighing.

In Lake of the Woods burbot growth stanzas were not evident, and calculations did not include young-of-the-year fish. Older fish constitute a small percentage of the total sample, and their effect is not considered important. Only data collected from June through October were used in the length-weight calculations to exclude the effects of spawning.

The influence of stomach contents was considered the most likely source of error. Several investigations indicate that burbot have voracious appetites and consume large quantities of food at one time. Therefore, a heavy meal could add substantially to the total weight of the fish. No significant studies of this problem were found in the literature.

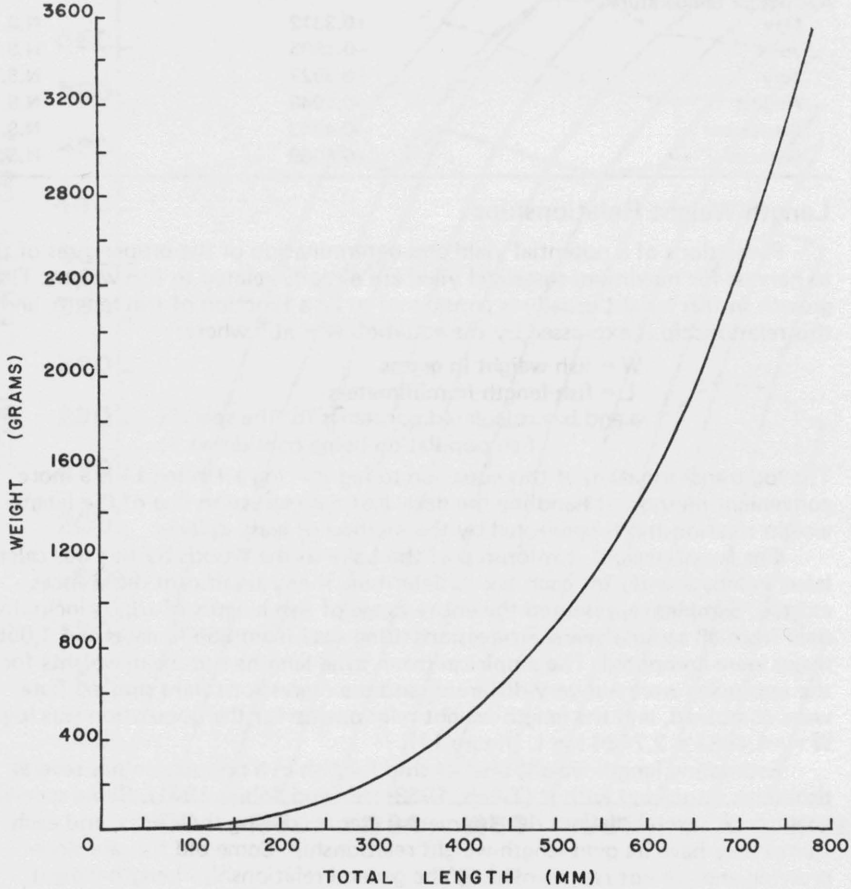

Figure 11. Length-weight relationship of 1 year or older burbot in Lake of the Woods.

The volume of stomach contents was determined for all stomachs collected. Because the specific gravity of the food items was approximately one, the volume estimates were considered a reliable means of determining the weight of stomach contents. Stomachs containing less than 1 cubic centimeter (1 gram) of food material were listed as empty. The weight of stomach contents in fish that contained food varied greatly in the 624 samples. The average weight of stomach contents was 3.6 percent of the total weight of the fish in the combined data, with values greater than 10 percent frequent at certain seasons of the year. One large fish contained food comprising 27.9 percent of its total weight. Chen (1969) reported similar values of stomach contents in Alaskan burbot but did not analyze the effect this weight had on the length-weight relationship. Of the 1,237 fish examined, 613 had empty stomachs.

Length-weight regressions were calculated for fish with empty stomachs and for those with food. These regressions were tested for differences using the analysis of covariance (Snedecor and Cochran, 1967). The two regressions were significantly different ($P = 0.01$).

The length-weight regression calculated on the total sample fell between the regressions for empty stomachs and stomach contents, as expected because it included both classifications. Covariance analyses showed no significant differences between the total length-weight regression versus empty stomach regression and the total regression versus stomach content regression.

This analysis shows that the weight of food in the stomach can adversely influence the length-weight relationship if the sample size is small or collected over a short time interval when feeding rates are great. Under these conditions, fish samples with empty or nearly empty stomachs would provide the best estimate of the length-weight relationship of the population.

An attempt was made to remove the bias of stomach content weight by calculating the length-weight regression after the weight of stomach contents had been subtracted from the total sample weight, but the results were not entirely satisfactory.

The total length-weight regression does not differ significantly from either of the other two regressions because the samples were collected over a long time interval and the sample size is large. Because this spread results in a sample distribution that is not dominated by either empty or full stomach conditions, the regression calculated for the total 1,912 samples is the best estimate and is used in other calculations.

Description of Growth in Weight

Growth in weight was calculated at the time of annulus formation for both males and females by using the back-calculated lengths and applying these values to the length-weight regression (table 16). Maximum weight increments occurred in the 4th year of life for both sexes, but maximum percentage increments were in the 2nd year. The slightly greater length and weight values of the males during the 2nd year probably are not significant, but the growth advantage enjoyed by the females thereafter is never overcome by the males (figure 12). The divergence of weights is very gradual and the general pattern of growth in weight reflects the calculated growth in length.

Average weights of age groups of burbot were tabulated from empirical weight values at time of capture (table 17). These data were collected throughout the growing season and represent some additional growth in weight beyond the value at annulus formation. Tables 16 and 17 show that the average weight at capture of each age group is between succeeding calculated weight values in nearly all cases. Weight at capture data also show that females weigh more than males of the same age.

Table 16. Calculated weights (grams) determined from the length-weight relationship using average calculated lengths at time of annulus formation

Age group	Females Calculated weight	Females Weight increment	Females Percentage increment	Males Calculated weight	Males Weight increment	Males Percentage increment
I	21.6	–	–	21.1	–	–
II	194.1	172.5	798.6	196.9	175.8	833.2
III	486.2	292.1	150.5	478.9	282.0	143.2
IV	817.0	330.8	68.0	792.0	313.1	65.4
V	1089.0	272.0	33.3	1058.0	266.0	33.6
VI	1352.0	263.0	24.2	1314.0	256.0	25.2
VII	1602.0	250.0	18.6	1550.0	236.0	17.9
VIII	1849.0	247.0	15.4	1782.0	232.0	14.9
IX	2084.0	235.0	12.7	2003.0	221.0	12.4
X	2242.0	158.0	7.6	2193.0	190.0	9.5
XI	2477.0	235.0	10.5	2335.0	142.0	6.5
XII	–	–	–	2488.0	153.0	6.6
XIII	–	–	–	2669.0	181.0	7.2

Table 17. Average weights (grams) at time of capture of various age groups of burbot

Age group	Males Mean weight	Females Mean weight
I	74.8	49.5
II	275.9	241.9
III	668.9	653.9
IV	1008.0	1020.1
V	1103.0	1196.0
VI	1383.0	1395.6
VII	1632.1	1748.6
VIII	1886.1	1968.6
IX	1978.4	2113.2
X	2226.5	2374.0
XI	2252.8	2237.8
XII	2777.5	–
XIII	2997.0	–

Alaskan burbot (Chen, 1969) represents fish geographically removed from the Lake of the Woods population and occupying a totally different habitat. The growth data were taken from fish in Alaskan rivers where growth is slower and the population lives longer. One specimen 972 mm long and 26 years old is reported, and fish 15 to 18 years old are not uncommon. Growth rates of the Alaskan burbot are distinctly slower than those in any other population. Table 18 data indicate that the length of a X annulus Alaskan burbot is comparable to a VI annulus fish from Lake of the Woods, and the Alaskan burbot's weight approximates that of a V annulus fish from Lake of the Woods.

Growth Comparisons With Other Populations

Table 18 compares growth of burbot in Lake of the Woods to growth of burbot in Lake Superior; Ocean Lake, Wyoming; and Alaskan rivers. They represent a diversity of habitats and geographic locations and demonstrate the variability of growth of the species.

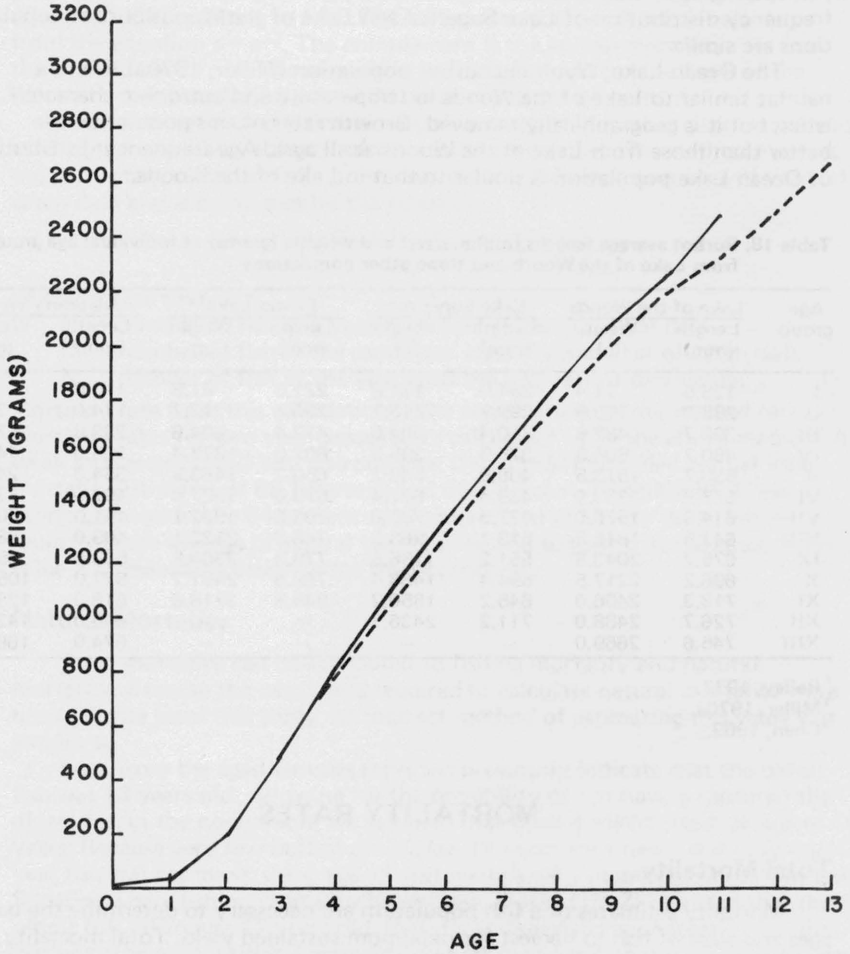

Figure 12. Growth of burbot expressed as weight at time of annulus formation. Solid line, females; broken line, males.

The Lake Superior burbot population (Bailey, 1972) has the fastest initial growth rate of the four populations in both length and weight. However, the annual length and weight increments decline during the 3rd year of life of Lake Superior burbot, and older fish are shorter and weigh less than similar aged fish in either Lake of the Woods or Ocean Lake, Wyoming. Aside from this difference, Lake Superior burbot growth is most comparable with that of the Lake of the Woods population. Similarities of growth in these two populations might be attributed to similar geographic locations, but the deeper, colder, oligotrophic characteristics of Lake Superior contrast sharply with Lake of the Woods. Age-frequency distribution of Lake Superior and Lake of the Woods burbot populations are similar.

The Ocean Lake, Wyoming burbot population (Miller, 1970a) live in a habitat similar to Lake of the Woods in temperature and eutrophic characteristics, but it is geographically removed. Growth rates of this population are better than those from Lake of the Woods at all ages. Age-frequency distribution of Ocean Lake population is similar to that in Lake of the Woods.

Table 18. Burbot average lengths (millimeters) and weights (grams) of individual age groups from Lake of the Woods and three other populations

Age group	Lake of the Woods		Lake Superior[1]		Ocean Lake[2]		Alaskan rivers[3]	
	Length (mm)	Weight (g)	Length (mm)	Weight (g)	Length (mm)	Weight (g)	Length (mm)	Weight (g)
I	128.5	21.4	254.0	131.8	221.0	81.8	110.0	7.8
II	288.2	195.5	299.7	213.7	325.1	213.7	174.0	30.4
III	398.7	482.6	340.4	304.6	472.4	604.6	238.0	76.7
IV	480.7	804.5	375.9	395.5	602.0	1377.4	298.0	149.0
V	533.7	1073.5	408.9	509.2	650.2	1463.8	354.0	247.9
VI	577.8	1333.0	439.4	627.4	670.6	1527.5	407.0	374.4
VII	614.3	1576.0	477.5	795.6	703.6	1932.1	451.0	507.2
VIII	647.5	1815.5	513.1	968.3	746.8	2132.1	499.0	683.8
IX	675.7	2043.5	551.2	1186.5	779.8	2304.8	538.0	854.1
X	696.2	2217.5	594.4	1468.4	769.6	2491.2	577.0	1050.4
XI	713.3	2406.0	645.2	1850.2	845.8	3718.6	618.0	1286.6
XII	726.7	2488.0	711.2	2436.7	–	–	640.0	1426.7
XIII	745.6	2669.0	–	–	–	–	674.0	1669.8

[1] Bailey, 1972.
[2] Miller, 1970a.
[3] Chen, 1969.

MORTALITY RATES

Total Mortality

Mortality estimates of a fish population are necessary to determine the best ages and sizes of fish to harvest for maximum sustained yield. Total mortality, fishing mortality, and natural mortality can be calculated. Several ways may be used to estimate total mortality rate, but the most common method is catch curve analysis. The catch curve is the plot (of all fish caught) of log frequency on the ordinate against the age on the abscissa. The ascending left limb and the dome of the resulting curve represent age classes that are not adequately sampled; this curve segment does not provide useful information. The curve's descending right limb represents the instantaneous survival rate. Unchanged mortality rate with time, uniform survival rate for each year class, and constant fishing and natural mortality rates are assumed in this analysis. These assumptions were not tested in Lake of the Woods but are believed to be reasonable for burbot.

The catch curve for burbot data (figure 13) was derived from the age-frequency data previously provided. Some flattening of the curve's dome suggests that recruitment to the catch is not complete until age VII. Therefore, the linear regression that best describes the descending right limb of the curve was calculated from data for age classes VII through XII by the method of least squares and is $Y = 5.6792 - 0.4320 X$. The instantaneous mortality rate (i) is obtained by changing the sign of the slope value and multiplying it by 2.3026 (Ricker, 1958) resulting in $i = 0.9947$. The annual survival rate is calculated from the equation $s = e^{-i}$. The complement is the annual mortality rate from the equation $a = 1 - s$. The respective values calculated for the Lake of the Woods burbot population are s = 36 percent and a = 64 percent.

A second method to estimate mortality rates of individual year classes was used to test the reasonableness of the catch curve value. This method involves the percentage reduction of a given year class in the catch over several years of catch data and is calculated by the equation:

$$s = \frac{N_2 + N_3 + \ldots\ldots\ldots N_r}{N_1 + N_2 + \ldots\ldots\ldots N_{r-1}}$$

where: s = survival rate

N_1 = number of fish in a year class the 1st year of catch data

N_2 = number of fish in the same year class the 2nd year of catch data

N_r = number of fish of the year class the last year of catch data.

Mortality rate from this calculation is the complement of the survival rate. Mortality rates for two year classes were calculated using the above method. A weak year class (1963) and a strong year class (1964) provided annual total mortality estimates of 69.1 percent and 56.1 percent, respectively. These estimates bracket the 64 percent catch curve total mortality value, which represents the average of several year classes, and suggest that the catch curve value is a reasonable estimate for the population.

Natural Mortality

Total mortality can be attributed to fishing mortality and natural mortality. Because the usual data required to calculate natural mortality were not available from this study, an indirect method of estimating this value was employed.

Data from the aged samples reported previously indicate that the oldest fish was 13 years old. Allowing for the possibility of not having captured the oldest fish in the population, we assumed that burbot might attain an age of 15 years. Because very few burbot older than 11 years were taken and only one 13-year fish was captured, using age 15 was considered a usable maximum. In Lake Superior where fishing mortality is very low, Bailey (1972) reported that the oldest fish taken was 12 years old. It was also assumed that natural mortality was not affected by fishing mortality and remained constant from year to year. The natural mortality rate was estimated to be 38 percent. This was determined by applying various trial rates in a sequential manner to an initial cohort population of 1,000 and reducing the remaining population by that trial rate for each year of the assumed 15-year life span. If the natural mortality rate of 38 percent occurred during the 1st year on a population of 1,000 fish, only 620 fish would remain at the beginning of the 2nd year. If 38 percent of these 620 fish died during the 2nd year, only 384 fish would remain at the beginning of the 3rd year. An assumed constant 38 percent natural mortality rate applied in this manner would result in total mortality of the cohort at the end of 15 years.

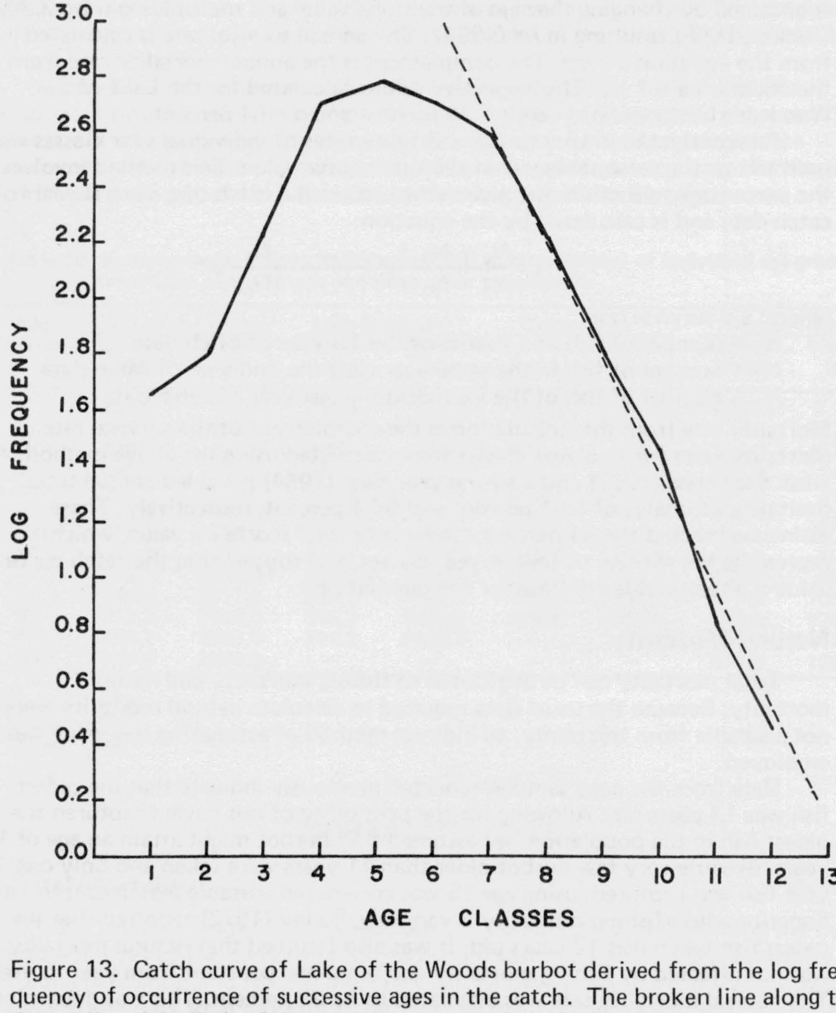

Figure 13. Catch curve of Lake of the Woods burbot derived from the log frequency of occurrence of successive ages in the catch. The broken line along the descending right limb of the curve represents the calculated regression equation of Y = 5.6792 – 0.4320 X.

This rate may be too high in the age groups subjected to the fishery and almost certainly is a maximum in Lake of the Woods.

Fishing Mortality

Fishing mortality rate was determined from the relationship

$$a = m + n - \frac{mn}{100}$$

where:

a = total mortality rate
m = fishing mortality rate
n = natural mortality rate.

Applying the total and natural mortality rates of 64 percent and 38 percent, the estimated fishing mortality rate is 41.9 percent.

GROWTH OF YOUNG-OF-THE-YEAR BURBOT

The growth rate of fish during the 1st year of life is very different from growth rates at older ages during the same year (Pycha and Smith, 1954; Hile, 1941). This difference can be explained by changes in behavioral patterns and/or shifts in food utilization. During the 1st year, deviations in growth caused by varying environmental factors may have long-term effects on growth and survival during succeeding years. Because of these considerations, growth of young-of-the-year burbot was considered separately from growth of older fish in the population.

Young-of-the-year burbot were taken in an ecological trawl from July through October. Sampling at monthly intervals in 1970, 1971, and 1972 yielded 127, 143, and 199 fish, respectively. Sampling dates during 1971 and 1972 did not coincide exactly with those in 1970. Some of the differences in average monthly lengths and weights (table 19) may result from these time differences. For example, the August sample in 1970 was taken during the 1st week of the month and in 1971 and 1972 was collected during the 3rd week. This difference probably accounts for the monthly differences evident between years.

Length-weight relationship equations are:

$$1970 \quad \text{Log } W = -4.5292 + 2.6676 \log L$$
$$1971 \quad \text{Log } W = -5.1090 + 3.0051 \log L$$
$$1972 \quad \text{Log } W = -4.9825 + 2.9258 \log L$$

Differences from year to year may be caused by climatological factors (appendix tables 1 and 2) which influenced the growth. Associated with the poorest growth in 1970 is a shorter period of consecutive frost-free days during the year, colder average monthly temperatures during the egg incubation and hatching period of March through May, and higher average monthly precipitation during the same period. Hatching time may have been retarded by these factors, or food availability for the fry may have been less abundant with resulting poor growth.

Table 19. Mean lengths and weights of young-of-the-year burbot in succeeding months (July – October) in 1970, 1971, and 1972 (Lengths in millimeters, weights in grams)

Year		Months			
		July	Aug.	Sept.	Oct.
1970	Length	37.4	48.2	57.3	–
	Weight	0.481	1.021	1.487	–
1971	Length	36.7	65.2	87.4	115.7
	Weight	0.404	2.273	5.253	14.401
1972	Length	52.0	77.6	–	101.0
	Weight	1.132	3.840	–	7.948

Variability of growth rate within an age class may influence the length-weight relationship. Figure 14 shows an example of such variability in length of fish from a single age class. The fish were collected during mid-August in 1971 and measured 47, 54, 66, and 77 mm in total length. If the weights of these variable length fish are different than weights of similar length fish taken at other times during the summer, the length-weight relationship will be influenced. This consideration is particularly important when length-weight relationship is calculated from relatively small sample sizes such as were available for this study.

A more representative estimate of the length-weight relationship of young-of-the-year burbot in Lake of the Woods is provided by the equation

$$\log W = -4.9168 + 2.8957 \log L$$

derived from the combined data of 3 years (figure 15).

The condition factor (K) was calculated from the equation

$$K = \frac{100{,}000W}{L^3}$$

where: W = weight in grams

L = total length in millimeters.

The factors were compared with the chi-square test and were not significantly different ($P = 0.05$). All data were therefore combined and K was determined to be 0.7913.

FOOD OF BURBOT AND ASSOCIATED SPECIES

The food habits of burbot from a wide range of habitats have been studied (Van Oosten and Deason, 1938; Bjorn, 1940; Clemens, 1951a; McCrimmon and Devitt, 1954; Beeton, 1956; Bonde and Maloney, 1960; Chen, 1969; Bailey, 1972). The most frequent conclusion drawn from these observations is that the burbot has a voracious and omnivorous appetite. Volumetric data on stomach contents and the high percentage of fish in the diet strongly imply that burbot may compete with other predatory fish for food resources. The usual definition of competition is the simultaneous demand for a resource by more than one organism at a time when the resource supply is insufficient to meet the demand (Larkin, 1956). Nearly all previous studies lack sufficient information to determine abundance and availability of the food items found in burbot diets. Many studies also lack food data for other fish taken at the same time and in the same area as the burbot. Where comparable data are available, the competitive relationship has not been established. Starret (1950) indicated that fish may change their diet rather than compete for a food source when its availability is low, and therefore the stomach contents do not necessarily reflect the fish's usual or preferred food choices. This kind of opportunistic feeding behavior seems highly probable with burbot because a wide range of food is found in the stomachs. Indiscriminate feeding by burbot was suggested by Bailey (1972) because he found many nonfood items and inorganic material in the stomachs of Lake Superior burbot.

Previously reported burbot food analyses frequently have other biases. Some studies were limited to short-time intervals and reflect seasonal effects. Bonde and Maloney (1960) reported 93.8 percent of the burbot stomachs examined during December and February contained fish while 18.8 percent contained invertebrates. The ratio of fish to invertebrates eaten may be very different at other times of the year, however. Furthermore, a psychrophyllic species such as burbot may feed more at this time of the year than do other species in the ecosystem.

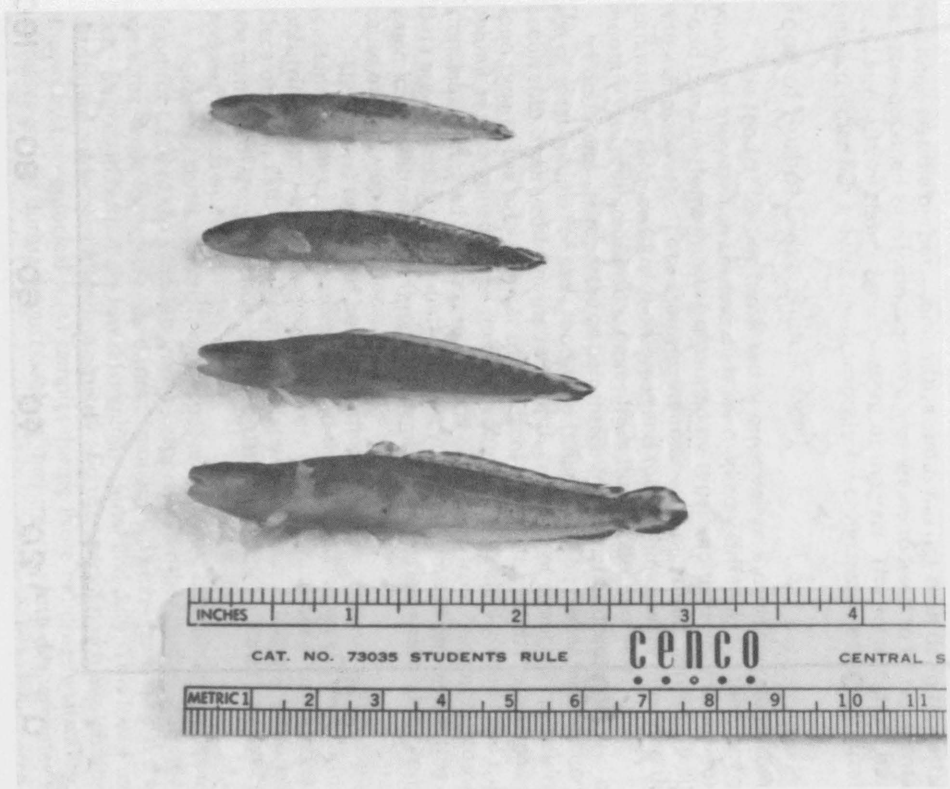

Figure 14. Young-of-the-year burbot collected in mid-August 1971. Total lengths of these fish were 47, 54, 66, and 77mm.

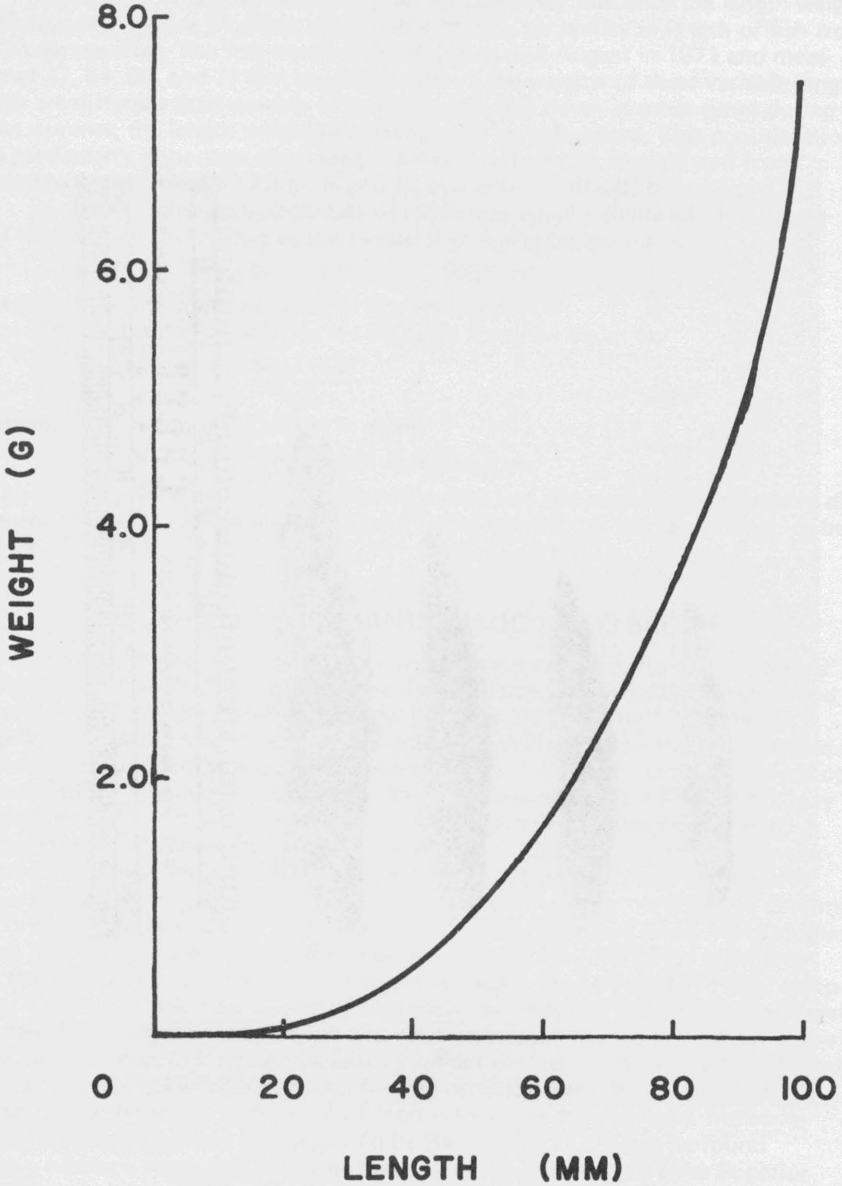

Figure 15. Length-weight relationship of young-of-the-year burbot in Lake of the Woods.

Many food studies are restricted by the size of fish sampled. Beeton (1956) and Clemens (1951a) both concluded that there is a distinct correlation between fish size and food volume and item size consumed. A dietary shift from plankton and invertebrates to fish is common in many species as fish grow larger. If stomach samples were primarily from larger fish, the results may indicate a higher use of fish than actually occurs in the entire population.

The food study from Lake of the Woods has minimized many of the above problems, but the burbot's competitive status has not been definitely established. Samples obtained with various fishing gear are considered to be representative of all age and size classes for all seasons of the year. The present study has also sampled other fish species simultaneously for comparisons of food utilization.

Food of Burbot Older Than 1 Year

The food of burbot 1 year old or older was analyzed separately from the young-of-the-year fish because diets are markedly different for these age groups. Food items in stomachs were separated by types and their volume measured by water displacement. Total stomach volumes were measured, and final volume summations for individual food types and total volumes were tabulated on a monthly basis for combined samples from the 5 collection years.

Food items are reported as percentage frequency of occurrence and percentage of total volume for each food type (table 20). The percentage frequency of occurrence is derived from the ratio of the number of stomachs containing a given food type to the total number of stomachs containing food. Percentage of total volume is determined as the summed volume of a particular food type from all stomachs compared to the total volume of all food from nonempty stomachs. Data are available for all months except April and limited samples during May when ice conditions were unsafe. November samples were restricted similarly because of freeze-up conditions.

The general pattern of burbot feeding varied throughout the year with the greater number of empty stomachs and the smaller average volumes of food occurring from June through September. Feeding increases from October through December, and although it remains relatively high from January through March, the number of empty stomachs in February probably indicates that feeding is reduced by spawning activity.

Seasonal shifts in use of food types are evident, but fish are an important food for Lake of the Woods burbot as reported in other studies. Juvenile perch were the single fish species used most frequently. Perch occurrence and stomach volumes in burbot are low during May, June, and July. This lower use is attributed to depressed feeding activity and the lack of perch availability as shown by the ecological trawl samples during those months. Availability of perch increases greatly during August because they migrate into deeper water and are larger. Burbot use of perch increases correspondingly. Numbers of perch ingested by burbot can be great. One stomach collected in March from a spent female contained 288 juveniles.

The apparent use of tullibee must be interpreted cautiously. Trawl-caught burbot during the ice-free periods use some tullibee, but from November through March tullibee are consumed in large numbers. Because winter samples are collected with fyke nets, burbot may be gorging on captured tullibee that might not otherwise be available. This gorging phenomenon of trapnet-caught burbot is reported in several other studies also. The stomach analysis of fish caught in pound nets during September and October 1972 confirm that gorging does occur. Most stomachs contained tullibees, each several hundred grams in weight; often one stomach contained two or three fish. These samples (not included in the final data tabulation) show that walleyes and saugers of sizes comparable to the

Table 20. Monthly food utilization of burbot older than 1 year expressed as percentage frequency of occurrence (and percentage by volume in parentheses) for all stomachs containing food

Food item	January	February	March	April	May	June
Total number stomachs	78	105	93	—	4	257
Empty stomachs	26	79	41	—	0	135
Average volume (cc)	29.5	32.6	29.4	—	35.1	9.6
Fish	76.9(60.0)	38.5(58.4)	46.2(71.0)	—	50.0(23.3)	14.8(17.6)
Perch	53.8(14.8)	15.4(52.4)	26.9(51.3)	—	—	0.8(<0.1)
Tullibee	34.6(37.9)	26.9(5.8)	11.5(7.1)	—	—	4.9(8.3)
Shiners	9.6(0.7)	3.8(0.2)	9.6(3.5)	—	—	0.8(0.4)
Saugers	1.9(4.5)	—	1.9(4.1)	—	—	—
Walleye	1.9(1.3)	—	1.9(0.1)	—	—	—
Troutperch	—	—	—	—	50.0(22.6)	4.1(8.7)
Darters	1.9(<0.1)	—	—	—	—	—
Sucker	—	—	1.9(2.1)	—	—	—
Unidentified	3.8(0.7)	—	5.8(2.8)	—	25.0(0.7)	2.5(0.2)
Crustaceans	80.0(33.7)	92.3(41.5)	78.8(27.9)	—	100.0(72.5)	23.0(31.6)
Decapoda	80.0(33.7)	92.3(41.5)	78.8(27.9)	—	100.0(72.5)	23.0(31.6)
Insects	26.9(3.0)	—	15.4(0.9)	—	25.0(0.1)	74.6(50.5)
Ephemeroptera	26.9(3.0)	—	15.4(0.9)	—	25.0(0.1)	74.6(50.5)
Trichoptera	—	—	3.8(<0.1)	—	—	—
Chironomidae	—	—	1.9(<0.1)	—	—	0.8(<0.1)
Odonata	1.9(<0.1)	—	—	—	—	—
Dytiscidae	—	—	—	—	—	0.8(<0.1)
Mollusca	1.9(<0.1)	3.8(<0.1)	—	—	—	0.8(<0.1)
Clams	1.9(<0.1)	3.8(<0.1)	—	—	—	0.8(<0.1)
Annelida	—	—	5.8(0.2)	—	—	4.1(0.2)
Hirudinea	—	—	5.8(0.2)	—	—	4.1(0.2)
Amphibia	1.9(3.3)	—	—	—	25.0(4.1)	—
Frog	1.9(3.3)	—	—	—	25.0(4.1)	—

Table 20 continued

Food item	July	August	September	October	November	December
Fish	18.9(29.6)	72.9(49.5)	81.3(61.6)	71.4(18.2)	85.7(45.4)	96.4(83.9)
Perch	6.7(0.6)	54.1(20.5)	48.2(32.0)	31.4(7.4)	85.7(14.3)	57.1(26.9)
Tullibee	4.4(19.5)	8.3(11.4)	5.4(11.5)	11.4(1.1)	42.9(26.2)	57.1(45.3)
Shiners	–	–	1.8(0.4)	–	–	3.6(0.4)
Saugers	–	1.5(6.0)	1.8(7.1)	5.7(0.7)	–	3.6(2.1)
Walleye	–	–	–	–	–	–
Troutperch	7.8(5.4)	19.5(10.6)	15.2(8.7)	28.6(8.8)	14.3(4.9)	–
Darters	4.4(1.5)	1.5(0.2)	1.8(0.3)	–	–	–
Suckers	–	–	–	–	–	–
Burbot	1.1(<0.1)	0.8(0.6)	0.9(<0.1)	–	–	–
Bullhead	–	–	–	–	–	7.1(0.1)
Unidentified	6.7(2.6)	2.3(0.2)	17.9(1.6)	5.7(0.2)	14.3(<0.1)	3.6(9.1)
Crustaceans	32.2(34.8)	53.4(48.2)	73.2(37.4)	91.4(73.6)	85.7(53.5)	82.1(15.7)
Decapoda	50.0(34.8)	52.6(48.2)	73.2(37.4)	91.4(73.6)	85.7(53.5)	57.1(15.7)
Cladocera	–	0.8(<0.1)	–	–	–	–
Amphipoda	1.1(<0.1)	0.8(<0.1)	–	–	–	–
Insects	50.0(35.3)	12.0(2.0)	20.5(0.2)	37.1(7.7)	42.9(0.9)	3.6(<0.1)
Ephemeroptera	54.4(35.0)	7.5(0.1)	12.5(0.2)	28.6(7.7)	42.9(0.9)	3.6(<0.1)
Trichoptera	1.1(<0.1)	–	1.8(<0.1)	–	–	–
Chironomidae	11.1(0.3)	5.3(1.9)	1.8(<0.1)	8.6(<0.1)	–	–
Odonata	–	–	–	–	–	–
Corixidae	3.3(<0.1)	–	0.9(<0.1)	–	–	–
Dytiscidae	–	–	–	–	–	–
Mollusca	–	2.3(<0.1)	1.8(<0.1)	–	14.3(<0.1)	7.1(<0.1)
Clams	–	2.3(<0.1)	1.8(<0.1)	–	14.3(<0.1)	7.1(<0.1)
Snails	–	–	–	–	–	3.6(<0.1)
Annelida	–	0.8(0.2)	–	–	–	–
Hirudinea	–	0.8(0.2)	–	–	–	–
Amphibia	–	–	–	–	–	–
Frog	–	–	–	–	–	–

tullibees in burbot stomachs were also captured in the pound nets but were seldom eaten. Assuming that the three species were equally vulnerable to burbot predation in the nets, it appears that walleye and sauger were not a preferred food.

Troutperch is the only other fish species that was used consistently by burbot. Its abundance, as determined from trawl catches, was relatively high throughout the summer with greatest concentrations in deep water. Although volume and frequency of occurrence of this species in burbot stomachs were never large, it may contribute significantly to the burbot diet during periods of reduced feeding. The game species and other forage fish in the stomachs do not indicate that the burbot is a serious predator in Lake of the Woods.

The crayfish *(Orconectes sp.)* is the most important single food item in the diet of Lake of the Woods burbot. Its frequency of occurrence is always high and frequently it ranks first in percentage of total stomach volume. Insects are used by burbot throughout the year, but the volumes are small and the total contribution, with one exception, is minor. Mayflies *(Hexagenia limbata* (Serville)*)* dominate burbot food, both in amount and frequency, during June and July.

Inorganic debris and aquatic vegetation frequently were found in the stomachs and are believed to have been ingested accidentally.

Food Utilization by Burbot, Walleye, and Sauger

Data on food of the walleye and sauger in Lake of the Woods are available from a previous study (Swenson, 1972). These data and the first 3 years' samples of burbot stomachs were collected simultaneously and, therefore, permit comparisons of food habits.

Comparisons were limited to June through September because data for all three species were available only during this period. Food types considered were the items commonly occurring in the diets of all three species of fish (table 21), and percentage frequency of occurrence was used for comparison.

Table 21. Monthly percentage frequency of occurrence of common food items found in the stomachs of burbot, walleye, and sauger from Lake of the Woods

Species	Food item	Frequency of occurrence (%)			
		June	July	Aug.	Sept.
Burbot	Ephemeroptera	74.6	54.4	7.5	12.5
	Chironomidae	0.8	11.1	5.3	0.0
	Decapoda	24.6	50.0	52.6	73.2
	Perch	0.8	6.0	54.1	48.2
	Troutperch	4.1	7.8	19.5	15.2
	Tullibee	4.9	4.4	8.3	5.4
	Darters	0.0	4.4	1.5	1.8
	Shiners	0.8	0.0	0.0	1.8
Walleye	Ephemeroptera	38.0	41.0	4.0	1.0
	Chironomidae	4.0	1.0	0.0	0.0
	Decapoda	1.0	2.0	2.0	0.0
	Perch	5.0	76.0	76.0	93.0
	Troutperch	10.0	2.0	3.0	1.0
	Tullibee	15.0	1.0	6.0	7.0
	Darters	1.0	1.0	2.0	1.0
	Shiners	11.0	9.0	4.0	3.0
Sauger	Ephemeroptera	8.0	8.0	0.0	0.0
	Chironomidae	1.0	1.0	0.0	0.0
	Decapoda	0.0	1.0	0.0	0.0
	Perch	3.0	65.0	80.0	66.0
	Troutperch	78.0	38.0	15.0	29.0
	Tullibee	1.0	1.0	1.0	10.0
	Darters	4.0	2.0	1.0	1.0
	Shiners	5.0	4.0	2.0	3.0

Testing for similarity of food utilization was done with an analysis of variance of a factorial design including three species of fish X 4 months X eight food items. An arcsin transformation of the data provided the best test.

The effect of food type on the frequency of occurrence for the combined diets of the three fish species during all months was highly significant ($P = 0.01$, $F = 20.21$). The interactions of monthly differences with respect to food items utilized and species differences with respect to food items utilized were also highly significant ($P = 0.01$, $F = 4.77$, and $F = 7.65$, respectively) and are of primary consideration.

Perch, mayflies, troutperch, and crayfish in decreasing order were the items most heavily used, but the time of use and the fish species preference for individual foods were different. Perch ranked first in the walleye and sauger diets but third for burbot. Mayflies ranked second in the sauger diet, fourth in burbot, and fifth in walleye. Crayfish are first in the burbot diet but eighth in both walleye and sauger diets.

Monthly differences in food use by all species was especially apparent during June and July. In June, mayflies, troutperch, and crayfish were the order of use, but this changed in July to perch, mayflies, and crayfish. August and September orders of use were perch, crayfish, and troutperch.

The reasons for the fish species' monthly changes in food use and differences of food habits cannot be determined easily. Availability and abundance of perch restrict its use during June. On the other hand, mayflies are most available in June and July when large hatches occur and, therefore, are prevalent in the diets then. Although certain foods are abundant, they may not be equally available to all fish species because of restrictive habitat preferences. Another source of variation is the flexibility of individual fish species in feeding habits. Swenson (1972) lists 17 food items in the diets of walleye and sauger, while burbot stomachs included 23 food items. Feeding behavior also influences food habits. The tendency of burbot to feed more on the bottom than either walleye or sauger probably accounts for their greater use of crayfish. Burbot also feed more during the colder seasons than do the other species. These analyses and considerations indicate that burbot food habits are different than those of walleye and sauger in Lake of the Woods and that competition for the food resources appears to be slight.

Food Habits of Young-of-the-Year Burbot Compared to Other Species

Juvenile game species and small forage fish species were collected simultaneously with young-of-the-year burbot in the ecological trawl. Randomly selected samples of these species and the burbot were analyzed. Food items were estimated or enumerated by direct count, and the percentage frequency of occurrence was tabulated in the same manner as with adult fish (table 22). Final comparisons were made based on frequency of occurrence.

Juvenile burbot were compared to the other species using Spearman's coefficient of rank correlation (Snedecor and Cochran, 1967) and analysis of variance. In the first method food types that occurred in both burbot and the fish species being compared were ranked in decreasing order of occurrence. If a tie occurred between any two categories, the largest item was ranked first. Differences in ranks were determined, and the correlation coefficient was calculated using the equation

$$r_s = 1 - \frac{6D^2}{N(N^2 - 1)}$$

where:

r_s = rank correlation coefficient

D = difference between two ranks

N = number of categories ranked

An r_s value of +1 indicates that the various food categories were eaten in the same order of preference by both fish species being compared; a 0 value indicates no relationship; and a −1 value indicates opposite food preferences.

Correlation coefficients (table 23) show that only burbot and darters commonly utilize the same food resources to any significant degree and that both species have the same decreasing order of food preference.

Table 22. Food of young-of-the-year burbot and other forage-size fish species in Lake of the Woods expressed as percentage frequency of occurrence

Food item	Percent frequency of occurrence							
	Burbot	Perch	Shiners	Troutperch	Tullibee	Darters	Walleye	Sauger
Insects								
Chironomidae	84.8	6.3	44.1	60.0	18.2	82.9	7.0	6.3
Ephemeroptera	15.9	5.8	—	46.0	0.9	12.4	4.7	2.3
Trichoptera	2.0	—	16.9	0.9	2.7	1.9	—	—
Coleoptera	0.7	—	—	—	0.9	—	—	—
Odonata	0.2	—	—	—	—	—	—	—
Corixidae	0.4	3.9	3.4	0.9	1.8	1.0	—	—
Notonectidae	0.4	—	—	—	0.9	—	—	—
Diptera	—	0.5	3.4	3.8	3.6	2.9	14.0	11.7
Hemiptera	—	—	—	—	0.9	—	—	—
Hymenoptera	—	—	15.3	—	4.5	—	—	—
Crustaceans								
Decapoda	8.5	—	—	1.7	—	—	—	—
Daphnia	72.7	85.9	49.2	66.0	98.2	57.1	72.1	71.9
Leptodora	11.2	31.1	13.6	40.4	50.9	7.6	79.1	43.8
Alonella	1.6	1.5	—	5.5	1.8	19.0	—	—
Copepoda	46.8	52.9	6.8	18.3	16.4	26.7	34.9	46.9
Amphipoda	18.8	2.4	1.7	8.5	0.9	8.6	7.0	2.3
Ostracoda	4.0	—	—	3.0	—	3.8	—	—
Annelida								
Hirudinea	0.2	—	—	0.4	—	—	—	—
Mollusca								
Clams	0.4	—	—	—	—	—	—	—
Snails	—	0.5	—	—	—	—	—	—
Hydracarina	0.4	—	—	—	—	—	—	—
Fish remains	7.8	2.9	5.1	—	—	7.6	18.6	9.4
Total stomachs	465	225	75	279	110	127	44	148
Empty stomachs	18	19	16	44	0	22	1	20

Table 23. Food comparisons of young-of-the-year burbot with other forage size species by rank correlation coefficient (r_s) of food categories (N) utilized by both species

Comparison	N	r_s	Significance level
Burbot vs. perch	9	+.617	N.S.
Burbot vs. shiners	8	+.524	N.S.
Burbot vs. troutperch	12	−.455	N.S.
Burbot vs. tullibee	11	+.446	N.S.
Burbot vs. darters	11	+.791	0.01
Burbot vs. walleye	7	−.143	N.S.
Burbot vs. sauger	7	+.214	N.S.

The second method was an analysis of variance of a factorial design that included seven fish species X 3 months X eight food items (table 24). Juvenile walleye and sauger were combined in a category because their diets were very similar.

The difference in use of individual food items by all fish species during the 3 months was highly significant (P = 0.01, F = 36.71) (table 24), and the interactions of the three factors are important. The relationships of different species taking certain food and various foods being used during different months were both highly significant (P = 0.01, F = 3.60, and F = 2.51, respectively). However, individual fish species did not change their food preferences significantly from month to month.

Additional analyses of significant interactions were conducted in an attempt to clarify specific differences in feeding habits. Tests of month-to-month differences in use of the food resources by all fish show the four major food items, in decreasing order of preference, during July were *Daphnia,* Chironomidae, Copepoda, and fish remains. This sequence changed to *Daphnia,* Chironomidae, Copepoda, *Leptodora,* and Chironomidae. The other four food items also had some monthly changes in order of use but usually contributed only small amounts to the total food. Although no data on availability of these foods are available, this factor probably would be a major cause of monthly changes.

Finally, the four major food items were separated from the ones of minor importance, and their use by all fish species was tested. Significant differences in levels of food use occurred among the fish species (P = 0.01, F = 3.52), but the general patterns of food use were similar. A good example of this phenomenon is the comparison of burbot with darters during August. The burbot order of preference of the four major food items was Chironomidae, *Daphnia,* Copepoda, and *Leptodora.* The same order of preference occurs for the darters, but the frequency of occurrence is lower in most cases.

Table 24. Monthly percentage frequency of occurrence of common food items in the stomachs of young-of-the-year burbot and other forage size species in Lake of the Woods

Months	Food item	Percent frequency of occurrence						
		Burbot	Perch	Shiners	Troutperch	Tullibee	Darters	Walleye, sauger
July	Chironomidae	64.6	4.5	11.1	77.1	33.3	72.7	0.0
	Ephemeroptera	4.4	0.0	0.0	25.7	0.0	27.3	0.0
	Trichoptera	1.8	0.0	0.0	2.9	0.0	0.0	0.0
	Daphnia	58.4	72.7	38.9	57.1	99.9	27.3	0.0
	Leptodora	8.8	13.6	16.7	25.7	50.0	0.0	0.0
	Copepoda	54.9	90.9	0.0	25.7	33.3	36.4	0.0
	Amphipoda	0.0	0.0	0.0	8.6	16.7	18.2	0.0
	Fish remains	6.2	0.0	16.7	0.0	0.0	45.5	99.9
August	Chironomidae	90.3	3.4	40.0	68.6	23.1	91.5	5.1
	Ephemeroptera	8.7	1.7	0.0	36.4	1.5	10.2	0.0
	Trichoptera	2.1	0.0	35.0	0.0	1.5	3.4	0.0
	Daphnia	86.7	95.8	55.0	87.3	98.5	69.5	93.2
	Leptodora	7.2	30.5	20.0	46.6	41.5	6.8	27.1
	Copepoda	53.3	44.9	0.0	16.9	4.6	25.4	50.8
	Amphipoda	26.2	0.8	0.0	10.2	0.0	10.2	0.0
	Fish remains	11.3	0.0	0.0	0.0	0.0	0.0	3.4
Sept.	Chironomidae	97.8	1.9	68.8	21.2	7.7	60.0	1.7
	Ephemeroptera	36.0	13.0	0.0	61.5	0.0	20.0	0.0
	Trichoptera	2.2	0.0	18.8	0.0	5.1	0.0	0.0
	Daphnia	86.5	87.0	56.3	53.8	97.4	70.0	96.7
	Leptodora	28.1	44.4	6.3	46.2	66.7	20.0	83.3
	Copepoda	43.8	66.7	25.0	25.0	33.3	45.0	66.7
	Amphipoda	20.2	1.9	6.3	7.7	0.0	5.0	1.7
	Fish remains	3.4	0.0	0.0	0.0	0.0	0.0	0.0

REPRODUCTION

The spawning habits of burbot are difficult to determine because they spawn during mid-winter under the ice. Cahn (1936) presented one of the few descriptions of spawning in a natural environment. He stated that spawning occurs at night in shallow water over gravel or sand bottoms when males and females form writhing globular masses and simultaneously deposit milt and eggs. Fabricius (1954) studied burbot spawning in the laboratory and noted the stimulating body contact between males and females at the time eggs and milt were shed and also verified the nocturnal pattern of spawning.

The time of spawning is reported to be from as early as November in European populations to as late as April in Lake Erie (Clemens, 1951b). Spawning occurs during February and March in most North American populations. The Lake of the Woods population is typical with males and females reaching the peak of ripeness during the last 2 weeks of February in 1970, 1971, and 1972. Females collected after the 1st week of March were nearly all spent, and some unspent females contained impacted eggs that probably would not have spawned at all.

The age at sexual maturity varies in different populations with 2- to 3-year-old fish from the Susquehanna River being the youngest (Robins and Deubler, 1955) and 6- to 7-year-old Alaskan burbot (Chen, 1969) being the oldest. Hewson (1955) suggested that size of burbot rather than age determined sexual maturity. In Lake of the Woods sexual maturity is usually reached at 4 years and sizes between 400 and 500 millimeters total length. A few 3-year-old fish were taken during spawning runs, but were mostly immature or precocious males.

Burbot spawning grounds in Lake of the Woods were not determined. Spawning fish were captured at the mouth of the Warroad River in an area of shallow water with a muddy bottom. Because this type of substrate is not that reported in the literature, spawning probably did not occur there. Several spawning migrations from lakes up rivers have been reported, but McCrimmon (1959) attributes these movements to feeding rather than spawning. L. L. Smith (personal communication) reports collecting juvenile burbot in south shore tributary streams of Lake Superior. Numerous attempts to collect eggs, fry, or juveniles in various sections of the Warroad River were unsuccessful. Other possible spawning grounds in the lake include several shallow rock reef areas well offshore, the sand and gravel inshore areas along the south shoreline, and shallow rocky channels among the islands in the northern areas of the lake. None of these locations could be reached in the winter from the field station at Warroad, Minnesota.

Fecundity

Fecundity estimates for burbot in Lake of the Woods were made from 158 ovary samples representing all ages and sizes during 1970, 1971, and 1972 spawning runs. The ovaries were placed in Gilson's solution for several weeks to permit digestion of the ovarian tissue and hardening of the eggs. The total volume of eggs in each of 33 samples was measured by water displacement, and two aliquots of known volumes were counted and averaged. A final estimate of total eggs was then made.

The number of eggs in each of the remaining 125 samples was estimated by measurement of diameter of 25 eggs. The relationship of average egg diameter to number of eggs per milliliter was calculated by the method of least squares. The resulting regression equation was $Y = 6437.875 - 5471.056\ X$. This equation was used with total egg volume and average egg diameter to estimate total egg numbers. Estimates determined by both methods were similar.

Egg size increased from an average of 0.599 millimeters in December to 0.716 millimeters in January and finally reached 0.819 millimeters at the time of spawning. The final diameter is much smaller than the 1.25 mm size reported from Burntside Lake, Minnesota, (Cahn, 1936) or the 1.04 mm eggs from the Ring Lake, Wyoming, population (Bjorn, 1940). The maximum egg size observed from Lake of the Woods samples was 1.12 mm.

The range in estimated egg numbers per female from Lake of the Woods varied from a low of 142,442 to a high of 1,380,640 with an average number for all fish of 364,342 eggs. These numbers are considered minimum estimates because a few eggs were lost during the ovary cleaning process. The average number of eggs per fish is smaller than reported for many populations. The average number of eggs per female in Lake of the Woods is about half the 812,282 eggs per female reported by Bailey (1972) for the Lake Superior population. Fecundities of other North American burbot populations vary from 64,000 eggs per female (Bjorn, 1940) to 1,363,000 eggs per female (Lawler, 1963).

The relationship of egg number to female size is not direct; some large females have fewer eggs than smaller fish. Attempts to determine the causes of this phenomenon were made by calculating female condition factors (K). Ovaries averaged 14.54 percent of the total body weight at spawning time, and the prespawning condition factor was significantly different from the postspawning condition factor ($P = 0.05$, $T = 9.25$). Prespawned condition factors were used and were not significantly different from 1970 to 1971 to 1972 for similar length fish as determined by the T-test ($P = 0.05$, $T = 0.20$). The data were then combined in an attempt to correlate condition factor with egg numbers, but no significant relationship ($r = -0.001$) was found.

Correlation coefficients for age vs. egg number and age vs. egg diameter were also calculated. These were $r = +0.51$ and $r = +0.18$, respectively. Although egg number correlates more closely to age than does egg diameter, neither value was significant.

Male Spawning Characteristics

Because male gonads constitute an average of 10.50 percent of the total body weight when the fish are ripe, the prespawning condition factor was significantly different from the postspawning factor. Condition factors calculated for similar length male fish before spawning were not significantly different for 1970 and 1971, but the 1972 condition factor was significantly lower ($P = 0.05$, $T = 3.08$). A comparison between male and female condition factors indicated no difference for 1970 and 1971, but the male condition factor in 1972 was significantly different from the female value. Reasons for the decline in male condition in 1972 were not determined.

EMBRYOLOGY AND LARVAL DEVELOPMENT

Literature about the embryological development of burbot is not available, and incubation times under natural conditions are only estimates. These times vary from 1 to several months depending on water temperatures. Bjorn (1940) incubated eggs in the laboratory at a constant temperature of 6.1°C and determined that 30 days were required for hatching. McCrimmon (1959) reported a 71-day incubation period for eggs held near 0°C with hatching occurring when water warmed to about 1.5°C.

In the present study, eggs were incubated in the laboratory at 1.0°C ± 0.5°C. Photographic records of egg development were made throughout the incubation period. Eggs were fertilized on February 22, 1972. Cell division progressed from the two-cell stage recorded after 18 hours of incubation (figure 16) to the blastula stage at 180 hours (figure 17). Folding of the blastoderm around the yolk is evident in the gastrula stage (figure 18) after 250 hours. Development progresses slowly until a recognizable fish embryo with well developed head and tail structures is evident after 582 hours (figure 19). Increased embryo length with the tail folding back around the yolk and a well developed optic area on the head are evident after 870 hours (figure 20). First embryo movements within the egg were noted at this time, and heart beat was apparent. First hatch was observed when the water warmed somewhat after an incubation period of 1,110 hours (46 days), but eggs in the ice water did not hatch at this time.

Some eggs were placed in separate containers, and the water was allowed to warm gradually to approximately 4°C over a 24-hour period. Hatching was rapid with no apparent mortality or indication of stress from the warmer conditions. Eggs held in ice water hatched slowly during the next 25 days with no apparent adverse effects other than a delay in hatching.

Newly hatched fry from the warmer water averaged 3.87 mm in length and eventually reached 4.6 mm in length while still sac fry. Increased pigmentation and enlargement of the head within 5 days after hatching (figure 21) accompanied the length increase. Broadening of the body, development of the mouth, and decreasing yolk sac are evident in succeeding development stages (figure 22).

Fish hatched in the ice water were 4.19 mm long, or 0.32 mm longer at the time of hatch than the earlier hatched fish. This larger size at hatch apparently does not compensate for an earlier hatching time because fish in the warm water environment had reached 4.56 mm by this time. One expression of these different hatching times may be the variable growth noted previously for young-of-the-year fish.

MANAGEMENT IMPLICATIONS

Critical Size to Harvest

One objective of management of a commercial fishery is to obtain the maximum yield over a sustained period of time while minimizing the effort and cost of the operation. This objective can be attained only if fish are harvested at or somewhat below their "critical size." Critical size, as defined by Ricker (1945), is reached when the instantaneous rate of increase in the population from growth in weight equals the instantaneous rate of loss due to natural mortality.

An estimate of the instantaneous rate of increase to the population can be determined by Ricker's (1958) method of calculating instantaneous growth rate. The instantaneous rate of growth is expressed as the natural logarithm of the ratio of final weight to initial weight for each year of life. These instantaneous rates of growth (G) are tabulated for Lake of the Woods burbot in table 25 and follow the usual pattern of decreasing increments with increasing age.

The instantaneous rate of loss to the population can be determined from the natural mortality rate. The previously estimated value of 38 percent gives an instantaneous rate of loss of 0.48, which falls between the IV and V year old instantaneous growth rates.

The critical size of harvest from these calculations would be somewhere between 480 mm and 540 mm (18.9 – 21.3 inches) long. Often the smaller size

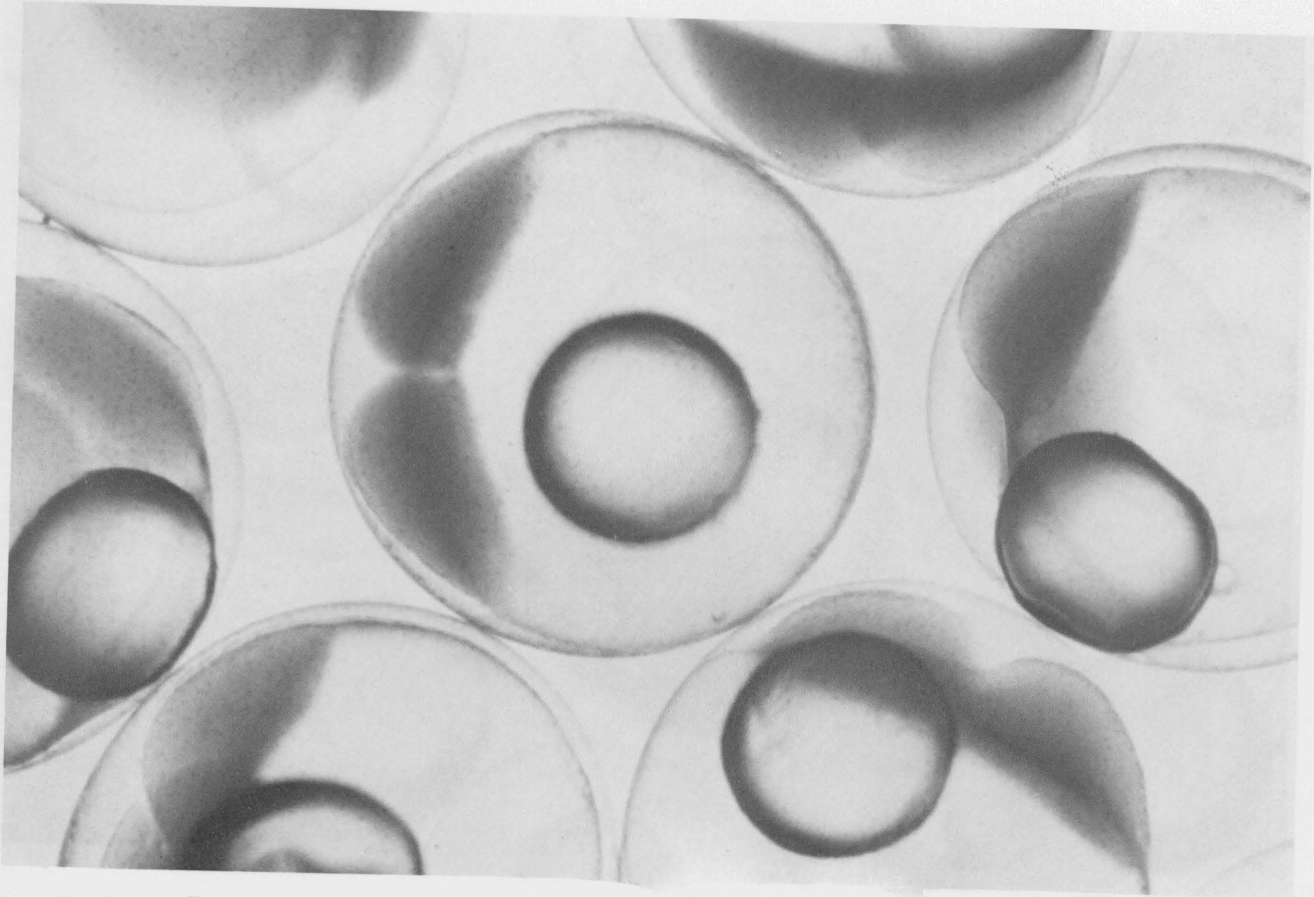

Figure 16. Two-cell embryo stage after 18 hours of incubation (50X magnification).

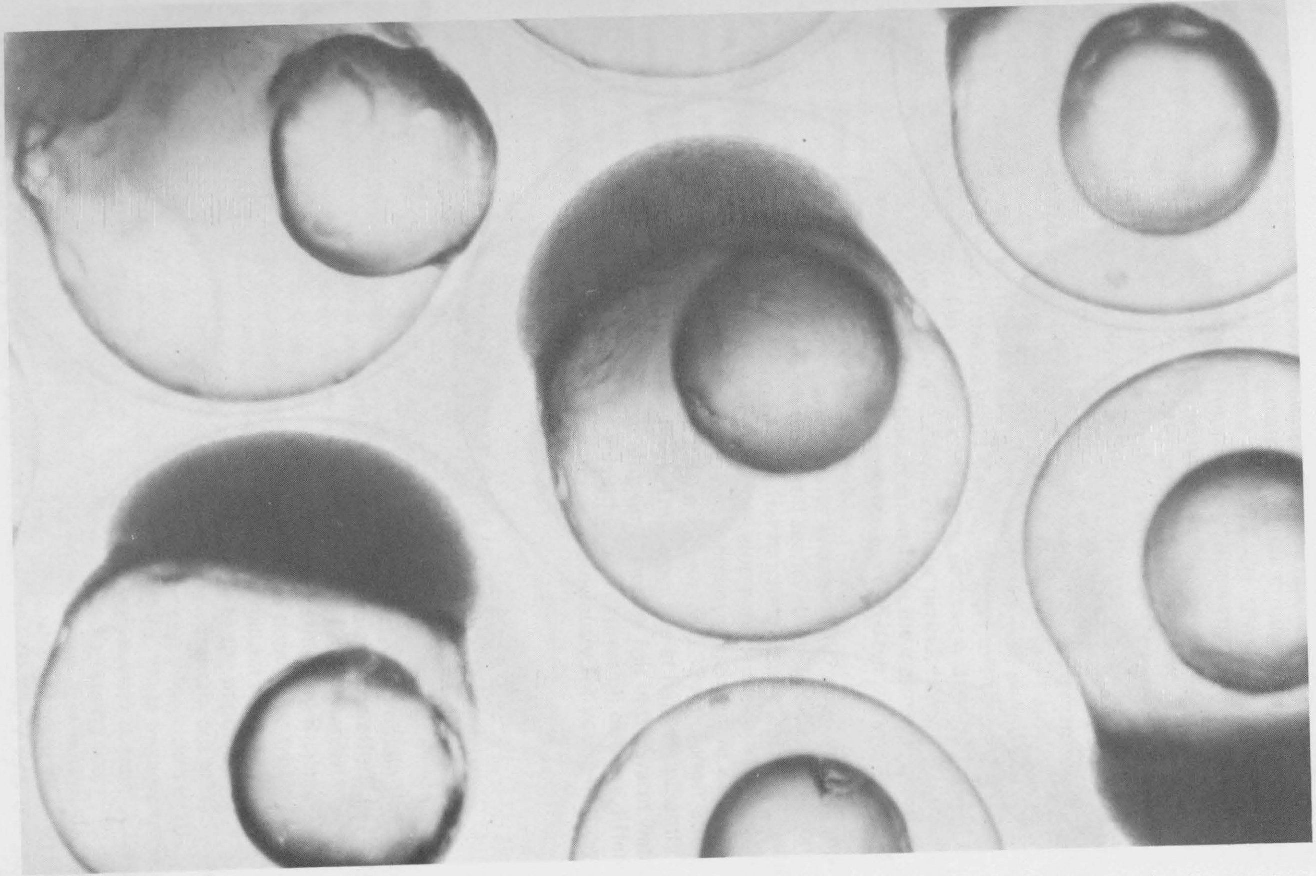

Figure 17. Blastula stage in burbot eggs after 180 hours of incubation (50X magnification).

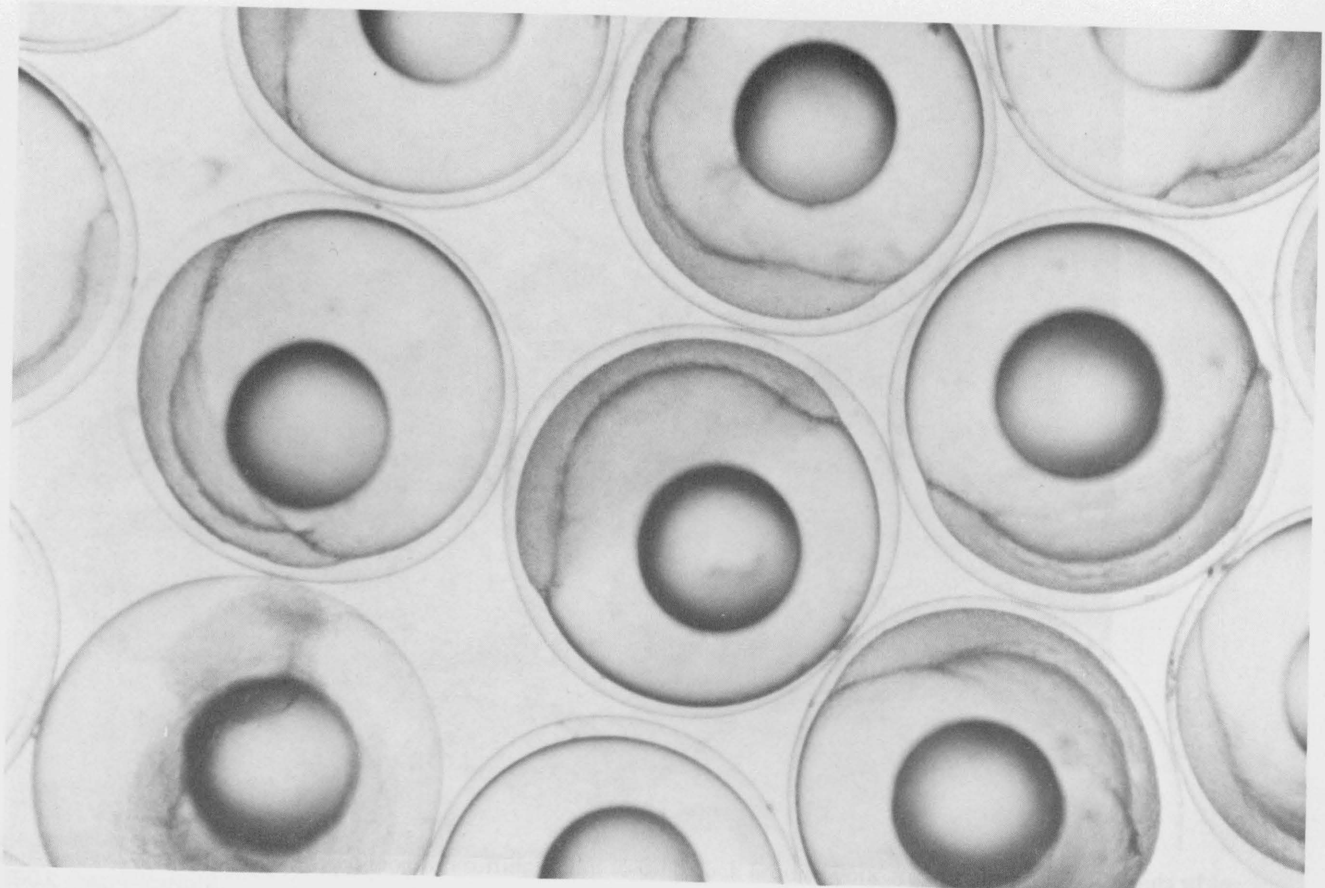

Figure 18. Gastrula stage of embryological development in burbot eggs after 250 hours of incubation (30X magnification).

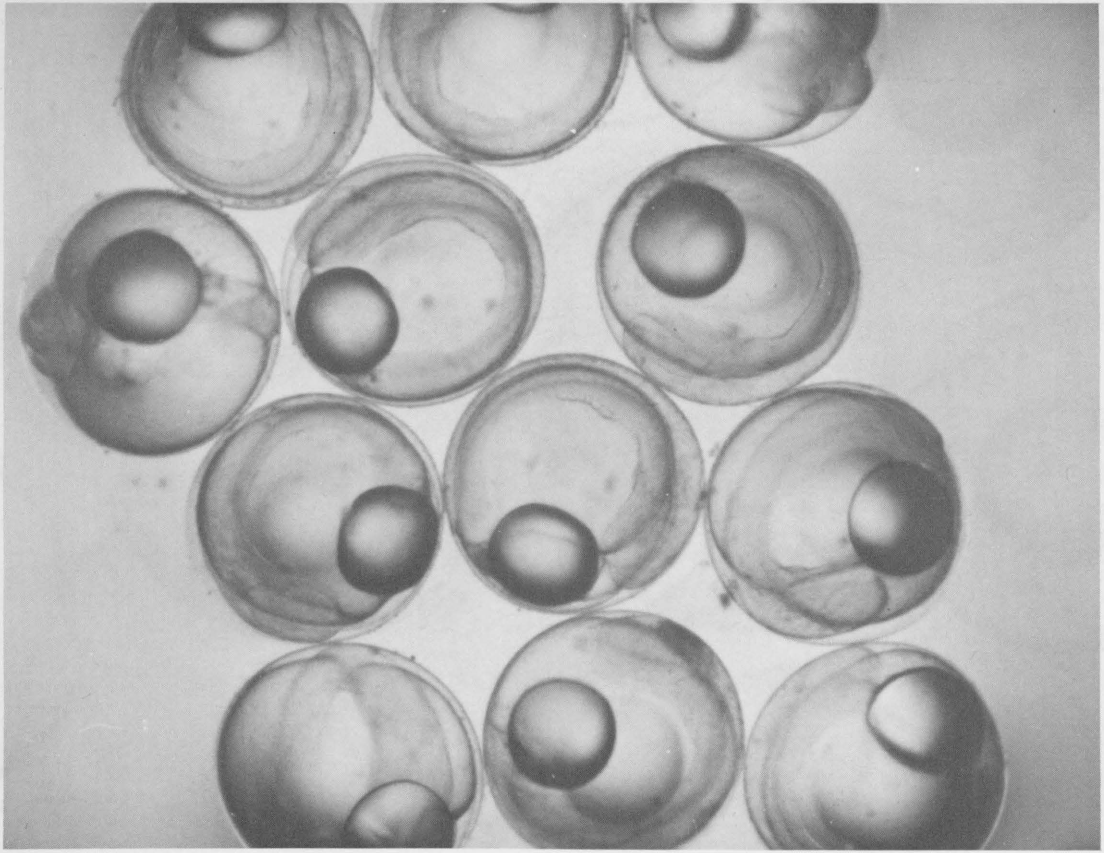

Figure 19. Recognizable fish embryo after 582 hours of incubation (25X magnification).

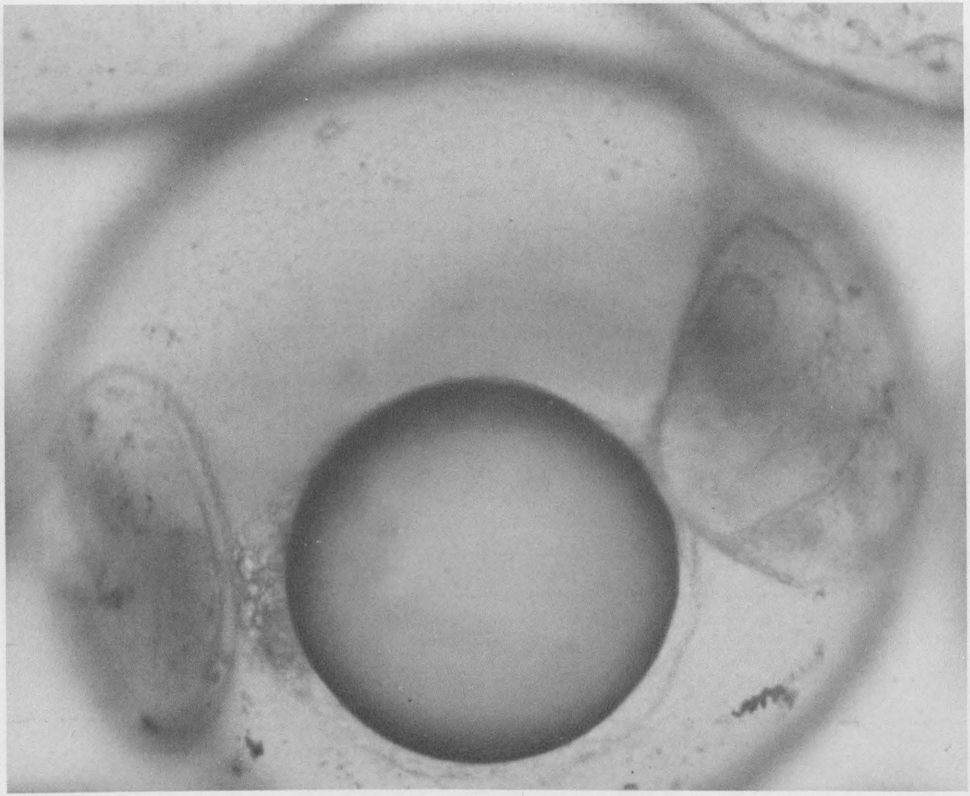

Figure 20. Eye development and increased length resulting in tail folding back around yolk are evident after 870 hours of incubation (90X magnification).

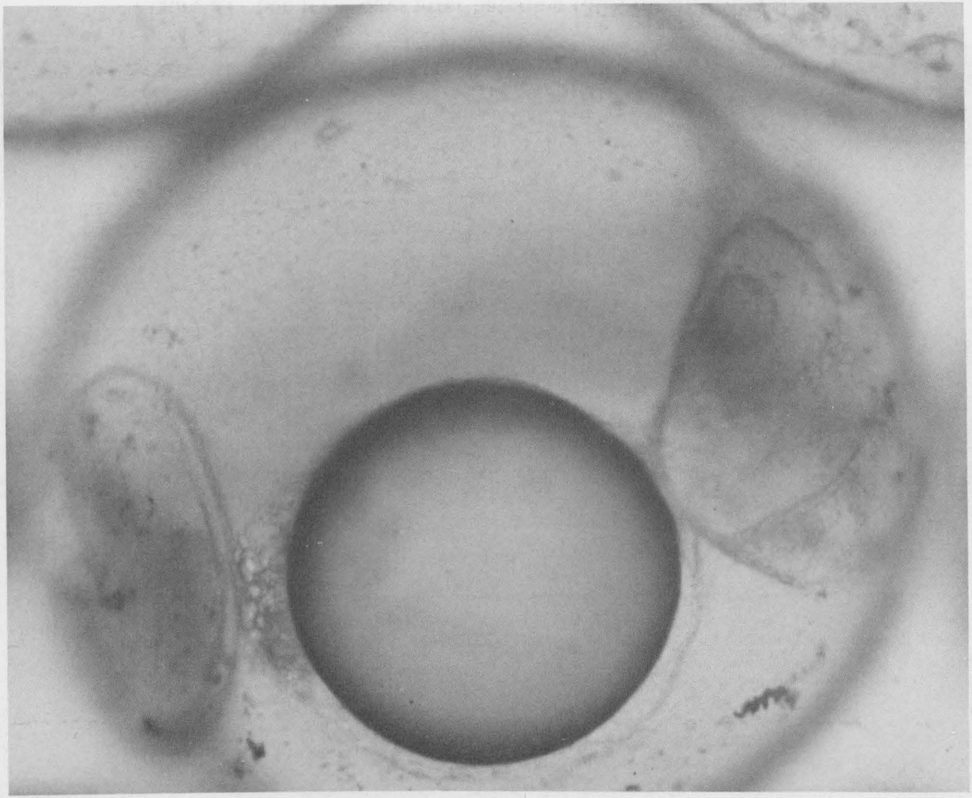

Figure 20. Eye development and increased length resulting in tail folding back around yolk are evident after 870 hours of incubation (90X magnification).

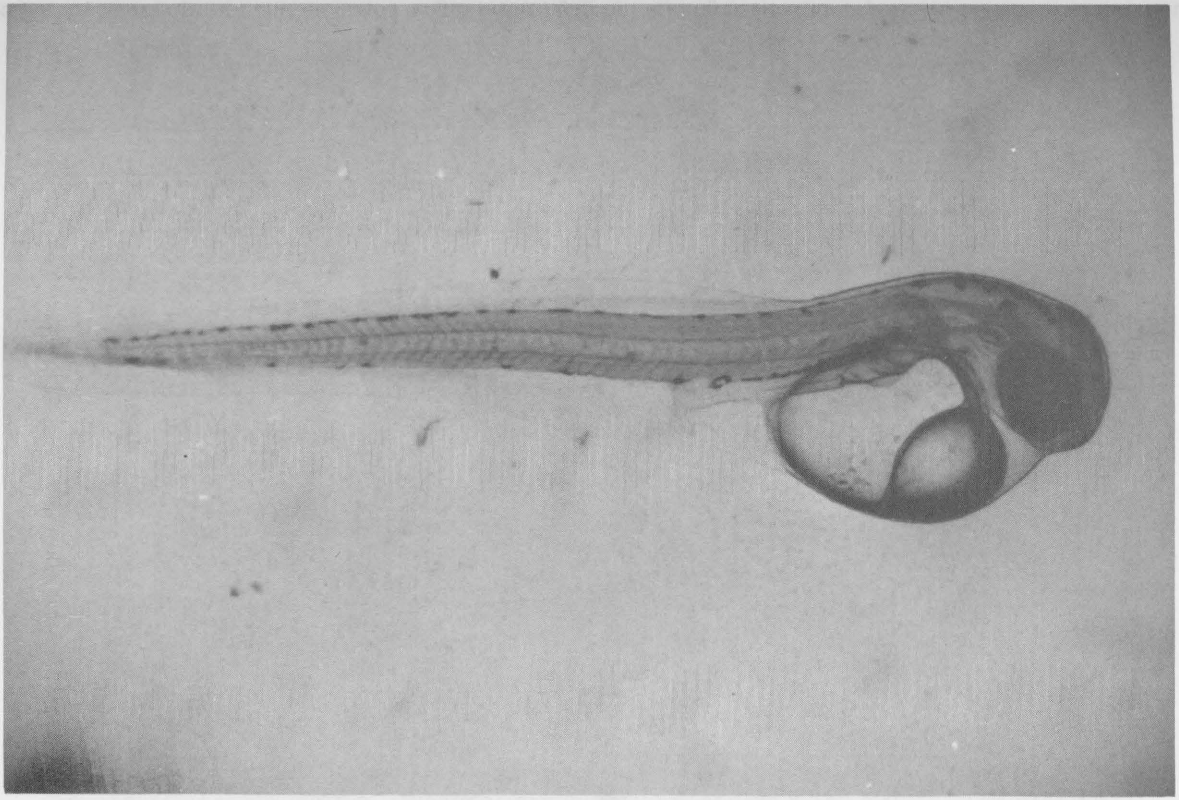

Figure 21. Sac fry 5 days after hatching (30X magnification).

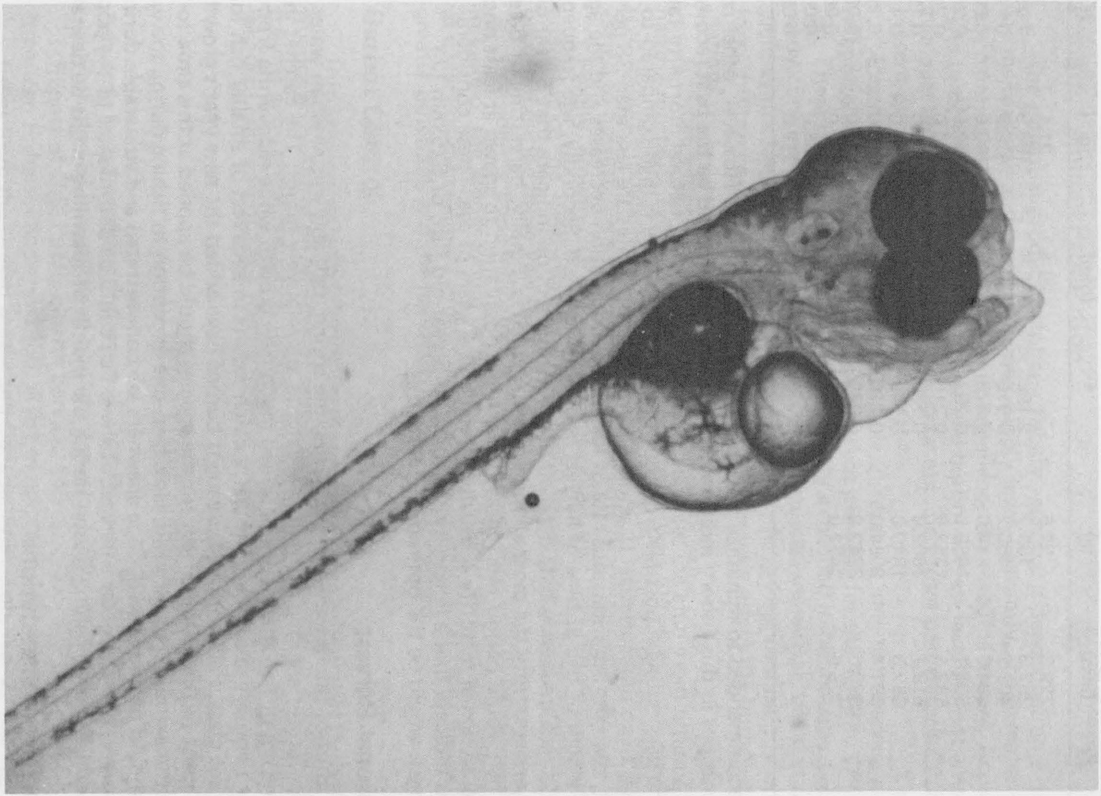

Figure 22. Sac fry 12 days after hatching showing the development of the mouth and digestive system and decreasing yolk sac (30X magnification).

Table 25. Instantaneous growth rates, G, for male and female burbot from Lake of the Woods.

Age group	Females			Males		
	Mean length (mm)	Mean weight (g)	G	Mean length (mm)	Mean weight (g)	G
I	129.3	21.6	–	129.1	21.1	–
II	287.3	194.1	2.196	288.8	196.9	2.233
III	401.2	486.2	0.918	399.0	478.9	0.888
IV	484.6	817.0	0.519	479.2	792.0	0.502
V	538.1	1089.0	0.287	532.3	1058.0	0.289
VI	582.1	1352.0	0.216	576.1	1314.0	0.216
VII	619.1	1602.0	0.169	611.8	1550.0	0.165
VIII	652.3	1849.0	0.140	643.7	1782.0	0.139
IX	681.4	2084.0	0.119	671.6	2003.0	0.115
X	699.6	2242.0	0.072	694.0	2193.0	0.090
XI	725.6	2477.0	0.099	710.2	2335.0	0.062
XII	–	–	–	726.7	2488.0	0.063
XIII	–	–	–	745.6	2669.0	0.069

is recommended to minimize the natural loss to the fishery. However, other considerations in this fishery indicate that the larger size would be the best recommendation until more data are available. First, the 38 percent natural mortality rate is the best estimate possible from our data, but this value is high compared to values from other studies. If actual natural mortality rates are less than 38 percent, then the instantaneous rate of loss to the population decreases and the age and length of fish at time of harvest could be increased. Secondly, age frequency and length frequency data detailed in a previous section indicate that 5-year-old fish are currently the most abundant in the catches. Finally, harvesting of 5-year-old fish would permit most individuals in the population to spawn at least once because sexual maturity is usually attained at 4 years of age. These considerations indicate that a length most typical of 5-year-old fish, or 525 mm (21 inches), would be the optimim harvest size.

Seasonal Harvest

Burbot catches are greatest during the spring, fall, and winter when water temperatures are low, and summer catches are relatively minor. The catches in the spring are of fish that have not added much new growth while recovering from their February spawning. This early catch results in a harvest of smaller fish for any age class. Fall- and winter-caught burbot have added the new year's growth and most of the fishing effort for the species should be applied at this time to attain maximum annual yield. However, one exception to fishing during the winter should be considered. Ripe spawners are concentrated and vulnerable during February, and too great a harvest of these fish could be detrimental to the population. A closed fishing season during the month of spawning might be desirable.

Gear Recommendations

The fishing gear currently used by the fishery is adequate to maintain the annual burbot yields that now exist. Pound nets and hoop nets are the most effective gear, and the only changes might be in number of nets licensed or the season when these gear could be fished. However, if burbot production is to be increased significantly while minimizing effort and cost, the use of the trawl is necessary. The efficiency of this gear in catching burbot was demonstrated when commercial trawling on the lake was licensed from 1961 to 1964. Record burbot catches harvested during these years are partly attributable to the use of trawls.

Subsequent trawling under experimental permit during 1968 to 1970 further indicated the suitability of trawling for burbot harvest. This gear proved to be only effective to catch burbot during the warm summer months when passive fishing gear (pound and gill nets) catches were very low.

Potential Annual Production

The potential production of any fishery resource is dependent on a demand for the resource and on its sustained supply level. Currently, the demand for burbot from Lake of the Woods does not challenge the resource supply. Accurate data to determine the potential sustained burbot harvest level are not always available but a reasonable estimate can be obtained from past burbot catches and present population dynamic characteristics.

Examination of annual catches (table 2) reveals a long-term harvest average of approximately 500,000 pounds of burbot per year for the 1948 to 1964 period. These catches occurred when the greatly expanded mink industry provided a ready consumer for the resource. Catches fluctuated somewhat, but sustained yield at this level of harvest did not indicate any long-term declining trend. Therefore, this level of harvest apparently did not adversely affect the burbot populations.

Another indication of the present under-utilization of the resource is the natural mortality estimate. The low of 38 percent of the population as unutilized resource indicates inefficient management. Part of this loss might be converted to harvested resource without detrimentally influencing the population.

Finally, growth characteristics of the population have not been unusually altered since the 1948-1964 period as would be the case if over-harvesting had occurred during those years.

Considering these indicators, a recommended safe level of harvest of burbot in Lake of the Woods would be between 500,000 and 600,000 pounds per year as a starting management production quota. Subsequent data may indicate greater potential, and the harvest could then be increased.

Burbot Control

Information collected during these studies does not show that burbot influence any control on walleye or sauger population in Lake of the Woods. Their harvest and annual reduction should, therefore, be regarded as utilization of the resource base and not as a mechanism for increasing walleye production.

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APPENDIX

Appendix table 1. Average air temperatures reported by the U.S. Weather Bureau Station located at Warroad, Minnesota, during each month for the years representing the oldest fish and for the ice-free seasons of those years along with consecutive frost-free days

	Average temperatures F°													
Year month	59	60	61	62	63	64	65	66	67	68	69	70	71	72
Jan	−2.8	7.6	0.9	−1.3	−4.3	10.0	−4.7	−11.5	5.0	2.6	−1.4	−1.1	−7.2	−3.7
Feb	3.8	9.4	15.5	1.7	2.5	10.8	3.1	1.9	0.2	4.0	9.4	4.8	9.5	0.8
Mar	23.9	14.6	27.6	23.0	26.3	14.8	10.5	24.5	21.1	28.1	17.4	13.9	21.6	18.8
Apr	38.2	37.1	33.8	35.0	38.7	38.1	38.1	33.1	35.8	40.2	42.2	34.7	38.6	35.6
May	52.0	51.8	51.1	51.4	51.6	54.3	52.7	46.7	46.5	50.3	52.4	47.0	51.2	57.7
Jun	64.9	60.2	65.4	63.4	65.1	60.8	62.1	64.4	61.6	60.7	55.9	65.8	64.3	62.5
Jul	68.7	66.8	67.8	65.5	69.6	68.6	65.0	70.4	67.1	65.7	66.3	70.6	62.7	63.1
Aug	68.4	66.7	69.3	66.0	66.0	59.8	64.6	65.1	65.4	62.9	70.5	65.4	66.3	65.5
Sep	55.8	56.4	54.9	54.1	—	52.2	47.5	57.9	60.0	57.5	57.2	57.1	56.9	52.7
Oct	38.2	44.8	45.5	47.0	54.6	43.3	46.3	43.4	42.9	44.4	37.8	45.3	45.7	41.6
Nov	17.2	27.8	27.3	31.3	31.8	26.1	21.1	19.9	26.4	28.9	28.4	25.2	24.7	26.0
Dec	20.2	5.8	8.5	11.4	3.0	1.6	16.0	8.5	11.6	9.3	14.6	3.7	8.0	3.7
May – Oct	58.0	57.7	59.0	57.9	61.3	56.5	56.3	57.9	57.2	56.9	56.6	58.5	57.8	57.1
Frost-free days	118	99	78	133	130	80	105	121	126	136	97	110	130	136

Appendix table 2. Average precipitation reported by the U.S. Weather Bureau Station located at Warroad, Minnesota, during each month for the years representing the oldest aged fish and total annual precipitation

Year month	Average precipitation, inches 59	60	61	62	63	64	65	66	67	68	69	70	71	72
Jan	.17	.28	.41	1.00	.24	.22	.04	.15	.98	.95	1.70	.80	.40	.50
Feb	.35	.37	.44	1.11	.54	.06	.24	.40	.42	.19	.40	.30	.20	.50
Mar	.45	.48	.35	1.19	.15	.64	.84	1.95	.70	1.11	.10	1.30	.60	.80
Apr	.55	1.58	1.48	.61	2.79	3.68	1.44	.92	3.84	1.18	1.00	2.20	.80	1.00
May	2.67	1.60	.93	5.56	2.69	2.42	2.72	1.83	.63	1.74	1.90	3.70	1.70	1.90
Jun	2.04	3.66	.40	3.52	5.66	6.02	4.28	3.56	2.65	5.98	1.90	3.20	4.00	3.70
Jul	3.45	2.28	1.60	4.29	3.13	3.01	3.00	3.28	3.36	2.81	2.60	2.30	2.40	.70
Aug	4.84	2.07	1.86	4.78	1.32	2.96	1.55	4.26	.99	6.34	3.80	1.10	.40	1.10
Sep	1.33	1.49	5.90	2.04	.98	4.75	3.76	.63	.27	1.60	1.70	3.40	1.10	4.33
Oct	2.35	1.98	1.12	.34	.25	1.11	1.49	.51	.62	2.60	1.50	1.80	4.00	.90
Nov	.68	.89	.63	.96	.43	.73	2.12	.76	.47	.30	.20	.50	.70	.38
Dec	.60	1.10	.82	.61	1.05	.81	.92	.82	1.05	.20	.60	.80	.50	.40
Annual total	19.48	17.78	15.94	26.01	19.23	26.41	22.40	19.07	15.98	25.00	17.40	21.40	16.80	16.21

Appendix table 3. Representative water temperatures in Lake of the Woods compiled from data collected from 1969 to 1972. Temperature values are estimated mid-month conditions at the lake bottom in 8 meters of water with surface temperatures during ice-free periods

Month	Water temperatures F°	
	Surface	Bottom
Jan	—	36
Feb	—	38
Mar	—	—
Apr	—	—
May	56	46
June	67	60
Jul	69	69
Aug	70	69
Sep	56	56
Oct	46	46
Nov	—	—
Dec	—	34