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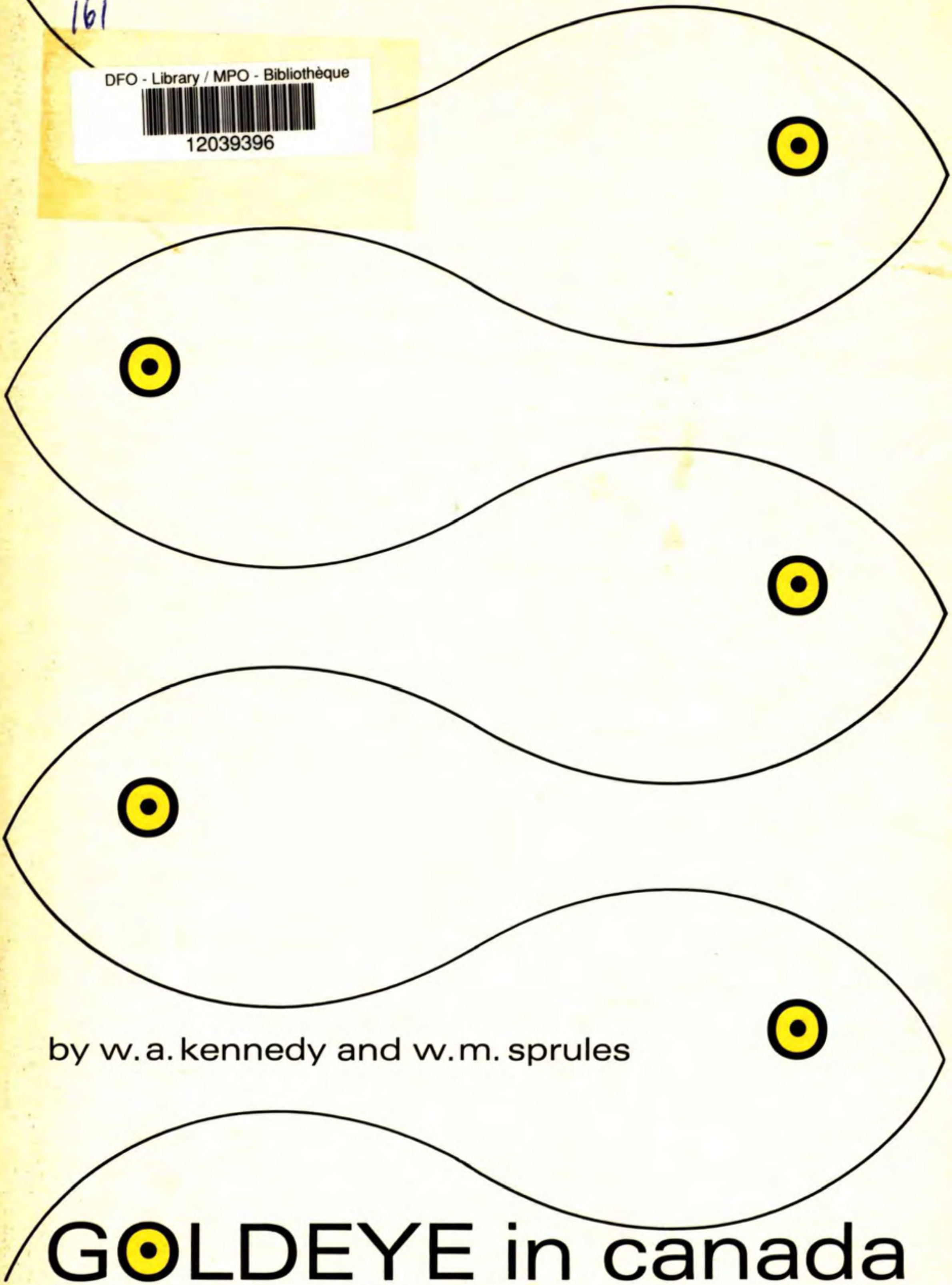

by w. a. kennedy and w. m. sprules

GOLDEYE in canada

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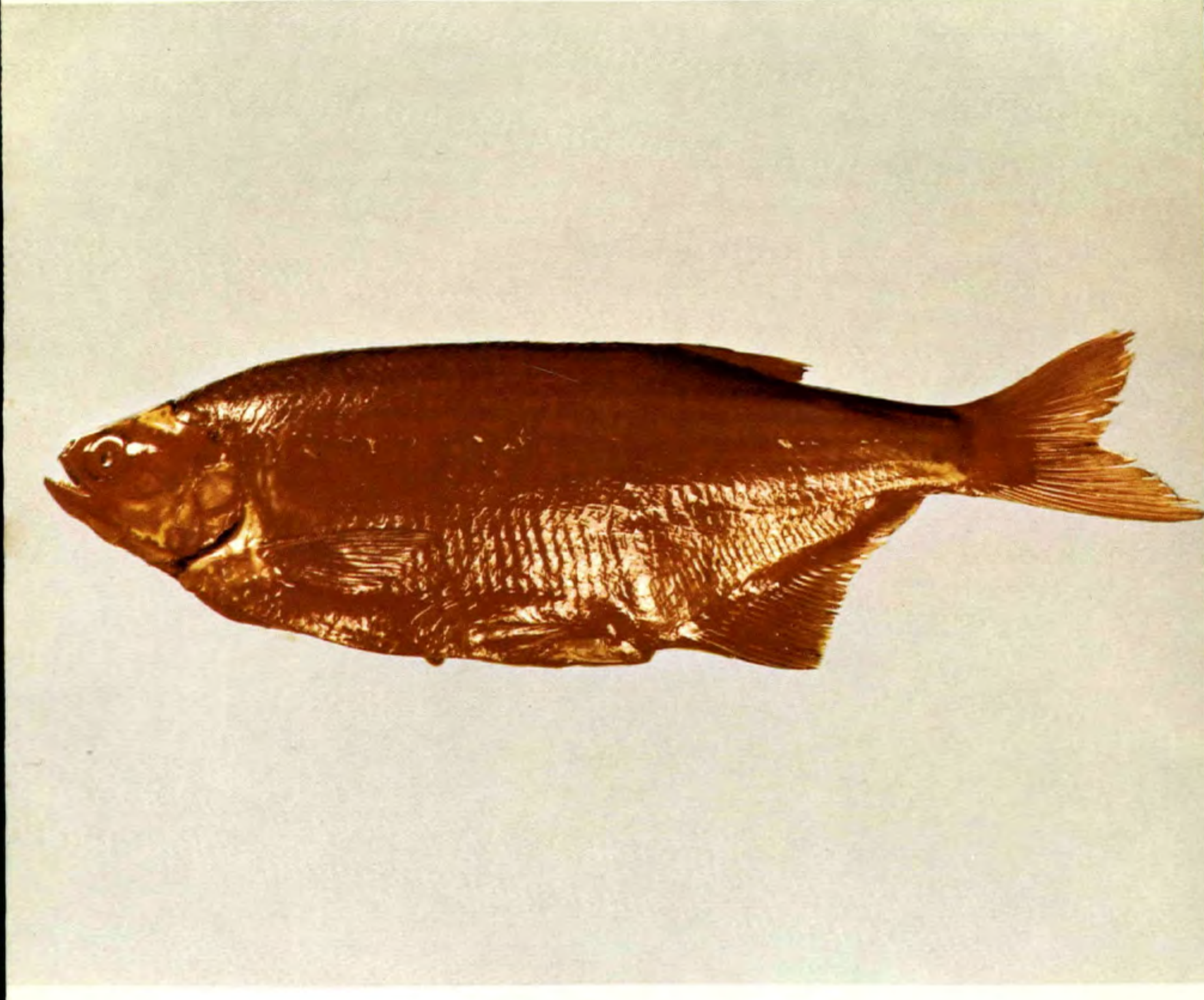

A Winnipeg Goldeye, *Hiodon alosoides*

BULLETIN 161

GOLDEYE IN CANADA

By W. A. Kennedy and W. M. Sprules

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EDITOR'S FOREWORD

This investigation was planned and carried out by Dr W. M. Sprules, while employed at the Fisheries Research Board of Canada Biological Station, Winnipeg, Man. He supervised field studies in 1945, 1946, and 1947, and arranged for additional data to be collected between 1948 and 1953. Unfortunately, other commitments prevented him from completing the study and from preparing the results for publication. Arrangements were made for collaboration with Dr W. A. Kennedy, while he was at the Board's Biological Station, London, Ont., so that the results of the investigation might be published. The London Station has since been relocated at Winnipeg, Man., and Dr Kennedy is now at Board's Biological Station, Nanaimo, B.C. Dr Sprules is presently with the Department of Fisheries of Canada, Ottawa, Ont.

J. C. STEVENSON

ABSTRACT

Goldeye, *Hiodon alosoides*, are found in turbid water, in several of the river systems of central North America. Of the four areas where most goldeye are produced commercially, growth is slowest in Sandy Lake, faster in Lake Claire, and fastest in Lake Winnipegosis and in the lower Saskatchewan River. They grow faster in the United States than in Canada. Females grow faster than males. Total mortality rate at ages 6–10 was 74% in a heavily exploited population, and 42% at ages 8–10, 48% at age 11, 57% at age 12, 73% at age 13, and almost 100% at age 14 in an unexploited population. Sex ratio is roughly 1:1. Spawning occurs between late May and the end of June, starting when the water warms to about 50–55 F. In the populations studied mature goldeye appear to spawn annually. Representative ovaries held 5,000–25,000 eggs about 1/12 inch in diameter. In the summer a wide range of organisms are eaten, including quantities from the water surface; in winter the diet seems restricted. *Esox lucius, Stizostedion vitreum,* and *S. canadense* are predators. Commercial production has declined greatly since 1929. Goldeye are particularly susceptible to overfishing and strict regulations are recommended.

INTRODUCTION

The goldeye, *Hiodon alosoides* (Fig. 1), is a laterally compressed, deep-bodied, shad-like fish covered with large, silvery, deciduous cycloid scales. Fresh specimens have a dark blue-green sheen along the dorsum and a faint gold sheen along the lateral aspects.

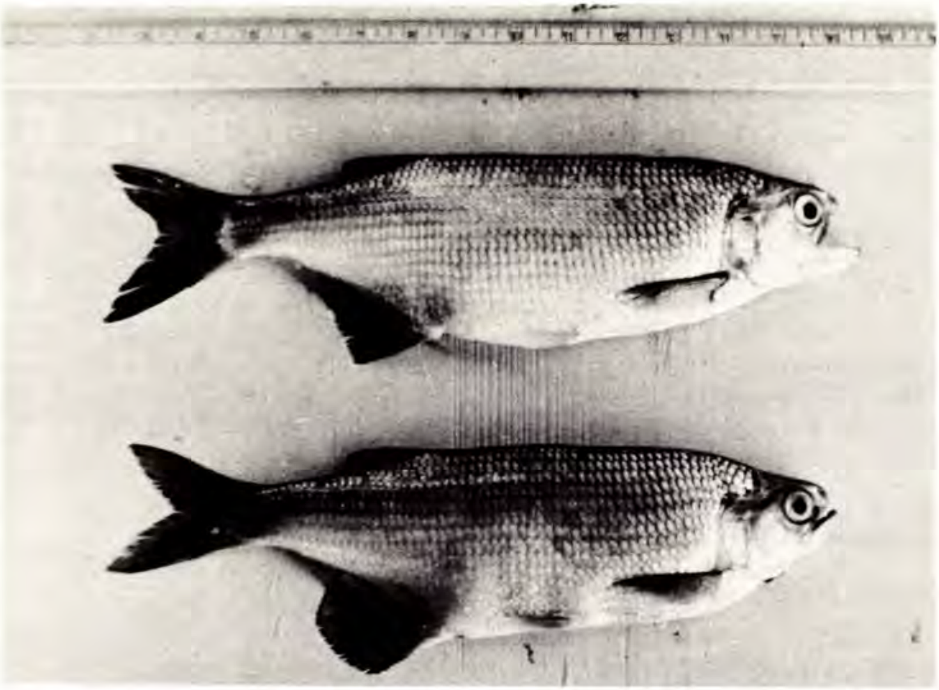

FIG. 1. Photographs of goldeye, adult female above, adult male below. Note lobe on anal fin of male only, a characteristic by which the sexes may be distinguished by external examination.

Few freshwater fish have been so highly rated by connoisseurs. Earlier this century, the fame of "Winnipeg goldeye" spread throughout most of North America through inclusion on the menus of Canadian railway diners. Goldeye were featured, when available, during the Prairie crossing of the transcontinental runs and travellers began to look forward with anticipation to the feature dinner on this part of the trip. Transient Canadian and American sportsmen were mainly responsible for the spread of its popularity.

Smoked goldeye is a truly Canadian product. Until 1948, most of the commercial catch was taken in Manitoba, but more recently, production in other provinces has become increasingly important. Whatever the source, most goldeye have been, and are, prepared for market in Winnipeg, Manitoba, and carry the name "Winnipeg goldeye." Although the species is widely distributed in the central United States, it is regarded as an inferior food fish and is not marketed there, although commercially caught goldeye from Red Lake, Minnesota, have been processed in Winnipeg.

For many years, the goldeye fishery has been of considerable local importance, particularly in Manitoba. There is a great demand for goldeye by restauranteurs and others in the Prairie Provinces and, since the supply is limited, the price to the fisherman is relatively high, so that even small operations are financially successful. Further, since goldeye frequent large rivers, small lakes, and shallow shore regions of the larger lakes, fishermen can take them with smaller craft and less expensive equipment than are needed for most commercially important species; thus, men with limited capital can participate in the fishery.

Although goldeye are relatively small, averaging about 1 lb, they provide interesting sport when taken with light tackle and are regarded as a game fish in some areas. Various artificial flies and live insects such as grasshoppers provide satisfactory lures when goldeye rise to the surface to feed during quiet evening hours throughout the early summer months.

The present investigation was considered necessary because of the steady decline in annual production of goldeye after 1929. This decrease seemed to represent an actual decline in the abundance of goldeye, since increased demand for the species coupled with a short supply had caused high prices, which were responsible for an ever increasing fishing effort.

In addition, there was, and is, insufficient literature dealing with the general biology and ecology of goldeye in contrast with an abundance of articles on other commercially important fishes. The commercial fishermen, generally well acquainted with the fundamental habits of the species taken in their nets, knew little of the habits of goldeye and gave confused and contradictory statements when questioned about them. Several factors contributed to this lack of knowledge, foremost of which was the fact that goldeye normally frequent very muddy waters where it is impossible to observe their habits.

The investigation was undertaken to determine the habits and ecological requirements of goldeye, to find, as far as possible, the reasons for a dwindling supply, to discover and draw attention to hitherto unexploited populations, and to establish sound management policies which could be applied to goldeye fisheries.

NOMENCLATURE

The goldeye belongs to a small family of freshwater fishes, the Hiodontidae or "mooneye" family, which is confined to the waters of North America. The closest relatives of the mooneyes in North America appear to be in the Clupeidae, a primitive family of the order Isospondyli. The family Hiodontidae is represented by only one genus, *Hiodon,* which includes three species, *H. tergisus* and *H.*

selenops, the northern and southern mooneye respectively, and the goldeye, *Hiodon alosoides*.

The family name Hiodontidae and the generic name *Hiodon* are derived from two Greek words which signify "toothed hyoid." The specific name *alosoides* is derived from the Latin for "shad" and the Greek for "form" and it means "shad-like" (in form).

Hiodon alosoides has relatively few common or vernacular names. The species is universally recognized as "goldeye" (English) or "laquaiche aux yeux d'or" (French) throughout its Canadian range. The names "naccaysh" and "la quesche" used by nineteenth century authors are obviously variants of the French name. Indians of the part of Canada where goldeye are common (Cree, Ojibway, Saulteaux, Naskapi) call it "wepicesis" (phonetic) or "weepicheesis" (Anglicized).

Jordan and Thompson (1910), quoting then almost inaccessible literature, say that Rafinesque first described the species in 1819 as *Amphiodon alosoides* (misprinted *"alveoides"*). Richardson (1836) described it for the first time from Canada as *Hyodon crysopsis* from a specimen taken from the Saskatchewan River at Cumberland House, now in Saskatchewan. Jordan and Gilbert (1883) recognized the species as *Hyodon alosoides.* Jordan and Thompson (1910) regarded the goldeye as generically distinct from the mooneye and accepted the original name *Amphiodon alosoides*. More recently, Bailey (1956) recommended *Hiodon alosoides* (Rafinesque) which is now the accepted scientific name for goldeye.

DISTRIBUTION

The goldeye is found only in North America. The shaded area of Fig. 2 indicates its range, as far as is known.

The following records were particularly useful as a guide to distribution in the United States: Red Lakes, Minnesota (Grosslein and Smith, 1959); Lake Pepin, Wisconsin (Greene, 1935); Sugar and Kickapoo Creeks, Illinois (Starrett and Latimore, 1949); White River, Indiana (Jordan and Thompson, 1910); State of Ohio (Trautman, 1957); western Pennsylvania (Bean, 1903); State of Kentucky (Clay, 1962); Whéeler Reservoir, Alabama (Tarzwell, 1941); Eagle Lake, Mississippi (Cook, 1959); Lake Texoma, and Chickaskia and Washita rivers, Oklahoma (Paden, 1948); several rivers in Wyoming (Simon, 1946); and Fort Peck Reservoir, Montana (Alvord, MS, 1957). Unpublished information supplied by Drs Reeve M. Bailey and Milton B. Trautman has also been very helpful.

The following records were used as a guide to the limits in western Canada: Bow River near Bassano, Alberta (Miller, 1949); Red Deer River at Morrin, Alberta (D. E. McAllister, personal communication); near Jasper, Alberta (Bajkov, 1927); Lesser Slave Lake (Dymond, 1947); Peace River in Alberta to the British Columbia border (J. M. Paetz, personal communication); Fort Nelson and Liard rivers, British Columbia (Carl et al., 1959); Bear River at Norman, N.W.T. (Preble, 1908); Great Slave Lake, Lake Athabasca, and Slave and Athabasca rivers (Rawson, 1947, 1949, and 1951); Lakes Sipiwesk and Pukatawagan (present

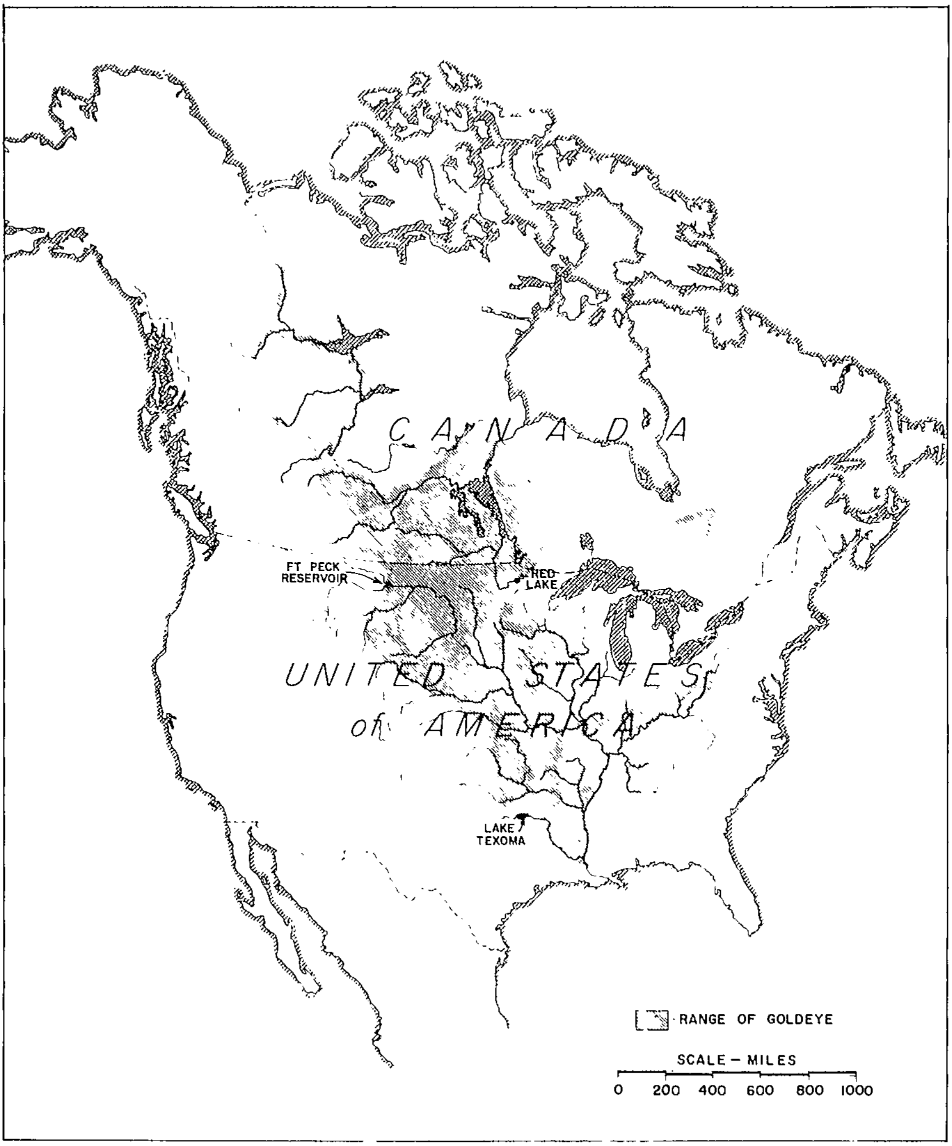

FIG. 2. A map showing the area within which goldeye have been reported.

authors); Nelson River below Limestone Rapids (Hinks, 1943); Sandy Lake, Rainy Lake, and Lac Seul, Ontario (Radforth, 1944).

The following records were used as a guide to the limits of the isolated part of the range northeast of the Great Lakes: Lake Abitibi and tributaries (Dymond and Hart, 1927); two locations northwesterly from Lake Abitibi (Radforth, 1944); Lake Timiskaming (Scott, 1963); and Lake Waswanipi and connecting waters

(Magnin, 1964, and Le Jeune, 1965). The presence of goldeye in Lake Timiskaming, where it is common, is of particular interest since the species has not been reported from any other waters in the St. Lawrence drainage.

Goldeye are almost always found in quite muddy water, usually in large rivers and in small lakes, ponds, and marshes closely connected to them, but sometimes in the shallower parts of large lakes. Within the range indicated by shaded areas in Fig. 2, goldeye occur sporadically, presumably because suitable habitat is discontinuous. Over much of the indicated range they are rare, but there is no sizeable area within the indicated boundaries from which goldeye have never been collected. Because goldeye are rare over much of the area, particularly at its periphery, it is quite possible that the known range will be extended by further investigation.

AGE STUDIES

Materials and Methods

Most of the specimens used were collected by fishing various combinations of 1½-, 2¼-, 2½-, 3-, 3½-, 3¾-, 4-, 4¼-, 4½-, and 5½-inch mesh[1] gill nets of cotton web, about 4–5 ft from leadline to corkline when in use. A few samples were also procured from commercial fishermen who used gill nets which ranged from 3¾- to 4¼-inch mesh. A few were collected by fyke nets. Small goldeye were taken by seining or by pulling dam stop-logs and straining the water through small mesh seines. By these means, sizeable collections were made on Lake Winnipegosis and connecting waters in 1945 and 1946; in the lower Saskatchewan River and vicinity in 1945, 1946, and 1947; in Lake Claire and vicinity, Alberta, during 1947 and 1948; and on Sandy Lake, Ontario, and connecting waters in 1953. In addition, 31 larger fish were procured from Pukatawagan Lake, Churchill River system, Manitoba, and 60 underyearlings from the upper Saskatchewan River system. Also, scales from a few goldeye became available for study as follows: 6 (as well as 20 underyearlings) collected from Lake Abitibi in 1925, provided by the Royal Ontario Museum of Zoology; 10 collected from Great Slave Lake in 1944 and 1945 and 37 collected from Lake Athabasca in 1945, donated by Dr D. S. Rawson. Figure 3 shows in general where goldeye were collected, and Fig. 4–6 show the same in detail; some of the collections indicated by Fig. 3 were not used in the age studies.

Most of the goldeye so collected, with the notable exception of the underyearlings, were used for growth studies. For this purpose, shortly after capture a number of scales was taken from each fish, usually from the left side just above the lateral line and anterior to the dorsal fin, and stored in individual scale envelopes on which pertinent data were recorded. Subsequently, a few scales from each fish were mounted and examined under a microscope. Standard criteria were used for identifying annuli.

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[1]In this paper mesh size is always given as stretched measure in inches.

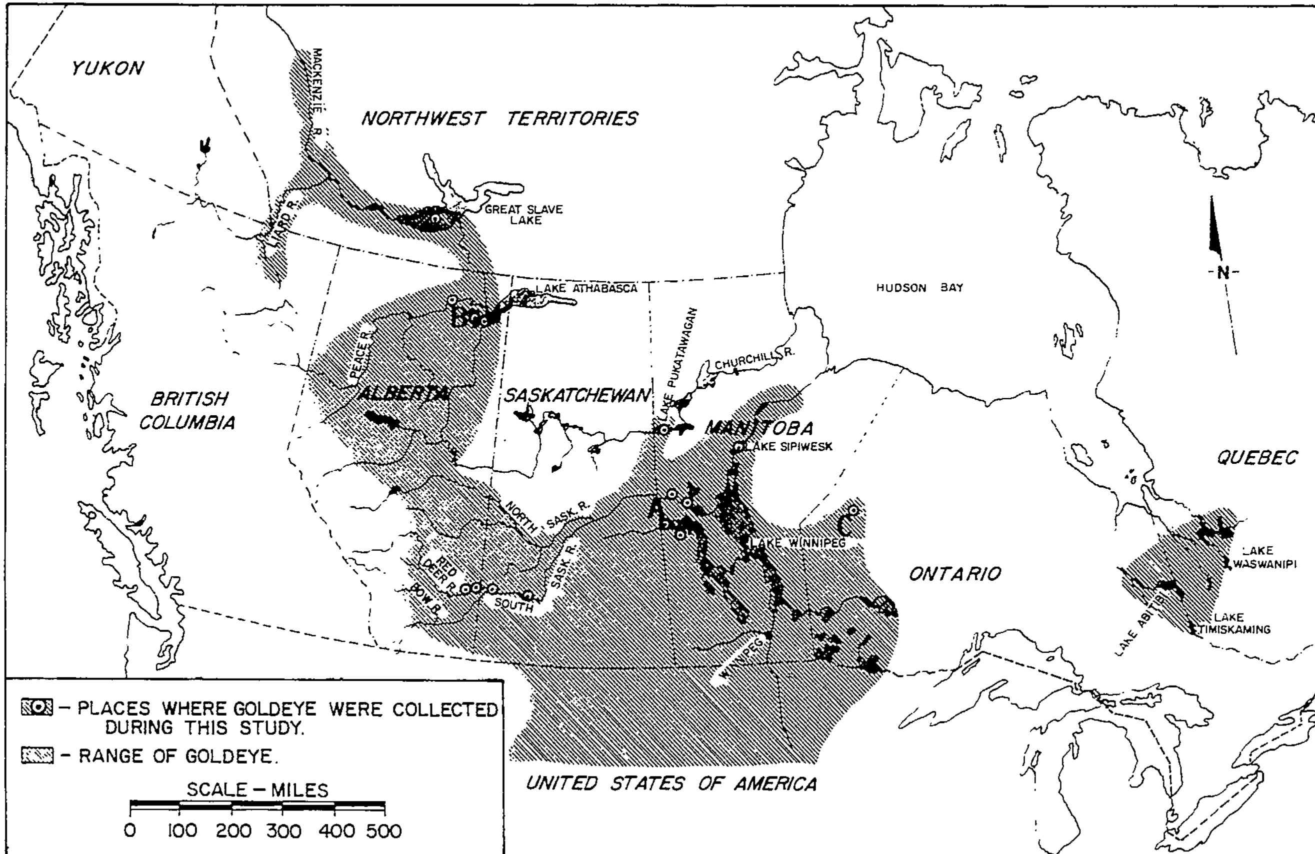

FIG. 3. A map showing the area within which goldeye have been reported in Canada and specific localities where they were collected for the present study. The location of areas which the maps of Figs. 4, 5, and 6 show in detail are indicated by A, B, and C respectively.

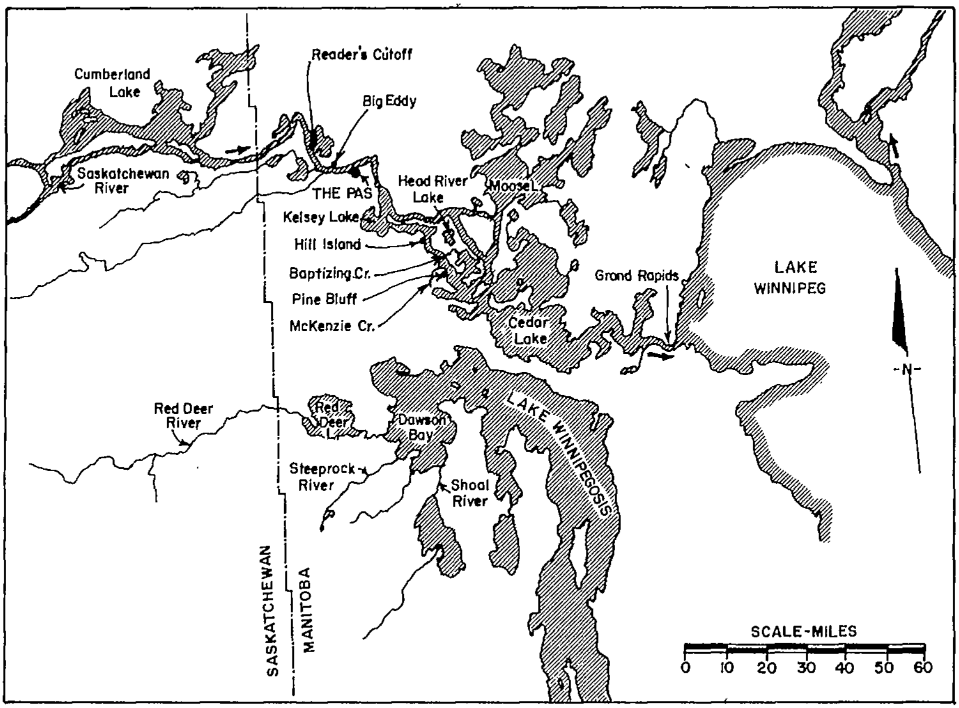

FIG. 4. Detailed map of the area in which the Lake Winnipegosis and Saskatchewan Delta samples were taken.

GROWTH DURING THE FIRST SUMMER

Lengths in millimeters and weights in grams were determined for 1295 underyearlings collected during the study and for the 20 underyearlings from Lake Abitibi. Average lengths and weights are shown in Table I.

The average sizes derived from the 1946 Saskatchewan River Delta data are plotted against date in Fig. 7. Smooth curves are fitted to each set of points by inspection. The curves indicate that in 1946 newly hatched goldeye from the Saskatchewan River grew slowly until early July, that rate of growth then increased to a maximum in late July and early August, then declined to a slow rate of growth by mid-September. The shape of the curve in Fig. 7 suggests that most of the growth for the year is attained during July and August.

Goldeye taken during 1945 in the Saskatchewan River Delta were notably smaller by a given date than those taken in 1946. Presumably, the start of the rapid growth phase was later in 1945 than in 1946. A comparison between average sizes in September 1946 and in October 1947 indicates very little growth, if any, after the end of September. Goldeye taken in 1948 from the South Saskatchewan and Red Deer rivers were slightly, but definitely, smaller by a given date than 1946 Saskatchewan River Delta goldeye. Goldeye taken from Lake Claire in 1947 and in 1948 and from Lake Abitibi in 1925 were notably smaller by comparable dates than Saskatchewan River Delta goldeye taken in 1946.

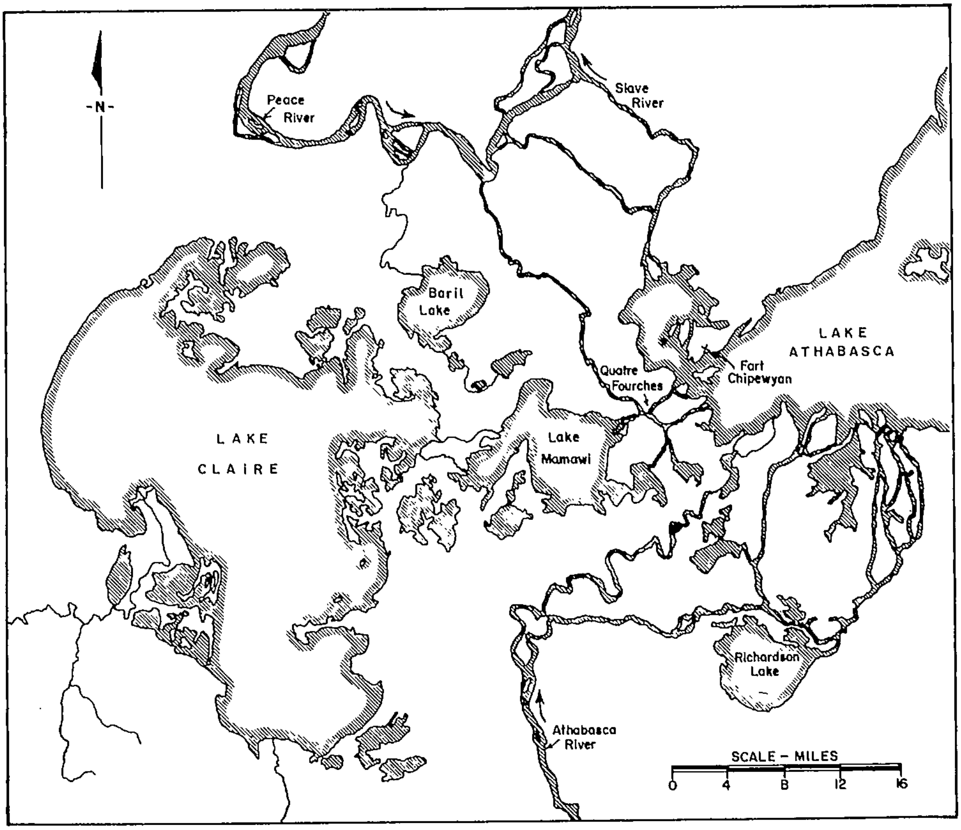

FIG. 5. Detailed map of the area in which the Lake Claire sample was taken.

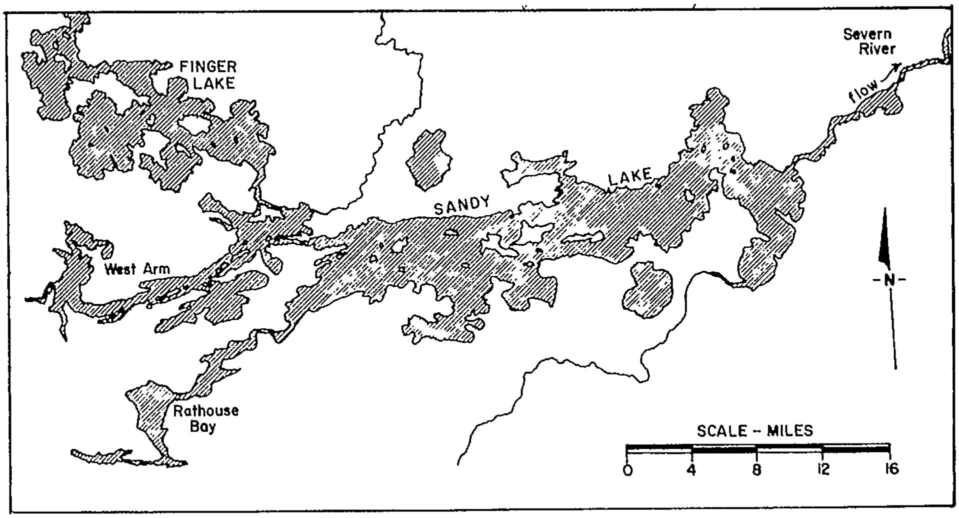

FIG. 6. Detailed map of the area in which the Sandy Lake sample was taken.

Lake Claire goldeye actually do grow considerably during their first year. A sample of 67 Lake Claire goldeye hatched in 1947 and taken on June 3, 1948 averaged 2.7 g and 67.6 mm; this must have been more or less the size attained by the end of 1947.

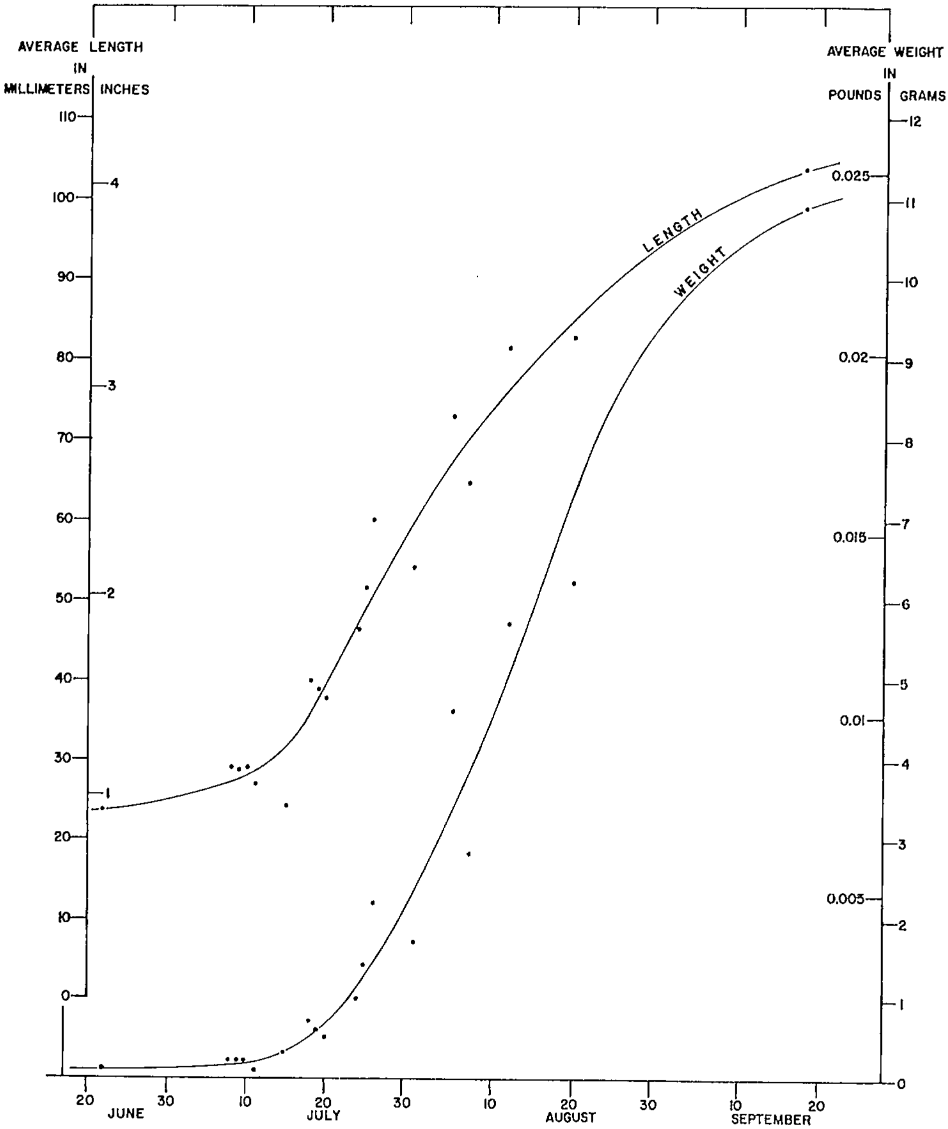

FIG. 7. The relationship between average size (length and weight) and date of capture for 395 goldeye fry from the Saskatchewan River Delta in 1946.

TABLE I. The average length and weight of underyearling goldeye from various localities.

Area	Date	No. of specimens	Weight Range	Weight Avg	Length Range	Length Avg
			g	*g*	*mm*	*mm*
Manitoba (Saskatchewan River Delta)						
Baptizing Creek	Aug. 14, 1945	235	1.1 – 3.4	2.2	51– 73	62.5
	July 8, 1946	11	0.1 – 0.4	0.2	22– 37	28.3
	July 18, 1946	23	0.3 – 1.7	0.7	31– 55	40.3
	July 24–26, 1946	35	0.5 – 3.1	1.8	38– 69	54.8
	Sept. 17–19, 1946	125	4.5 –18.1	10.9	81–121	103.8
McKenzie Creek	Aug. 15, 1945	130	1.2 – 4.6	2.6	52– 82	67.4
	July 9, 1946	7	0.1 – 0.2	0.1	22– 27	24.4
	July 18, 1946	1	0.1 –	0.1	23–	23.0
	July 25, 1946	4	0.5 – 2.2	1.4	38– 61	50.3
	Aug. 5, 1946	2	1.9 – 7.2	4.6	57– 88	72.5
	Aug. 12, 1946	18	2.0 – 9.7	5.7	60– 98	81.4
	Aug. 19, 1946	19	1.7 –10.2	6.2	59– 99	82.6
Miscellaneous localities in marshes of delta	Aug. 23, 1945	2	5.2 – 5.5	5.4	83– 84	83.5
	July 6, 1946	1	0.1 –	0.1	20–	20.0
	July 9, 1946	5	0.1 – 0.2	0.1	24– 30	26.0
	July 19, 1946	1	0.5 –	0.5	36–	36.0
	July 20, 1946	28	0.3 – 0.6	0.4	33– 41	36.6
	July 20, 1946	13	0.1 – 1.2	0.5	25– 51	37.3
	July 24, 1946	15	0.4 – 1.7	0.9	36– 55	45.7
	July 31, 1946	9	0.8 – 3.4	1.7	43– 68	54.0
	Aug. 7, 1946	8	1.5 – 3.5	2.8	54– 70	64.5
Saskatchewan River	Aug. 23, 1945	105	0.8 – 9.2	3.9	46– 94	72.4
	June 22, 1946	11	–	0.1	20– 26	23.3
	July 9–11, 1946	49	0.1 – 0.7	0.2	22– 44	27.9
	July 15, 1946	3	0.3 – 0.4	0.3	33– 36	34.0
	July 19–20, 1946	5	0.2 – 0.8	0.6	30– 44	40.2
	July 25, 1946	3	0.4 – 2.0	1.1	38– 59	47.7
	Oct. 7–30, 1947	49	3.1 –19.6	10.2	68–130	101.4
Saskatchewan-Alberta						
Red Deer and South Saskatchewan rivers	July 18–19, 1948	52	0.1 – 0.9	0.4	27– 45	35.7
	July 23, 1948	8	0.5 – 0.8	0.6	37– 44	41.0
Alberta						
Lake Claire	July 14, 1947	35	0.1 – 0.2	0.11	23– 30	26.5
	July 17, 1947	5	0.1 – 0.2	0.10	25– 30	27.2
	July 20, 1947	49	0.1 – 0.3	0.15	25– 35	30.1
	June 11, 1948	33	–	0.01	10– 15	13.0
	June 14, 1948	96	–	0.02	10– 16	13.2
	June 19, 1948	42	–	0.03	11– 21	15.6
	June 25, 1948	41	0.01– 0.14	0.05	20– 28	23.2
	June 29, 1948	17	0.1 – 0.3	0.13	24– 33	26.5
Ontario						
Lake Abitibi (from R.O.M.Z. collection)	July 25, 1925	20	–	0.14	22– 28	26.0

Seasonal Growth after First Summer

Observations made while determining ages provide useful information regarding seasonal growth in older fish. Scales from fish captured in early May show considerable growth between the outermost distinguishable annulus and the edge. Starting in late May, some scales show a new annulus at the very edge. By early June most scales show a new annulus on or near the edge, and by late June almost all goldeye show an annulus near the edge plus limited marginal growth. By the end of July a typical goldeye scale shows about half as much growth outside the outermost annulus as between it and the second annulus from the edge. By mid-September marginal growth is almost as great as in May. These casual observations suggest that, in the area studied, seasonal growth in some goldeye starts in May, that the number which are growing increases steadily until all are growing by the end of June, that growth is rapid during July, that it becomes slower and slower during August and September, and that very little growth, if any, occurs between October and the following June.

Relationship Between Average Size and Age in Four Localities

The goldeye collection consisted of a large number of subsamples, a subsample being all the goldeye taken on one day at one place; in most cases each subsample consisted of only a few fish. In order to allow meaningful comparisons, subsamples have been grouped to represent four geographical areas, as indicated in the following paragraphs. There is reason to believe that, within each of the four geographical areas, goldeye move freely from one to another of the various connected bodies of water.

A considerable number of subsamples were taken from Dawson Bay, Lake Winnipegosis, and it seemed natural to group them together. Then the subsamples from each of several nearby localities were grouped and size-at-age for each locality was compared with that of Dawson Bay. In no case was there an appreciable difference in the relationship. Data from the localities in question – Shoal River, Steeprock Bay, Steeprock River, Red Deer Lake, and Red Deer River[2] (above Red Deer Lake) – were therefore pooled with Dawson Bay data to form the "Lake Winnipegosis" sample.

Another natural grouping seemed to be subsamples from the Saskatchewan River between Pine Bluff and Hill Island, plus subsamples from McKenzie Creek, Baptizing Creek, Kelsey Lake, and Head River Lake. On the basis of similarity in the size-age relationship, data from subsamples taken at Readers Cutoff, Big Eddy, and Cumberland Lake were also included in this "Saskatchewan Delta" sample.

Data from Lakes Claire, Mamawi, and Athabasca were also grouped after it had been established that age-size relationships were comparable. The grouped data are designated as the "Lake Claire" sample.

The "Sandy Lake" sample consisted entirely of fish taken on September 29, 1953, mainly from Finger Lake, with a few from Sandy Lake.

[2]The Red Deer River to which reference is made above under "Growth during the first summer" and shown in Fig. 3 is a different river.

TABLE II. The relationship between age and average weight in ounces of goldeye in each of four areas.

	Average weight at age:														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
L. Winnipegosis ♀	—	3.0	4.3	9.3	—	14.5	15.7	16.5	—	—	—	—	—	—	—
L. Winnipegosis ♂	—	1.5	4.2	8.4	11.8	11.9	12.1	12.5	—	—	—	—	—	—	—
Saskatchewan Delta ♀	1.4	3.4	7.0	10.1	13.1	15.8	17.3	18.7	20.0	33.0	20.0	34.0	—	—	—
Saskatchewan Delta ♂	1.6	3.2	6.0	8.9	11.6	12.6	14.1	15.5	16.0	21.0	—	—	—	—	—
L. Claire ♀		0.9	2.0	3.5	4.8	7.5	11.8	15.0	18.0	20.9	24.0	25.8	27.4	34.0	—
	0.1														
L. Claire ♂		0.9	2.1	3.0	5.7	7.7	11.9	15.1	17.4	19.2	20.0	20.1	18.0	—	—
Sandy L. ♀	—	—	—	—	—	7.6	9.9	9.0	12.0	11.8	11.6	—	—	18.0	25.0
Sandy L. ♂	—	—	—	—	5.0	7.0	9.0	10.0	10.5	11.1	11.3	12.7	13.3	13.0	—

TABLE III. The relationship between age and average fork length in inches of goldeye in each of four areas.

	Average length at age:														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
L. Winnipegosis ♀	—	7.2	8.7	10.8	—	12.4	13.6	12.8	—	—	—	—	—	—	—
L. Winnipegosis ♂	—	6.2	8.6	10.4	11.7	11.9	12.0	12.4	—	—	—	—	—	—	—
Saskatchewan Delta ♀	6.2	8.4	10.1	11.3	12.0	12.8	13.4	13.8	14.2	15.5	14.5	17.0	—	—	—
Saskatchewan Delta ♂	6.5	8.3	9.9	11.0	11.7	12.3	12.9	13.2	13.9	14.5	—	—	—	—	—
L. Claire ♀		5.2	7.0	8.3	10.0	10.4	12.0	13.2	13.7	14.8	15.2	15.3	16.0	17.2	—
	2.7														
L. Claire ♂		5.4	7.0	8.2	9.2	10.3	12.1	13.1	13.8	14.3	14.5	14.5	14.2	—	—
Sandy L. ♀	—	—	—	—	—	10.4	11.4	11.0	11.9	12.2	12.0	—	—	13.2	14.5
Sandy L. ♂	—	—	—	—	9.5	10.2	11.2	11.2	11.5	11.7	11.8	11.9	12.2	12.0	—

Tables II and III show average weight in ounces and average fork length in inches respectively at every age represented in each of the four samples. Table IV shows the number of fish on which each average is based.

Growth Rates

Values from the first six lines of Table II are plotted in Fig. 8 and curves are fitted to them by eye. On the basis of the seasonal growth pattern described above and on the average date of capture, it is estimated that goldeye in the Winnipegosis sample had achieved, on the average, roughly 50% of their annual growth, and that those in the Saskatchewan and Claire samples had achieved roughly 30%. The "ages" used for plotting Fig. 8 take account of seasonal growth; for example, the average weights for the Claire sample are plotted at "ages" 1.3, 2.3, 3.3, etc., rather than at ages 1, 2, 3, etc.

The curves of Fig. 8 represent increase in average weight with age. Growth rate at any given age could be derived by drawing an appropriate tangent. In a general way, each curve represents the growth pattern of a typical goldeye in the specified locality, but strictly speaking, the curve required to represent the growth of a typical goldeye would resemble a flight of steps, each "riser" representing growth during June to September inclusive, each "tread" representing the other eight months when there was little or no growth.

Although goldeye in the lower Saskatchewan River and its delta grow slightly faster than in Lake Winnipegosis, the difference is relatively small. By contrast, Lake Claire goldeye grow slower than either initially, then grow faster than either after about age 5.

Although not shown in Fig. 8, growth curves for Sandy Lake were compared with those for the other three localities. The Sandy Lake growth rate is roughly the same as the Lake Claire until age 5, and roughly the same as the Lake Winnipegosis after age 7. As a result, mature Sandy Lake goldeye are considerably smaller than those from the other three localities at a given age.

Sex and Growth

Tables II and III and Fig. 8 indicate that young goldeye of both sexes grow at approximately the same rate, but among older fish females grow faster than males. The age at which females begin to grow faster than males varies with locality. There is no obvious relationship between age at maturity and age at which growth rates of the sexes diverge.

Growth in Other Areas

Ages were also determined for a small number of goldeye from each of several other Canadian localities and appropriate comparisons (not illustrated) were made. These comparisons suggest a similarity between growth rates in Lake Pukatawagan and in the Saskatchewan Delta. Growth rates in both Lake Abitibi and Great Slave Lake seem similar to those in the Sandy Lake area, i.e. slower than any of the rates indicated by Fig. 8.

Table IV. The number of fish on which the averages of Tables II and III are based.

	Number of fish of age:														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
L. Winnipegosis ♀	0	3	89	126	0	85	297	56	0	0	0	0	0	0	0
L. Winnipegosis ♂	0	5	66	78	30	385	112	4	0	0	0	0	0	0	0
Saskatchewan Delta ♀	43	40	34	188	554	324	86	26	7	1	1	1	0	0	0
Saskatchewan Delta ♂	99	33	69	121	276	119	50	12	2	1	0	0	0	0	0
L. Claire ♀	122	19	174	119	2	52	177	300	241	112	53	33	15	1	0
L. Claire ♂		19	175	79	3	81	211	193	80	58	48	17	1	0	0
Sandy L. ♀	0	0	0	0	0	7	6	2	4	5	10	0	0	1	1
Sandy L. ♂	0	0	0	0	1	12	2	10	19	31	15	6	3	1	0

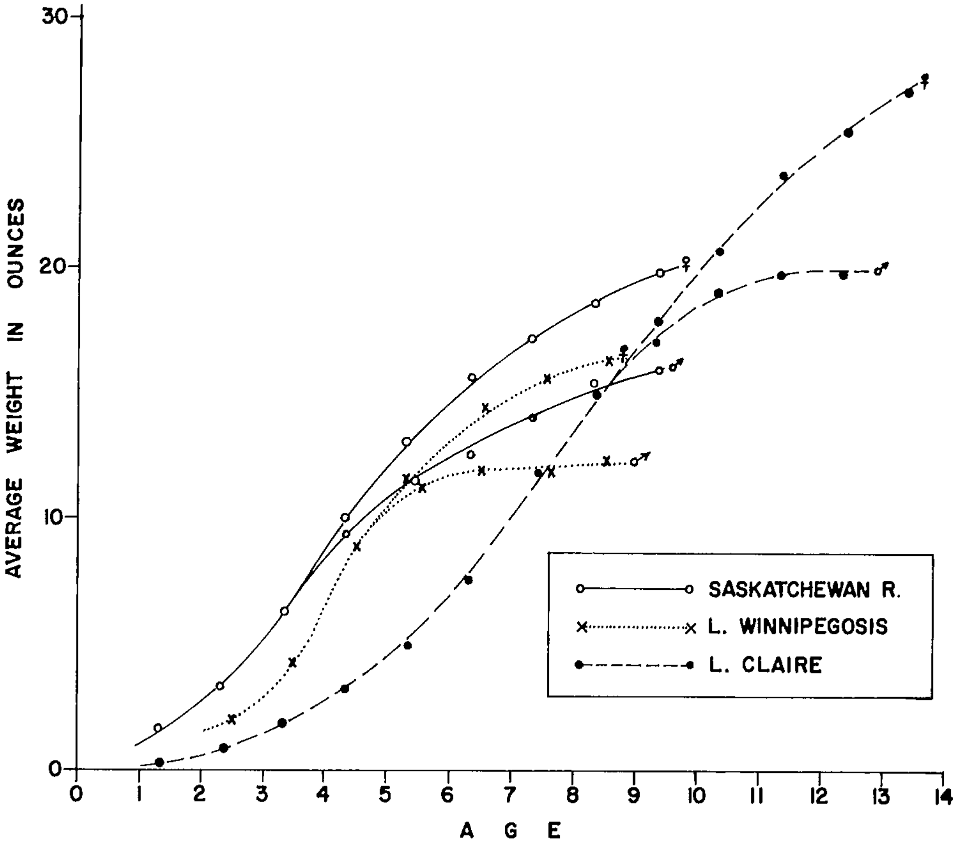

FIG. 8. The relationship between age and average weight in samples of goldeye from three localities.

Miller (1949) tabulates average size and age for goldeye from the Bow River, Alberta, based on 17 specimens. His limited data indicate a rate of growth slightly greater than the fastest rate indicated in Fig. 8. The rate is maintained over a relatively long period, with the result that adult goldeye from Bow River weigh almost twice as much at a given age as those from Lake Claire. Our data cannot be compared directly with those of Grosslein and Smith (1959) for goldeye in Red Lake, Minnesota; however, comparisons become possible if their length-weight formula is applied to their published total length data in order to derive approximate weights. It then becomes evident that the growth *rate* of Red Lake goldeye after the second year is much the same as that of Lake Claire goldeye after the sixth year. As a result, mature Red Lake goldeye are roughly 9 oz heavier than Lake Claire goldeye at any given age. The same length-weight formulas were used to calculate approximate average weights from average total length data which Alvord (1957) has tabulated for goldeye from Fort Peck Reservoir, Montana; it is noted that values very close to his actual overall average weights can be derived from his overall average lengths for each of three samples by use of the Red Lake formula, which inspires confidence in its applicability to Fort Peck Reservoir data. On the basis of average weights so derived, the growth curve for Fort Peck Reservoir goldeye (where rates for males and females are not shown separately) is almost exactly intermediate between those for Saskatchewan males and females. Age-weight data are also available for Lake Texoma, Oklahoma (Martin, 1952). Lake Texoma goldeye grow very rapidly during their first 2 years, then growth rate decreases rapidly until growth virtually stops. As a result, Lake Texoma goldeye are larger for their age than Saskatchewan Delta goldeye until age 5, after which they are smaller for their age.

It would appear that goldeye in the study area never reach a size comparable with the maximum size reached in some localities further south. The sizes of some goldeye that have been reported from the United States are: 20 inches and 50 oz in Ohio (Trautman, 1957); 18 inches and 3 lb in Iowa (Coker, 1929); and 16 inches and 43 oz in Wyoming (Simon, 1946).

LENGTH-WEIGHT RELATIONSHIP

After preliminary tests, which showed no appreciable differences between the sexes or between areas, the average weights from Table II were plotted on log-log paper against the corresponding average lengths from Table III and a straight line (not shown) was fitted by inspection. The line can be represented by the following equation:

$$Y = 3.20X - 2.37$$

where: $X = \log_{10}$ of fork length in inches
and $Y = \log_{10}$ of weight in ounces

or alternatively:

$$y = 0.0042\, x^{3.20}$$

where: x = fork length in inches
y = weight in ounces

Grosslein and Smith (1959) give the following relationship for goldeye in Red Lake, Minnesota:

$$\text{Log } W = -2.094 + 2.844 \log L$$

where: W = weight in ounces
and L = total length in inches.

Since they use total length while we use fork length, the two equations are not strictly comparable. However, the difference between total length and fork length should have little effect on the slopes of the straight lines represented by the two equations. The value 3.20 which represents slope for Canadian goldeye is considerably greater than the value 2.844 for the Red Lake data. In other words, within the size range considered, goldeye in each of the four Canadian areas sampled increase considerably more in weight for a given increase in length than do those of Red Lake.

Size Variability

Tables V and VI illustrate the amount of variability in size at a given age. Table V is based on the Saskatchewan Delta sample, which represents a goldeye population that has been heavily exploited for some time. Table VI is based on the Lake Claire sample, which represents a virtually unfished goldeye population.

In both tables even the youngest and smallest fish are well represented, unlike the usual situation where the smallest and youngest fish are poorly represented in a sample because of net selection. Apparently the wide range of mesh sizes used and the great variation in size of goldeye taken by a given mesh size (Table XV) has made net selection a less serious factor than usual.

As would be expected, large fish are comparatively more plentiful in the virtually unexploited population represented by the Lake Claire sample than in the heavily exploited population represented by the Saskatchewan Delta sample.

Five-Year-Olds

A striking feature of Table IV is the complete lack of age 5 females and the comparatively small numbers of age 5 males in the Lake Winnipegosis sample. Age 5 goldeye of both sexes are also scarce in the Lake Claire sample. Because of the wide range of mesh sizes used and of variation in size taken by each mesh, it seems very unlikely that this anomally is the result of net selection.

The anomaly could be explained by assuming a weak 1940 year-class in Lake Winnipegosis and a weak 1942 year-class in Lake Claire, since the Winnipegosis sample was collected in 1945 and the Claire sample mainly in 1947. However, this explanation would entail an unlikely coincidence of phenomenally weak year-classes and it is therefore rejected.

The following explanation is suggested. It can be postulated that, when they are about 5 years old, goldeye in lakes develop some unique behaviour which makes them much less vulnerable to gill nets than they were about a year earlier or will be about a year later. This unique behaviour could be associated with approaching maturity; no attempt is made to define it in detail. However, it is obvious that any of the following types of behaviour would greatly reduce the chances of capture: (1) avoiding the area which other goldeye frequent (commercial fishermen and scientists usually plan to fish where fish are concentrated); (2) frequenting a different depth than goldeye of other ages, although in the same general area; (3) remaining stationary (gill nets catch only moving fish). There is some suggestion in Table IV that some of the age 4 and age 6 goldeye also have the same behaviour. The postulated unique behaviour seems peculiar to lacustrine goldeye. In the Saskatchewan Delta sample, which represents a fluvial population, goldeye were more numerous at age 5 than at any other age. Do goldeye prefer rivers to lakes when 5 years old?

TABLE V. The number of Saskatchewan Delta goldeye of a given age which are of a given weight. Weights recorded originally in ounces, here grouped to the nearest ¼ lb.

Weight (*lb*)	1	2	3	4	5	6	7	8	9	10	11	12♂	Total
0	117	11	0	0	0	0	0	0	0	0	0	0	128
¼	25	60	56	27	0	0	0	0	0	0	0	0	168
½	0	2	41	147	98	6	0	0	0	0	0	0	294
¾	0	0	6	116	495	169	35	3	0	0	0	0	824
1	0	0	0	19	223	205	66	20	4	0	0	0	537
1¼	0	0	0	0	13	61	31	11	4	1	1	0	122
1½	0	0	0	0	1	2	4	4	1	0	0	0	12
1¾	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	1	0	1	2
Total:	142	73	103	309	830	443	136	38	9	2	1	1	2087

TABLE VI. The number of Lake Claire area goldeye of a given age which are of a given weight. Weights recorded originally in ounces, here grouped to the nearest ¼ lb.

Weight (*lb*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
0	122	39	276	6	0	0	0	0	0	0	0	0	0	0	343
¼	0	1	173	57	6	31	1	0	0	0	0	0	0	0	269
½	0	0	0	1	1	87	95	16	2	0	0	0	0	0	202
¾	0	0	0	0	0	16	237	177	26	0	0	0	0	0	456
1	0	0	0	0	0	1	51	215	136	41	11	2	0	0	457
1¼	0	0	0	0	0	0	6	81	133	86	41	15	2	0	364
1½	0	0	0	0	0	0	0	4	23	35	38	18	6	0	124
1¾	0	0	0	0	0	0	0	0	2	7	7	10	6	0	32
2	0	0	0	0	0	0	0	0	0	1	4	5	1	1	12
2¼	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Total:	122	40	349	64	7	135	390	493	322	170	101	50	16	1	2260

Mortality Rates

When the numbers of fish at each age are plotted against age on semi-logarithmic paper, the resulting curves are known as "catch curves." Several authors, including Ricker (1958), have described how catch curves can be used to derive information on mortality rates. Only the right limb of the catch curve, i.e. the part to the right of the highest point, is considered. If a straight line fits several points on the right limb, then the mortality rates for the ages represented by those points can be derived from the slope of that line. If a regular curve can be fitted for the points, then the mortality rate at any point on the curve can be derived from the slope of the tangent to the curve at that point.

The right limbs of growth curves for Saskatchewan Delta and for Lake Claire are shown on Fig. 9; they are based on the totals given at the bottom of Tables V and VI, respectively. Data for Lake Texoma (Martin, 1952) are also plotted for comparison.

Figure 9 offers a very interesting comparison between an unexploited population represented by the Lake Claire sample and a heavily fished population represented by the Saskatchewan Delta sample. Assuming full vulnerability to the gear, the slope of the right limb that represents the unexploited population must have been determined by natural mortality only, while that of the heavily exploited population must have been determined by natural mortality plus heavy fishing mortality over several years. The straight line which is the Saskatchewan Delta catch curve represents a total mortality rate (i.e. natural mortality plus fishing mortality) of 74% for ages 6–10 inclusive. The curved line which is the Lake Claire catch curve represents a natural mortality rate which increases with age; the rate is 42% for ages 8–10 inclusive, 48% at age 11, 57% at age 12, 73% at age 13, and very close to 100% at age 14. The two sexes have roughly the same mortality rates in each case.

The Lake Winnipegosis data (line 1 plus line 2, Table IV) are too erratic to give useful catch curves. It is noted, however, that the decline in numbers from age 7 to age 8 represents a total mortality rate of 86%, probably indicating that prior to the study fishing pressure had been even greater in Lake Winnipegosis and vicinity than in the Saskatchewan Delta and vicinity. There are not enough goldeye in the Sandy sample to justify a catch curve.

The Lake Texoma catch curve offers an interesting contrast to those derived from our data. The right limb of the curve represents a total mortality rate which increases with age; it is 74% at age 4, 90% at age 5, and very nearly 100% at age 6. Lake Texoma goldeye had been virtually unfished for several years before the sample was taken. The slope of the catch curve is therefore almost entirely the result of natural mortality. The steeper slope of the Lake Texoma curve shows that natural mortality rates are higher in there than in Lake Claire, which is not surprising since Lake Texoma is near the southern limit of the area in which goldeye are found.

SEX AND REPRODUCTION

Sex Ratio

The data given in Table IV show that 57% of the goldeye used for age studies were female. There were more females than males in the Saskatchewan Delta and Lake Claire samples, and more males than females in the Lake Winnipegosis and Sandy Lake samples. Consideration of subsamples indicates that

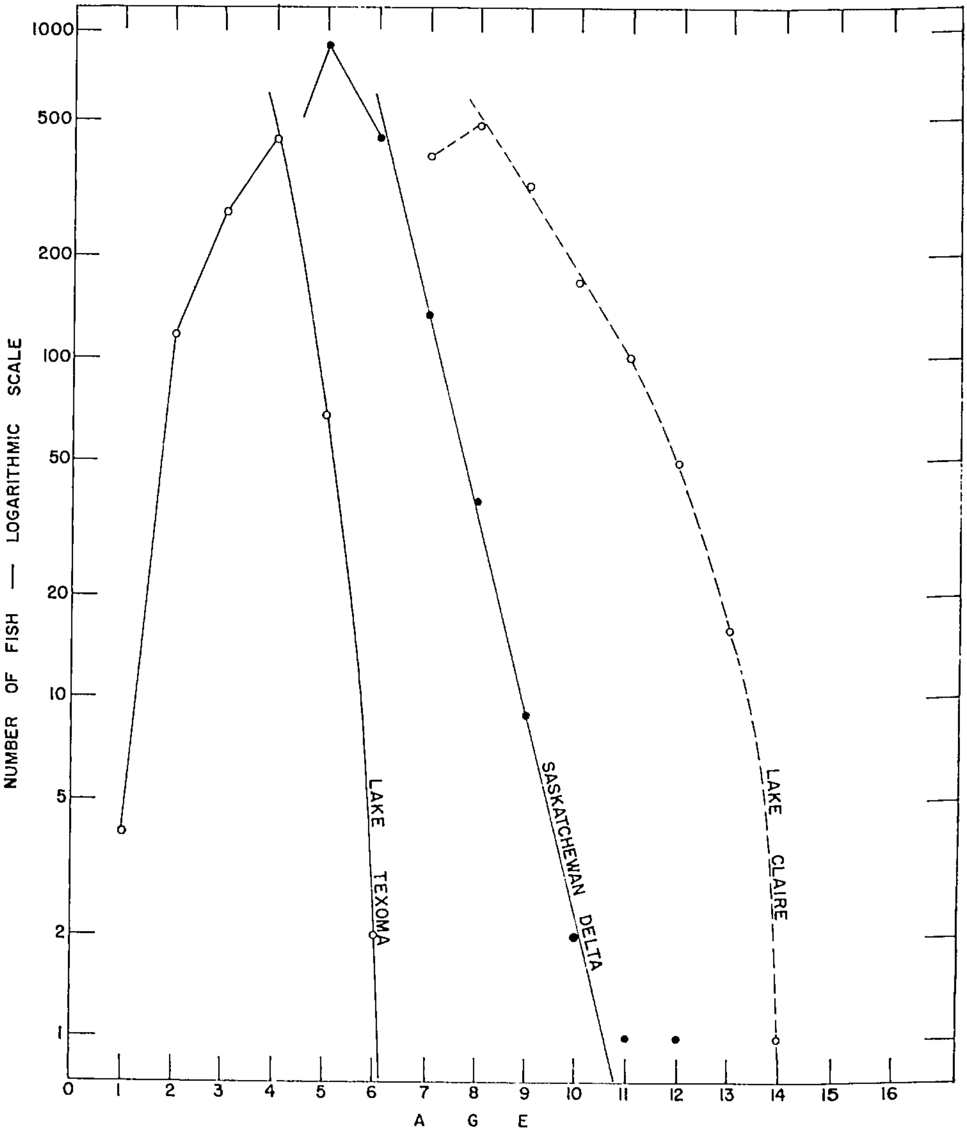

Fig. 9. Goldeye catch curves based on data from Table IV and on published data for Lake Texoma.

because there is sufficient variation in the sex ratios from time to time and from place to place the sex ratio in each of the above cases could have been reversed by suitable alterations of the sampling schedule. There are therefore no grounds for concluding that the sex ratio is appreciably different from one male to one female.

Martin (1952) reports that 72% of a sample of goldeye from Lake Texoma were female. Data presented by Grosslein and Smith (1959) indicate that 40% of a sample from Red Lake were female.

MORPHOLOGY

The immature ovaries are vertically striated in appearance and may be readily identified in specimens only a few months old. As maturity approaches the gonad increases in size and small white eggs become visible. The size and number of visible eggs increases during the summer prior to the first spawning season at which time the ovaries fill most of the body cavity. The eggs reach a diameter of about 1/12 inch by the end of the summer and are light grey in colour, with a large single oil globule which is a light slate colour. There is little change in appearance until just prior to spawning the next spring, when the eggs become steel blue. The ripening process evidently occurs very rapidly, since few individuals were taken from which the eggs could be expressed readily. There are no oviducts in the mature goldeye; the ripe eggs are shed into the body cavity and are then passed through a genital pore situated behind the anus. Eggs which remained in the body cavity after spawning and eggs in the ovaries of partially spent females were rather translucent. This may be the appearance of the ripe egg just prior to extrusion.

After spawning, the ruptured ovaries shrink back into a normal conditions and small undeveloped eggs, which are visible in the ovarian tissue at spawning time, rapidly increase in size. By late summer the ovaries are once again full of eggs and fill most of the body cavity.

The immature testes are unstriated and much smaller than the ovaries of corresponding age groups. The testes increase in size as the fish grows older, but remain as a straight band of tissue until the year preceding the first spawning season, when they become slightly convoluted. At this time, the testes are about 1/4 inch in diameter. The testes enlarge slightly just prior to spawning and convolution increases; there is no outstanding increase in size as is the case with other freshwater species. The usual reddish colour changes to a lighter shade, but the testes do not become white. There is a general milkiness throughout and small isolated white areas appear which may represent localized areas where spermatogenesis is occurring. Although several thousand specimens were examined at spawning time, not one completely white inflated testis was observed. Application of vigorous stripping techniques may express one drop of milt, but not more, from one individual. Because so little milt is produced, it seems likely that the sexes are in close proximity during the spawning act in order to ensure fertilization of the eggs.

There are no obvious secondary sexual characteristics developed at spawning time. The sexes may be readily distinguished at all times after maturity is reached, as the males develop elongated rays in the anterior part of the anal fin which form a conspicuous lobe (Fig. 1). The female anal fin lacks such a lobe, as do all immature specimens of both sexes. Such sexual dimorphism is rare among freshwater fishes.

Frequency of Spawning

Hinks (1943) states: ". . . the goldeye does not spawn every year after sexual maturity has been reached." He presents no data to support this statement and a diligent search through his original data has failed to uncover evidence which would support it. Spawning intervals of greater than one year have been reported for other species. There is evidence that mature female lake trout, *Cristivomer namaycush,* spawn roughly once every three years in Great Bear Lake (Miller and Kennedy, 1948), and roughly once every two years in Great Slave Lake (Kennedy, 1954), and that many of both sexes fail to spawn at least once after reaching maturity in Lake Opeongo (Fry, 1949). Adult female whitefish, *Coregonus cliupeaformis,* in Great Slave Lake apparently spawn roughly every two years (Kennedy, 1953). There is some evidence that adult female arctic char, *Salvelinus alpinus,* near Term Point, Hudson Bay, fail to spawn every year (Sprules, 1952).

On the basis of several thousand ovaries examined during the present study, we conclude that, apart from a very few individuals with abnormal gonads and except for a few cases where the fully developed eggs are retained and eventually resorbed, adult female goldeye spawn every year after they become mature. The nature of the testis makes assessment of spawning frequency more difficult in the case of mature male goldeye; however, no evidence was found that they fail to spawn annually.

Age at Maturity

The gonads of virtually all of the specimens used for the age studies were examined to determine state of maturity. Since the spawning season extends from about mid-May to the end of June, most goldeye taken before late June were easily distinguished as either (1) ready to spawn, partly spawned, or just finished spawning, or (2) immature. After mid-July there are three easily distinguishable categories: (1) mature fish, those that have spawned and will spawn again, (2) maturing fish, which have not spawned but will spawn next spawning season, and (3) immature fish, which have never spawned and are not expected to spawn next season.

A convenient and logical time to consider state of maturity is when a fish is exactly 1, 2, 3, etc. years old. Therefore, after a preliminary examination of the data to determine the best date the convention was adopted of regarding both "mature" and "maturing" goldeye of age n—1 taken on or after July 1 as fish that would be mature on their *n*th birthday; the rest would by definition be immature on their *n*th birthday. Also, fish of age *n* if taken before July 1 were regarded as mature on their *n*th birthday if they were about to spawn, were spawning or had just spawned; if not, they were regarded as immature on their *n*th birthday. The numbers of mature and immature at age *n* from both sources were summed and used to derive the values shown in Table VII. Strictly speaking, data for fish taken after July 1 should be given less weight because of expected mortality between date of capture and spawning time (roughly 10 months); however, because values derived from the after-July 1 fish agreed reasonably well with values derived from the before-July 1 fish, the data were not weighted.

It is evident from Table VII that males tend to mature about one year earlier than females, that they tend to mature slightly earlier in Lake Winnipegosis than in the Saskatchewan River Delta, and that maturity is about a year earlier in both than in Lake Claire. About four years elapses between the last spawning season when all goldeye in a category are immature to the first spawning season when all are mature.

Because of annual growth, the data cannot be used in the same way to derive a relationship between proportion of mature fish and size. It also would be misleading to derive relationships between maturity and weight and between maturity and length by combining information from Table VII with information from Tables II and III respectively, because the biggest fish in any year-class tend to mature first and the smallest tend to mature last. Table VIII indicates size ranges within which goldeye mature. It seems highly likely that some or all of the size ranges indicated by Table VIII could be appreciably extended by taking larger samples.

SPAWNING

Although spawning behaviour could not be observed directly because of high turbidity in the waters frequented by goldeye, a good deal could be deduced from observations on when and where ripe, partly spawned, and recently spent goldeye were captured. Apparently, in the area studied, when the ice begins breaking up in the spring, goldeye move to spawning areas from the deeper waters of lakes and rivers where they have wintered. They spawn in pools in turbid rivers or in lakes and ponds which form backwaters of such rivers. Many areas where goldeye spawn are shallow and either freeze to the bottom or are so stagnant in winter that goldeye could not survive in them. However, this is immaterial since goldeye normally leave these areas between spawning time and freeze-up. Most spawners are taken where the lake or river bottom is firm. In Canadian waters, spawning occurs some time during May or June; the exact time and duration depends on temperature. The first signs that spawning has begun are noted when mean water temperature is 50–55, and it would appear that spawning continues for 3–6 weeks. It is surmised that spawning occurs during hours of darkness, because of indications that goldeye are most active at night.

TABLE VII. The relationship between goldeye age and state of maturity in samples from three localities expressed as percentages mature at each age. Percentages are based on about the numbers of specimens indicated by Table IV.

Age	Winnipegosis		Saskatchewan		Claire	
	♀	♂	♀	♂	♀	♂
< 4	0	0	0	0	0	0
4	0	10	0	9	0	0
5	12	47	2	30	0	0
6	67	68	8	81	0	4
7	99	100	76	100	2	86
8	100	100	97	100	55	98
9	100	100	100	100	96	100
> 9	100	100	100	100	100	100

TABLE VIII. The relationship between size of goldeye and state of maturity in samples from three localities. [a]

	Females			Males		
	W	S	C	W	S	C
Min wt (oz) at which maturity was observed	9	10	8	5	6	6
Max wt (oz) at which immaturity was observed	12	20	15	12	16	9
Min fork length (inches) at which maturity was observed	10½	10¼	10½	9	9¾	9¾
Max fork length (inches) at which immaturity was observed	12¼	13½	12¾	11¾	12½	11½

[a] Localities abbreviated as follows: W, Winnipegosis; S, Saskatchewan; C, Claire.

Prior to this study, the season at which goldeye spawn was a moot question. During the study it was noted that immediately after spawning eggs in the ovary, which until then had been minute, began to increase rapidly in size. Within 2 months of spawning the eggs would be more or less the size found in spawning fish; there was almost no further change during the following 10 months. Unless an observer had access to a series of ovaries taken at very short intervals during the critical period, he would get the impression that female goldeye are ready to spawn at the time examined, regardless of when that might be. Casual examination of testes would be even more confusing, since they remain almost unchanged in appearance regardless of season, and even at the height of the spawning season milt can only be expressed with difficulty and in minute quantities. These facts seem to explain many conflicting and erroneous reports regarding the time at which goldeye spawn.

Eggs

Ovaries from 15 mature goldeye were preserved in 5% formalin. Later the eggs were separated from the connective tissue and every egg in each pair of ovaries was counted. Average egg diameters were also derived by measuring the total length of 15–20 eggs when placed in a straight line; 3–6 replicates were made for each fish. Pertinent information is presented in Table IX.

Table IX. Summary of information on 15 mature goldeye for which egg counts and average egg diameter were determined.

Capture date	Lake of origin	Fork length (*inches*)	Round wt (*oz*)	Age [a]	Total No. of eggs	Avg egg diam (*inches*)
Dec. 1945	Winnipegosis	12.00	13	7	9,443	0.068
		12.50	16	7	15,147	0.068
		13.00	17	6	14,931	0.068
		13.50	20	7	14,178	0.068
Mar. 6, 1947	Cedar	12.75	16	7	11,888	0.069
		13.00	19	7	6,227	0.078
		13.50	22	7	5,761	0.071
		14.00	27	10	15,441	0.090
Mar. 11, 1947	Sipiwesk	13.25	18	10	8,388	0.075
		14.00	20	12	17,020	0.080
Apr. 11, 1947	Pukatawagan	14.50	22	11	14,747	0.078
		14.75	23	11	17,906	0.078
		15.25	23	11	20,835	0.080
		15.25	24	12	15,107	0.082
		15.50	28	13	25,238	0.077

[a]Age is given in completed years; most of the fish are almost 1 year older than shown and all are essentially the same size as they will be on their next birthday.

There are no published records of goldeye egg counts or egg diameters. Dr M. Trautman has provided an unpublished record of a goldeye from Ohio waters, 341 mm in total length, which had 9052 developed eggs. Dr F. Neave has provided unpublished records of three goldeye of unspecified size taken from Lake Winnipeg in May 1936 with 7100, 6400, and 10,874 eggs, respectively.

Data on fertilized goldeye eggs and fry collected during the study have been reported by Battle and Sprules (1960). Of special interest is the fact that the eggs are semibuoyant.

FOOD

The stomach contents of goldeye used for the age studies were noted whenever circumstances permitted. For this purpose, the stomach was opened, the contents were removed and immediately examined microscopically. Organisms were identified to the finest taxonomic unit that was feasible; the effects of digestion and the conditions under which stomachs were examined usually made identification to species, often even to family, impracticable.

Type of Food Eaten

Stomachs were classified as "empty" if there was nothing present identifiable as organic by macroscopic examination. Two stomachs which contained only inorganic material were classified as empty.

The organisms found in the stomachs have been grouped under the following headings: Corixids, Other Aquatic Insects, Other Insects, Other Invertebrates, Pike, Other Fish, Other Vertebrates, Other Organic. Below are given definitions of these categories and details of the organisms that were included in each category.

Corixids included any species of the family Corixidae (order Hemiptera).

Other Aquatic Insects included insects which normally live on or below the water surface. For example, the term as used in this paper includes Chironomidae larvae and pupae but not adults, Ephemeroptera nymphs but not adults, and Notonectidae at all stages. The following were identified (an item which appeared in only one stomach is indicated by an asterisk): Plecoptera, including *Pteronarcys* sp., *Taeniopteryx* sp*., and *Isoperla* sp*.; Ephemoroptera, including *Hexagenia* sp., and *Stenonema* sp*.; Odonata, including Zygoptera; Hemiptera (exclusive of Corixidae), represented only by Notonectidae; Trichoptera, including *Rhyacophila* sp.; Diptera, including Ceratopogonidae and Chironomidae; and Coleoptera.

Other Insects included insects which normally do not live in or on the water, for example, all stages of Orthoptera and the adult stage of Chironomidae. This heading includes items recorded as "unidentified insects," also "beetles," both of which probably include a few "other aquatic insects." The following were identified (an item which appeared in only one stomach is indicated by an asterisk): Orthoptera, a grasshopper*; Ephemeroptera, including *Hexagenia* sp.; Odonata, both damselflies and dragonflies; Hemiptera, including Pentatomidae; Trichoptera; Lepidoptera*; Diptera, represented only by Chironomidae; Coleoptera, including Curculionidae, Buprestidae, Elateridae, Cerambycidae, and Coccinellidae, also *Phyllophaga* sp.; and Hymenoptera, including Formicidae.

Other Invertebrates included (an item which appeared in only one stomach is indicated by an asterisk): Nematoda; Nematophora; Annelidae, represented only by Hirudinea*; Arthropoda, represented by Arachnida (spider)*, Decopoda (crayfish), Ostracoda, Amphipoda, both *Gammarus* sp. and *Hyallela* sp.; Mollusca, mainly *Sphaerium* sp. and *Pisidium* sp.

Pike consisted entirely of relatively small *Esox lucius*.

Other Fish were predominantly those recorded as "unidentified fish remains" and presumably largely pike. In order of abundance, those identified were (an item which appeared in only one stomach is indicated by an asterisk): *Percopsis omiscomaycus, Perca flavescens, Notropis hudsonius**, *Percina caprodes**, *Etheostoma* sp*., *Pungitius pungitius**, and *Eucalia inconstans**.

Other Vertebrates included (an item which appeared in only one stomach is indicated by an asterisk): Amphibia represented only by Ranidae, including (probably solely) *Rana sylvatica**; and Mammalia, mice except for one shrew*.

Other Organic included: "eggs," plankton, and pieces of emergent aquatic vegetation.

Although several food items were recorded only once, and although "corixids" and "pike" occurred often enough to warrant separate unique treatment, most categories comprised moderate numbers of each of several food items, with no single item predominant. No item under "aquatic insects" appeared in more than 6% of the stomachs with food. Under "other insects," no item appeared in more than 10%, and in the other categories (excluding corixids and pike), none appeared in more than 2%.

Frequency of Occurrence of Various Foods

The last column of Table X shows the relative frequency of occurrence in the goldeye stomachs examined of the various categories of food. Plainly, in the stomachs examined the dominant food was insects, of which Corixidae was the most important family by far. Although a major part had fed on autochthonous insects, almost as many had fed on those normally associated with a non-aquatic environment and which could only become available through accidentally falling into or purposely alighting on the water.

TABLE X. Stomach contents of goldeye from four localities. Of those with food, the percentage with each type of food is shown; percentages total to more than 100%, since there was more than one type of food in some stomachs. See text for definition of food classifications.

	Lake Winnipegosis	Sask. Delta	Lake Claire	Sandy Lake	Combined
No. examined	296	155	141	9	601
Percentage empty	40	31	6	0	29
No. with food	178	197	133	9	427
Percentage with:					
Corixid	64	47	29	0	48
Other aquatic insects	19	23	26	0	22
Other insects	71	52	12	0	46
Other invertebrates	8	13	0	0	7
Pike	0	1	46	0	15
Other fish	4	2	24	0	10
Other vertebrates	0	7	0	100	4
Other organic	1	3	4	0	2

Comparisons among the first four columns of Table X demonstrate that goldeye food can vary considerably from place to place. There was comparatively little difference between Lake Winnipegosis and the Saskatchewan Delta, two adjacent localities; in both the diet was predominantly insects, particularly Corixidae. By contrast, the predominant item in Lake Claire stomachs was pike, particularly since a major part of "other fish" was probably actually pike. The Sandy Lake stomachs contained only mice; the sample was small and represents only one day, so it should not be assumed that mice are the usual diet in Sandy Lake.

An examination of Table XI shows that (1) goldeye food can vary from month to month at a given place and (2) the pattern of variation from month to month can differ from place to place. In Lake Claire the diet changed from mainly corixids and other aquatic insects in May to mainly pike in July. Although Lake Winnipegosis and the Saskatchewan River Delta are close to one another geographically, and although the diet was roughly similar in each during the spring and summer, the two differed in detail regarding the pattern of change from month to month. The fish taken in December from Lake Winnipegosis had a much more restricted diet than those taken in the spring and summer, no doubt a result of the ice cover on the lake in December.

Further analyses of the data (not shown here) failed to show noteworthy differences in the frequency of occurrence of food items related to (1) sex, (2) state of maturity, (3) size of fish, or (4) year of capture.

TABLE XI. Stomach contents of goldeye by months for each of three localities. Of those with food the percentage of each type of food is shown; percentages total to more than 100%, since there was more than one type of food in some stomachs. See text for definition of food classifications.

	Lake Winnipegosis				Sask. Delta			Lake Claire	
	June	July	Aug.	Dec.	May [a]	July	Aug. [b]	May	July
No. examined	42	107	47	100	12	16	127	49	92
Percentage empty	5	9	30	92	33	56	28	2	8
No. with food	40	97	33	8	8	7	92	48	85
Percentage with:									
Corixid	83	68	33	50	50	0	50	77	2
Other aquatic insects	20	19	9	62	12	14	25	52	11
Other insects	80	65	94	0	0	100	53	4	16
Other invertebrates	15	4	12	0	25	0	13	0	0
Pike	0	0	0	0	0	0	1	0	72
Other fish	10	2	3	0	0	0	2	35	17
Other vertebrates	0	0	0	0	50	0	3	0	0
Other organic	2	1	0	0	0	0	3	6	2

[a] Includes one empty stomach in April.
[b] Includes four with food in September.

FOOD OF SMALL GOLDEYE

In addition to the stomachs of larger goldeye examined during routine sampling, the viscera of 25 small goldeye, "fish-of-the-year," collected in the Saskatchewan

River Delta in 1946 (15 in July, 5 in August, 5 in September) and of four collected at Lake Claire in May 1947 were preserved for later examination. In 1948 Dr I. G. Arnason opened the 29 stomachs and intestines, removed their contents and examined them microscopically. The following microcrustacea, in order of abundance, were identified: *Daphnia longispina, Daphnia pulex, Diaphanosoma brachyrum, Acroperus harpae, Bosmina obtusirostrus, Bosmina longispina, Moina brachiata, Diaptomus manitobensis*[3], and *Cyclops bicuspidatus.*

The small goldeye had also eaten some of the kinds of food found in the stomachs of larger fish. Five had eaten aquatic insects, five other insects, three other invertebrates, and one had eaten part of a higher aquatic plant.

Quantities of Food

For about ⅓ of the stomachs examined the quantity of food was determined volumetrically to the nearest 0.1 cc. Those selected were mainly from Lake Winnipegosis with a few from the Saskatchewan River Delta and Lake Claire, and none from Sandy Lake. The frequency distribution of relative volumes for all stomachs sampled in which there was food is shown in the last column of Table XII. Notice that the volumes increase logarithmically.

Table XII. Frequency distributions of goldeye whose stomachs contained the indicated volumes of food. Frequencies are expressed as percentages of those examined which contained food. The final column includes the other data plus some for Saskatchewan River Delta and Lake Claire.

	Lake Winnipegosis				Total for which volume determined
	June	July	Aug.	Dec.	
No. examined	42	94	30	6	219
Percentage with:					
less than 0.1 cc	2	12	7	66	18
0.1 – 0.2 cc	0	11	10	17	8
0.3 – 0.4 cc	7	5	7	17	6
0.5 – 0.8 cc	15	20	16	0	16
0.9 – 1.6 cc	31	16	10	0	18
1.7 – 3.2 cc	26	16	30	0	18
3.3 – 6.4 cc	17	7	13	0	9
over 6.4 cc	2	13	7	0	7

The analysis of the Lake Winnipegosis data by months, which is shown in the other columns of Table XII, is more meaningful than the combined data. The quantities varied little during the months of June, July, and August; in each month there were slightly more than 2 cc of food per stomach. But in December, with lower temperatures and ice cover, quantities were much smaller.

The second lines of Tables X and XI, which show percentage of empty stomachs, are in a sense also quantitative since they indicate the proportion of stomachs

[3]New species (Arnason, 1950).

with zero volumes. Although the volume of food found in the stomachs of fish that had fed was essentially the same from June to August, the proportion of empty stomachs varied considerably during that period. Obviously, if a category for zero volume had been included in Table XII, then the frequency distributions, particularly for August, would represent distinctly bimodal distributions, with the strongest mode at 0 cc, and the other mode near 2 cc. It would therefore appear that an empty stomach has a deeper significance than merely that of a zero reading in a frequency distribution. There would seem to be some qualitative difference between feeding and not feeding which is unrelated to the amount eaten by those that do feed.

By contrast, the many empty stomachs in December could quite legitimately be regarded as zero quantities in the frequency distribution of food volumes for that month. In December, there seems to be only a quantitative difference between those which feed and those which do not.

Further analyses of the data (not shown) failed to demonstrate noteworthy differences in the pattern of frequency of distributions related to (1) sex, (2) size of fish, or (3) locality. The fact that most of the fish sampled were of medium size probably accounts for the failure to show a relationship between fish size and amount eaten. The fact that 79% of the volumetric determinations were made on fish from one locality might be the reason for the failure to demonstrate variation from place to place.

Unusual Cases

Each of the nine stomachs examined from Sandy Lake on September 29, 1953, contained one mouse and nothing else. Presumably, the mice had been swimming as a group. Since every goldeye examined had eaten mice exclusively, mice must have been locally abundant at the time. Since no stomach contained more than one, presumably one mouse represents a volume of food which inhibits further feeding.

In no other case did all stomachs in a subsample contain one food item exclusively. Three other cases, which approximated the situation on Sandy Lake, are shown in Table XIII.

Table XIII. Cases where the same food item appeared in most or all of the stomachs taken at the same time and place.

Place	Date	Food item	No. of stomachs		
			Examined	With food item	With food item exclusively
L. Winnipegosis	June 28, 1945	*Hexagenia* adults	8	8	4
L. Claire	July 5, 1947	Pike	34	30	26
L. Claire	July 15, 1947	Pike	30	26	23
Sandy L.	Sept. 29, 1953	Mouse	9	9	9

Discussion

As has been shown, the food of goldeye differs from place to place and from time to time at the same place. The smallest goldeye eat different food from the rest, and it seems likely that only the fact that most of the fish sampled were of medium size has prevented the demonstration of a relationship between type of food and size. Samples were taken from a comparatively limited number of localities during only 1 – 4 months at each locality, and mainly from a limited part of the size range. Extrapolations from these samples to goldeye food in general must therefore be made with caution.

Nevertheless, a few generalizations seem warranted. The surprisingly great variety in food found in the relatively few stomachs examined suggests that goldeye probably eat almost any organism encountered which is not bigger than a mouse. Diet probably depends on availability of food rather than on food preference; when mayflies are emerging or ovipositing, mayflies are eaten; where small pike are locally abundant, pike are eaten; if the migration route of mice brings them within reach, mice are eaten. Such windfalls are infrequent and the normal diet is a mixture of whatever is available, mainly insects, particularly corixids. During the open-water season, an important part of the diet is taken at the water surface, a surprisingly large proportion of it being allochthonous. Most Canadian lakes where goldeye are found are ice-covered for roughly 5 months of the year, which obviously precludes surface feeding. Very little is known about goldeye diet during the winter, although there is limited evidence that the diet is sharply curtailed, both in variety and in quantity.

ASSOCIATED SPECIES

Predators

The limited data available indicate that, if man is excluded, the goldeye's principal predators in order of importance are: pike, *Esox lucius,* walleye, *Stizostedion vitreum,* and sauger, *Stizostedion canadense.* Goldeye have been found in stomachs of inconnu, *Stenodus leucichthys,* but since the ranges of the two species overlap only slightly, inconnu predation must be regarded as insignificant. No other notably predaceous fish shares the goldeye's habitat, so the above named species probably represent a complete list for Canadian waters.

There is evidence that cormorants, *Phalacrocorax auritus,* eat many goldeye. Several other birds and mammals are regarded as possible predators, but there is no concrete evidence that they are.

Competitors

The following species were common in the same habitat as goldeye at one or more of the localities studied: lake whitefish, *Coregonus clupeaformis;* white sucker, *Catostomus commersoni;* longnose sucker, *Catostomus catostomus;* northern redhorse, *Moxostoma macrolepidotum;* flathead chub, *Hybopsis gracilis;* emerald shiner, *Notropis atherinoides;* spottail shiner, *Notropis hudsonius;* yellow perch, *Perca* *flavescens*. Along with the fish predators listed above, all may be considered as competitors for living space at least and to some extent they also compete for food. However, because goldeye take a large part of their food at the water surface, competition would seem to be of minor importance during open water. There are no data for assessing competition during the winter.

Parasites

A detailed examination for parasites was not made. However, two were frequently noted, namely, the cestode, *Bothriocephalus cuspidatus,* in the intestine and a species of *Bucephalus* in the body cavity. Dr J. A. McLeod (unpublished data) has identified parasites from Manitoba goldeye as follows: two trematodes, *Crepidostomum* sp. and *Heteophes* sp., and an ectoparasitic copepod, *Ergasilus* sp. On the basis of a search for parasites in 200 specimens from Lake Texoma, Oklahoma, Self (1954) reports *Bothriocephalus texomensis, Crepidostomum illinoiense,* and immature nematodes of the family Camallanidae.

FISHERIES

Commercial Production

Table XIV summarizes available data on the quantities of goldeye produced by commercial fisheries in the goldeye-producing provinces of Canada and in the United States. The main source of information for Canada is records kept by the Department of Fisheries and its predecessors, many of which have been published (Dominion Bureau of Statistics). Recent information was also supplied in personal communications from H. E. Corbeil, Fish and Game Branch, Quebec; M. J. Brubacher, Fish and Wildlife Branch, Ontario; K. H. Doan, Fisheries Branch, Manitoba; R. P. Johnson, Fisheries Laboratory, Saskatchewan; M. J. Paetz, Fish and Wildlife Division, Alberta; and J. P. Currier, Canadian Wildlife Service, Ottawa. Information on production in the United States was supplied by a personal communication from H. O. Swenson, Division of Game and Fish, Minnesota, or was taken from published data (Smith and Krefting, 1954; U.S. Department of the Interior). An unpublished thesis (Judson, MS, 1961) supplied useful supplementary information.

Although goldeye production was recorded as early as 1876, records prior to 1900 are so erratic that it seems likely that they are incomplete, and that it would be misleading to compare them with the data of Table XIV. Even the data given in the first two lines of Table XIV are suspect, because information from other sources suggests a smaller production until about 1910 than is recorded.

At first goldeye were taken only incidentally to a fishery for whitefish, walleye, and pike. However, by 1911 a Royal Commission (Prince et al., 1911) could draw attention to ". . . the increasing importance of that excellent food fish the goldeye which has acquired popularity as a smoked fish in recent years." Markets

TABLE XIV. Average annual goldeye commercial landings in thousands of pounds by 5-year intervals since 1901. A zero indicates less than 1000 lb. A dash indicates that data are not available, usually because too few were produced to warrant a separate category and they were recorded under a "miscellaneous" heading.

	Canadian						
Years	Que.	Ont.	Man.	Sask.	Alta.	Total Canadian	USA
1901–05	0	–	304	0	–	304	–
1906–10	0	–	649	12	–	649	–
1911–15	0	–	528 [a]	4	12 [a]	544 [a]	–
1916–20	0	–	558	4	3	567	67 [a]
1921–25	0	–	544	4	0	548	–
1926–30	0	–	1011	6	1	1018	31
1931–35	0	–	314	6	0	320	26
1936–40	0	–	446	8	0	454	143
1941–45	0	–	333	13	0	346	106
1946–50	0	54 [a]	142	0	81	253	36
1951–55	0	68	81	0	48	197	4
1956–60	0	37	75	10	112	234	49
1961–65	7 [a]	26	72	23	58	180	13

[a] Average based on less than 5 years.

were gradually developed for the smoked product over the next fifteen years, and fishermen increasingly set their nets specifically to take goldeye, although many were still produced as a by-product of fishing for other species. In each of the years 1926, 1927, 1928, and 1929 more than 1 million lb of goldeye were produced; neither before nor after were comparable catches made. Production until and during these years was mainly from Lake Winnipeg, with a minor but sizeable proportion of the record catches from Lake Winnipegosis. After 1930, Lake Winnipeg production decreased dramatically and 1938 was the last year during which a substantial quantity of goldeye was taken there. For a time the main source of supply was Lake Winnipegosis, where production also declined steadily after 1930, although commercial quantities are still taken. Since about 1930 a substantial part of the Manitoba production has been taken from the lower Saskatchewan River and related waters, mainly a few miles downstream from The Pas. Most of the goldeye produced recently in Saskatchewan have also been taken from the Saskatchewan River a few miles upstream from The Pas.

In recent years goldeye have been produced in the western part of Northern Ontario, particularly on and near Sandy Lake. At about the same time fisheries also developed in Northern Alberta, particularly in Lake Claire which is in Wood Buffalo National Park. In 1965, goldeye were taken commercially for the first time in the Province of Quebec.

Moderate quantities of goldeye have been produced sporadically in the United States. For all practical purposes, the only commercial fishery for goldeye in that country has been in Red Lake, Minnesota.

Commercial Fishing Methods

Gill nets are the only commercial gear used to take goldeye. Usually 3¾-inch mesh is used, although a substantial part of the total production is from nets of smaller mesh. In many cases, the twine in the web is heavier than is usual for taking inland fish commercially. For best results, nets are set in short gangs, perpendicular to the shoreline and with one end close to shore; unless the water is extremely shallow, the nets should be double-corked to bring the corkline to the surface. Canoes and rowboats with outboards are used almost exclusively. A high proportion of the fishermen are Indians who live near the goldeye fishing grounds.

Where the fishery is properly conducted, goldeye are iced in the boat shortly after being brought aboard. They are taken ashore within a few hours and immediately dressed (i.e. viscera are removed). In most cases, they are shipped in ice to Winnipeg, where they are frozen and held until needed. In some cases, they are frozen where produced and shipped frozen to Winnipeg for marketing. A few are processed locally for local sale.

Processing and Marketing

Published early comments on the taste of freshly caught goldeye include "insipid," "like brown paper salted," and "they eat like mud." However, as a a Department of Fisheries Report indicates as early as 1890 (Anon., 1890): ". . . when smoked their flavour is greatly improved and they command a much higher price." At first, only small quantities of smoked goldeye were sold, and they were smoked in small batches over willow fires at the fishing ports. By 1910, dealers in Winnipeg were processing most of the smoked goldeye and selling them under the name "Winnipeg goldeye," a name which is still retained even though only an infinitesimal part of the catch now comes from Lake Winnipeg. About the same time, smoked goldeye began to appear on the menu of railway dining cars, which did much to make the product widely known. However, it was not until 1925 that it was well enough known to ensure a strong market. Since 1930, demand has consistently exceeded supply, and in recent years prices have been appropriate to a luxury item.

The processing methods have changed very little since about 1910.[4] Frozen goldeye are removed from cold storage as required for immediate use. Only fish that have been frozen are used; if fish that had not been frozen were used they would become soft quickly after smoking. The frozen fish are thawed in water at room temperature, then scaled and placed in barrels of brine (½–1 lb salt/gal for 10 – 14 hr. They are next dipped in a solution which contains an

[4]In October 1965 the senior author had the privilege of talking with, and watching the technique of, Mr George Firth who processes goldeye for Booth Fisheries Canadian Co. Ltd. of Winnipeg, by far the largest producer of the smoked product. His grandfather, Robert Firth, began smoking fish for Booth in 1902 and the process is an art that has been passed from father to son to grandson.

aniline dye[5] which colors the skin but not the flesh. Next they are strung on metal rods, a dozen or more fish to a rod shoved through the skulls near the eyes. Several dozen rods are hung in layers on a metal rack which is moved into an oven-like enclosure on the bottom of which a fire of 4-ft oak logs is burning. The fish absorb smoke from the fire and at the same time its heat cooks them. After 5 – 7 hr the rack is withdrawn and allowed to cool. The rods are withdrawn, and when the fish are thoroughly cool, they are wrapped individually in paper, then packaged. They are kept cool but not frozen until sold, which must be in a very few days.

A "Winnipeg goldeye" represents the triumph of art over nature. Its characteristic color results from an aniline dye. Its characteristic taste is essentially that of oakwood smoke. Its texture has been improved by freezing. Its name is derived from a lake where it is no longer caught in appreciable quantities.

Unlike most Canadian fisheries products, which are sold mainly in the United States, Winnipeg goldeye are sold almost exclusively in Canada. In fact, when goldeye were produced in quantity in the United States, they were mainly exported to Canada for processing and consumption. In recent years the supply has been so limited that only favored customers have been able to get them. As a result, most of them are consumed in the city of Winnipeg or nearby places.

Because goldeye demand a high price and are in limited supply, unscrupulous dealers and restaurants have occasionally misrepresented cheaper smoked fish as goldeye. The species most commonly substituted is tullibee (*Leucichthys* spp.).

Since it has become customary to serve goldeye in restaurants with the head on, this form of misrepresentation is easily detected. More difficult to detect is the substitution of mooneye for goldeye. The two species look much alike and most people are unaware that they can be readily distinguished; the dorsal fin of goldeye is closer to the tail than is the anal fin, while the reverse is true in the mooneye.

SHRINKAGE

During this investigation 123 goldeye, which ranged from 11 to 17 inches in fork length and from 9 to 34 oz in weight, were weighed collectively at each of three stages in processing. Weights were as follows:

Total wt, round = 97.6 lb.
Total wt, dressed (viscera, kidney, and scales removed) = 82.6 lb.
Total wt, smoked (dressed, and in cold storage overnight after smoking) = 63.8 lb.
Dressed wt was 85% of round wt.
Smoked wt was 65% of round wt.
Smoked wt was 77% of dressed wt.

[5]Apparently both undyed and dyed goldeye look the same when freshly smoked, but the color of the undyed product fades after a day or two while the dyed product does not. Customers have long associated the dyed (i.e. freshly smoked) with "Winnipeg goldeye" and would reject one with faded color.

Sport Fishery

In many places within the Mississippi Valley goldeye are regarded as a sport fish. Many Canadians also angle for them, particularly in the southern Prairie Provinces, mainly on the Saskatchewan River and its tributaries.

Goldeye can be caught on both wet and dry flies, and their action on a light fly rod has been praised by many experienced anglers. They are also caught occasionally by small spinners and plugs. However, the usual method of angling, in Canada at least, is with a small float which supports a baited hook about a foot below the water surface. Worms, insects, and minnows are used for bait.

Whitehouse (1946) reports as follows: "I have caught Gold-eyes in the Assiniboine, Saskatchewan and Red Deer (Alberta) rivers. In the last mentioned, which is fairly shallow, the fish under normal water conditions, feed all over the river; but, in times of flood, seek the less silty water in the mouths of tributary creeks. They can then be taken in numbers with various baits, such as worms, grass-hopper, meat, etc.

"With the Red Deer river clear, a light rod is the tool, either from the bank or wading. I would try them with an artificially fly *au naturel*, or interest reluctant takers with the addition of a tiny tag of red meat or fragment of worm. Some fishermen will use a long bamboo pole, a tight line, and a worm with a cork 12 inches from the hook. I have myself. The float keeps the bait clear of the bottom to travel down stream with the current. This method is effective, but I prefer my light fly rod. The Gold-eye, like the Arctic Grayling, knows how to use the current in his fight; and a one pounder, on light trout tackle, will put up a very creditable performance."

MANAGEMENT OF COMMERCIAL FISHERIES

It would give us the greatest of pleasure if, at this point, we could specify in detail the regulations and procedures required to ensure maximum value in perpetuity from each goldeye fishery. Unfortunately, the type of advice on management which can be given falls far short of that ideal. It is possible, however, to indicate a few general principles which may be useful in developing specific policies. Also, some recommendations made earlier by the junior author regarding specific fisheries are reiterated.

General Principles

Since gill nets are the usual commercial gear for taking goldeye, it is pertinent to examine the relationship between the size of mesh used and the size of fish caught. All suitable data collected during the study are summarized in Table XV, which shows the size distribution of goldeye that each mesh took. In assembling Table XV, it was noted that for some mesh sizes the distribution of fish sizes varied considerably from subsample to subsample; the pattern of variation is not inconsistent with an hypothesis that the size distribution taken by

TABLE XV. Frequency distribution of round weights in ounces for goldeye taken in gill nets of various mesh sizes. Weights less than 0.5 are classified as 0 oz. See text for explanation of rules after 11, 15, and 22 oz.

	Mesh size – stretched measure *(inches)*									
Weight *(oz)*	1½	2	2½	3	3½	3¾	4	4¼	4½	5½
0	11	0	0	0	0	0	0	0	0	0
1	55	5	0	0	0	0	0	0	0	0
2	29	294	1	2	0	0	0	0	0	0
3	1	43	14	4	0	0	0	7	1	0
4	2	18	38	8	0	1	0	1	0	0
5	0	10	14	6	1	2	0	7	0	0
6	0	10	4	23	6	6	0	0	0	0
7	0	6	13	34	1	12	1	1	2	3
8	1	7	26	56	1	13	0	3	0	1
9	0	7	32	51	28	18	1	1	1	1
10	0	5	33	73	73	41	1	8	1	0
11	1	4	22	68	133	50	5	5	3	0
12	0	2	24	68	174	71	11	4	2	1
13	0	0	26	43	102	89	6	8	0	1
14	0	3	18	38	77	150	6	15	2	0
15	0	1	12	28	40	115	17	17	3	0
16	0	2	2	28	57	111	41	14	6	2
17	0	3	2	16	38	84	39	11	5	1
18	0	1	1	11	28	80	80	14	6	0
19	0	1	0	8	20	35	50	13	5	0
20	0	2	0	6	18	25	56	15	6	0
21	0	1	1	5	6	15	34	4	5	0
22	0	0	0	1	5	12	20	2	5	0
23	0	0	0	1	3	11	14	0	2	1
24	0	1	0	1	2	2	13	0	7	1
25	0	0	0	1	1	4	10	0	4	1
26	0	0	0	0	0	1	9	0	4	0
27	0	0	0	1	1	0	5	0	1	0
28	0	0	0	0	0	4	5	0	1	0
29	0	0	0	0	0	1	0	0	0	0
30	0	0	0	0	0	0	1	0	1	0
31	0	1	0	0	1	0	1	0	0	0
32	0	1	0	0	0	0	0	0	2	0
33	0	0	0	0	0	1	0	0	0	0
34	0	1	0	0	1	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	1	0

a given mesh varies from day to day at a given place, or with exact locality within an area, or both. It is common knowledge that the size of thread used in the web of a gill net influences the size of fish caught, and variation in thread size is a reasonable explanation for many of the differences between subsamples. In general,

Table XV probably represents a reasonable composite of the relationship of fish size to mesh size in the study area. However, it should be noted that the 4¼-inch mesh samples were taken entirely from Lake Winnipegosis and the Saskatchewan River with relatively coarse twine, while the 4½- and 5½-inch mesh samples were taken entirely from Lake Claire with relatively fine twine.

Most commercially caught goldeye are used in restaurants where they are cooked and served with the head on. The trade is interested in a medium sized fish which fits nicely on a dinner plate and provides an adequate but not excessive meal for one person. In terms of smoked weight, less than 8 oz is regarded as decidedly too small and over 14 oz is too big. The greatest demand is for fish between 8 and 10 oz, a limited number of restaurants prefer them from 10 to 12 oz, and a few feature 12 – 14 oz goldeye. On the basis of data given in the section on "Commercial Fishing," the relationship between pertinent round weights and smoked weights is:

12 oz round wt becomes 8 oz smoked wt.
15 oz round wt becomes 10 oz smoked wt.
22 oz round wt becomes 14 oz smoked wt.

Therefore, in terms of round weight, a goldeye is:

too small if less than 12 oz,
the preferred size if 12—15 oz,
a size for which there is a limited market if 15—22 oz,
too large if more than 22 oz.

The values given in Table XV are in round weights; the lines in the table represent the limits of the above categories.

Table XVI shows the percentage of each size category taken in each mesh. It is obvious that there is no gill-net mesh which is ideal for taking goldeye of marketable size. The best compromise would seem to be 3¾ inches, although local conditions

TABLE XVI. The percentage of goldeye in certain size categories taken by various sizes of mesh. Based on the data in Table XV.

Category	Mesh size – stretched measure *(inches)*									
	1½	2	2½	3	3½	3¾	4	4¼	4½	5½
	%	%	%	%	%	%	%	%	%	%
Preferred size (12–15 oz)	0	1	28	30	48	45	9	29	9	15
Acceptable but less desirable size (15–22 oz)	0	3	2	13	21	37	75	49	50	23
Acceptable size – includes preferred size (12–22 oz)	0	4	30	43	69	82	84	78	59	38
Too small (11 oz or less)	100	95	70	56	30	15	2	22	11	38
Too large (23 oz or more)	0	1	0	1	1	3	14	0	30	24

and changing markets may warrant either a smaller or a larger mesh size somewhere within the range 3½ to 4 inches.

The tendency for goldeye to be caught by their teeth rather than wedged in the mesh is well illustrated by the fact that almost any size can be taken by a given mesh. It is common knowledge, supported by field observations made during the study, that more goldeye are caught by their teeth in fine twine than in coarse twine. Therefore, in order to maximize the proportion caught which are of optimum size, it is essential that relatively coarse twine be used in the web of gill nets fished for goldeye. The requirement is less restrictive than it would be for most species, since goldeye are usually taken in areas where snags that tear gill nets are unusually abundant so that, from the viewpoint of advantage to the fishermen, the durability inherent in coarser twine probably compensates for decreased catch per net.

The possibility of introducing or inventing some type of fishing gear which would take only those goldeye which were of optimum size should also be considered. Although the fyke nets used during the study failed to take appreciable quantities of goldeye, the possibility of adapting fyke nets or other impounding gear to goldeye fishing should be further investigated. A commercial fisherman, Mr John Knox of North Bay, Ontario, reports that he has on occasion taken commercial quantities of goldeye on Lake Timiskaming by pound nets. Impounding gear has the advantage that fish of the preferred size can be retained and the rest can be released alive. The possible use of trammel nets is also worth investigating.

Comparison of Tables VIII and XV shows that many goldeye reach the most desirable commercial size before they mature. Thus, unlike the case of most commercial species in inland Canada, a large proportion of goldeye become a valuable commodity before they are of spawning size. It therefore follows that the amount of fishing pressure required to reduce the parent stock sufficiently that the number of offspring is curtailed will be less for goldeye than for most of our freshwater species. The most likely explanation for the dramatic decline in goldeye catches in Lake Winnipeg is that heavy fishing left too few spawners for adequate reproduction. In order to ensure adequate spawning, it is essential that the annual catch of goldeye be rigidly limited in each area where they are produced commercially.

The limits set for Lake Claire and for Sandy Lake *(see below)* offer some guidance to appropriate permissible annual catches elsewhere. However, it is essential to realize that the appropriate limit for a given fishery can only be determined by an experimental approach. All known facts should be used as a basis for estimating sustainable yield. Based on this estimate, a preliminary limit should be set and its effect on the population in question observed. If evidence of insufficient spawning should appear, the preliminary limit should be immediately decreased. Alternatively, if, after, say, 10 years at a steady limit it becomes evident that there is sufficient spawning to maintain the population, the limit should be increased moderately on a trial basis. Over several decades, the information which accumulates from such adjustments will eventually clearly indicate an appropriate rate of harvesting which can be maintained indefinitely.

Where goldeye is the only species of commercial importance, as in Lake Claire, the above management techniques are fairly straightforward. Where other species equal or exceed goldeye in value, the proper course of action becomes more obscure, because of difficulties in cropping the other species without over-exploiting the goldeye. In some cases, as for example Lake Winnipeg, the restrictions on fishing that would be required to ensure adequate goldeye spawning would probably decrease the production of other species by an amount equal to several times the potential value of a revived goldeye fishery. In such cases, there is no alternative to accepting the fact that a goldeye fishery is not feasible.

It seems questionable whether maximum production of goldeye and a fishery for other species will ever be compatible, but it is worthwhile to try for both. Perhaps some impounding gear can be developed for taking the other species efficiently and from which goldeye caught in excess of the desirable annual crop can be released alive. There may also be situations in which goldeye can be protected sufficiently by prohibiting the gear used for the other species in areas or water strata, or both, frequented by goldeye. Consideration of the goldeye's somewhat unique spawning and feeding habits may provide clues to suitable management techniques.

There may be misgivings about exploiting goldeye at an intermediate size rather than exploiting only those large enough to be mostly mature, as is the practice for most freshwater species. To allay such fears, attention is drawn to the sardine industry where the fish used (small herring) are all far below the maximum size reached and in fact well below the minimum size for maturity. Heavy exploitation at the immature stage for decades has not adversely affected the supply of sardines.

Flushing in Saskatchewan Delta

In 1946, one of the authors made certain recommendations regarding goldeye in the marshes of the Saskatchewan River Delta. Because of increased September water levels behind a recently constructed dam further downstream at Grand Rapids, the recommendations are mainly invalid in the area to which they originally applied, but the principle may be useful elsewhere.

Until recently, when the Saskatchewan River was in flood immediately after break-up and again in early summer, water backed up into the many small lakes and ponds which were closely connected to it. When the river level dropped in late summer, the water ran back into the river in most cases. But on several channels the Manitoba government had installed small dams which maintained some parts of the marsh at flood level in order to increase muskrat production. Large numbers of goldeye hatched in the flooded areas, either because the parents spawned there, or because semibuoyant eggs, though spawned elsewhere, were carried there by water currents. Young goldeye throve in such areas and, where there was no impediment, left them in late summer. But where dams had been erected, young goldeye were trapped behind them because, by the time that they would normally migrate to the river, water levels had dropped enough that none ran over the spillways. During winter, dissolved oxygen approached zero in these waters while dissolved noxious gases accumulated, so that any goldeye trapped behind the dams were doomed unless action was taken.

It was therefore recommended that the dams in question be flushed annually to give the young goldeye a reasonable chance of survival. For this purpose, a sufficient number of stop-logs were to be removed from one control gate in each dam to permit a flow at least eight inches deep. Time of flushing was to vary from year to year, depending on water levels; it was to take place as soon as water levels on the two sides of the dam differed enough that water would drop freely when the required number of stop-logs were removed. This would usually be in mid-August or later. Flushing was to continue for from 3 to 7 days, depending on the amount of water held by the dam. It was noted that the objective could be achieved with minimum loss of water by removing the stop-logs only during periods of maximum goldeye activity, such as at the hours of sunset and of sunrise.

Lake Claire

The following recommendations, which were made in 1948, regarding the management of a commercial fishery on Lake Claire are still valid. Not more than 250,000 lb round wt of goldeye should be taken annually. The web of the gill nets used should be of coarse twine not more than 24 inches deep and preferably not more than 18 meshes deep. The use of both 3¾- and 4-inch mesh, stretched measure, were approved.

Sandy Lake

The following recommendations for managing the commercial fishery on Sandy Lake, which were made in 1954, are still valid. The then prevailing limit of not more than 120,000 lb round wt of goldeye annually was to be continued, as was the practice of using 3¾-inch mesh nylon gill nets.

SUMMARY

1. Goldeye, *Hiodon alosoides,* occur sporadically throughout much of the lowland area of central North America. Typical habitat is turbid water in large rivers and their flood plains, also in the shallower parts of some lakes.
2. The present study is based mainly on material from Lake Winnipegosis, from the lower Saskatchewan River, from Lake Claire, Alberta, and from Sandy Lake, Ontario, and the statements which follow refer only to goldeye from these localities unless otherwise indicated.
3. Most of the annual growth is made between June and September.
4. Females grow faster than males.
5. Growth is slowest in Sandy Lake, faster in Lake Claire, and fastest in Lake

Winnipegosis and the Saskatchewan River. Growth tends to be faster in the warmer, more southern waters of United States than in Canada.

6. There was an unexplained dearth of 5-year-old goldeye in the samples from Lakes Winnipegosis and Claire.
7. Catch curves indicate a total mortality rate (fishing mortality plus natural mortality) of 74% at ages 6–10 in the heavily exploited Saskatchewan River Delta, but in unexploited Lake Claire mortality (presumably all natural mortality) was 42% at ages 8–10, 48% at age 11, 57% at age 12, 73% at age 13, and almost 100% at age 14.
8. There are about equal numbers of males and females.
9. Goldeye mature when 6±3 years old in Lake Winnipegosis and the Saskatchewan River and when 7±3 years old in Lake Claire. Males mature about 1 year earlier than females.
10. Mature goldeye spawn annually some time between late May and the end of June, depending on when water temperature rises to about 50–55 F. Typical females shed roughly 5000–25,000 eggs which are about $\frac{1}{12}$ inch in diameter and are fertilized externally. The ovary recovers so quickly and completely after spawning that earlier observers were misled regarding spawning time.
11. The fertilized eggs are semibuoyant.
12. During open water goldeye eat a wide variety of food, including quantities of allochthonous organisms from the surface. Apparently their diet is sharply curtailed both in quantity and in variety by the winter ice cover.
13. Excluding man, the significant predators in order of importance are pike, walleye, and saugers. Limited data on competitors and parasites are recorded.
14. Commercial production of goldeye in recent years has been about 20% of the peak of over 1 million lb per year in the late 1920s. On Lake Winnipeg, originally the only, and long the greatest, producer, catches have been negligible in recent years, and on Lake Winnipegosis, more recently an important source, catches are now comparatively small. The main goldeye fisheries are now in the lower Saskatchewan River, in and near Lake Claire, Alberta, and in and near Sandy Lake, Ontario.
15. The somewhat unpalatable freshly caught goldeye is converted to a gourmet's dish, the "Winnipeg goldeye," by a process which includes smoking.
16. Goldeye are sought by anglers in many places.
17. Gill nets are the only gear used to take goldeye commercially. Because of a tendency to be caught by the teeth, there is a surprising spread in the size range taken by a given mesh size.
18. Goldeye seem particularly susceptible to overfishing, meaning fishing to the point that spawning becomes inadequate. Rigidly enforced limits on annual catch where feasible and other measures are recommended.

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