A REVIEW OF THE CHANGES IN THE FISH SPECIES COMPOSITION OF LAKE ONTARIO

Great Lakes Fishery Commission

TECHNICAL REPORT No. 23

The Great Lakes Fishery Commission was established by the Convention on Great Lakes Fisheries, between Canada and the United States, ratified on October 11, 1955. It was organized in April, 1956 and assumed its duties as set forth in the Convention on July 1, 1956. The Commission has two major responsibilities: the first, to develop co-ordinated programs of research in the Great Lakes and, on the basis of the findings, recommend measures which will permit the maximum sustained productivity of stocks of fish of common concern; the second, to formulate and implement a program to eradicate or minimize sea lamprey populations in the Great Lakes. The Commission is also required to publish or authorize the publication of scientific or other information obtained in the performance of its duties.

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by

W. J. CHRISTIE

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GREAT LAKES FISHERY COMMISSION
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FOREWORD

This paper is one of seven lake case histories-Lake Superior, Lake Michigan, Lake Huron, Lake Erie, Lake Ontario, Lake Opeongo, and Lake Kootenay. Concise versions of these papers, together with other lake case histories developed for and by an international symposium on Salmonid Communities in Oligotrophic Lakes (SCOL) appeared in a special issue of the Journal of the Fisheries Research Board of Canada (Vol. 29, No. 6, June, 1972).

While this and each of the others in this series is complete in itself, it should be remembered that each formed a part of SCOL and is supplemented by the others. Because much detail of interest to fisheries workers in the Great Lakes area would not otherwise be available, this and the other case histories revised and refined in the light of events at the symposium are published here.

SCOL symposium was a major exercise in the synthesis of existing knowledge. The objective was to attempt to identify the separate and joint effects of three major stresses imposed by man: cultural eutrophication, exploitation, and species introduction on fish communities. Recently glaciated oligotrophic lakes were chosen as an "experimental set." Within the set were lakes which have been free of stresses, lakes which have been subjected to one stress, and lakes which have been subjected to various combinations of stresses. The case histories provide a summary of information available for each lake and describe the sequence of events through tune in the fish community. Some of these events were inferred to be responses to the stresses imposed. Lakes Opeongo and Kootenay were included in this set somewhat arbitrarily, with the case histories of the Laurentian Great Lakes, to illustrate similarities and differences in the problems associated with other recently glaciated oligotrophic lakes.

We began organizing SCOL in 1968 and were later supported by a steering committee: W. L. Hartman of the U.S.A., L. Johnson of Canada, N.-A. Nilsson of Sweden, and W. Nümann of West Germany. After two years of preparation, a work party consisting of approximately 25 contributors and a similar number of interested ecologists convened for two weeks in July, 1971 at Geneva Park, Ontario, Canada.

Financial support was provided by the Great Lakes Fishery Commission, Ontario Ministry of Natural Resources, Fisheries Research Board of Canada, Canadian National Sportsman's Show, and University of Toronto.

Editorial assistance was provided by P. H. Eschmeyer, K. H. Loftus, and H. A. Regier.

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by

W. J. Christie

ABSTRACT

The statistics of the commercial fish catch, along with data from past surveys of the fish species composition of Lake Ontario, are reviewed. This provides a chronicle of the progressive deterioration of the fish fauna in terms of numbers of economically valuable species present. In the original condition the lake supported stocks of Atlantic salmon, lake trout, lake whitefish, and a number of lesser Coregonid species. At present all of these are extinct or virtually so, and the open waters of the lake are occupied mainly by the non-indigenous rainbow smelt and alewife.

Many important changes in the fish stocks occurred in the early years of man's interference with the lake. Some effects of the deforestation of the watershed, and damming the streams are suggested, but in general it is felt that the major effects of changes in the abiotic environment on the fish stocks, have only manifested themselves recently. Overfishing appears to have been the major destabilizing influence. It is suggested that the depression of piscivore stocks by excessive fishing permitted the proliferation of the colonizing rainbow smelt and alewife. This depression may also have increased the impact of the sea lamprey on the premium fish stocks, and the proliferation of other native fishes may have acted along with the colonists, to prevent return of the premium species upon relaxation of the fishing pressure.

The abyss of the main lake is not inhabited by fish except in winter at present. It is suggested that the lake trout and burbot stocks were the main vectors of materials and energy in the lake previously. No comparable circulatory system can be identified in the current circumstances.

INTRODUCTION

This paper is primarily a chronicle of the major events in the succession of fish species change in Lake Ontario. The changes are discussed against the background of known biotic and abiotic changes in the fish environment, and to the extent that interpretation seemed allowable, possible relationships have been suggested. The more detailed discussion of the various important species, and the extensive commercial fish catch data compendium, form the background materials for a shorter paper (Christie 1972) which has appeared elsewhere.

The fish productivity of Lake Ontario was historically lower than that of the other Great Lakes chain (Rawson 1952). The early fisheries were of substantial economic importance however, and they were supported by an array of coregonine and salmonine fish stocks which was typical of large oligotrophic lakes. Nearly all of these fish have disappeared and the open waters of the lake are now dominated by the introduced smelt and alewife. Of these only the smelt is utilized by man, and the yield is only a small fraction of that formerly obtained from lake trout, lake herring, ciscoes, and whitefish. The annual commercial yield has been held at about two million pounds in recent years, by virtue of progressively greater contributions from inshore fish. The trend has been towards production of low value fish, and both commercial and sport fisheries have been severely depressed.

Clearly all the changes can be attributed to man's influence. The Lake Ontario watershed was settled early and developed thoroughly. It has been subjected to all of the stresses man applies to his water supplies. The alteration of the fish environment began with the clearing of the land. The streams became warmer and siltier and the nearshore bottom deposits were probably changed in character. Dams were built in the streams in order to operate sawmills and gristmills. The sawmills ran until the land was cleared, and the water-powered gristmills ran until the drainage from the cleared land became too light in the fall to operate them. The dams not only warmed the water, but also blocked fish migrations-which in turn prevented reproduction and allowed increased exploitation.

Beeton (1965) showed that the water chemistry in the main body of the lake was not greatly changed at the turn of the century, but changed rapidly thereafter. However, the effects of municipal and industrial wastes were probably being felt in some degree in the littoral areas well before 1900. The major destabilizing force recognized as arising from pollution is that of artificially accelerated eutrophication (Vollenweider 1968). The open lake still seems a suitable fish environment to the extent that turbidity is not excessive, oxygen concentrations are satisfactorily high, and none of the chemical constituents which have been measured approach levels known to be toxic to fish. In contrast, eutrophication is well advanced in inshore areas such as the Bay of Quinte, (Hurley, 1970).

New species of fish have entered the lake with varying degrees of success and have had varying degrees of influence on the biota. They too were man's responsibility because those that were not introduced directly by fish culturists or others gained access through the Erie Barge Canal. The new colonists have arrived sporadically, but their effect on the fishes and fisheries of the lake was progressively greater as the stability of the ecosystem decreased.

The pressure of fishing on the stocks of fish has also increased. In the earliest settlements fishing was confined to the streams and nearshore areas, and the fish resources were ample for the community needs. Commercial fishing similarly began with inshore operations involving seines and other gear. The nearshore resources dwindled but the fishery expanded and turned to gillnets, operated first from sailboats. Efficiency increased as the boats were equipped first with engines and then with mechanical lifters. The boats became larger, because as one fisherman who began his career at the turn of the century put it, "they began to make boats to carry nets rather than fish." When nylon replaced cotton and linen as the principal netting material in 1950, the force of fishing increased greatly (Christie, 1963), and the lower maintenance requirements of the nylon nets permitted significantly more netting to be fished.

There is evidence that cultural eutrophication can be decelerated, or even reversed by control of phosphorus loading (Vollenweider 1968). Fishing can also be restricted or banned. The central question, however, is whether the fish stocks can be manipulated to restore productivity, even with these rehabilitation measures. Clearly no such measures can be intelligently undertaken without full understanding of the present fauna and the interrelationships within it. Such understanding goes beyond the limits of present information, but it is hoped that this paper will stimulate and perhaps guide research in appropriate directions.

The various kinds of influences which can act to alter the competitive position of a fish stock often interact. This paper makes the simplifying assumption that most water quality changes of significance to the major offshore fish stocks at least, are of comparatively recent origin. It thus becomes possible to interpret change in terms of the effects of fishing and the introduction of new species into the system. This approach results in an indictment of overfishing as the principal destabilizing influence. It is stressed however, that even though a species population may have been initially disadvantaged in its community by fishing, recent water quality deterioration may have provided insurance that the stock cannot return, and any management efforts to restore it must take this into account. Similarly, the ascension of certain non-native species is attributed to the depletion of the piscivorous species, but as indicated above it is clear that these species shifts are not readily reversible.

MATERIALS AND METHODS

This paper relies heavily on commercial catch statistics. The Ontario statistics were available from the various counties fronting Lake Ontario and thus permitted examination of regional differences. These data were therefore often used, and the U.S. catch data, which in any case represented only a small part of the total catch for most species, were excluded. Yearly catch values are presented only for periods in which short-term fluctuations seemed of special significance; for most periods the data presented are five-year averages, usually from the turn of the century to 1970. The summaries appear in the Appendix. Catch per unit of effort can be computed only for recent years, but it is felt that the average catches are generally meaningful indices of relative abundance. Available data on the amounts of gear licensed have also been given (Appendix Table 2). Although these data are not sensitive to year-to-year changes in effective effort applied to particular species, they provide useful measures of the levels of activity in the various fisheries.

Figure 1 is a map of Lake Ontario showing the major urban centres and fishing ports mentioned in the text. Rivers referred to are not shown. For the various summaries of commercial fishery statistics given here, the Canadian waters are arbitrarily divided into three areas: western-fronting the Counties of Lincoln eastward to and including York; central-the frontage of Ontario and Durham Counties; and the eastern-from (and including) Northumberland County, to Wolfe Island at the mouth of the St. Lawrence River, exclusive of the Bay of Quinte.

The western and central geographical divisions are both in a single

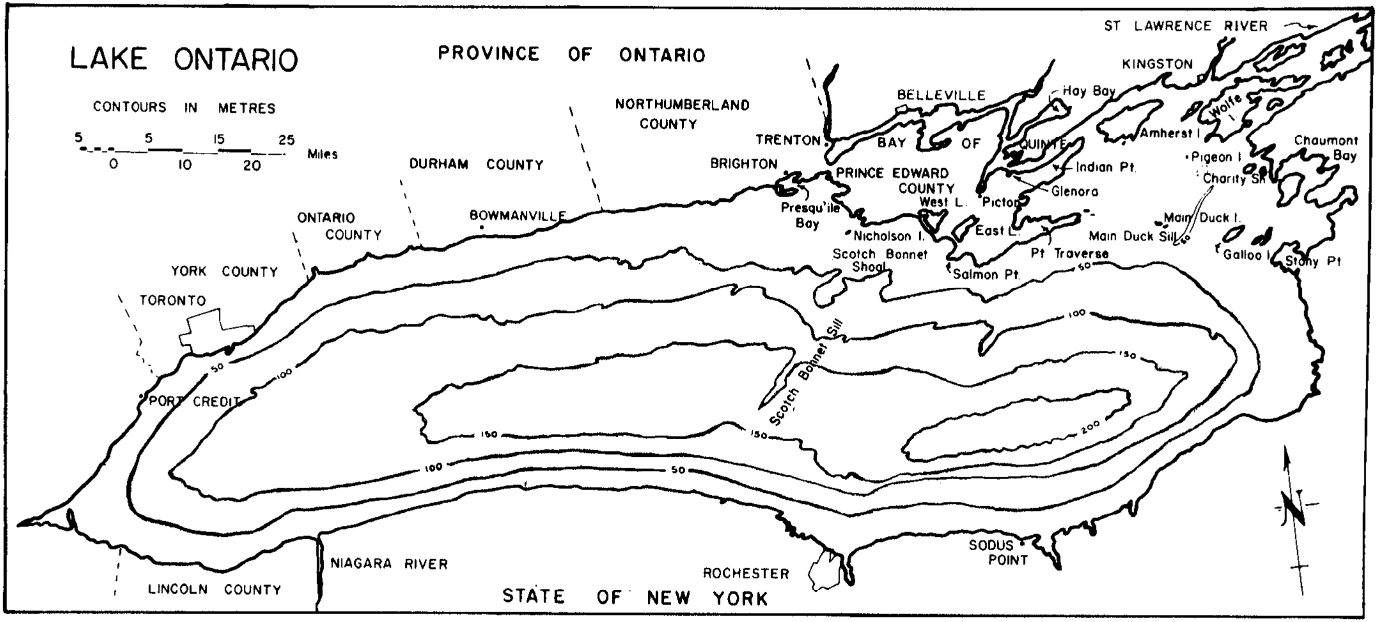

Fig. 1. Lake Ontario, showing major bathymetric features and place names mentioned in the text.

bathymetric unit of the lake, the Western Basin. This basin slopes continuously deeper towards the east until it meets the Scotch Bonnet Sill, a prominent ridge which runs southwestward from Scotch Bonnet and Nicholson Islands. The eastern area consists of the deep Eastern Basin, and the shallower Eastern Outlet Basin, separated by the chain of islands and shoals known as the Main Duck Sill running ESE from the Prince Edward County peninsula to the U.S. shore.

The only fishery of consequence in Northumberland County was that at Brighton. The fishery statistics for Northumberland County appeared in the records alone in some years and in combination with those for Prince Edward County in others; so for consistency, the Brighton statistics are included with those for the eastern geographical division. This unavoidable arrangement is unfortunate since the catches of the Brighton fishery are more properly assignable to the western basin.

Some original data from the files of the Glenora Fisheries Station have been presented. These are usually referenced according to their appearance in annual reports, but the sources also include unpublished file reports.

The catch statistics have the advantage that they usually concern species with significant biomass in the lake. Reliance upon them is not to be taken to imply that lesser species have not been subject to important changes however-only that we know much less about them. Similarly, little information is available concerning yields of game fish that do not also enter the commercial catch.

The known fishes which have inhabited or still live in Lake Ontario are classified here according to their status in the lake, reduced natives, successful colonists, persisting natives, and those species of uncertain status. The list is probably especially incomplete with respect to the cyprinids. The principal sources were Smith (1892), Nash (1913), Dymond, Hart, and Pritchard (1929), Greeley (1939), Wells (1969), and unpublished records of the Glenora Fisheries Station. In compiling it, those fish species in the watershed which live above the lake level for all or most of their lives have been omitted. Many of these fish have important indirect roles in the biological economy of the lake, but knowledge of their present status is less complete than for the lake species.

The names of fish in Table 1 follow “A List of Common and Scientific Names of Fishes” (Spec. Pub. No. 6, Am. Fish Soc. 3rd Ed. 1970).

GENERAL OBSERVATIONS ON SUCCESSIONAL CHANGES

Appendix Table 1 summarizes the commercial catches of all species from the various areas of Lake Ontario since the turn of the century. Fish production in U.S. waters has always been small; it has contributed only 16% of the total yield for the period. Further, of the remaining 84%, 63% of the poundage came from the area between Brighton and the mouth of the St. Lawrence River.

Koelz (1926) noted that nearly all lake whitefish are caught inside the 30 fathom contour. This generalization applies in fact to many species because relatively few are caught at greater depths. In Lake Ontario this contour is

Table 1. Fishes of Lake Ontario

A. Species Extinct or Greatly Reduced	
Before 1900	
Lake sturgeon	*Acipenser fulvescens* Rafinesque
Atlantic salmon	*Salmo salar* Linnaeus
Blackfin cisco (Ontario bloater)	*Coregonus nigripinnis (Gill)*
After 1900	
Lake trout	*Salvelinus namaycush* (Walbaum)
Shortnose cisco	*Coregonus reighardi* (Koelz)
Bloater	*Coregonus hoyi (Gill)*
Kiyi	*Coregonus kiyi (Koelz)*
Burbot	*Lota lota* (Linnaeus)
Blue pike	*Stizostedion vitreum glaucum* Hubbs
Fourhorn sculpin	*Myoxocephalus quadricornis* (Linnaeus)
B. Species Colonized	
Before 1900	
Alewife	*Alosa pseudoharengus* (Wilson)
Gizzard shad	*Dorosoma cepedianum* (Lesueur)
Brown trout	*Salmo trutta* Linnaeus
Carp	*Cyprinus carpio* Linnaeus
Goldfish	*Carassius auratus* (Linnaeus)
After 1900	
Rainbow trout	*Salmo gairdneri* Richardson
Rainbow smelt	*Osmerus mordax* (Mitchill)
White perch	*Morone americana* (Gmelin)
C. Species Persisting	
Sea lamprey	*Petromyzon marinus* Linnaeus
Longnose gar	*Lepisosteus* osseus (Linnaeus)
Bowfin	*Amia calva* Linnaeus
Mooneye	*Hiodon tergisus* LeSueur
Brook trout	*Salvelinus fontinalis* (Mitchill)
Lake herring (cisco)	*Coregonus artedii* LeSueur
Lake whitefish	*Coregonus clupeaformis* (Mitchill)
Round whitefish	*Prosopium cylindraceum* (Pallas)
White sucker	*Catostomus commersonii* (Lacepede)
Greater redhorse	*Moxostoma valenciennesi* Jordan
Lake chub	*Couesius plumbeus* (Agassiz)
Longnose dace	*Rhinichthys cataractae* (Valenciennes)
Golden shiner	*Notemigonus crysoleucas* (Mitchill)
Common shiner	*Notropis cornutus* (Mitchill)
Spottail shiner	*Notropis hudsonius* (Clinton)
Spotfin shiner	*Notropis spilopterus (Cope)*
Brown bullhead	*Ictalurus nebulosus* (LeSueur)
Stonecat	*Noturus flavus* Rafinesque
Central mudminnow	*Umbra limi* (Kirtland)
Grass pickerel	*Esox americanus vermiculatus* LeSueur
Northern pike	*Esox lucius* Linnaeus
Muskellunge	*Esox masquinongy* Mitchill
American eel	*Anguilla rostrata* (LeSueur)
Banded killifish	*Fundulus diaphanus* (LeSueur)
Trout-perch	*Percopsis omiscomaycus* (Walbaum)
White bass	*Morone chrysops* (Rafinesque)

Table 1 (Continued)

C. Species Persisting (Continued)	
Yellow perch	*Perca flavescens* (Mitchill)
Walleye	*Stizostedion vitreum vitreum* (Mitchill)
Logperch	*Percina caprodes* (Rafinesque)
Johnny darter	*Etheostoma nigrum* Rafinesque
Smallmouth bass	*Micropterus dolomieui* Lacepede
Largemouth bass	*Micropterus salmoides* (Lacepede)
Pumpkinseed	*Lepomis gibbosus* (Linnaeus)
Bluegill	*Lepomis macrochirus* Rafinesque
Black crappie	*Pormoxis nigromaculatus*
Brook silverside	*Labidesthes sicculus* (Cope)
Freshwater drum	*Aplodinotus grunniens* Rafinesque
Mottled sculpin	*Cottus bairdii* Girard
Slimy sculpin	*Cottus cognatus* Richardson
Threespine stickleback	*Gasterosteus aculeatus* Linnaeus
Brook stickleback	*Culaea inconstans* (Kirtland)
D. Species of Uncertain Status	
Coho salmon	*Oncorhynchus kisutch* (Walbaum)
Chinook salmon	*Oncorhynchus tshawytscha* (Walbaum)
Sockeye salmon (kokanee)	*Oncorhynchus nerka* (Walbaum)
Quillback	*Carpiodes cyprinus* (LeSueur)
Longnose sucker	*Catostomus Catostomus* (Forster)
Silver redhorse	*Moxostoma anisurum* (Rafinesque)
Shorthead redhorse	*Moxostoma macrolepidotum* (LeSueur)
Northern hog sucker	*Hypentelium nigricans* (LeSueur)
Fallfish	*Semotilus corporalis* (Mitchill)
Sauger	*Stizostedion canadense* (Smith)
White crappie	*Pomoxis annularis* Rafinesque
Spoonhead sculpin	*Cottus ricei* (Nelson)
Ninespine stickleback	*Pungitius pungitius* Linnaeus

usually only 5-10 miles from shore on the north side of the lake and within three miles on the south. A summary of the average annual catch by species in the various Canadian waters (Fig. 2) illustrates the higher yield and broader species base in the shallow Eastern Outlet Basin. The period 1925-49 was used for the summary because the species composition of the “mixed coarse fish” varied in the years outside this time span.

Since 1900 fisheries in the central and western areas of Lake Ontario were strictly gillnetting operations, whereas hoopnets and setlines were used as well, in the east. On the U.S. side, also, gears other than gillnets were used only in the extreme east. This situation was in part due to the lack of shallow water to the westward, but it seems likely also, that littoral zone fishes were more abundant in the east than in the west because of the much greater length of the shoreline in the east. The Canadian eastern region, the Bay of Quinte and the U.S. part of the Eastern Outlet Basin have 72.4% of the total lake shoreline (Table 2).

The Canadian western and U.S. fisheries had collapsed or were greatly reduced by the mid-1940’s, whereas the eastern fisheries were not so drastically affected (Appendix Table 1). The western and central fisheries in the Canadian waters lost their stocks of ciscoes, whitefish, and lake trout and the fisheries collapsed because there were no alternative species available. In

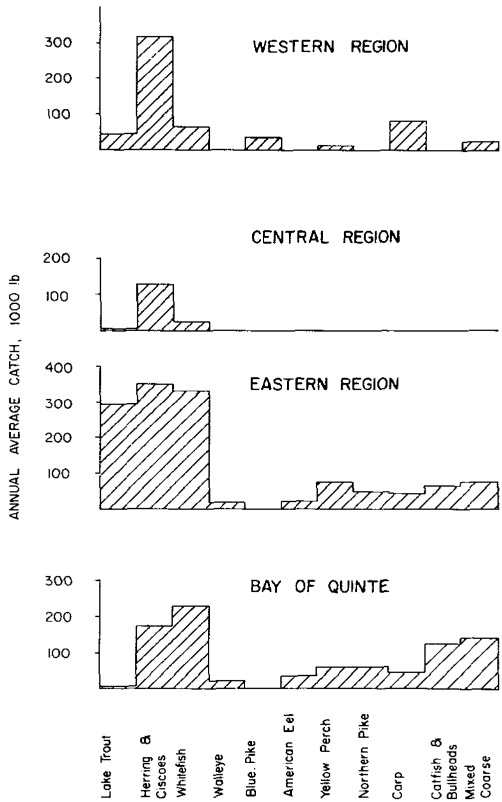

Fig. 2. Species composition of the commercial catch from various areas of Canadian Lake Ontario, 192549. Boundaries of the area are shown in Fig. 1.

the eastern waters, the lake whitefish persisted through the 1950's and increased yields of warm water fishes partly compensated for the disappearance of the important offshore species. Whereas the average yield fell 64% in the western region, it decreased only 40% in the eastern region and 27% in the Bay of Quinte (Appendix Table 1).

The changes described above shifted the fishery from operations which captured relatively small numbers of large, valuable fish, to those which depend on large numbers of small, lower value fish. The fisheries began to operate closer to shore to capture such species as yellow perch and white perch and this permitted the use of smaller boats and crews. This saving has by no means compensated for the additional labour costs in removing the smaller fish from the nets, and the ultimate limit on poundage which can be produced in a day, imposed by the time required to handle gillnets. Because the fisheries have dwindled under this economic pressure present production may be below the maximum that the inshore fisheries could attain.

The yield statistics are probably not reliable indices of changes in the lake's biomass. Certainly, the annual catch of smelt is not a good indicator of

Table 2. Some physical dimensions of Lake Ontario.

Region	Shoreline length in statute miles	Lake area in square miles (statute)	
		0-20 fa.	0-30 fa.
Canadian western	83	278	355
Canadian central	56	146	231
Canadian eastern	253	1032	1237
Bay of Quinte	185	92	98
U.S. western*	184	475	737
U.S. eastern**	146	272	272

*Stoney Point to Niagara River.
**Eastern Outlet Basin, Stoney Point to Cape Vincent.

the great abundance of this species, and some species of small fish that have not been adequately sampled in the past, may represent large biomass units. The abyss of the lake at present seems strangely devoid of fish, and perhaps the very abundant invertebrates are the ultimate converters of the ecological productivity in the deepwater areas.

THE COLD WATER FISH ASSOCIATION

The species discussed in this section are those whose shifts in status have been the most dramatic, and those most important economically. The first species to be described are the ones that inhabit the open (and usually deeper) waters of the lake. Next, in order of appearance are the forms which spawn near shore and typically live in the thermocline (in Lake Ontario, at least) during the summer. Finally, those species that spend part of their lives in streams and part in the lake, are considered. The lake herring is included with the first group rather than the second, where it rightfully belongs, because all ciscoes (herring and chubs) were combined in the Ontario fishery statistics until 1952.

Chinook salmon were stocked in Lake Ontario in the 1800's and again in the 1920's but with no apparent success. Recently, a new effort has been undertaken to establish this species, along with the coho salmon and the kokanee. Results are not yet conclusive, so these species are not considered in the text.

Lake trout and burbot

These species were the major deepwater piscivores in Lake Ontario. They are combined here because they seem to have had similar histories. Christie (1963) drew attention to the fact that the whitefish, lake trout, and burbot were all scarce at the turn of the century, but present in peak numbers during the 1920's. The burbot and lake trout declined steadily to virtual extinction by about 1950, whereas the whitefish catch statistics exhibited little trend from the mid-1930's to the 1960's when the stock collapsed. The

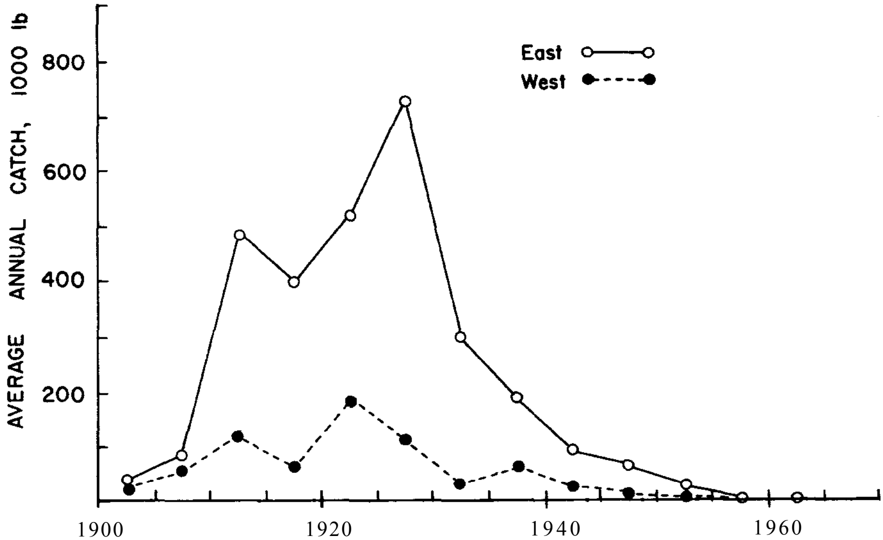

Fig. 3. Trends in the lake trout catch in Canadian Lake Ontario.

trends in lake trout abundance were readily discerned in the reports of commercial fishermen (Fig. 3) but shifts in burbot abundance had to be inferred from comments of fishermen, and from reports of the smaller New York fishery.

Burbot entered the commercial catch incidentally but were evidently captured in sufficient quantities at times to make it a major nuisance to the fishermen. The lake trout, on the other hand, was the most valuable fish in the lake and was widely sought. Both species were captured in the four and one-half inch mesh (stretched) whitefish gillnets, and in six to seven inch mesh gillnets.

Lake trout catches were always higher in the eastern than in western waters of Canadian Lake Ontario, although the catch trends for both areas were rather similar. For example, the 1910-15 peaks in catch in the two areas coincided. The second peak fell in the first half of the 1920 decade in the western fisheries, however, and in the second half for the eastern fisheries. This difference is likely explained by the fact that two of the largest western fishing companies began shifting their fishing operations seasonally to the principal eastern trout fishing base, Main Duck Island, during the 1920's.

Dymond et al. (1929) commented on the high abundance of the burbot in western Lake Ontario in the late 1920's. They recorded a single lift of whitefish nets containing 5,000 lb of burbot in late February 1929. They made no comment on the abundance of this species at the eastern end of the lake, except to note that it was seldom caught within the Bay of Quinte. Fishermen who operated during that time recall a heavy abundance of burbot in the eastern waters but there are no supporting statistics. Although it is commonplace to assume that a species can be regarded as unexploited if it is not commercially marketed, burbot, in fact, were sufficiently vulnerable to large-mesh gillnets, to be regarded as heavily exploited. The U.S. fishermen who operated mainly in the eastern area adjacent to the Canadian trout grounds reported an average of 45,000 lb of trout and 60,000 lb of burbot per year in the 1920's.

The spawning grounds of the western stocks of lake trout are unknown but in the east, spawning was confined to a few well-known lake shoals: Scotch Bonnet Shoal, Nicholson Island, Main Duck Island, Charity Shoal, and Pigeon Island. During peak abundance trout were also captured in spawning condition along shore, but these occurrences did not persist, suggesting that spawning stocks were not permanently established along the eastern coastline.

Little is known about the reproduction of the burbot other than that spawning occurred in late January or early February (Dymond et al. 1929).

Dymond (1928) indicated that the alewife was the dominant item in the diets of both species and suggested that the burbot was a serious competitor of the lake trout. Ciscoes predominated in trout stomachs after the inshore migration of the alewife. Both species utilized slimy sculpins, deepwater sculpins, and sticklebacks; burbot stomachs also contained appreciable quantities of invertebrates. Fish size was rather uniform in his samples and Dymond (1928) was unable to assess differences in diet among different life history stages in these species. During the 1950's a series of experimental plantings of juvenile lake trout was undertaken (Christie 1971) in the Eastern Outlet Basin. It was observed that they became piscivorous almost immediately on release (as spring yearlings, usually) and that they included progressively larger forage fishes in the diet as they grew. Darters and smaller sculpins were taken first, juvenile smelt and alewife next, and finally adult smelt and alewife were added to the diets.

Dymond (1928) apparently did not consider the sea lamprey an important threat to the lake trout in his review of factors affecting its production. Dymond et al. (1929), however, indicated that at Port Credit most trout bore many lamprey marks (superficial wounds) and some fish had as many as fourteen. These authors also recorded the following note from the diary of the Provincial biologist, C. W. Nash under date of March 16, 1899.-

> Saw another lake trout washed up today evidently killed by a lamprey. I must have found a dozen this winter along the beach (East Toronto) killed in this manner. This is the first season I have noticed them.

Recent observations have differed considerably from those of Dymond et al. (1929). In the trout planting experiment (Christie, 1971) referred to above, the lamprey appeared an important factor preventing the reestablishment of the trout stocks. The incidence of lamprey wounds was well in excess of that associated with the collapse of the South Bay, Lake Huron, lake trout (Budd, Fry and Pearlstone, 1969). The trout survived and grew well from the time of their introduction to age III, but ensuing mortality ranging up to 75% per year, prevented most fish from reaching sexual maturity. Fishing remained constant during the experiment and the variation in mortality levels was closely correlated with the sea lamprey abundance indices.

The early and recent observations are not obviously compatible with each other. A predator which increases its stress on a prey population as that population becomes less abundant, and less fecund by reason of the small size of its members, seems an ecological anomaly. The explanation may be that before man's arrival, the lamprey parasitized large fish, and killed relatively few of them. The evidence of Budd, Fry, and Pearlstone (1969), indicated that lampreys prefer large trout, and the observation of multiple attacks on large fish cited above, alone suggests that the large fish are more likely to survive than smaller trout. The unfished trout population under these conditions should be buffered against lampreys over a broad range of natural population variations. This would be so because most such fluctuations would normally arise because of recruitment variations, and result in larger fish in periods of low trout population. It is assumed that lamprey numbers were regulated by stream carrying capacity and to some extent by host fish density, and that the numerical threshold at which lamprey density would be sufficient to depress host survival would be infrequently attained. The hypothesis is, therefore, that the sea lamprey played an important role in the demise of the lake trout of Lake Ontario, but only after extremely heavy fishing pressure had depressed both the abundance of trout and size of individuals in the population.

The burbot was also known to serve as prey for the sea lamprey, and because of its smooth skin it is thought by some to be especially vulnerable (F. E. J. Fry, personal communication). Its relationship to the sea lamprey in Lake Ontario is unknown but the foregoing speculations concerning the lake trout are tentatively applied here as well.

The correspondence between the abundance peaks for whitefish and the two piscivores during the 1920's deserves comment. In the case of the whitefish, a sequence of years with favourable climatic conditions apparently preceded that period of abundance (Christie, 1963) and it is possible these years may have favoured the trout and burbot stocks as well. The occurrence of peak catches of whitefish in the first half of the 1920's (Fig. 5) and of lake trout in the second half may reflect the recruitment of the same large year classes of the two species at different ages. The catch peaks for both lake trout and whitefish occurred earlier in the western than in the eastern areas, but the time lags between species were similar at both ends of the lake. Possibly the eastern fisheries for trout and whitefish were slow to return to full intensity after the period of low abundance at the turn of the century.

Deepwater ciscoes and lake herring

The lesser coregonines played a very important role in the Lake Ontario fishery (Table 3) and the declines in their stocks had profound economic consequences.

Although the group offered some taxonomic difficulties the four species generally recognized were the lake herring, shortnose cisco, bloater, and kiyi. A fourth deepwater cisco, the blackfin cisco, was thought to have become extinct by the turn of the century (Koelz, 1926). The catch at the shallower eastern end of the lake was made up principally of lake herring whereas both deepwater ciscoes and lake herring were taken to the westward (Pritchard, 1931). Ciscoes and lake herring were a much more important component of the commercial catch in the west; their disappearance virtually eliminated the fishery there.

The long term trend in the combined cisco and herring catches of the

Table 3. The contribution of ciscoes and lake herring to the total commercial catch in Lake Ontario.

Decade	Average annual catch (thousands of pounds)	Percentage of total lake catch
1890-99	1755	40.8
1900-09	1347	41.1
1910-19	1495	31.9
1920-29	1010	19.4
1930-39	1308	35.1
1940-49	969	32.9
1950-59	112	4.6
1960-69	48	2.1

western fishery is downwards, but the collapse in the 1940's was particularly striking. In the space of about four years, the catch dropped from great importance (they made up the largest component of the lake's commercial harvest) to insignificance.

It was unfortunate that the catch reports did not require the commercial fishermen to distinguish between deepwater ciscoes and lake herring over most of the years of record. Pritchard (1931) however, summarized certain comments of commercial fishermen which are useful in the interpretation of Fig. 4. Lake herring were evidently scarce over most of the lake from the 1860's to the turn of the century. There was a surge of abundance at the turn of the century followed by a decrease. From 1909 to 1920 the herring were plentiful at both ends of the lake but interest in the fish developed somewhat later in the eastern fishery, delaying the appearance of high catch levels. Deepwater ciscoes were plentiful at the turn of the century but aside from one report of an increase in 1911 no further information was given in Pritchard's review. It is assumed, therefore, that the similar peaks of 1915 and 1919 for the two

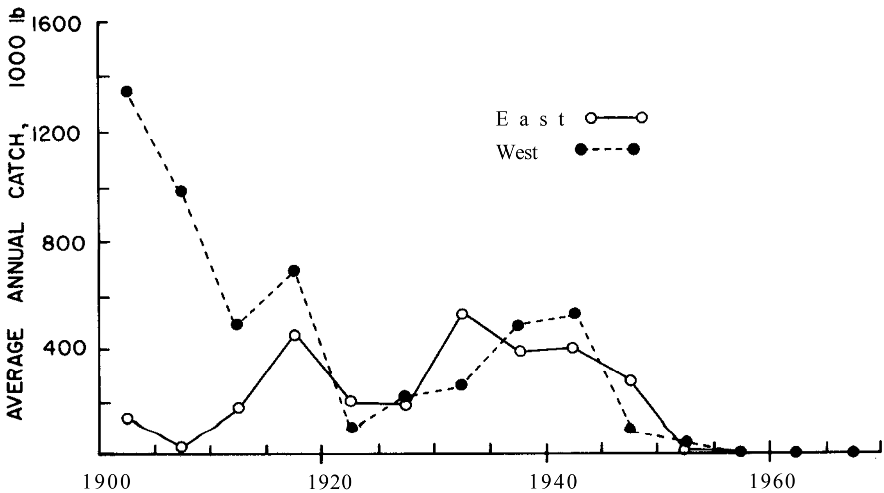

Fig. 4. Trends in the catch of lake herring and deepwater ciscoes in Canadian Lake Ontario. Pastern waters are exclusive of the Bay of Quinte.

areas both represented herring catches, and that the trend in deepwater cisco abundance was generally downwards from the turn of the century into the 1920's. This interpretation is supported by the data for the Bay of Quinte (Fig. 6), representing lake herring catches exclusively.

The reduction in the catches of the lesser coregonines during the 1920's was common to both ends of the lake, and was, in part, attributable to the intensification of effort directed towards the capture of lake trout and whitefish. As fishing shifted back to the ciscoes and herring in the late 1920's, however, there was no evidence of a large accumulated stock in the western end of the lake at least. The western stocks probably increased substantially in abundance through the 1930's, however. Total gillnet yardage licensed for these waters increased by 30% between the first and second halves of the decade but the licensed yardage per vessel only increased by 10%. Most of the additional effort was accounted for by an increase in the fishing fleet from an average of 34 vessels in 1930-34 to 40 in 1935-39. It is argued that the fishermen shifted to the coregonines primarily because of the loss of the trout and whitefish stocks and only an attractive increase in the abundance of the coregonines could have brought about an expansion of the fishery.

The differences in life histories of the lesser coregonine species make it unlikely that the abrupt collapse of the western stocks illustrated in Fig. 4, could have involved all the species, and there is some evidence that the failures of the different species occurred at different times. Pritchard (193 1) found all species well represented in his 1927 collections at Port Credit, but Stone (1947), by contrast, found a great predominance of C. hoyi in all his collections along the south shore of Lake Ontario in the summer of 1942 (Table 4). Stone's (1947) Youngstown and Wilson, N.Y., collections came from approximately the same fishing grounds frequented by the Port Credit fishermen but it will be appreciated that there are limitations on the comparability of the two sets of observations. Pritchard's data, for example, include more catches from shallow waters, and this precludes comparison of the lake herring data.

Stone's (1947) survey was undertaken in response to a request by fishermen for a reduction in the legal minimum mesh size. This suggests that the preponderance of bloater, the smallest of the ciscoes, in the 1942 catches was more than a short-term variation in the species composition. It seems

Table 4. Changes in the relative abundance of lesser coregonines in western Lake Ontario. Gillnet samples of Pritchard (1931) and Stone (1947).*

Species	Percentage of total sample: Port Credit, 1927 (395 fish)	Percentage of total sample: Youngstown-Wilson, 1942 (899 fish)
Bloater	21.0	98.6
Kiyi	52.8	0.1
Shortnose cisco	3.4	
Lake herring	22.8	1.3

*Pritchard mesh sizes 2-1/4 to 2-3/4 inch (stretched)
Stone mesh sizes 2-3/8 to 2-3/4 inch (stretched)

likely therefore, that two of the deepwater forms disappeared between 1927 and 1942 leaving C. hoyi as the only deepwater species. The collapse of the cisco fisheries in western Canadian Lake Ontario occurred in the mid-1940's but the more limited fisheries in the east persisted longer and the Salmon Point and Point Traverse fisheries in particular enjoyed moderately successful fishing for ciscoes until 1950.

The foregoing suggests that cisco abundance rose during the period of low predator abundance near the turn of the century, fell when the lake trout and burbot stocks climaxed in the 1920's, and again rose in the 1930's and early 1940's as the predators once more decreased. The deepwater forms apparently disappeared successively, perhaps according to size-the largest, the blackfin cisco, was the first to disappear, and only the bloater remained when the fishery collapsed. The abundance of those species surviving after each collapse may have increased sufficiently to permit the total catches to be maintained at comparable magnitude.

The catches of the U.S. research vessel Cisco (Wells, 1969) in 1964 included small numbers of ciscoes, and all three deepwater species were found. Thus all of the coregonines (including lake herring, as noted below) apparently still reproduce, but are suppressed by some persisting factor or factors.

The collapse of the bloaters coincides in time with the expansion of the smelt population. The adults of the two species appear to have occupied different depth strata-smelt to 27 fathoms (Wells, 1969) and bloaters deeper (Stone, 1947). This suggests there would be little contact between the species, but little is known about the extent of the lakeward pelagial distribution of smelt, or the depth distribution of bloater eggs and juveniles. Neither competition for food, nor predation by smelt, during the early life history stages of the bloater, can therefore be discounted altogether. This matter should be more thoroughly explored because it is very difficult to understand how the two major coincident events-smelt ascendancy, and bloater collapse-could have been unrelated.

Other explanations for the decline of the bloaters can be found, but seem less credible than the foregoing, as a possibly lakewide phenomenon. For example, Stone (1947) documented a high degree of variability in the condition (i.e. fatness) of C. hoyi in the summer of 1942, and this might suggest the fish were being harmed by some such factor as food shortage, or a debilitating parasite. Some 13% of all the bloaters examined were too emaciated for sale and these fish tended to be the smaller individuals. It was also noted that 82% of his total catch of 2225 C. *hoyi,* were females. Similarly, the Point Traverse and Salmon Point fishermen recall seeing a black "worm" in the gill chambers of bloaters towards the end, and suggest the population was wiped out by an epizootic.

Lake herring have experienced a severe decline also, but the pattern is somewhat different. As indicated above, the herring predominated in the Eastern Basin but supported a regular fishery only out of Point Traverse and Salmon Point. Pritchard (1931) noted that the herring were at a low ebb in the eastern area in 1922 but increasing by 1925; he also drew attention to the low commercial appeal of these fish when the whitefish runs to the Bay of Quinte were plentiful. The catches of herring in the Bay increased from the turn of the century to the record 1915-20 period. A general decline then followed until the resurgence in the late 1930's. Thereafter, the trend of the catches was irregularly downward. The catch had ebbed below 100,000 lb/yr by 1945 and by 1960 the Bay of Quinte stock had fallen to insignificant numbers. The year-to-year catch levels varied greatly because of weather influences. The herring spawned in late November and the time of ice cover formation determined the duration of the herring fishing period.

During the summer herring were fished occasionally in the open waters of the Eastern Outlet Basin, and regularly in autumn along the sand beaches of the south coast of Prince Edward County east and south from Brighton. This fishery is still pursued in October each year; nearly all of the catch data in Appendix Table 4 for recent years in the eastern end of the lake (since about 1950) are from this source. There has been a slight trend towards increase in late years but the indications are that this stock is also much reduced from former levels.

Lake herring and lake whitefish have in common a period of juvenile life in the inshore waters. This was not true of the deepwater ciscoes, and it is felt that as a consequence of the longer seasonal period of contact with the lake trout and burbot, the latter forms may have been subjected to more intense predation by these species.

Herring runs declined earlier than the whitefish runs in the Bay of Quinte (Figs. 5 and 6). Hart's (1930) observations on the use of the same spawning areas by the two species, and the mingling of the fry after they hatch in the spring make it difficult to appreciate how the effects of either eutrophication or new species could have affected the two species differently. One possibility is that the herring were more readily killed by the sea lamprey, and were depleted when sea lampreys were forced to alternate prey

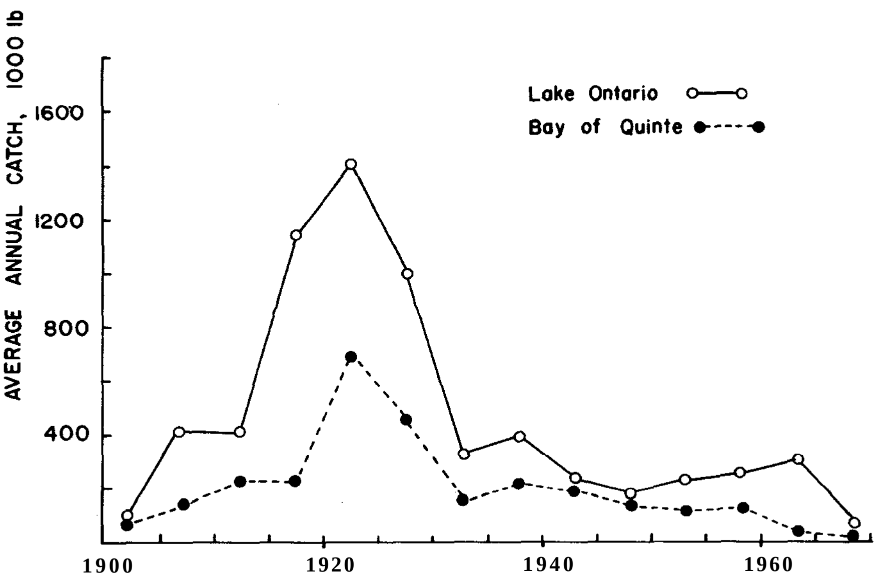

Fig. 5. Trends in the catch of lake whitefish in the Bay of Quinte and other waters of Canadian Lake Ontario.

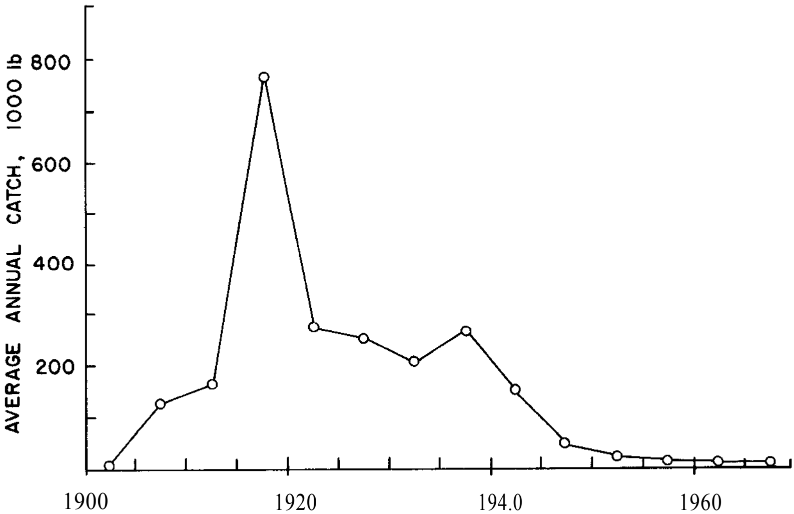

Fig. 6. Trends in the Bay of Quinte lake herring catch.

species by the reduction of trout and burbot. On the other hand, the lake herring collapse coincided with the increase of smelt, and unlike the bloaters, the herring and smelt distributions are much more completely overlapped, and both predation on juveniles by smelt and competition with smelt for food would be possible. It seems a tenable hypothesis that the pressure of lamprey and fishing were such as to make the reduced stocks of herring especially vulnerable at the time of the smelt population increase. The whitefish populations conceivably were not so fragile at that time, and as will be seen later, the Bay of Quinte smelt population did not persist.

In the latter connection it may be noted that the only persisting stocks of both whitefish and lake herring are those which spawn on the south coast of the Prince Edward County peninsula. It has been pointed out (Christie, 1968) that the whitefish of this stock may not be so subject to predation by white perch. A study to determine whether or not the lake herring juveniles of that area also have some protection from smelt predation would provide at least a partial test of the hypothesis.

Sculpins and other offshore forage species

Species reported as common in the offshore waters of Lake Ontario at one time or another, but which are not of sporting or commercial importance, are the johnny darter, fourhorn sculpin, slimy sculpin, threespine stickleback, trout-perch and spottail shiner; in addition, lake chubs are fairly common at the west end of the lake. These fishes are all native species and with the exception of the fourhorn sculpin, they appear to be persisting.

The apparent disappearance of this deepwater sculpin is of particular interest. The last identified specimens were collected in 1953 and are preserved in the collection of the Glenora Fisheries Station. This species was not captured in the cruise of R. V. ***Cisco*** in 1964 (Wells, 1969). Appreciable netting activity throughout the 1960's, including three lake-wide cruises in 1964, 1965, and 1969 in the north half of the lake, failed to take a single specimen.

The fourhorn sculpin was reported by Dymond et al (1929) as very abundant in the deepwater areas. Stone (1947) took relatively few in the course of his 1942 survey but many were caught by commercial fishermen in 1950. So many large deepwater sculpins were taken in a cisco gillnet set south of Point Traverse in the fall of 1950, that several days were required to clear the nets (Captain R. C. McIntosh, personal communication). This example serves to illustrate the concensus of opinion of fishermen of the time that the sculpins were plentiful. How long they persisted beyond the early 1950's is not known because the termination of the deepwater cisco fishing effectively ended sampling until the investigations with the R. V. *Namaycush* were begun in the 1960's.

By contrast, the slimy sculpin is presently very abundant. Wells (1969) commented as follows:

> The catches of sculpin at 30 and 40 fathoms (1618 and 2369, respectively) were much larger than any ever made by the *Cisco* in the other Great Lakes.

At similar depths and dates and using similar gear, Wells (1968 and 1969) took about 10 times more slimy sculpins in Lake Ontario than in Lake Michigan (Table 5).

Wells' (1969) gillnet and trawling data suggest that the slimy sculpin is the only fish below 25 fathoms in summer in Lake Ontario, and that the areas below 50 fathoms appear to be unoccupied by fish.

The depth ranges occupied by the fourhorn and slimy sculpins are distinctly separate (Table 5; see also Deason, 1939). That the Lake Ontario slimy sculpins evidently have not extended their range into deeper water in the absence of the deepwater form suggests that interaction between the species was not involved in the segregation.

The mottled sculpin and the Spoonhead sculpin have both been reported from Lake Ontario. Hubbs and Brown (1929) recorded mottled sculpin specimens at three nearshore locations. Dymond (1926) noted that the Spoonhead sculpin was known from Lake Ontario but gave no particulars. Neither species has been recorded in the subsequent surveys, and their present

Table 5. Average number of sculpins caught per lo-minute tow of a bottom trawl at different depths in Lake Michigan (July-August) and Lake Ontario (September). Data from Wells (1968 and 1969).

Depth (fathoms)	Slimy sculpin		Fourhorn sculpin
	Lake Ontario	Lake Michigan	Lake Michigan
10	0	0	0
15	17.5	0.5	0
20	17.5	42.5	0.5
30	911.0	92.5	0.5
40	1190.5	99.0	21.0
50	136.5	21.5	325.0

status in the lake proper is uncertain. The mottled sculpin is still known to occur in the tributary streams (Coleman, 1971).

The small catch of threespine stickleback made by the R. V. cisco in 1964 (Wells, 1969) may not have reflected the true abundance of this species because only bottom trawls were used. Nighttime pelagic trawling in 1964 in Canadian waters suggested that the species may be quite abundant, at least in certain areas.

Lake whitefish

The lake whitefish for many years was the mainstay of the Lake Ontario gillnet fishery. The bulk of the catch came from the Eastern Outlet Basin and as pointed out earlier, the persistence of the supporting stocks permitted the survival of the fishery after the lake trout and cisco stocks declined.

The economic importance of the whitefish fishery made it the subject of considerable investigation. Hart (1930, 1931) reported on studies of the spawning and early life history in the Bay of Quinte and of the growth characteristics of several Lake Ontario stocks. Christie (1963) who reviewed a long sequence of age composition data, found that fry plantings did not contribute significantly to the strength of year classes. As noted earlier he showed that whitefish, lake trout, and burbot populations all dropped to critically low levels near the turn of the century, peaked in the early 1920's and declined thereafter (Fig. 5). The data suggested that oscillations of the whitefish stocks were related to weather conditions. Earlier than normal winters, with corresponding early springs, favoured large year classes and the reverse conditions were associated with smaller year classes. It was suggested that fast cooling in the fall when the whitefish spawn, provided the protection of early ice cover for the eggs, and helped prolong the incubation period. An early spring, it was felt, prevented the hatch of the whitefish fry from preceding the spring plankton pulse and thus ensured the food supply of the young fish during the brief critical period.

More recent studies (Christie, 1968; Christie and Regier, 1973) which concerned the effects of fishing, and the relations between stock and recruitment, suggested that the stress induced by the fishery alone was sufficient to account for the decline of the whitefish. After the loss of the lake trout and cisco stocks, the fishery turned its full attention to the whitefish. The introduction of nylon gillnets in 1950 permitted fishing to continue at levels of stock density which previously would not have been economically feasible, and increased the level of fishing intensity almost three-fold (Christie, 1963). The strong whitefish catches of the middle and late 1950's resulted from a sequence of successful year classes. Their appearance did little however, to stop the steady reduction of the brood stock. In the late 1950's exploitation rates of 50-65% were measured (Christie, 1968) and the average age of the fish in the commercial catch was much reduced. Stock density was so far below maximum carrying capacity over the whole period of study (1944-60) that growth and survival compensation were inoperative. Most year classes in this series failed to replace themselves and this appeared a function of the longevity of the fish, and the climatic conditions associated with their various reproduction opportunities.

Poor reproductive conditions for a year class could be compensated if the fish lived longer and had more spawning opportunities. Conversely, year classes suffering high mortality required good reproduction years, climatically, to achieve replacement in the stock. It also appeared that a minimum of about 1.0 spawnings per female was requisite for a year class to be replaced in the stock, regardless of weather conditions.

There is evidence that predation by sea lamprey imposed an additional and appreciable stress on the whitefish during the 1950 decade-probably because the whitefish was the only prey remaining after the stocks of trout and burbot declined.

The general impression is that the frequency of wounds and scars on the whitefish must have been low before 1950. Hart (1930) made no reference to the lamprey in his examination of factors limiting the abundance of whitefish. Dymond, Hart, and Pritchard (1929) mentioned the whitefish among the prey fishes of the sea lamprey, indicating that lamprey wounds and scars were seen at least occasionally. Prior to 1953 no records of lamprey wounding frequency on the whitefish were maintained, and no reference to the lamprey was found in the field notes of the investigators who sampled the whitefish catch in the 1944-52 period.

By contrast, attack rates as high as eight wounds per 100 fish were observed after 1953. The average size of fish in the principal age groups moreover, was smaller in the early 1950's than in the 1944-49 period. In the late 1950's, lamprey wounding declined and the size of the fish increased-the reverse of what might have been expected to result from the intensification of the fishing effort of that time. Stock density did not seem to be implicated in the size change because the strengths of year classes were not correlated with sizes of their members.

There were two major stocks of whitefish supporting the fishery in the Eastern Outlet Basin, and the larger one, that spawned in the Bay of Quinte, declined before the other. The generally similar trends in catches of the spawning run fishery in the Bay of Quinte and catches in Lake Ontario as a whole (Fig. 5) are indicative of the important contribution of the Bay of Quinte stock to the large fishery in the open lake. The Bay catches failed to increase to the extent the lake catches did in the 1915-20 period but it is felt that the record lake herring runs (Fig. 6) to the Bay in those years probably led fishermen to concentrate their efforts on this species rather than on whitefish. Similarly during the 1940's the collapse of the Bay of Quinte lake herring stock probably caused an intensification of large mesh gillnetting for whitefish that led to the relatively higher catches of whitefish in the Bay. The recent deviations arose from the failure of the Bay stock after 1960.

The fish which spawn along the south coast of the Prince Edward County peninsula from Point Traverse westward to Salmon Point are called lakeshore whitefish and they constitute the only other population of significant size in eastern Lake Ontario. Commercial fishermen have always distinguished these fish from the Bay of Quinte whitefish by their larger size and more silvery appearance. Hart (1931) reported that fish of the lakeshore stock grew faster than the Bay fish. Spawning takes place somewhat later than in the Bay, and the November and December catches reported for the Brighton to Kingston area were mainly from this run. These catch data are found in Table 6, where they can be contrasted with the comparable catch and relative abundance statistics for the Bay of Quinte fall fishery, and the Eastern Outlet Basin fishery in summer.

Until 1960 the trends in the summer fishery more closely paralleled the Bay of Quinte fall catch trends than those for the lakeshore fishery, illustrating the heavy contribution of the Bay of Quinte fish to the total whitefish yield. The Bay of Quinte catches averaged three times higher than the lakeshore values up to 1960, moreover, and this is probably an accurate indicator of the relative sizes of the two stocks.

The earlier collapse of the Bay stock is also evident in Table 6. The 1957 year class was the last large brood produced in the lake and it appeared first as age III (probably mostly male) spawners at the lakeshore in 1960, before producing the record fishing of 1961. The Bay of Quinte brood stock was scarcely improved by this year class, and it is likely that most of the 1961 lake catch originated from the lakeshore stock. Since 1960 the catches in the Bay have averaged less than one-half those of the lakeshore.

When the 1957 year class declined, the catches made during the months outside the spawning period in the Eastern Outlet Basin declined precipitously. A minor recovery occurred after 1966, with the recruitment of the 1962 year class, but in general, recent year classes have been too small to sustain the fishery, and effort has been gradually diverted to yellow perch and white perch. The decline of the lakeshore catches is not so evident in the spawning run data, as in the summer catch values. This is partly attributable

Table 6. Relative abundance of lake whitefish in eastern Lake Ontario, 1953-70.

	Spawning run fisheries[a]				Summer fishery[b]	
	Bay of Quinte		Lakeshore			
Year	C[c]	C/E[d]			C	C/E
1953	338.0	20.8	140.7	40.9	429.4	37.9
1954	400.8	24.9	370.7	55.1	629.6	38.6
1955	560.0	34.5	319.9	94.1	1284.3	43.7
1956	860.0	35.8	383.2	53.2	2260.7	55.2
1957	474.5	23.2	135.9	35.3	1113.0	30.4
1958	672.2	27.0	202.4	36.6	1027.9	32.7
1959	522.6	25.8	87.1	31.7	1237.6	26.2
1960	357.5	18.9	754.0	126.1	695.3	26.5
1961	378.4	24.4	1110.1	92.4	2336.3	51.5
1962	78.6	9.0	163.0	48.3	1564.9	39.1
1963	34.6	5.6	227.5	50.2	1414.0	41.1
1964	82.3	10.4	130.3	56.2	500.4	33.1
1965	63.0	14.2	175.3	81.5	354.2	26.6
1966	46.8	13.4	167.2	100.0	94.2	22.7
1967	18.9	19.7	154.1	69.4	155.8	33.1
1968	8.8	40.3	194.0	70.9	332.3	35.6
1969	6.9	87.8	118.2	50.5	427.6	41.0
1970	0.1	0.4	109.8	70.3	264.5	41.1

a October-December statistics used in Bay of Quinte, November-December statistics used for lakeshore.
b June through September.
c C = reported catch in hundreds of lb.
d C/E = lb per 1000 yards gillnet lifted.

to the diversion of gillnetting effort during the summer, but it is also possible that a prohibition of fishing after November 15 at the lakeshore, which was introduced in 1962, may have helped to temporarily conserve this stock reserve. Data bearing on this question have not yet been analyzed. It should be noted that the catch-per-unit effort rose with the recent stock declines. This is attributed to relaxation of gear competition as fishing effort diminished. The most obvious differences between the two spawning areas are that 1) the lakeshore did not have large populations of small predacious fish like white and yellow perch, and 2) effects of eutrophication were much more pronounced in the Bay. As noted elsewhere, both these circumstances have changed. Recently the yellow perch population has burgeoned in the lake, and through the 1960's the alga Cladophora has become a more serious problem in the lakeshore spawning areas.

There is no indication in Table 6 of a progressive weakening of the contribution of the Bay of Quinte stock to the open water fishery. Between 1953 and 1960 spawning run catches in the Bay averaged about one-half the catches in the lake in the preceding summers; the proportion ranged from 0.4 to 0.8, with no discernible trend. Since 1960 the proportion averaged less than 0.1. This suggests that the factors which were involved in the failure of the Bay of Quinte stock to reproduce from 1957 onwards had a sudden effect. This sort of threshold effect could arise if, for example, eutrophication effects were progressively lowering over-wintering egg survival, while improved feeding conditions for the fry acted to compensate up to some limit. Alternatively, the deciding factor may have been the coincidental appearance of the first significant concentrations of white perch (Table 9) in the area. Hart (1930) found that yellow perch preyed heavily on newly-spawned whitefish eggs, but it seems likely that adult perch had little effect on the larvae in the spring when their own spawning activities normally reduce the rate of feeding. White perch, by contrast, are more abundant in the spring than in fall at Hay Bay which was formerly an important whitefish spawning area. They feed actively in the spring and adults commonly eat small fish (Leach, 1962), and so might prey on whitefish larvae.

The time lag between the collapse of the lake herring (1944-46) and the whitefish decline (1959-61) in the Bay of Quinte seems paradoxical. The two species spawned in the same areas, and the fry apparently intermingled freely (Hart, 1930). Levels of algal density sufficient to cause gillnet fouling, and thus perhaps sufficient to endanger fish eggs incubating on the bottom through the winter, did not develop until the 1950's. As pointed out earlier, the ascendancy of the smelt coincided with the loss of the lake herring, and predation on the herring eggs and fry by smelt may well have been important. The most tenable explanation for the persistence of the whitefish after this event appears to be that they were still abundant enough in the mid-1940's, to absorb a further increase in juvenile mortality, whereas the herring were not. The numbers of whitefish in turn, were severely reduced during the 1950's, and the explosion of the white perch population may have been the factor which triggered their collapse after the critical population level was reached.

The failure of the stock to recover after reduction of fishing in the Bay of Quinte suggests that mortalities from predation pressure are still sufficient to keep the stock suppressed. There is, as indicated above, the additional possibility that the effects of cultural eutrophication may be limiting. These latter considerations are held to apply to lake herring as well as whitefish.

Alewife

The alewife apparently colonized Lake Ontario in the 1860's. It was contended by Miller (1957) and previous authors that the species was inadvertently introduced during an unsuccessful effort to stock American shad *(Alosa sapidissima)* in Lake Ontario between 1870 and 1873. Smith (1970) however, pointed out that several sightings of large numbers of alewife during 1873 suggest that the alewife penetrated somewhat earlier. He found no reports prior to this and concluded that the alewife was not native to the lake. The lack of historically early reports is not always a good basis for reaching such a conclusion, but this is probably not so of the alewife. The springtime mortalities of unspawned fish makes the species a rather conspicuous one, even when the abundance is low, so it seems likely that dead alewives would have come to the attention of the early ichthyologists had they indeed been present in the lake much before 1870.

Alewives appeared in Cayuga and Seneca Lakes of the New York Finger Lakes chain in 1868, and Smith (1970) favoured the theory that the species entered these lakes and Lake Ontario by way of the Erie Barge Canal system; probably around the same time. This evidently was true of the invasion of the white perch (Scott and Christie, 1963), and appears a plausible explanation for the entrance of the alewife also.

Smith's (1970) contention that the colonization of Lake Ontario by the alewife was the central cause of most of the Lake's ensuing fishery misfortunes is not, in my opinion, consonant with all the facts. His view seems to be that the stocks of lake herring, ciscoes, whitefish, lake trout, and burbot collapsed after the ascendancy of the alewife, and after a long wasting period all disappeared. The resurgence of the major species in the 1920's was apparently regarded as only a minor and temporary recovery in the slide to extinction. Why such a process should require 80 years or more to complete is not explained. Equally important is the failure to appreciate the importance of the "fishing-up" effect (Graham, 1935). The offshore gillnet fisheries were not operational until the last half of the 1800's, and the catches of the 1850's and 1960's reflected levels of abundance which will never again be seen while the lake is exploited. I suggest therefore, that the resurgence of the 1920's was an important shift in abundance which took place in the presence of high alewife populations (Pritchard, 1929). Another point is that the 1900 peak of cisco and herring catches for the whole lake was almost matched by that in the 1930's. It is pointed out in the section on ciscoes and lake herring that the first peak probably consisted of the contributions of five species, whereas the second may have been supported by a single species, or at most two. Had the alewife been a serious competitor for these fishes (and it was shown by Pritchard (1929) that the diets of adult ciscoes and alewives were not similar) surely the loss of a cisco species would have resulted in its replacement by the alewife, and subsequent reduction of cisco catches to a much greater extent than that observed.

Table 7. Average catch of deepwater ciscoes and alewives per lift of a standard gillnet gang in two Lake Ontario depth ranges in summer (percentages are shown in parentheses; data from Stone, 1947).

Depth of capture (fathoms)	Deepwater ciscoes	Alewives
25 and less	21.6 (17.2)	5.3 (88.3)
26 and greater	104.3 (82.8)	0.7 (11.7)
Total	125.9	6.0

A further objection is based on the observation that the deepwater ciscoes varied in degree of contact with the alewife. That the three deepwater ciscoes were all primarily residents of the hypolimnion in summer was shown by Stone (1947; see Table 7), and recent surveys have shown that alewives and smelt scarcely penetrate the hypolimnion in summer (unpublished data, Glenora Fisheries Station). The data from the 1964 cruise of R. V. cisco (Wells, 1969) were equally convincing. Bottom trawling in September yielded an average of 81.2 alewives per 10 minute drag at 20 fathoms or less, but only 7.2 per drag at 30 fathoms and deeper. If the alewife inhabits the middle depths in summer, and extends pelagically over a broader area of lake surface, it would compete for food with the ciscoes. Pelagic fish sampling has not been extensive in Lake Ontario so a conclusive answer is not possible. Several 24-hour pelagic sampling experiments conducted over the past several years in late summer have shown that at middle depths (20 fathoms) in the Pastern Outlet Basin, the alewife are found close to the bottom during the day, and they ascend to the surface, or close to it, during the night. Alewives spawn along the shorelines in June and early July and it presumably would take time for the fish to spread over the areas of great depth after the spawning period. Patalas (1969) showed that concentrations of crustacean plankton were late in appearing in these open areas; consequently pelagic alewives would have to swim along a gradient of decreasing food supply as they move offshore. Although further work is required, these observations favour the view that summertime competition for food between ciscoes and alewives was limited.

Well's (1968) observations in Lake Michigan showed that alewives descend to deep water in winter, and Stone's (1947) data for Lake Ontario indicated that they were abundant to at least 60 fathoms by November. Although ciscoes and alewives thus live at the same depths in winter, competition for food probably is not intense because feeding rates are low. The alewives may have descended to the spawning areas of both the bloater and the kiyi by the time of their spawning periods in the fall, raising the possibility that the alewives could have eaten the eggs of these species. The shortnose cisco on the other hand, spawned in late April or early May (Pritchard, 1931) in deep water. Wells (1968) found the alewife were no longer in deep water by April in Lake Michigan and inshore mortalities have been reported as early as May 2 (Pritchard, 1929) in Lake Ontario. It seems unlikely, therefore, that the alewife could have interfered with the reproduction of this species.

The data in Table 9 provide relative abundance indices for alewives during spawning runs at a single index station in Hay Bay during 13 of the past 14 years. No trends can be discerned, but the amplitude of the year-to-year variations is large. The largest run was 9 times heavier than the smallest, and the 6 heaviest runs observed (7520 fish per lift) averaged 4 times larger than the 4 weakest (186 fish per lift) runs.

The lack of commercial catch statistics makes inferences about the long-term abundance trends of the alewife difficult. Pritchard's (1929) documentation of reports of mortalities did suggest that these dieoffs occurred more frequently before the turn of the century than they did at the time of his observations. Heavy mortalities seemed relatively infrequent through the 1950 and 1960 decades. It seems likely that the alewife passed through a period of high density following establishment, but the short period of the population explosion in Lake Michigan suggests that only a few years are required for such a short-lived fish to achieve equilibrium. Graham (1956) attributed the springtime mortalities to the effects of lethal water temperatures and this would suggest that climatic conditions as well as fish abundance may be involved in the mortalities. The severity of the spring mortality may not therefore, be an altogether reliable indicator of abundance.

The corollary of the last point is that although a dieoff need not be expected simply because the fish are numerous, mortalities of sufficient magnitude to cause comment in the major newspapers were unlikely in periods of low population density. The mortalities of 1922 and 1928 recorded by Pritchard (1929) in Lake Ontario thus occurred during the period of peak predator density. Similarly, the collapse of the cisco and herring stocks has been followed by a period in which relatively few mortalities of serious proportions have occurred. Alewives are still very plentiful in the lake, but they apparently have not "exploded" in response to the removal of their alleged competitors, or of their known predators.

One of the interesting features in the life history of the alewife is that at one time or another it utilizes nearly all types of lake habitat. Alewives spawn in the littoral zone and the juveniles spend some time there. The fish retreat to the deepest waters in winter presumably because of the warmer temperatures there. In late summer they are common at depths down to 20 fathoms. This seasonal behaviour implies, that the alewife has access to more of the lake's resources than other species. It also suggests that the alewife may represent an important vector in the transport of nutrients.

Adult alewives are a favoured prey of the walleye, but the eggs and young may be extensively utilized by other species as well, during the inshore phase. That no obvious change in alewife abundance followed the demise of the lake trout and burbot stocks, and the more recent reduction in the Bay of Quinte walleye population, may suggest that alewife population numbers are limited in the early part of the life cycle.

Rainbow smelt

There has been some contusion in the literature concerning the origin of the smelt of Lake Ontario. Van Oosten (1937) suggested that the fish were introduced in the late 1920's or early 1930's and this was also the opinion of Scott (1956) and Dymond (1944). Hubbs and Lagler (1947) on the other hand, took the view that the species was a relict of the last marine invasion, comparable to the Champlain Sea relict populations reported for the Ottawa Valley region (Dymond, 1944). This suggestion was subsequently endorsed by MacKay (1963) and Smith (1968). The basis for this new argument is not known, but it implies that the smelt were at such a low density level that they escaped the attention of generations of ichthyologists and commercial fishermen and in my opinion, this is unlikely.

The first smelt record for the lake was a specimen taken one mile off Sodus Point on October 9, 1929, and deposited in the University of Rochester collection (Greeley, 1939). The next record was that of Mason (1933) who examined a specimen at Bowmanville, Ontario in September 1931. Mason noted that the fisherman, Wm. F. Depew, indicated that the fish was new to that locality, and that several were captured there during the summer of 1932. The publication of "The Fishes of the Canadian Waters of Lake Ontario" (Dymond, Hart, and Pritchard, 1929) resulted from several years of experimental fishing with various gears, and analysis of commercial catches at the western end of Lake Ontario near Port Credit, and in the Eastern Basin area. That no smelt were seen during these intensive investigations suggests a low level of abundance. Many commercial fishermen who operate in the eastern waters recalled seeing the smelt for the first time between 1938 and 1940.

Scott (1956) suggested that the fact that the first sighting in Lake Ontario preceded the first sighting in Lake Erie (Van Oosten, 1937) by 4 years (sic) indicated that the fish were probably introduced, and possibly on the New York side. The possibility remains however, that some of the early migrants from the upper Great Lakes entered Lake Ontario via the Niagara River or the Welland Canal.

The evidence available suggests that the smelt population remained at a low level of abundance in the lake for many years. Stone (1947) captured only 10 smelt in his experimental gillnetting program of 1942. His nets were set mainly for ciscoes in water somewhat below the normal depth range for smelt, but the fishing was intensive and comparison with the recent experimental fishing efforts at comparable depths suggests that the smelt population was still small at that time.

Residents of Prince Edward County, Ontario recall the beginnings of large smelt spawning runs, and the establishment of the spring sport fishery at the end of World War II. Although the occurrence of smelt in the offshore commercial gillnets had been increasing in frequency it was not until "1944 or 1945" that smelt taken from spawning runs were shipped for sale, according to a local fish buyer, Mr. J. Buchanan of Picton. These first commercial smelt were taken with dipnets by farmers, but during the following several years the commercial fishery adopted the use of small mesh gillnets for the capture of smelt on the spawning run. This fishery (and the sport fishery as well) was conducted principally within the Bay of Quinte in the first few years, but smelt fishing swiftly became profitable elsewhere in the lake as well. Smelt catch data were not listed separately in the reports of the commercial fishery until 1952, but by that year the total annual harvest reported for the lake had reached 253,000 lb.

In the years since 1952 the total commercial smelt catch has averaged 211,000 lb per year. The New York contribution to the catch has been trivial. The yearly values in the eastern waters oscillate widely but they trended downwards from the 1953 high of 212,000 lb until 1967. More recent catches were somewhat higher.

Little can be inferred from the commercial catch statistics about smelt population changes since the ascendancy. The much larger catches of smelt produced in Lake Erie affected the sale of the Lake Ontario product, often causing suspension of the fishing before the end of the spawning run. In Lake Erie the fishery first adopted trapnets for the spring catches and later introduced bottom trawls for high volume production over a longer season. The Lake Ontario fishery in fact has probably survived the competition of the technologically advanced Lake Erie fishery only by reason of the typically earlier spring start possible in ice-free' Lake Ontario, and the fact that the fishery uses gillnets of approximately 1% inch (stretched) mesh, to select for the larger fish which have a modest market premium.

There have been however, significant changes in the status of the smelt population. After the early 1950's the runs of smelt within the Bay of Quinte progressively declined and by about 1960 there were no stream runs of sufficient density to attract either sport or commercial fishermen. Runs to the south coast-line of the Prince Edward County peninsula replaced the Bay of Quinte sport fisheries and the smelt are still taken in large numbers on shelf limestone and sandy shores. The course of these events is traced in Fig. 7 where the commercial catch data for the Bay of Quinte are contrasted with those for the adjacent Lake Ontario waters.

Local sportsmen believed that the greatly reduced spring runoffs in the years after the high-water period of the early 1950's affected the Bay of Quinte smelt runs and this may have indeed been an important factor. Precipitation rose again after the mid-1960's, however, with no evident

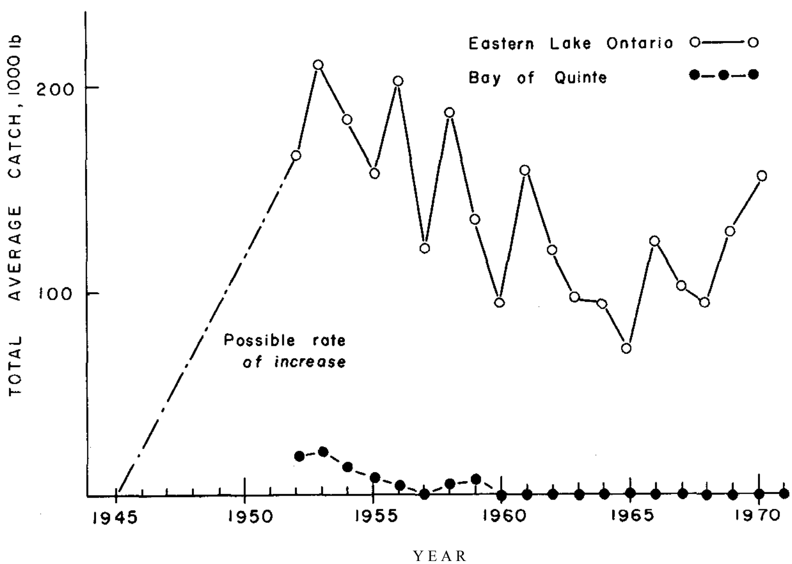

Fig. 7. Trends in the commercial catch of smelt in Canadian Lake Ontario. Values for eastern Lake Ontario exclude data from the Bay of Quinte.

corresponding increase in the Bay of Quinte smelt population density. Other factors would thus seem to be implicated.

The smelt lives in the thermocline during the summer (Wells, 1969). Judging by the Lake Michigan data of Wells (1968), it does not inhabit great depths in winter, since none were taken below 35 fathoms. The coincidence of the smelt ascendance and the collapse of the bloater raises the possibility of interaction between these species, but the shallow distribution of the smelt would seem to argue against this. Adult smelt prey upon the same larger invertebrates formerly eaten by the deepwater ciscoes, but unless they live pelagically over the depths, they would probably not have competed for the same food. The smelt at larger sixes also eat fish, but they seem even less likely to have eaten the eggs or juveniles of the ciscoes. The possibility that the smelt caused the demise of the lake herring has already been discussed.

The final reductions of the trout and burbot stocks also coincided with the increase of the smelt, and it seems likely that a reduction in predation on adult smelt may have been a factor in their increase. However, the Bay of Quinte walleye and the smelt increased at the same time. Both these fish are spring spawners, and as noted in the later section on walleye, the post-war years were distinguished by warm springs. The evidence of increasing numbers of smelt in the early 1940's favours the predation theory, but favourable environmental factors could also have given the smelt population the extra impetus to explode.

Sea lamprey

The question of whether the sea lamprey was a member of the original Lake Ontario fish fauna has been debated for many years. If native, there must have been equilibrating mechanisms at work in Lake Ontario (and the Finger Lakes of New York State as well) to preserve the salmonid stocks. If so, such factors could have considerable practical significance in current and future efforts to control the abundance of the sea lamprey.

Part of the debate about the early status of the sea lamprey arose because few references were made to the lamprey in the pre-1900 literature. A. H. Lawrie (personal communication) however, cited Trautman's (1949) reference to a statement of concern made by Dr. Jared P. Kirtland (1851) over the danger of introducing *Petromyzon* to Lake Erie via the second Welland Canal. The species was also included in a list of fishes of the Toronto region published in "The Hand-Book of Toronto; containing its climate, geology, natural history, educational institutions, courts of law, municipal arrangements, etc., etc." This book was printed in 1858. Its author was anonymous, but the writer of the bird and mammal sections, Dr. S. P. May is believed to have also written the fish section. Any possible doubt left by the Kirtland reference as to the identity of the animal must be dispelled by the May reference, which notes, "This fish is common in the lake where it is a parasite on the salmon." This reference appeared in Scott (1957).

That the lamprey existed in Lake Ontario at least as early as -1850 appreciably increased the likelihood that it remained in Lake Ontario as a relict of the last glacial retreat-a view held by Radforth (1944) and other authors.

The contrast between the calamitous effects of the invasion of the upper Great Lakes by the sea lamprey and the harmony between salmonids and lamprey which must have prevailed in the past in Lake Ontario and the Finger Lakes if the lamprey was indeed native, can be explained in several ways. One of these might be termed the genetic argument. This has it that the lake trout of the south-east may have had their recent origin in south-eastern refugia whereas the upper Great Lakes were repopulated after the retreat of the Wisconsin ice sheet, from refugia in the Mississippi drainage. Thousands of years of exposure to the lamprey in the Lake Ontario drainage could have produced a strain of lamprey-resistant lake trout. The extent of lamprey predation on Atlantic salmon is not known, but similar arguments can be put forward in favour of adaptive protection for this species as well, and the fact that the salmon-lamprey association has a far longer history (in the sea) lends them strength.

The simpler hypothesis described in the lake trout section was that man's effect has been to shift the predator-prey ratio well beyond the capacity of the prey to compensate. From this viewpoint one need not visualize any adaptive response on the part of the trout. The hypothesis requires only that the lamprey evolved as a parasite on large fish rather than a predator on small fish.

The fact that the lamprey was not singled out as a threat to the salmonids in the last century, in the extensive literature concerned with stock declines, serves as evidence that the frequency with which lamprey wounds and scars were observed was low. A low attack frequency can, of course, reflect both high prey density and low predator density. That prey density was high is unquestioned, but it is suggested that predator density may have been low, as well. Dymond et al. (1929) documented high lamprey abundance in the 1920's when the lake trout and burbot populations were also abundant. The densities of these prey species probably were well below those during most of the 1800's, but they were nevertheless high, and the high frequency of lamprey marks in the 1920's suggest a real change in lamprey abundance.

Another change which has taken place is the removal or deterioration of many of the old mill dams in the early 1900's and this may have appreciably increased the stream habitat available to the lamprey. Many water courses were obstructed by many dams, and even some low structures which the salmon could surmount could not have been passed by sea lamprey. After removal of the forest cover, sawmill operations gave way to gristmills. The gristmills were eliminated by the reduced stream flows in the fall, caused by the drop in the water retention capacity of the watershed after it was deforested. Textile and other mill operations which operated in the spring persisted longest. The data in Table 8 which were recorded for the Ganaraska River (Richardson, 1944) illustrate the foregoing sequence. The location of the dams with respect to the river mouths was variable and very significant so far as the fish are concerned. The Ganaraska was dammed very early near its mouth, and has remained inaccessible to anadromous fish. The Ganaraska is one of the larger watersheds in the drainage however, and it seems possible that the medium sized streams which now support rainbow trout and sea lamprey populations may have been opened to fish migrants somewhat earlier than the larger streams. In summary, the evidence cited supports the

Table 8. Average number of mills and dams in the Ganaraska River watershed, Lake Ontario, in the different decades.1

Decade	Average number sawmills	Average number gristmills	Average number woolenmills	Average number dams
1800	2	2		2
1810	3	2		3
1820	5	4		5
1830		6		8
1840	20	12		18
1850	29	17	2	29
1860	34	19	4	34
1870	26	18	4	27
1880	15	14	4	26
1890	10	11	5	23
1900	9	9	5	23
1910	6	8	4	18
1920	5	7	2	17
1930	2	6	2	15

1 Numbers shown are mid-decade averages from graphs published by Richardson (1944).

hypothesis that man's early settlement acted to suppress the sea lamprey population, and it was not until early in the present century that the lamprey regained sufficient abundance to pose a threat to the fish stocks of Lake Ontario.

As pointed out in the section on lake trout and burbot, recent observations suggested that the abundance of sea lampreys limited the survival of stocked lake trout. The availability of alternate hosts may have acted to maintain high lamprey density or at least delay its decline, so as to intensify the already severe levels of mortality in the prey species. Although the general trend in lamprey abundance as indicated by mark incidence on whitefish has been downward since the early 1950's, strong lamprey year classes have occurred recently when density of all prey species was very low. In a lakewide survey in 1970 (Great Lakes Fishery Commission, 1971) sea lamprey ammocoetes were discovered in 22 Canadian and 7 U.S. streams. In many streams the densities of lamprey larvae were very high. It appears clear therefore, that the lamprey population can persist, and perhaps indefinitely, in the absence of salmonid prey.

Atlantic salmon and rainbow trout

These species are dealt with together in this section because of the similarities in their life history patterns. Both spawn in streams and inhabit streams for a period before going to the lake.

The story of the extinction of the Atlantic salmon of Lake Ontario has been well documented. It is generally agreed that the salmon was a land-locked form indigenous to Lake Ontario (Blair, 1938; Fox, 1930). The importance of salmon to settlers as a source of food readily (and abundantly) available in the rivers before the onset of the winter was commented on by every historian of the colonization of the area (cf. Canniff, 1867) (Fall runs were the rule to the eastwards but there were also spring runs to the streams to the west of Toronto-see Huntsman, 1944). The salmon appear to have continued at least locally plentiful up to the 1830's and then to have dwindled by 1866 to the point where Wilmot (1869) had difficulty obtaining enough parent fish for his program of artificial propagation. A limited recovery in the 1870's (Huntsman, 1944) which was attributed at the time to the hatchery operations, was short-lived. The last sighting of salmon in one of the tributary streams seems to have been that of "a pair of 7 to 8 lb fish seen in Wilmot Creek in 1896. . ." (Huntsman, 1944).

Huntsman (1944) suggested that the stocking program was a failure, and that the resurgence was the result of a period of more favourable natural conditions-most likely higher precipitation levels. He also reviewed the various conditions inimical to the salmon which had developed since the colonization of the watershed by man. He felt that over-fishing had not been a primary factor and cited as proof the failure of measures restricting fishing in the streams to stop the final collapse. Pollution was not believed to be a serious consideration, and deforestation per se was not held to be an important factor. Reduced late season flows in the streams were seen as capable of reducing the production potential. These also created impediments to the attraction of, or entry by, the spawning run migrants. The numerous dams undoubtedly seriously reduced the spawning and nursery areas also. Siltation, an indirect result of deforestation, was thought to be an especially serious obstacle to salmon reproduction.

Apropos the deforestation question, the following statement by Huntsman is open to question:

> . . . it is found that full forest along streams is associated with a sparse population of fish, which indicated that a certain amount of forest removed will increase salmon abundance.

Recent studies (Hynes, 1963) have emphasized the role of the annual leaf fall in raising stream productivity; consequently, at least for streams passing through deciduous forest, the reverse of Huntsman's statement may be true.

McCrimmon's (1954) studies established that the survival of juvenile salmon in Lake Ontario streams was limited and that three factors may have been important in lowering survival: the higher summer temperatures of the unsheltered streams, the reduced amount of cover available for the young fish caused by siltation, and predation by fish.

Of the factors, however, the most critical was likely flow rate. The clearing of the land increased the seasonality of the runoff such that flow rates during the spawning season were low. In recent years, studies at Shelter Valley Creek, a medium-sized (av. 27 cfs) north shore tributary, have revealed that the low flow rates in winter create anchor ice, and ice scouring of the gravel, both of which would be hazardous to incubating salmon eggs (unpublished data, Glenora Fisheries Station). The low summer flows along with lack of shade raised temperatures and probably reduced the carrying capacity of the streams.

The exact origins of the Lake Ontario rainbow trout are obscure, but it is clear that its successful establishment was recent. The first record of plantings were those in Caledonia Spring Creek and the Genesee River system in 1878 (Green, 1880). By 1884 these fish had moved downstream to the lower Genesee River and Lake Ontario (Annin, 1884). By 1920 they were established in most of the Finger Lakes, and thus had access to Lake Ontario. Plantings were undertaken on the Canadian side in 1929 and 1930 at Bronte Creek (Ontario Department of Game and Fisheries 1930, 1931). Since the species was not mentioned by Smith (1892) Dymond et al. (1929) or Greeley (1939) it apparently did not become acclimatized as a result of these plantings.

A series of introductions was undertaken at the Humber River over the years 193542 (Ontario Department of Game and Fisheries, various years), and then there were no plantings until 1959 with the exception of a single stocking at Bronte Creek in 1954. Beginning in 1959 plantings were more frequent and widespread. American workers (W. A. Pearce, personal communication) are unaware of any significant trout stocking programs in the streams of the U.S. side since 1940, and Greeley (1939), as noted above, did not describe any such efforts before that.

The first report of an established population with access to the lake appears to be that observed by McCrimmon (1954) in Duffin Creek in 1947. The trout were not judged abundant in that study. A weir was operated near the mouth of Bronte Creek in the springs of 1952, 1953, and 1954, to trap ascending sea lampreys. It was installed immediately after ice break-up, and operated until the end of May each year. Not only were rainbow trout runs not impeded (the trap type was not designed to capture salmonids) but no juveniles were encountered above or below the weir in the course of surveys to determine the presence of sea lamprey ammocoetes. In 1956 a regulation was instituted to extend the trout fishing season into November in downstream sections of the rivers fronting the central part of Lake Ontario. This was instituted by the province of Ontario to extend the trout fishing season into November in downstream sections of the rivers fronting the central part of Lake Ontario. This was done to give sportsmen a better chance to exploit the fall runs of trout, and probably accurately reflects the growth of public interest in the expanding stocks. By the 1960's many Canadian streams west of the central area (Bronte, Credit, Duffin) were also supporting important trout runs. Four or five apparently smaller rainbow trout runs have recently been observed on the U.S. side.

Obviously nothing can be inferred from these observations about the source of the Lake Ontario rainbow trout population. The colonists could have either immigrated from elsewhere in the Great Lakes or have come from the early plantings. It is clear that the rainbow trout appears to have become abundant after a long period during which no plantings were made. Since the niche now occupied by the rainbow trout is that which was vacated by the Atlantic salmon, the reasons for the long delay are of particular interest.

At present there are significant rainbow trout populations in many relatively unobstructed streams on the Canadian side. The adults ascend from the lake and spawn in April. As indicated above, there is typically a second ascent of adults in autumn and some of these fish over-winter in the streams. The young remain in the streams for 1 or 2 growing seasons before making the descent to the lake. The number of adults in the spawning run averages about 500 fish in Shelter Valley Creek. Production of juveniles in this stream approximates 11 g/m^2 and the annual smolt output appears to be in the order of 5,000 fish (Coleman, 1971).

The Shelter Valley Creek study began in 1964 with attempts to establish kokanee in Lake Ontario. One especially interesting observation has been that the lakeward migrating salmon fry are intensively preyed upon by juvenile rainbow trout resident in the stream. The output of salmon into the lake can only be increased by releasing the fry close to the lake, or by "saturating" the predators with very large stockings. If the kokanee were naturally colonizing, stream predation by trout would seriously impede population increase. Coleman (1971) has also found that sculpins prey on kokanee fry, but are less important predators than the trout. Sculpins might be a serious predator on eggs or fry however, and it is not inconceivable that they, or other stream fishes, could have been the cause of the slow development of the rainbow trout stocks.

The rainbow trout appears to have several advantages over the Atlantic salmon insofar as survival in the Lake Ontario watershed is concerned. The first is that as spring spawners, rainbow trout are free of the problems caused by low water which must have faced the salmon through the fall and winter. Secondly, the trout select, and probably have a better tolerance for warm water than do salmon (Javaid and Anderson, 1967). It seems likely, therefore, that the streams provide more suitable habitat for the trout than for salmon at present.

The third possible advantage and a possible explanation for the time lag, is the environmental one. Urbanization has caused further deterioration of streams in the regions of the cities, but many other streams have improved. As Huntsman (1944) pointed out, land clearance in the drainage area reached its maximum by the 1860's. Since that time there has been stabilization through the regression (or conversion to pasture) of formerly tilled lands, and through watershed improvement efforts of government agencies. Many dams have disappeared since the turn of the century so the total trout habitat has probably both improved and increased substantially.

Some 20 Canadian Lake Ontario tributary streams have trout populations, or the potential to carry trout, and the trout runs in a few of the larger streams are large enough to support significant sport fisheries. No accurate inventory of the whole trout population has been made, but the limited data from a few streams suggests that it probably does not exceed 20,000 or 30,000 sexually mature animals. The small numbers suggest that rainbow trout play an insignificant role in the economy of the lake probably mainly because of the limited productivity of the watershed.

The extent to which the Atlantic salmon may have been subject to the same productivity limitations deserves comment. The early accounts of the quantities of salmon speared on the spawning runs suggested rather larger numbers of adult salmon than the numbers of trout now observed. The salmon, moreover, were larger. Some streams evidently produced salmon which averaged 14 lb and specimens up to 40 lb were reported (Huntsman, 1944) whereas the average size of trout in the present day runs seldom exceeds 5 lb. The old reports were almost always recorded many years later, and it is typical for people to recall only the best of "the good old days." It is suggested therefore, that the fabled runs of the pioneer days may have consisted of concentrations in the order of tens of thousands of animals at most in any stream, because even if the streams were then more productive and had better late summer flow rates, the total salmonid production capacity has changed only in degree and not in order of magnitude.

The question addressed by this inquiry is what did the loss of the Lake Ontario salmon do to the biological economy of the lake? Obviously, virtually any change has significance, but in this case one immediately wonders if the lake trout benefited much by the extinction of the salmon.

THE WARM WATER FISH ASSOCIATION

As indicated earlier, the broad species array and sharp changes in abundance characterizing warm water fishes makes generalization of long-term trends very difficult. Moreover, there are few records concerning the yield to anglers, and the commercial catch statistics often do not recognize species differences (as for example between the sunfishes) which may be of great biological significance.

There are however, important events to be recorded that have been important to both the inshore and offshore communities: The introduction of carp; the dramatic changes in the walleye stock; the dominance of the white perch; and finally, the apparent encroachment of yellow perch into open lake waters. The meaning of these events in terms of species succession is difficult to assess, but their occurrence must be documented.

The data in Table 9 chronicle recent changes in the fish species captured at a single monitoring station in Hay Bay within the Bay of Quinte. The species chosen for inclusion in this table are those which were taken consistently in all years. The sampling was carried out with gillnets whose mesh sizes ranged from 1% inch through 4% inch (stretched measure) in ½ inch steps. Nets were set for a single night from once to several times per month during the open water season. The same location was used each time, and the "gang" of nets was placed in a continuous line perpendicular to the shore. The nets were rotated so that the section grading from 1%3 inch mesh started nearest the shore on one occasion, and the sections containing the meshes 3½-4½ started from shore at the next setting. Some shifts in relative abundance can be noted in Table 9 but possibly the greatest contribution of the series is that of showing the current depreciated condition of these waters and of the "normal" oscillations in abundance to be expected from year-to-year.

Walleye

This species has been of only modest importance to the commercial fishery over the years, and was almost entirely limited to the eastern end of the lake. Except for several years of high production in the early 1920's the catches were consistently low for many years after the walleye and blue pike catches were first recorded separately (1918). In the late 1940's the population underwent a spectacular increase in abundance (Fig. 8), and the stock supported an important sport fishery through the 1950 decade. The 1959 year class in the Bay of Quinte was the last of any consequence and the stock has declined steadily since this year class passed through the fisheries. The Bay of Quinte appears to have been the principal spawning area.

Information on the life history of the walleye in the Bay of Quinte summarized here is from Payne (1963) and Christie (1965). The Bay of

Table 9. Average numbers of fish of various species caught per lift of a standard experimental gillnet at Hay Bay in June through August, 1958-71.[1]

Year	1958	1959	1960	1961	1962	1963	1964	1965	1967	1968	1969	1970	1971
No. of lifts	20	10	10	6	6	7	4	3	6	4	4	3	6
Species													
Alewife	64.2	364.3	528.7	185.9	596.3	117.5	144.8	522.0	573.7	377.0	686.0	207.3	521.6
White sucker	25.8	48.1	19.6	19.2	26.1	23.5	5.7	0.7	7.7	9.0	1.0	8.0	10.3
carp	0	2.4	13.3	0.4	0.9	0.1	0.7	12.7	0	0.7	0	0	0.3
Bullhead	12.7	8.1	5.9	13.8	25.0	6.3	5.8		7.0	53.0	18.7	22.7	64.3
White perch	166.9	266.7	197.8	182.2	248.7	267.0	172.3	608.0	134.0	219.0	649.0	646.7	642.3
Yellow perch	157.8	172.9	225.5	197.3	253.6	230.8	135.5	(63.3)[2]	233.3	187.8	111.0	123.3	362.7
Walleye	17.2	43.1	25.7	47.8	29.8	19.0	16.3	2.7	0	20.2	11.2	0.7	1.0
Smallmouth bass	8.4	9.1	8.2	3.8	2.3	1.1	1.8		0	1.7	1.3	0	5.3
pumpkinseed	10.3	4.1	17.9	4.4	0.3	0.7	0.7	5.3	0	3.7	(46.8)[2]	1.3	10.3
Rock bass	14.7	4.1	13.4	3.2	5.6		0.3	2.0	0	1.0		0.7	4.0

1 A standard gillnet consisted of 100 yards each of 1½, 2, 2½, 3, 3½, 4, 4½ inch mesh (stretched measure). Values are the arithmetic averages for the three months. No data for 1966.

2 Exaggerated by one unusually heavy catch.

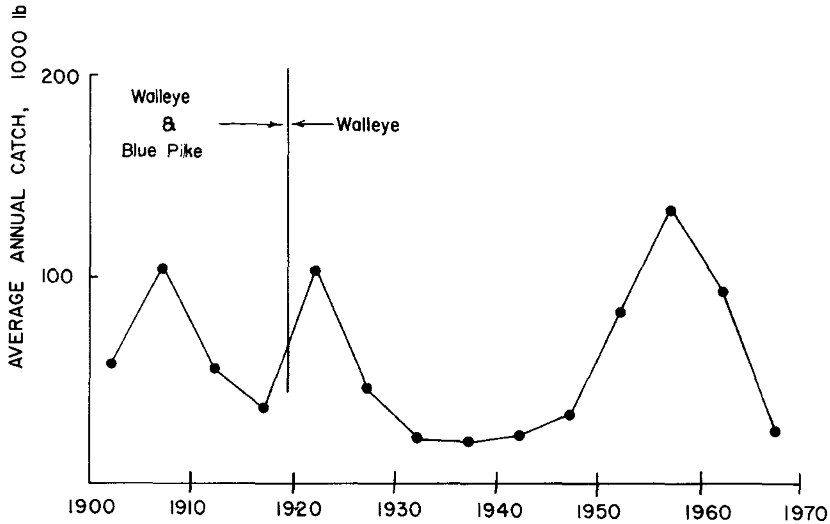

Fig. 8. Trends in the catch of walleye in Lake Ontario. Walleye and blue pike were combined in the catch statistics before 1920.

Quinte population consisted of a number of component spawning stocks, which used the major tributary streams and in some cases, shoals. The fish typically spent two or three years resident in the bay before beginning an annual summer migration into the Eastern Outlet Basin. The sports fishery depended mainly on the young resident fish and the commercial fishery caught the larger fish on their return to the bay in the autumn. The larger fish were scarcely exploited in summer, and tagging studies indicated that the rate of exploitation was rather low. The walleye, from age I onwards, subsisted primarily on alewives. Of 1,937 walleye stomachs examined in the years 1958 to 1962, 716 had contents, of which 99.3% consisted of fish remains. Of the 396 stomachs with identifiable fish, 93% contained alewife (Payne, 1963). The growth rate of the fish was very fast at all ages and the imported nutrient supplied by the alewife was thought to be an important factor in this rapid growth.

The last Bay of Quinte run to decline was that of the Trent River at the extreme inner end of the bay. The growth rate of juveniles here was slower than elsewhere in the bay and Payne (1963) felt that the young of this stock were probably confined to the partly discrete waters of the bay westwards from Belleville. This raises the possibility that this stock was under different and perhaps lighter stresses than those to which other Bay of Quinte stocks were subject.

The last two significant year classes of walleye were produced in 1957 and 1959. This coincides in a general way with the period of ascension of the white perch (Table 10) in the Bay of Quinte and suggests that white perch predation on walleye eggs or larvae may have contributed to the demise of the major stocks. The Trent River stock by contrast produced a significant 1962 year class, and in fact appears to be still producing, but at a reduced level. White perch had invaded the inner Bay of Quinte area by 1960 and were common in springtime trapnet catches by 1962. There is evidence, however (Glenora Fisheries Station, unpublished), that they are not as abundant here, as in the Hay Bay area even at present, and their effects on the walleye may not have been as severe as elsewhere in the bay. In West Lake which is near the Bay of Quinte, white perch do not achieve significant biomass and the walleye stock is abundant. The degree of impact on the walleye may thus be related to the degree of instability present in an area which the white perch invades.

The foregoing would be much more convincing if some explanation could be offered for the original increase in walleye abundance in the late 1940's (Fig. 8). The late 1940's were characterized by increased precipitation levels. Spring water temperatures were also higher then, and through the whole 1950 decade than during any other period between 1925 and 1971. Walleye production-also surged in the 1940's and 1950's in the other Great Lakes (Baldwin and Saalfeld, 1962) and the importance of periodically favourable climatic cycles cannot be overlooked. One is led to speculate, however, that in stable communities, walleye populations should have compensators to restrict their oscillations within certain limits. If so, one should look for a "releaser" to explain the postwar upsurge. No obvious change in the fish population of the Bay of Quinte can be isolated. It is tempting, on the other hand, to suggest that eutrophication increased the food supply for walleye juveniles, and, along with the improved climatic circumstances, greatly increased the survival of walleyes. Since other predators were reduced during the increase in stocks however, a response to the relaxation of "normal" predation pressure may also have contributed to the marked increase in walleye abundance.

The dependence of the juvenile walleye on food imports to the Bay of Quinte and the summer feeding of adults in the adjacent lake gave the fish a special position in the ecosystem. It can be argued therefore, that the presence or absence of a large walleye population might not be critical in maintaining species balance in the Bay of Quinte. In West Lake, by contrast, the invasion of the white perch did not upset the predator-prey balance, and here (there are very few alewives) the walleye is integrated in the sense that it depends primarily on that lake's production of prey species.

Blue pike and white bass

These species are discussed together here because they were the only fishes taken in significant quantities which were possibly not native to the lake.

The white bass was more prominent in the catches at the western end of Lake Ontario than to the eastward. The highest catch recorded for the western waters since 1952 (when the catches were first reported separately) was 64,206 lb in 1962. Catches in the Eastern Outlet Basin have exceeded those in the west each year in 1964-70; the record catch was 79,055 lb in 1965. This catch may have come from migrants with the same origin as those that supported the high catches in 1962-63 at the western end of the lake. The overall shift however, was probably due to the increased netting intensity directed towards white perch beginning in 1964 in the east, and the continued

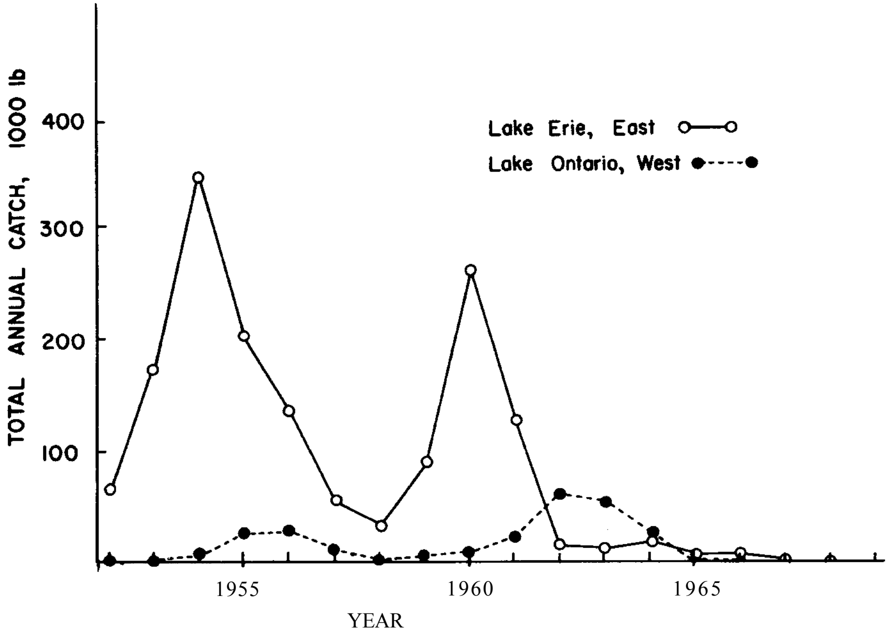

Fig. 9. Catches of white bass in eastern Lake Erie (data for New York and Pennsylvania are combined) and the Canadian waters of western Lake Ontario.

decline of the western fisheries. There has been no evidence of a spawning stock at the eastern end.

The time span is too short to permit a detailed comparison between the catch data from eastern Lake Erie and western Lake Ontario, but the available data (Fig. 9) suggest that the two catch pulses recorded for each lake may have had the same year class origin.

The blue pike data offer the same suggestion of identical year class origins of fish in eastern Lake Erie and western Lake Ontario based on a longer time span (Fig. 10). Here also, Eastern Outlet Basin catches were minor compared with those made in the western part of the lake, except in the 1950's, when intensified whitefish fishing probably increased exploitation and made the eastern catches somewhat larger relative to those in the western part of the lake. With this species also, catches in the spring spawning season were not known in the eastern waters.

The general similarity in frequency and amplitude of the blue pike catch peaks observed in the two lakes, and the collapse of both stocks within a few years of each other, provide evidence of a relationship between them. The Lake Ontario peaks generally preceded those in Lake Erie, as did the disappearance of the species. The single exception to the sequence was the absence of a Lake Ontario peak to coincide with the 1931 eastern Lake Erie (New York and Pennsylvania) peak.

One interpretation of this coincidence is that the Lake Ontario blue pike originated in Lake Erie. Stone (1948) however, found an appreciable dif-

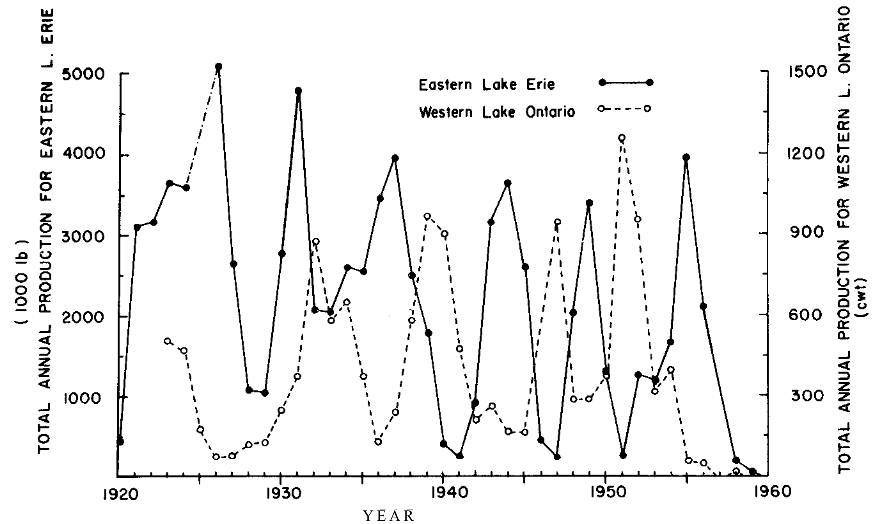

Fig. 10. Catches of blue pike in eastern Lake Erie (data for New York and Pennsylvania are combined) and the Canadian waters of western Lake Ontario.

ference in growth rate between the stocks of the two lakes. Lengths estimated for the end of the first growing season by back-calculation from scale measurements were about the same in both lakes-approximately 11 cm total length. Thereafter however, fish in Lake Ontario grew much faster than in Lake Erie. Lake Ontario fish attained 30 cm after three growing seasons, but the Lake Erie fish did not achieve this size until they had completed five growing seasons. The Lake Erie growth rates reported by Stone (1948) were similar to those reported by Parsons (1967). These data support the view that the catch peaks in the two lakes were produced by strong coincident year classes, but that the fish were recruited to the fishery about two years later in Lake Erie than in Lake Ontario.

Stone (1948) reported observing the capture of blue pike in spawning condition in the western end of Lake Ontario. The clustering of these fish in commercial gillnets suggested spawning activity to him. He held that the stocks represented discrete subspecies. The meristic differences he found were too small however, to permit the assignment of an individual specimen to one or the other subspecies. The morphometric comparisons Stone used were invalid, moreover, since the distinctions he found rested on absolute rather than relative dimensions. Replotting his data in relative terms eliminated all differences between populations of the two lakes, save for the larger eye size of the Lake Erie fish. Larger relative eye size has been found to be associated with slower growth rates among different populations of the same species Martin, 1949), so this difference alone may be of little taxonomic significance. It cannot be concluded, therefore, that the two stocks of blue pike were genetically discrete. The parallel development of year classes in adjacent waters as a result of climatic events is a well-known phenomenon, but the almost simultaneous collapse of populations of blue pike in Lakes Ontario and

Erie is hard to explain on any basis other than that most or all of the fish originated in Lake Erie.

American eel

The catch data for American eel reveal little about trends in abundance. The catch has to a large extent been confined to the area eastward from Brighton in all years, and the periods of higher catch there-1924 to 1927, and 1958 to 1970-reflect improved saleability of the eels or the relatively lower availability of alternative commercial species. Since 1958 the lakewide annual catch has never fallen below 150,000 lb and in 1964 the all-time high catch of 279,000 lb was recorded. Since about 1963, the reduced eel catches in Europe have created a demand for the North American product, and although the Lake Ontario (yellow) eels are not extensively exported to Europe, they enjoyed a sharply increased demand during the middle and late 1960's. The improved prices have made the eel one of the few remaining species supporting the commercial fishery. The fishery was traditionally pursued by means of hoopnets and setlines, but trapnets are now also used.

The increased catch of eels has now been sustained for seven years (1964-71). The St. Lawrence River has been obstructed by the Seaway since 1958. Elvers reach Lake Ontario between three and five years of age, and begin the descent to the sea between 10 and 15 years of age (Hurley, 1972). In the lake the distribution is localized and the fish appear to have a well-developed home range tendency. Any effects of reduced recruitment owing to the Seaway dams should have been apparent beginning about 1966, as the first post-impoundment recruits matured, but seemingly this has not occurred. It is difficult to imagine how the elver immigration could have remained unaffected by this obstruction. Hurley (1973) reported that the catch levels have been sustained by increasing fishing effort. He found, further, that the intensification of the fishery has resulted in a significant reduction in the relative abundance of large eels, but that the relative abundance of smaller eels has increased since 1964, when catch sampling was started. He believed that the fishery was sacrificing considerable poundage by not permitting the eels to fatten, but his analysis revealed no imminent threat to the stock. Clearly, the eel stock must have previously represented a very large biomass which was not heavily exploited. It is possible that fewer elvers are immigrating at present, but that more of them survive.

White perch

The invasion of Lake Ontario by this species was chronicled by Scott and Christie (1963). They believed that the fish penetrated from the Atlantic watershed via the Erie Barge Canal system, around 1950. I identified the first specimen from the Bay of Quinte, in 1952. In 1953, 11 specimens were taken by seining a few miles to the east of Toronto. Specimens were regularly taken in test netting in the Bay of Quinte for the first time in 1955, but they were not yet plentiful. A rapid build-up in the population then followed and by 1960, the Bay of Quinte stock was dense. After 1960 the stock oscillated widely but showed no pronounced tend until 1969 (Table 9). Trapnet

Table 10. Average number of white perch caught per trapnet-night in the Bay of Quinte, 1955-67.

Year	Hay Bay April-May	Hay Bay Oct.-Dec.	Indian Point May
1955		1.2	0
1956		17.2	8.3
1957		6.1	2.8
1958	34.1	17.2	0.3
1959	77.8	125.3	
1960		10.8	
1961	262.1	43.1	
1962	159.0	21.5	
1963	166.5	32.1	
1964	332.0	16.1	
1965		15.8	
1966		13.3	
1967		13.7	

catches further illustrate the history of the species (Table 10). A few were seen in the fall of 1955 (none in 1954) at Hay Bay, but continuous trapnetting from May through September at Indian Point with a large net produced only 17 white perch (none in May, the only records included in Table 10). White perch became common at Hay Bay, after 1955. Although the spring trapnetting at Hay Bay spanned fewer years than the fall netting, the records indicate that the sharpest increase was in 1960 or 1961. The spring catches averaged eight times higher than the fall catches in Hay Bay in 196 l-64.

The fish were first captured in large quantities by commercial fishermen in the winter of 1964-65. This fishery is mainly pursued in a small area at the mouth of the Bay of Quinte by gillnetting under the ice. It has continued each winter to the present and additional small mesh gillnetting has been carried on in the Pastern Outlet Basin at other times in recent years. The annual catch exceeded 500,000 lb in 1965, and the landings have been appreciable in all years since 1964 (Appendix Table 11). Catches have been much larger in the Bay of Quinte than in Lake Ontario proper in all years (Fig. 11). Further, the recent increases in the bay have not been paralleled in the lake.

In the Bay of Quinte the white perch growth rate became progressively slower in the years from 1958 to 1966 (Sheri, 1968). Hurley (1973b) has shown that growth is strongly density-dependent among all but young-of-the-year white perch, and that the growth rate reductions have not matched the gains in population density. Biomass has thus continued to increase.

The relative abundance of white sucker, walleye, and smallmouth bass decreased conspicuously beginning in the early 1960's (Table 9). The relationships between these species and white perch are not understood. The invasion by the white perch was unquestionably important to the other species, and several of them may have been directly or indirectly harmed. Many species of less frequent occurrence were omitted from Table 9 and it is significant that all of the major predators except walleye were scarce from the beginning of this observational series. It is suggested therefore, that the low capture

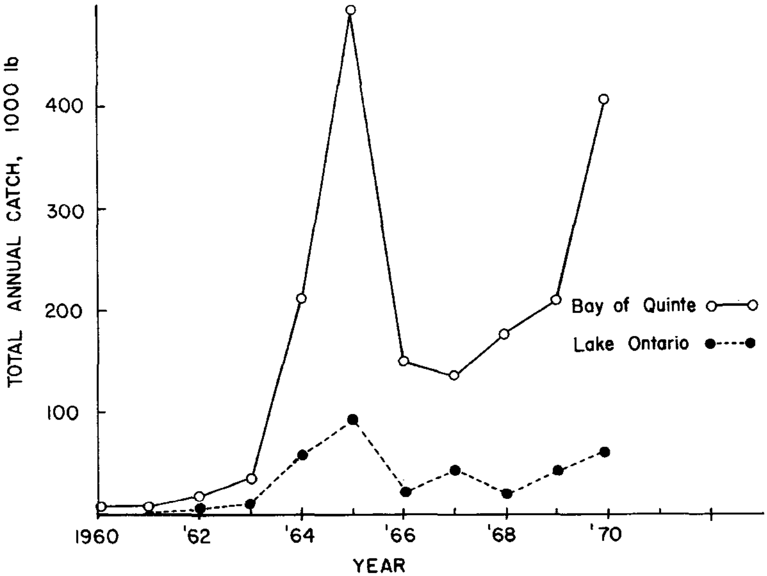

Fig. 11. Trends in the commercial catch of white perch in the Bay of Quinte and in all other Canadian waters of Lake Ontario.

frequencies of such fish as northern pike, bowfin, muskellunge, largemouth bass, and longnose gar were caused by events which predated the explosion of the white perch population. On the other hand, their absence may well have had significant bearing on the success of the white perch invasion.

During the past several years a comparative fish population and limnological survey has been under way at Hay Bay and Baker Island (near Trenton) representing the middle and inner portions of the Bay of Quinte, and at West Lake, a partially blocked embayment of Lake Ontario, on the Prince Edward County peninsula. West Lake is subject to the same kinds of local agricultural pollution as the Bay of Quinte but is not subject to the heavy nutrient loading contributed by the Bay of Quinte municipalities, or the associated industrial pollution. Hurley (1970) however, has pointed out that the dissolved nutrient levels in the two waters have been similar at any point in time. Algal densities are lower in West Lake than at the head of the Bay of Quinte and West Lake also has much denser growths of macrophytes. The inner end of the bay, in turn, has lower levels of algal density (McCombie, 1967) than the middle bay areas. The fish populations are strikingly different, the most prominent difference being that piscivores are abundant in West Lake, uncommon in the inner bay (Baker Island), and scarce at Hay Bay. West Lake has virtually no alewife population, even though these fish have access, but has large populations of black crappies and bluegills. These centrarchids are scarce at Baker Island-though formerly plentiful there. They are virtually absent from the Hay Bay experimental trapnet and gillnet catches and from catches of the commercial hoopnet fishery of that area (J. Buchanan, Picton, personal communication). White perch are abundant in all three areas, but the West Lake population consists of large, fast growing fish that appear to be somewhat less abundant than at the other two study areas. Pumpkinseeds and rock bass are about equally abundant in trapnet catches in all three areas at present. These two species (disregarding sampling anomalies resulting from lower sampling frequency in the more recent years) have both declined substantially since gillnet sampling began (Table 9) at Hay Bay. An informant (F. Greatrix, Picton) recalls deliberately fishing for large rock bass 30 to 40 years ago in West Lake and suggests they are no longer available. Yellow perch have been very scarce in the recent West Lake catches compared to the other areas, although they are still taken by anglers fishing through the ice in winter. It is not known if this also represents a change from earlier years.

The foregoing description may provide support for the hypothesis advanced earlier, that penetration of white perch met with greater resistance in West Lake than elsewhere because of the density of piscivores. It caused no major dislocation of the West Lake fishery (or loss of game fish) and stabilized in a niche which permits fast growth and the achievement of large size. In the Bay of Quinte, by contrast, the white perch entered a system which lacked abundant piscivores and prospered, perhaps at the expense of the rock bass and pumpkinseed, but in the absence of piscivores stunted populations developed.

The Bay of Quinte fish stocks have shown no signs of stabilization yet. The white perch is now an established member of the community and it may still be increasing in abundance. If so, this may suggest that the continuing stresses of eutrophication may be favouring this evidently adaptable species and helping it to gain further advantage over native species.

Yellow perch

Until recently the yellow perch was a secondary, though never insignificant, component of the commercial catch of Lake Ontario. Between 1913 and 1960 the combined U.S. and Canadian catch ranged from the low of 60,000 lb in 1959 to the peak of 244,000 lb taken in 1942. During this period the principal factors involved in the variations appear to have been the marketability of the perch and the availability of higher priced fish. The catch was taken mainly by small-mesh gillnets and typically during periods when offshore fishing was poor. For example, the two major depressions in the perch catch were in the first half of the 1920 decade and the second half of the 1950 decade. During the first period whitefish and trout were very abundant, and in the second, the whitefish fishery prospered. Conversely peak perch catches were made at the turn of the century and in the 1960's when high-priced fish were scarce.

The yellow perch catch from the western and central areas of Lake Ontario was never large. In these areas the highest combined Canadian catch recorded before 1960 was 24,000 lb in 1933, as compared with the high of 156,000 lb in 1942 in the Eastern Outlet Basin and Bay of Quinte. The long-term catch averages within the Bay of Quinte generally paralleled those made elsewhere in the lake, but three distinct phases can be recognized in Fig. 12 for the years after 1905. First, in the 1905-24 period, the Bay of Quinte catches ranged from 60-65% of the annual lake total. From 1925 to 1959 the relative catch in the bay dropped in a few years to between 36 and 38% of

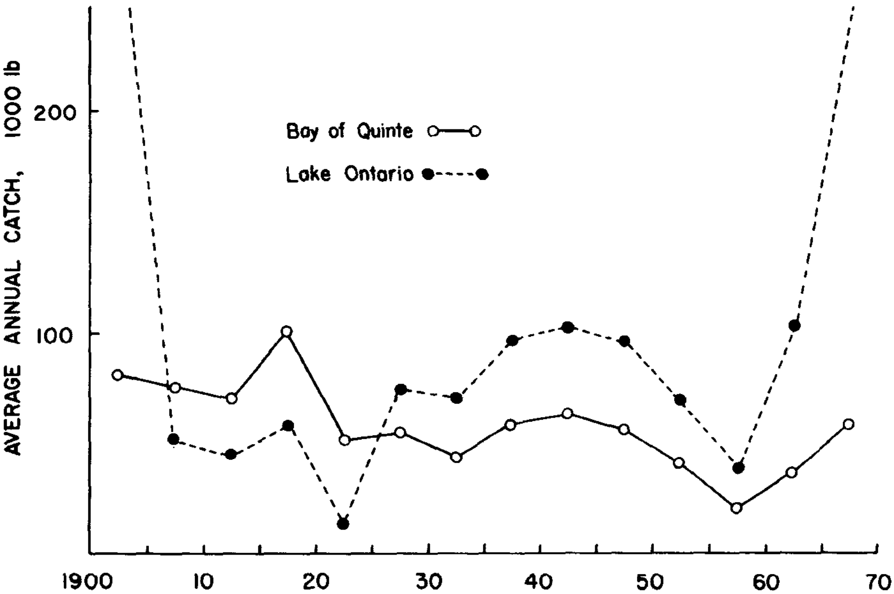

Fig. 12. Trends in the catch of yellow perch in the Bay of Quinte and in other waters of Lake Ontario.

the lake total, on the average. Finally, in 1960-64, the bay catch contributed 25% of the lake total and then 19% in the 1965-69 period. The first shift, in the 1925-29 period resulted from intensification of yellow perch fishing effort by the eastern fisheries outside the Bay of Quinte, in response to reduction in the abundance of premium species. Loss of the whitefish stocks in the 1960's was also the main factor involved in the increased perch fishing effort outside the Bay of Quinte. The development of the white perch gillnet fishery in the mid-1960's acted as a catalyst to increase the intensity of yellow perch fishing (2¾-3¼ inch mesh gillnets are used for both). The increase in yield from the Bay of Quinte since the late 1950's (Fig. 12) can be contrasted with the experimental fishing data in Table 9. The catch per unit effort values are highly variable, but they exhibit no real trend, while the commercial catch levels increased three-fold in the Bay of Quinte in the same period because of intensified fishing effort.

In contrast with the Bay of Quinte, it is felt that the catch increase in the Eastern Outlet Basin in recent years represents a real increase in yellow perch abundance. In 1970, for example, the Bay of Quinte catches reached 150,704 lb but the Eastern Outlet Basin yield totalled 824,539 lb-nearly half of the total catch of all species in the lake. The difference between the catches in the first and second halves of the 1960 decade (Fig. 12) for the lake proper, is seven-fold, and it is known that the corresponding change in fishing effort is not greater than that which occurred in the Bay of Quinte. It is also the view of the commercial fishermen that yellow perch are now more abundant in the Eastern Outlet Basin. They report catching yellow perch in waters not previously known to be frequented by the fish, and finding spawning concentrations along extensive areas of shoreline not previously used for spawning.

Centrarchids

The stocks of smallmouth bass of the shoals and islands of the Eastern Outlet Basin were mentioned in the reports of various fishery overseers and others from time to time from the 1860's to 1920. They appear to have remained stable and abundant from the 1950's when they were studied by Stone, Pasko, and Roecker (1954) to the present, with no major changes evident.

The stocks of smallmouth bass in the Bay of Quinte have not fared so well. The appreciable fishery these stocks have been known to support in the past has seriously declined in late years. No data are available for the years before 1958, but the course of the decline has been traced since then (Table 9).

All three summer-spawning centrarchids which were formerly common in the middle and lower Bay of Quinte-smallmouth bass, pumpkinseed, and rock bass-have declined in the same period. Loss of the smallmouth bass might have been thought attributable to water quality depreciation, but the parallel decline of the other, ostensively more tolerant species, arouses suspicion. The timing of the declines is generally coincident with the ascendancy of the white perch, but confirmation of a causal relationship must await analysis of the statistics of year class strength for all four species.

Large piscivores

As noted elsewhere, the most conspicuous feature of the Bay of Quinte fish community at present is the lack of large piscivorous fish. Northern pike evidently declined after the early 1950's. According to local tourist outfitters, a resurgence is currently in progress in the Big Island area (near Belleville), but stock levels are still low compared with those seen before World War II.

The commercial catch statistics for northern pike (Appendix Table 13) must be interpreted with care. On the Canadian side, pike may still be marketed commercially, but over the years regulations have gradually confined them more to the sporting catch. For many years the hoopnet fishermen of the Bay of Quinte were discouraged from keeping and marketing the pike catch. Northern pike captured in the fall gillnetting were marketed until 1966, when large-mesh gillnet fishing was discontinued. The recent reduction (1966-70) probably resulted from this restriction.

The distribution of largemouth bass was apparently always rather localized in the bay, but local opinion is that the abundance is not as great as in earlier times.

The muskellunge are also reported to have decreased in abundance from earlier times. During the past 15 years, however, the fishery has followed a stable pattern. For about three weeks-typically the last two weeks of August and the first week of September of each year-anglers capture muskellunge in the Glenora area of the bay. The productive area amounts to perhaps two miles of shoreline, and the catch consists of numbers in the order of 6 to 20 fish per year. The fish are large, weighing from 1545 lb. Since no juveniles have been encountered in 14 years of fairly intensive test netting, these muskellunge may immigrate from other waters each year.

Carp

The exact origin of the carp in Lake Ontario is not known. McCrimmon (1968) recorded stockings in the watershed in the late 1880's or early 1890's during the period of great interest in the species, when it was stocked in many other areas. McCrimmon also noted that carp were being captured in considerable numbers in the Grand River, a tributary to Lake Erie, by 1893. Smith (1892) recorded the presence of the fish in Lake Ontario in 1891, and it probably was not in the lake earlier than 1880.

Smith (1892) made no reference to the abundance of the species in 1891, but the carp was segregated from other coarse fish in the Canadian commercial fishery statistics in 1908-normally a sign that a species has achieved importance to the fishery. The total yield recorded in that year was 21,000 lb for Lake Ontario (Baldwin and Saalfeld, 1962).

Market considerations have figured importantly in the oscillations of the catch of this species, and no statement of trend since its introduction can be made. The species has achieved considerable significance in the total catch, however. The New York contribution to the catch has typically been small, but in 1939 and 1940 the values reported exceeded those reported for the. Canadian side, and in fact, made 1939 the all-time record year, with a catch in excess of one million pounds. The trend has been towards increased catches; the annual total has scarcely dropped below 300,000 lb per year since 1952.

The carp catches at the western end of the lake have been larger in relation to the lake total than has been the case with most other species. This relation is no doubt a reflection of the scarcity of other fish in the western area, but the presence there of enough carp to support a fishery suggests that the habitat is suitable.

The demand for carp has always lagged behind the supply, because the market is a rather localized and specialized one. This has placed constraints on the fishery which seem almost to guarantee the prosperity of the species. For years, for example, it has been the convention to accept only carp which weigh 8 lb or more, headless and dressed for market. In recent years it has also been the practice to accept only female carp, apparently because the flesh of the males is darker in colour after smoking. According to the data of McCrimmon (1968) the restriction of the catch to large fish should ensure that the carp have many years of sexual maturity before entering the fishery, and further suggests that the catch represents a rather small part of the total carp biomass.

No effects on other species are immediately obvious from the catch records, perhaps because the introduction took place so long ago. As the largest of the species that feed on benthic organisms, however, the carp must have had an important effect on the fish community during the period of its integration.

Bullheads and catfish

Bullheads and channel catfish were combined in the reports of the fishery until 1952. At least for the recent period, bullheads constituted the bulk of the catch of these two species (Appendix Tables 15 and 16). Catfish may have been relatively more important in some past periods but the general impression is that they have always represented a small fraction of the poundage. Bullheads have been the principal catch of the hoopnet fisheries of Presqu'ile Bay (Brighton), the Bay of Quinte, the Amherst Island-Wolfe Island area, and Chaumont Bay (in the U.S.). Channel catfish are taken by setline, principally in the Bay of Quinte.

The intensity of the hoopnet fishery seems to vary according to the abundance of bullheads, but the bullhead catch is probably not influenced much by market vagaries or the availability of more valuable species which are caught by other gears. The fisheries are licensed to fish specific areas, and this tends to stabilize the effort and minimize competition between units of gear. The catch is therefore thought to be a fairly reliable indicator of the relative abundance of the fish.

The catches of bullheads have always constituted a significant fraction of the total yield from the lake, and they are especially impressive if compared with total catch in limited areas like the Bay of Quinte. The totals for the lake have normally varied between 100,000 and 500,000 lb per year, with a slow oscillation. The most striking abundance peak occurred in 1948-57, a period during which no single year's catch was less than 350,000 lb. The catches built steadily towards this productive period from 1942, and then declined equally slowly afterwards. The lack of sharp fluctuations in the catches is in contrast with many other warm water fishes. Since virtually nothing is known about the biology of the species in the Bay of Quinte, I cannot even speculate about the factors which may be involved.

Substantial increases in bullhead catches during the past several years are shown by both the commercial statistics (Appendix Table 16) and the experimental fishing data (Table 9).

Lake sturgeon

This species is included here to complete the historical perspective. The stocks had declined to commercially insignificant levels by the turn of the century. A small setline fishery for sturgeon persisted into the early 1960's in the upper St. Lawrence River and the small size of many of the fish taken suggested that some reproduction was still taking place. This river may have been the source for many of the sturgeon taken occasionally in the lake proper over the years following the decline of the fishery.

The sturgeon is often cited as the exemplar victim of overfishing. The details of its early exploitation and wastage as a coarse fish have been provided by Harkness and Dymond (1961). The basis of the conviction that overfishing was the cause of the decline was that the quality of the waters had scarcely changed at the time of its demise and no great changes in the biota which could have influenced the sturgeon were known. Since the fish were, moreover, very long-lived and apparently quite vulnerable to gillnets, this contention seems well supported. The damming of rivers and their pollution with sawdust and other wastes, however, may well have had some influence.

The sturgeon biomass was probably large in the early part of the last century. Similarities in diet suggests that the carp may have filled the niche vacated by the sturgeon.

DISCUSSION

The chronology of major successional events outlined in the foregoing is as follows:

1830-40	Collapse of Atlantic salmon stocks.
1860's	Reduction of deepwater ciscoes; colonization by the alewife.
1890-1910	Whitefish, lake trout, and burbot scarce; deepwater ciscoes abundant.
1920's	Whitefish, lake trout, burbot, and sea lamprey abundant; deep-water ciscoes scarce.
1930'S	Lake trout, burbot, whitefish, and herring decline; deepwater ciscoes increase.
1940's	Lake trout, burbot, herring, and deepwater ciscoes collapse; smelt rise to dominance.
1950's	White bass, blue pike, and deepwater sculpin disappear; walleye dominant ; whitefish abundant.
1960's	White perch reach dominance; walleyes decline; Bay of Quinte whitefish collapse; yellow perch abundant in open Lake Ontario.

It is not likely that the changes which took place before 1900 among the open lake fish stocks were much affected by environmental deterioration. Weather cycles could have influenced the abundance of those species whose members had been seriously reduced at or before the turn of the century, but the most significant factor must have been overfishing. This was a view expressed by many authors who attempted to diagnose the ills of the commercial fishery at the beginning of this century. More recent authors, however, have been skeptical of this judgment, and have pointed out that the early fishery was capable of generating only a fraction of modern fishing intensity. On the strength of the present appraisal, however, I believe the effect of the fishery must have in fact been substantial. The collapses of whitefish, lake herring, and sturgeon stocks in the last century; reductions in the whitefish and piscivore stocks at the turn of the century; and progressive loss of the several deepwater cisco species; all seem to support this conclusion.

The seine fisheries of the last century were probably especially effective in eliminating the lake herring and whitefish because of the discreteness of the stocks of these species, and the habit of spawning close to the shore. In most other cases however, the collapse of species populations was probably more often an indirect result of fishing. The deepwater ciscoes, for example, were thought to be very vulnerable to fishing pressure, but the elimination of the various species could have been caused by loss of competitive position, or by shifts in the predator-prey ratios induced by fishing.

The general increase in the levels of abundance of whitefish, lake herring, and the piscivores in the 1920's suggests some common improvement in environmental conditions. The subsequent declines, however, were attributed to the combined effects of fishing and the sea lamprey. Loss of the predators seemed at first to permit the increase of deepwater ciscoes, but later may have produced several undesirable effects. The trout and burbot for example, may have acted to keep the smelt suppressed for some years. Further, the proliferation of the open lake forage species may have placed new and severe stresses on the stocks of deepwater ciscoes and deepwater sculpins. There are many deficiencies in this explanation of the sequence of change in the principal species, but the most obvious one lies with the last statement. The loss of the deepwater sculpin is an especially troubling consideration, and the collapse of the bloaters had no obvious ecological connection with the increase in smelt abundance. The open waters of the lake, though now appreciably richer than in the 1800's, are still mesotrophic, and dissolved oxygen levels or turbidity in the hypolimnion have not yet become problems (Allen, 1969). The benthic fauna, moreover, appears to be profuse and qualitatively and quantitatively similar to that in Lake Michigan (Hiltunen, 1969). In short, the abyss of Lake Ontario still appears to be suitable fish habitat. Consequently, if environmental deterioration is responsible for the loss of the deepwater fishes, then it must have involved water quality characteristics that have not yet been identified.

Considering that the alewife probably represents the largest species biomass now in the lake, it is surprising that no major impact on other species can be imputed to it. I believe, however, that the alewife may have established its niche at the expense of some species as yet undetermined (the lake emerald shiner, for instance, a species never known to be abundant in the lake) or perhaps the lake herring.

The upsurge in abundance of premium fish in the 1920's was seen as evidence that the deepwater association had sufficient resilience to protect it against permanent damage. Fishing intensity increased in the later years, and was probably a progressively more important factor as the base for the fishery narrowed and the fishermen fished to progressively lower levels of catch per unit effort, in the absence of alternative species. In the same way, I believe the effect of the lamprey also increased because of the reduction in the numbers of prey species available and also because of the reductions in abundance within species.

The role of the smelt in recent species succession may not be fully appreciated. These fish constitute a biomass so large that it seems unlikely to have been attained without damage to other species. The smelt feeds on the larger invertebrates, preys on small fish, and is found in association with many species.

The suggested effects of the dominance of white perch in the Bay of Quinte ecosystem may also represent a minimum possible impact. The difference suggested by the comparison of the populations in West Lake and the Bay of Quinte is that the fish arrived in the bay in a period of low density of predators other than the walleye. Walleyes were not known to eat white perch but northern pike did. In West Lake therefore, white perch appear to have been able to become established in the face of abundant competitors, but may have been prevented from gaining undue advantage by those predators present.

The proliferation of yellow perch in Lake Ontario may reflect an appreciable habitat change. Food for the perch must be at a very high level since so few other fish are present in the Eastern Outlet Basin. That the white perch are not apparently also increasing in this area suggests a difference in habitat requirements. This might be a fruitful subject for research.

The evidence of environmental deterioration is, as pointed out earlier, far more marked in the inshore areas than offshore. In the Bay of Quinte, fishermen began to complain of fouling of the gillnets by algal slimes in the early 1950's. The oxygen depletion which is often associated with such dense algal growth was not detected until 1970 (Hurley, 1971) but the habitat could have become inhospitable for many species of fish before this because of other factors associated with the algae (like turbidity). Localized deoxygenation developing over the winter could have occurred years before the major summer oxygen depletion was found, and if so, smothering of the eggs of whitefish could have been an additional source of mortality contributing to the disappearance of the stock. In any event, it seems unlikely that either lake herring or whitefish could reproduce successfully in present conditions.

The effects of eutrophication may also lead to stress which reduces the ability of a fish species to compete. This appears a special threat in productive waters like the Bay of Quinte where many species share common food resources. The highly specialized diet of some, like the smallmouth bass (crayfish) may make them especially vulnerable. These are considerations which are now under study in the Bay of Quinte, but at present the real effect of eutrophication in the events discussed here is not known. It is felt, however, that although localized areas of pollution near large industrial centres may have had impoverished fish faunas for many years, most of the more obvious deteriorative changes arising from cultural eutrophication have been evident only for the past 20 years. Subtle but very important changes may have occurred earlier, but they-like the identity of the possible substance or substances which may now be making the deep waters unsuitable for fish-are not known.

In the primeval condition it appears that the lake trout was a key vector in the transport of material and energy through the lake. To judge by its known food habits (Dymond, 1928), its distribution ranged from the great depths to the comparative shallows of the spawning grounds. Even in summer it was found in water as shallow as 20 fathoms. The diet of deepwater sculpins and deepwater ciscoes effected vertical circulation of the productivity of the offshore photic zone and the migrations of the trout and burbot added a horizontal circulation vector. This pathway is no longer open since the disappearance of the lake trout and the deepwater forms. On the basis of present knowledge, therefore, it is difficult to understand how matter and energy are circulated in the lake. Only the alewife occupies the extreme depths and only in winter when it must make only maintenance level demands on the system. The slimy sculpins extend to considerable depth, and probably exploit the abundant macrobenthos, but no species is foraging on the sculpins offshore. To judge by Wells' (1968) data, moreover, the sculpins do not move en masse over broad horizontal distances. Therefore, a link appears to be missing in the food chain. The need for intensive investigations on the present fish fauna and its food relationships will have become very obvious throughout this paper, but this apparent discontinuity in the food chain especially emphasizes the need for investigation of the pelagic fauna of the open lake.

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APPENDIX

Appendix Table 1

Total annual commercial production (thousands of pounds) of fish from Lake Ontario, 1900-69, averaged by S-year periods.

Period[1]	Canada				U.S.	Lakewide Total
	Western	Central	Eastern	Bay of Quinte		
1900-04	1538.8	248.9	878.7	447.8	1073.0	4187.4
1905-09	1274.3	31.1	739.7	863.4	817.0	3725.5
1910-14	962.6	24.3	1469.3	1061.9	252.0	3770.1
1915-19	1239.4	196.6	2216.4	1750.0	472.8	5875.2
1920-24	623.8	289.2	2328.7	1617.5	1008.6	5867.8
1925-29	501.9	137.0	2016.5	1247.6	746.8	4649.8
1930-34	455.9	103.3	1370.7	862.6	577.8	3370.3
1935-39	815.3	240.8	1165.6	943.4	827.0	3992.1
194044	765.0	239.6	1018.6	685.4	615.2	3323.8
1945-49	255.2	116.1	908.5	743.2	415.4	2438.4
1950-54	259.5	49.1	932.8	833.8	372.4	2447.6
1955-59	155.3	42.4	900.6	928.0	221.6	2247.9
1960-64	96.2	53.4	847.0	754.1	221.8	1972.5
196569	45.3	40.3	824.2	849.0	270.0	2028.8

1 Averages for the periods from 1900-04 to 1920-24 in the Canadian statistics and from 1900-04 to 1910-14 and 196569 in the U.S. statistics, are for less than 5 years.

Appendix Table 2

Total amounts of gillnet (thousands of yards) licensed for use in Canadian waters of Lake Ontario, averaged by 5-year periods.

Period1	Area		
	Western	Central	Eastern
1900-04	263.7	73.8	38.0
1905-09	320.0	55.2	133.1
1910-14	243.0	54.0	391.8
1915-19	320.1	147.3	551.6
1920-24	285.6	304.2	1026.3
1925-29	259.0	189.4	958.7
1930-34	238.4	114.6	650.3
1935-39	314.1	200.5	697.1
1940-44	326.0	265.6	651.6
1945-49	179.5	238.0	686.0
1950-51	127.1	189.8	522.4

1 Averages for the periods from 1900-04 to 1920-24 are for less than 5 years.

Appendix Table 3

Commercial production (lb) of lake trout in Canadian waters of Lake Ontario, 1900-70, averaged by 5-year periods.

	Area				
Period[1]	Western	Central	Eastern	Bay of Quinte	Total
1900-04	25,210	10,288	38,790	nil	74,288
1905-09	56,181	2,229	82,817	1,010	142,237
1910-14	115,338	1,860	485,028	10,283	612,509
1915-19	60,570	10,350	398,779	393	470,092
1920-24	180,341	21,856	512,190	25,509	739,896
1925-29	102,482	9,924	740,324	22,328	875,058
1930-34	28,096	5,019	293,382	10,097	336,594
1935-39	59,594	99.5	181,295	3,039	247,962
1940-44	22,907	35	90,776	311	114,029
1945-49	9,062	15	55,691	124	64,892
1950-54	6,202	4	15,230	288	21,720
1955-59	279		1,523	13	1,819
1960-64	23	4	1,225	6	1,258
196569	3	nil	nil	nil	3

1 Averages for the periods from 1900-04 to 1920-24 are for less than 5 years. Northumberland was included in the central section 1900-04.

Appendix Table 4

Commercial production (lb) of lake herring and ciscoes in Canadian waters of Lake Ontario, 1900-70, averaged by 5-year periods.

	Area				
Period1	Western	Central	Eastern	Bay of Quinte	Total
1900-04	1,371,031	85,386	137,093	6,500	1,600,010
1905-09	984,020	20,919	30,566	129,817	1,165,322
1910-14	494,655	18,742	175,335	167,130	855,862
1915-19	693,825	31,241	444,113	767,106	1,939,285
1920-24	96,167	3.158	200,236	275,188	574,749
1925-29	218,642	48,659	199,012	254,381	720,694
1930-34	261,179	80,916	526,755	206,602	1,075,452
1935-39	485,623	202,101	371,149	265,490	1,324,363
1940-44	522,603	231,395	391,249	151,412	1,296,659
1945-49	89,459	110,670	261,520	48,584	510,233
1950-54	27,893	38,799	29,675	22,488	118,855
1955-59	780	145	30,510	18,966	50,401
196064	94	902	33,113	12,605	46,714
196569	4	-	35,915	3,766	39,685

1 Averages for the periods from 1900-04 to 1920-24 are for less than 5 years. Northumberland was included in the central section 1900-04.

Appendix Table 5

Commercial production (lb) of whitefish in Canadian waters of Lake Ontario, 1900-70, averaged by S-year periods.

	Area				
Period1	Western	Central	Eastern	Bay of Quinte	Total
1900-04	30,048	5,787	63,275	35,750	134,860
1900-09	81,264	3,588	332,826	152,166	569,844
1910-14	113,360	9,596	284,864	226,189	634,009
1915-19	235,499	150,453	753,325	231,557	1,370,834
1920-24	235,722	242,052	926,023	692,467	2,096,264
1925-29	129,264	70,288	786,578	446,585	1,432,715
1930-34	48,454	18,788	259,148	153,995	480,385
1935-39	69,114	30,434	290,920	220,768	611,236
1940-44	31,257	5,570	186,351	186,225	409,403
1945-49	17,010	3,945	155,562	137,016	313,533
1950-54	11,178	788	207,240	111,906	331,112
1955-59	2,946	171	250,628	121,027	374,772
196064	361	8	299,309	40,748	340,419
1965-69	16		62,432	11,527	73,983

1 Averages for the periods from 1900-04 to 1920-24 are for less than 5 years. Northumberland was included in the central section 1900-04.

Appendix Table 6

Annual commercial production (lb) of smelt in Canadian waters of Lake Ontario, 1952-70.

	Area				
Year	Western	Central	Eastern	Bay of Quinte	Total
1952	28,068	11,417	166,761	18,780	225,026
1953	35,342	13,707	211,927	21,507	282,483
1954	45,997	18,761	184,020	15,823	264,601
1955	48,085	24,784	157,517	8,069	238,455
1956	27,912	34,293	202,148	4,668	269,021
1957	28,544	26,094	121,005	1,909	177,552
1958	19,835	49,356	186,502	3,007	258,700
1959	27,393	61,569	135,076	6,159	230,197
1960	7,706	32,293	94,776	387	135,162
1961	10,059	31,781	157,786	334	199,960
1962	17,509	73,034	119,387	83	210,013
1963	12,041	61,640	96,786	59	170,526
1964	10,008	21,444	94,165	2,440	128,057
1965	84,438	43,601	72,917	651	201,607
1966	3,148	14,000	123,562	425	141,135
1967	1,377	50,628	102,074	16	154,995
1968	865	72,775	93,949	226	167,815
1969	872	14,470	127,545	471	143,358
1970	6,811	5,390	152,295	494	164,990

Appendix Table 7

Commercial production (lb) of walleye in Canadian waters of Lake Ontario, 1920-70, averaged by S-year periods.

			Area		
Period1	Western	Central	Eastern	Bay of Quinte	Total
1920-24	423	-	13,872	89,418	103,713
1925-29	290	-	7,972	39,428	47,690
1930-34	716	-	2,548	20,291	23,555
1935-39	807	-	1,418	18,049	20,274
1940-44	372	-	6,562	16,315	23,249
1945-49	889	-	10,815	22,548	34,252
1950-64	154	1	21,567	61,352	83,074
1955-59	84	**1**		97,079	133,889
196064	35	**6**	36,725 22,910	70,004	92,955
196569	6	-	4,441	22,484	26,931

1 Averages for the period from 1920-24 are for less than 5 years.

Appendix Table 8

Annual commercial production (lb) of blue pike in Canadian waters of Lake Ontario, 1918-63.

			Area		
Year	Western	Central	Eastern	Bay of Quinte	Total
1918	14,941	-		-	14,941
1919	2,692	-	—	-	2,692
1921	8,924	502	**8,700**	4,908	23,034
1922	28,706	-	-	-	28,706
1923	50,000	-	-	-	5 0,000
1924	47,801	-	-	-	47,801
1925	15,380	-			15,380
1926	7,307		136	-	7,443
1927	7,873	—	314	-	8,187
1928	12,517	—		1,500	14,017
1929	13,177	—		415	13,592
1930	25,035	—	-		25,035
1931	37,329	—		-	37,329
1932	88,275	—	1,782	1,894	91,951
1933	59,112	—	1,770	1,151	62,033
1934	65,333	—	1,356	864	67,553
1935	37,547	—	881		38,428
1936	13,017	—	661	273	13,951
1937	24,179	—	136	1,888	26,203
1938	57,775	—	1,351	396	59,522
1939	97,466	—	1,064	2,012	100,542
1940	90,117		4,357	1,443	95,917
1941	48,319		7,085	2,375	57,779
1942	21.796		3,966	1.967	27,729

Appendix Table 8 (Continued)

Year	Area				
	Western	Central	Eastern	Bay of Quinte	Total
1943	26,385	90	9,285	8,181	43,941
1944	16,174	-	3,986	2,468	22,628
1945	16,469	-	2,163	-	18,632
1946	57,340	-	5,007	683	63,030
1947	94,189	-	9,775	2,486	106,450
1948	29,597	-	10,355	2,031	41,983
1949	29,623	-	15,757	1,713	47,093
1950	37,190	-	14,899	1,840	53,929
1951	126,659	-	57,611	4,263	188,533
1952	95,964	-	78,285	5,673	179,922
1953	31,353	-	32,757	2,243	66,353
1954	39,772	-	17,459	1,662	58,893
1955	66,187	-	18,212	8,617	93,016
1956	5,488	-	10,794	1,507	17,789
1957	368	-	5,954	2,454	8,776
1958	1,234	-	7,546	941	9,721
1959	616	-	1,233	609	2,458
1960	129	-	298	71	498
1961	549	-	38	24	611
1962	-	-	-		-
1963		-	11		11

Appendix Table 9

Annual commercial production (lb) of white bass in Canadian waters of Lake Ontario, 1952-70.

Year	Area				
	Western	Central	Eastern	Bay of Quinte	Total
1952	960	-	-	2	962
1953	869	-	199	4	992
1954	6,661	-	1,152	272	8,085
1955	26,263	-	8,937	504	35,704
1956	27,267	162	12,672	4,270	44,371
1957	12,493	62	5,863	1,049	19,467
1958	3,439	-	1,604	2,164	7,207
1959	4,146	-	4,539	9,154	17,839
1960	7,122		536	491	8,149
1961	23,281	-	4,094	1,308	28,683
1962	64,206	-	10,313	9,397	83,916
1963	54,121	1	19,378	14,003	87,503
1964	28,364		3,120	38,211	69,695
1965	3,251	-	2,556	76,499	82,306
1966	296	-	672	18,127	19,095
1967	184	13	894	1,407	2,498
1968	713		760	4,051	5,524
1969	953	-	964	1,583	3,500
1970	1,521		2,384	943	4,848

Appendix Table 10

Commercial production (lb) of American eel in Canadian waters of Lake Ontario, 1900-70, averaged by 5-year periods.

Period1	Area				
	Western	Central	Eastern	Bay of Quinte	Total
1900-04	588	nil	27,336	27,500	55,394
1905-09	2,965	300	12,325	5,778	21,368
1910-14	2,672	nil	172,912	63,310	238,894
1915-19	1,125	nil	64,985	74,898	141,008
1920-24	1,224	261	58,217	70,464	131,166
1925-29	619	nil	51,281	60,114	112,014
1930-34	915	nil	24,111	42,226	67,252
1935-39	790	nil	16,514	30,227	47,531
1940-44	2,163	nil	12,803	14,743	29,709
1945-49	90	nil	17,178	22,187	39,455
1950-54	21	nil	36,351	18,787	55,159
1955-59	1,297	156	61,900	28,358	91,711
1960-64	798	283	90,754	61,003	152,838
1965-69	nil	9	116,403	45,745	162,157

1 Averages for the periods from 1900-04 to 1920-24 are for less than 5 years. Northumberland was included in the central section 1900-04.

Appendix Table 11

Annual commercial production (lb) of white perch in Canadian waters of Lake Ontario, 1960-70.

Year	Area				
	Western	Central	Eastern	Bay of Quinte	Total
1960	83	-	8,987	9,380	18,450
1961	-	-	4,244	9,380	13,624
1962	-	-	7,496	15,799	23,295
1963	-	-	12,984	39,130	52,114
1964	-	-	59,138	211,395	270,533
1965	1	-	92,637	492,314	584,952
1966	-	-	22,942	149,525	172,467
1967	-	-	41,018	137,891	178,909
1968	-		20,195	175,847	196.642
1969	-	-	43,685	205,145	248,830
1970	-	-	44,677	401,840	446,517

Appendix Table 12

Commercial production (lb) of yellow perch in Canadian waters of Lake Ontario, 1900-70, averaged by 5-year periods.

	Area				
Period1	Western	Central	Eastern	Bay of Quinte	Total
1900-04	45,228	20,582	231,300	80,000	377,110
1905-09	9,825	88	42,241	76,646	128,800
1910-14	10,494	58	36,027	71,191	117,770
1915-19	4,198	8	53,665	102,426	160,297
1920-24	3,900	90	23,884	52,211	80,085
1925-29	2,007	6,127	66,355	55,866	130,355
1930-34	15,766	7,792	47,586	44,183	115,327
1935-39	15,597	836	81,026	58,178	155,637
1940-44	11,141	345	92,413	63,021	166,920
1945-49	5,675	578	90,754	56,986	153,993
1950-54	4,252	1	65,894	42,612	112,759
1955-59	1,293		37,412	21,866	60,571
1960-64	678	-61	103,121	36,927	140,787
1965-69	2,904	51	256,050	59,663	318,668

1 Averages for the periods from 1900-04 to 1920-24 are for less than 5 years, Northumberland was included in the central section 1900-04.

Appendix Table 13

Commercial production (lb) of northern pike in Canadian waters of Lake Ontario, 1900-70, averaged by 5-year periods.

	Area				
Period1	Western	Central	Eastern	Bay of Quinte	Total
1900-04	7,540	45,132	101,240	140,000	293,912
1905-09	35,805	394	82,011	121,488	239,698
1910-14	26,782	479	53,312	107,281	187,854
1915-19	1,104	486	109,236	135,571	246,397
1920-24	1,463	159	96,583	142,428	240,633
1925-29	46	-	62,952	84,170	147,168
1930-34	170	10	59,006	102,486	161,672
1935-39	79	185	56,538	55,853	112,655
1940-44	60	74	31,341	29,862	61,377
1945-49	464	-	18,685	32,126	51,275
1950-54	3	3	10,242	13,938	24,186
1955-59	571	-	7,843	21,019	29,433
196064	478	-	17,417	22,921	40,816
196569	80	-	14,756	9,707	24,543

1 Averages for the periods from 1900-04 to 1920-24 are for less than 5 years. Northumberland was included in the central section 1900-04.

Appendix Table 14

Commercial production (lb) of carp in Canadian waters of Lake Ontario, 1905-70, averaged by 5-year periods.

	Area				
Period[1]	Western	Central	Eastern	Bay of Quinte	Total
1905-09	11,365	nil	2,900	2,100	16,365
1910-14	42,090	nil	46,845	1,900	90,835
1915-19	130,838	2,077	85,869	15,583	234,366
1920-24	24,040	689	50,455	13,250	88,434
1925-29	9,130	498	25,639	36,891	72,158
1930-34	18,686	726	17,859	30,598	58,313
1935-39	95,246	425	49,055	43,060	187,786
1940-44	113,384	318	57,260	23,922	194,884
1945-49	86,293	340	72,350	28,687	187,670
1950-54	94,451	-	93,078	90,980	278,509
1955-59	97,926	-	100,550	230,284	428,760
196064	36,130	3,707	162,608	111,045	313,490
196569	19,669	385	236,146	135,868	392,068

1 Averages for the periods from 1905-09 to 1920-24 are for less than 5 years. Northumberland *was* included in the central section 1900-04.

Appendix Table 15

Commercial production (lb) of catfish and bullheads in Canadian waters of Lake Ontario, 1900-70, averaged by 5-year periods.

	Area				
Period1	Western	Central	Eastern	Bay of Quinte	Total
1900-04	3,385	7,845	123,301	50,500	185,031
1905-09	12,639	-	60,626	198,682	271,947
1910-14	1,237	-	95,615	214,995	311,847
1915	2,001	725	111,535	122,067	236,328
1920-24	160	1,190	55,153	114,113	170,616
1925-29	318	74	48,166	76,683	125,241
1930-34	1,642	4	54,263	117,179	173,088
1935-39	9,082	60	54,158	112,413	175,713
1940-44	1,559	19	46,766	75,706	125,050
1945-49	632	-	102,507	244,189	347,328
1950-54	2,333	-	195,078	297,603	495,014
1955-59	2,908	-	112,178	252,436	367,522
1960-64	202	4	143,655	115,829	259,690
1963-69	5	2	79,819	91,820	171,646

1 Averages for the periods from 1900-04 to 1920-24 are for less than J-years. Northumberland was included in the central section 1900-04.

Appendix Table 16

Annual commercial production (lb) of bullheads in Canadian waters of Lake Ontario, 1952-70.

Year	Area				
	Western	Central	Eastern	Bay of Quinte	Total
1952			117,881	332,532	450,413
1953	-	-	142,453	254,335	396,788
1954	1,000	-	146,560	196,572	344,132
1955	4,500	-	113,930	238,861	357,291
1956	-	–	139,143	278,443	417,586
1957	709	–	100,730	271,699	373,138
1958	1,500	-	102,915	166,154	270,569
1959	1,400	-	83,559	194,931	279,890
1960	-		217,275	49,246	266,654
1961	-	-	146.217	118,373	264,590
1962	327	-	133,353	124,735	258,415
1963			68,461	140,305	208,766
1964	-	-	65,353	81,239	146,592
1965			44,918	78,750	123,668
1966	-	-	39,177	58,040	97,217
1967	-	11	49,150	64,021	113,182
1968	-	-	62,974	82,559	145,533
1969			88,601	128,055	216,656
1970			78,632	127,818	206,450

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