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LIFE HISTORY, ABUNDANCE, AND POTENTIAL HARVEST OF CARP (*CYPRINUS CARPIO* LINNAEUS) FROM MICHIGAN WATERS OF THE GREAT LAKES

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ABSTRACT

The commercial fisheries of the Great Lakes would benefit if the value of underutilized species was increased. Carp are an underutilized fish and this paper reviews the biology and what is known about the abundance of the species in Michigan waters of the Great Lakes.

The abundance of carp is greatest in the western end of Lake Erie, in Saginaw Bay of Lake Huron, and in Green Bay of Lake Michigan. In 1976 the total of U.S. landings of carp from the Great Lakes was 2,092,000 kg. This production probably does not represent a concerted fishing effort due to poor market demand. It is difficult to predict beyond such figures as to potential harvests.

Harvest methods and techniques are discussed. Some hope for increased value appears possible due to new food science technology. Any increased development of the commercial fishery for carp must be done gradually and with careful monitoring.

INTRODUCTION

This review of the biology, distribution, abundance, harvest, and management of carp (Cyprinus carpio Linnaeus) in Michigan waters of the Great Lakes has been made to provide background information for use in the development of commercial fisheries for underutilized Great Lakes fish species (see also Galloway and Kevern 1976, O'Neal 1978). Data presented are incomplete and often qualitative in nature, and therefore may not adequately describe potential problems and special considerations which should be taken into account in expanding the fishery. However, the information should serve to characterize the issues involved, and the state of knowledge, and thereby have bearing on future (requisite) research.

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Introduction of carp into U.S. waters

Carp, generally assumed to be native to eastern Asia, may in fact have originated in the foothills of the Danube River (Balon 1974). They were introduced into Europe as early as 1227, and into North America from France in 1831 and from Schleswig-Holstein in 1872. The Fish Commission distributed them from 1879 to 1897, so that they are now well-established throughout the conterminous United States.

Carp were successfully planted in the lower Great Lakes in the early 1880's following the Fish Commission introductions (Berst and Spangler 1972). It is not possible to determine whether larger catches reflect greater productivity or increased fishing effort, but since 1952 the annual catch of carp in Lake Ontario has scarcely fallen below 136,078 kg (300 lb x 10^3) (Christie 1972). Considerable quantities of carp have been available but little used since the early days of the Lake Erie fishery. Because the market can absorb only limited amounts of low-value fish, carp cannot compensate for the Lake Erie fishery's recent loss of high-value species (Buettner 1965). Carp invaded Lake Huron proper about 1900, and populations there have supported a moderate commercial fishery since that time (McCrimmon 1968). It is not known when they first appeared in Lake Michigan, but production was nearly 226,796 kg (500 lb x 10^3) in 1908, and over 453,592 kg (1000 lb x 10^3) in 1934. The catch prior to 1900 may reflect the low abundance of carp soon after its introduction, and the great increase soon thereafter, reflecting a rapid increase in the population. However, subsequent changes in production have followed changes in market demand rather than abundance, with southern Green Bay providing a large proportion of the catch (Wells and McLain 1973). Carp have long been established in small numbers in certain shallow bays along either side of Lake Superior, but are not abundant enough to be fished commercially (Lawrie and Rahrer 1973).

Sporadic introductions in the early 1880's preceded distribution of carp in Michigan in 1885. Peterson and Drews (1957) detail the history of carp introduction into the United States, and particularly into Michigan waters.

Economic Importance

The cyprinids include at least 2,000 species which inhabit every continent except Australia and South America; approximately 250 species are known from North America. The genus *Cyprinus* contains several species of important food fishes, among them *Cyprinus carpio* Linnaeus, variously known as German carp, European carp, mirror carp, leather carp, and carpe.

Because of its wide distribution, the carp is among the world's most valuable fish (Peterson and Drews 1957). Its economic importance lies primarily in its value as a food, sport, and forage fish, in its effect on aquatic habitats, and in its interactions with other fish species. This fish readily meets requirements for artificial culture (detailed by Gerking 1967, Hickling 1971, and Bardach *et al.* 1972), a very ancient practice in some parts of the world. Carp culture has been practically discontinued in the United States. However, retention ponds are still used in the Great Lakes region to contain large numbers of the spring and summer catch until winter when they command a higher price. Carp often grow rapidly and achieve large size in waters that support few other fish species.

The historical development of the commercial fishing industry in each of the Great Lakes is said to have followed a similar general pattern (Great Lakes Basin Commission 1975). During the middle and late 19th and 20th centuries, there was a period of development and rapid expansion when nearly half the total landings were highly-valued coldwater species. Landings decreased from 1910 to 1940 when the fishery probably was stabilizing. The number of commercial fishermen also decreased during this period, and has continued to decline. Fish resources have been unstable since 1940 and the percent contribution of many high-value species has decreased markedly. This has been attributed in large part to the invasion and successful establishment of the sea lamprey and alewife in the three upper Great Lakes, to significant over-exploitation of certain species by the commercial fishery, and to general deterioration of Lake Erie and isolated portions of Lakes Ontario, Huron, and Michigan. Additional information concerning the development of the fisheries of respective Lakes Superior, Michigan, Huron, Erie, and Ontario is provided by Lawrie and Rahrer (1973), Wells and McLain (1973), Berst and Spangler (1972), Hartman (1972), and Christie (1972). Changes occurring in the fish stocks of the Great Lakes are detailed by Smith (1968, 1972) and the Great Lakes Basin Commission (1975).

Most of the annual carp harvest is marketed in large cities such as Chicago, Detroit, and New York. These fish are generally shipped alive, or dressed and iced. Smoked carp, gefilte fish, and caviar are widely consumed. The Great Lakes Basin Commission (1975) indicates that carp prices followed a general downward trend from 1945 to 1970, peaking during World War II and in the mid-1950's. Current prices are 2-8 cents (average 4 cents) per pound to the fisherman. The wholesale price depends on market conditions, but the price of smoked boneless carp often exceeds $1.00 per pound. In Ontario 362,874 to

453,592 kg (800 to 1,000 lb x 10^3) of carp are landed annually with a market kg (800 to 1,000 lb x 10^3) of carp are landed annually with a market value of approximately $70,000 to $100,000. Carp comprised 64% of the total catch in the Mississippi River in 1976, but accounted for only 34% of the wholesale value of that fishery (Fernholz and Crawley 1976). Thus irrespective of their value in the Old World, and the large quantities marketed annually in this country, carp are not generally popular in the United States. Limited use of carp as food has been attributed to their sometimes "muddy" flavor and abundance of small bones, the availability of other species, and the high cost of harvesting and processing (Sigler 1958). Peterson and Drews (1957) detail the early market conditions and value of carp in Michigan and stress the need for research into means of processing this fish. Public prejudice hampers utilization, but McCrimmon (1968) believes this can be overcome by public education and product development. Consumption, particularly of smoked carp, could increase with promotional work (Great Lakes Basin Commission 1975).

Carp can be prepared simply and acceptably by skinning, cutting out and discarding the dark streak along either side, and then soaking the flesh in salt water for 2-6 hours. They may be cooked by any usual method, salted or smoked.

Carp are being increasingly recognized for their value as a sport fish. They have long been enthusiastically sought after by English anglers (Hilton 1972). Bait fishing with dough balls, worms, or corn is the usual method used, and sometimes a weighted sack of green corn is used to lure them to the bait. Bow and arrow fishing for carp is becoming increasingly popular.

Carp are used as a forage fish, although this is limited because they spend their early lives hiding in aquatic vegetation. Hybrids between carp and goldfish have been produced with the idea that reduced fertility of the hybrids would make them safer than either species if they happened to be released into the environment. Hybrids may be fertile, however, and over 90% of some populations in the Great Lakes are hybrids. Carp pituitary extract has been used to speed up and increase the success of artificial reproduction and to advance the spawning time of other fishes.

Carp are also marketed as fertilizer, fish meal, and animal food. The mink food market is currently depressed, however, because of suggestions of pesticide concentrations of Great Lakes fishes might be partially responsible for the failure of mink to reproduce satisfactorily (Great Lakes Basin Commission 1975).

Mraz and Cooper (1957) report detrimental effects of carp populations on aquatic vegetation. Carp, more than any other factor, were responsible for a decrease of vegetation in Lakes Waubesa and Kegonsa, Wisconsin (Frey 1940). In Neosha Mill Pond, Wisconsin, carp rooted out vegetation to such an extent that it disappeared (Cahn 1929). In this regard carp have been suggested for use in aquatic plant control.

Recent data from Union Lake, Minnesota, suggest that carp can internally load a lake with orthophosphate. Thus, not only must external phosphorous loadings be calculated in determining lake budgets, but also the internal loadings from bottom-feeding fishes, especially in lakes with extensive littoral areas and highly organic sediments (Lamarra 1975).

The effects of carp on other fishes may be subtle. They are remarkably adaptable animals, with broad spectra of tolerances to chemical concentrations, temperatures, currents, foods, and spawning conditions. They probably influence most cohabiting species directly or indirectly.

The competition carp afford other species is not understood. The catch of some fishes sometimes appears to decline as carp populations increase, reflecting either competition for food and space between carp and the native species or a deterioration of habitat in ways detrimental to native species. For example, when carp became established in Neosha Mill Pond, Wisconsin, the water became very turbid and native game fishes disappeared (Cahn 1929). Carp are often found in shallow water, and their presence may affect spawning fish, their spawn, and all fish that live there.

Alternatively, carp may help stabilize fish populations because their widespread occurrence and abundance tend to make them important in the food chains of predatory fishes. Young carp are probably consumed by such species as the northern pike, muskellunge, and largemouth bass, although it is not known to what extent. Sigler (1958) discusses interactions between carp and largemouth bass, green sunfish, and black bullheads. Jester (1974) reported interactions among carp, river carpsucker, and smallmouth buffalo. A large number of carp fry and fingerlings in Wisconsin in 1936 may have effected an increase in abundance of white bass and black crappies and a marked decrease in bluegill and perch (Frey 1940).

Information concerning species' interactions in the Great Lakes is limited. No noticeable changes in the competing warm-water fishes of Lake Ontario can be attributed to colonization by carp; however, the niche voided by the sturgeon may have helped the carp become established since these species are generally similar in distribution and feeding habits (Christie 1972). Hubschman (1971) notes the environmental changes occurring over the past 50 years in Lake Erie may have resulted in fish such as cisco, lake whitefish, and blue pike, once important commercial species, being replaced by carp and freshwater drum. Although the effects of carp often reported in other bodies of water are not documented for Lake Michigan, it appears that they caused certain changes injurious to native fauna in some areas, especially in Green Bay (Wells and McLain 1973). Present water quality trends in the Great Lakes (chemical and physical, including thermal) may lead to an ultimate condition of scarcity of fish in the deepwater regions, and a succession of less and less desirable species in shallow-water areas (Smith 1972). Thus it appears that preservation of fish populations unique to the Great Lakes warrants stimulation of the fishery for low-value species.

The enthusiasm with which carp were initially introduced and cultured in the U.S. and Canada waned as this species proliferated. Their impact on most warm-water areas has been considerable, and most managers believe carp should not be introduced into new areas. The literature on carp control for water clarity, forage base, space utilization, and reduced destruction of aquatic plants is extensive. Each year large sums of money are spent throughout the nation on rough fish removal projects.

Methods used generally include water level control, fish toxicants, and harvesting. Water drawdowns desiccate eggs and exert some influence on spawning success (Shields 1957, Jester 1974), but probably the most effective means are intensive commercial fishing in large bodies of water and use of selective fish poisons in small bodies of water. Gerking (1950) found that it was impossible to reduce carp numbers beyond a given margin in Lake Oliver, Indiana, without killing all the fish. Hooper _et al_. (1964) discuss lake rehabilitation with recommendations for Michigan waters, and Spitler (1970) has determined optimum conditions for a complete rotenone kill in southern Michigan lakes. Since eradication of carp from most bodies of water is highly unlikely, the best alternative appears to be to accept carp as part of the fauna and utilize this resource as fully as possible.

LIFE HISTORY

Description

Cyprinids are characterized generally by soft rays, toothless jaws, cycloid scales, abdominally-placed pelvic fins, and scaleless heads. More specifically, *Cyprinus carpio* has two pairs of maxillary barbels (the posterior pair being the larger), and sturdy serrated spines at the front of the dorsal and the anal fins. The anal fin has 5-6 soft rays, and the long, sickle-shaped dorsal fin, more than 16 soft rays; the pelvic fins contain 5-7 rays each and the caudal fin usually has 19 rays, 17 of which are branched.

The body of the carp is robust and laterally compressed, with the dorsal outline considerably more convex than the ventral one. The small head tapers to a blunt snout, and the subterminal mouth is slightly oblique and strongly protactile. They have teeth only on the pharyngeal arches in three rows arranged 1,1,3-3,1,1; teeth in the main row are molariform. The number of gill rakers on the first arch varies from 21 to 27, and the lateral line in full-scaled forms is complete with 32-38 scales.

The color of this fish varies but is brassy to dusky gray dorsally and yellowish ventrally. The fins are usually light yellow (orange in large adults), although the anal fin and the lower half of the caudal fin often have a reddish hue. The scales on the sides and back have a dark basal spot at their edges.

Carp are distinguished from goldfish, carpsucker, and buffalofish primarily by their barbels, and from suckers by the strong serrated spines in front of the dorsal and anal fins. Carp-goldfish hybrids have four barbels which are smaller than those of the carp, and pharyngeal teeth which are often 1,4-4,1 (or otherwise intermediate). These hybrids are fertile and backcrosses are abundant. In seine hauls from Sandusky and Maumee Bays, 30-90% of the carp-goldfish catch may consist of hybrids. The fact that carp are capable of forming deep-bodied forms when food is abundant (Balon 1977) may be of commercial interest. Years of cultivation have allowed for development of several varieties of carp, including those with scales (scale carp), those completely without scales (leather carp), and those with a few enormous scales along the middle of the sides and near the back (mirror carp). Scale carp are by far the most common. There is no natural division of mirror and leather carp under field conditions where interbreeding is possible (Sigler 1955).

Habitat

The carp is a warm-water species that thrives in standing or sluggish water and thus is most abundant in lakes and large rivers. Carp are tolerant fish and are generally associated with eutrophic waters with silty bottoms and good growths of submerged plants. They may alter their habitat so it is less suitable for game fish and for themselves as well. Their ability to survive under sub-optimal conditions (such as increased turbidity, sudden temperature changes, and low dissolved oxygen concentrations) is often cited as reason for their success. Abundance may decrease when land fertility or organic pollution decreases. Carp captured in the lower St. Lawrence River below Quebec City, and in Maine, indicate that carp will move into brackish water.

Carp seek quiet water and dark holes, and are rare or absent in clear cold water, or, except during spawning runs, in streams of high gradient. Their optimum water temperature is believed to be 21° C. However, preferred temperatures of Lake Monona, Wisconsin, carp were found to be 31.8° C in the laboratory and 30.6° C in the field (Neill and Magnuson 1974).

Carp generally aggregate in deep water to overwinter and move into shallow marshy areas in the spring to feed and to spawn (McCrimmon 1968). They spend daylight hours in rocky shoal areas and protected bays near deep water. Probably because of temperature decreases with depth (Sigler 1958), great areas of deep water may prevent them from becoming dominant (Gerking 1950).

Carp are common throughout most of the eastern part of North America, and in Canada north to Lake Winnipeg, including the vicinity of Nipigon Bay in Lake Superior and its tributaries. In the Great Lakes region carp are found northward through the southern two-thirds of Wisconsin and the lower peninsula of Michigan. Areas (by county) along the Michigan shoreline which have been specifically designated for carp fishing by the Michigan Department of Natural Resources include Lake Erie (Wayne and Monroe); Lake St. Clair (Macomb); Lake Huron (Huron); Saginaw Bay (Bay); and Lake Michigan (Allegan, Berrien, Ottawa, Muskegon, Manistee, and Grand Traverse). In addition, Munuscong Lake (Chippewa) and Big and Little Bays de Noc (Delta) in the upper peninsula are designated carp fishing areas.

Major changes in bottom and fish fauna of Lake Erie in the past 60 years indicate an increase in the area said to be polluted (Beeton 1961, Carr and Hiltunen 1965). Because carp are able to live in waters rendered unsuitable for more traditionally desirable species by accelerating eutrophication, they are probably increasing in numbers. Available commercial fishery data, however, are of limited value in providing evidence for the extension of the range of carp because, in most cases, fishermen have not been actively fishing for this species.

Reproduction

Carp generally mature within 2 to 4 years. Although males tend to mature more rapidly than females, mature individuals of both sexes occur in age group II (Jester 1974).

The timing of spawning depends on water temperature (15.5-20° C) (Janković 1975). Carp move into shallow water in the spring as the temperature increases to 16° C. They require clear skies and calm weather; an increase in wind velocity may drive them out of the shallows (Wichers 1976). In the Great Lakes region, their spawning season may extend from May to August (Swee and McCrimmon 1966); spawning decreases when the water temperature reaches 26° C and ceases at 28° C.

Prior to spawning, large schools of carp swim slowly about in open water, usually close to the shore, with their dorsal fins and backs frequently breaking the surface. They then separate into smaller schools, each containing 1 to 3 females and 2 or 3 to as many as 15 males, which move into weeded bays and backwaters less than 1 m in depth, or move up tributaries into shallow headwaters in vast numbers.

Carp prepare no nests, but have adhesive eggs which, once fertilized, are broadcast in groups of 500-600 over vegetation and debris within an area approximately 2 m in diameter. The eggs are then deserted.

The number of eggs per female increases with age and size of the fish.

Age IV females average 181,000 eggs (Rehder 1959), and absolute fecundity of females ranges from 68,000 to 395,000 eggs (Janković 1975). Jester (1974) determined that carp fecundity varied from a mean of 19,578 ova for age group IV carp to 1,835,694 ova in an 18-year old fish. Table 1 presents relative fecundity of Lake St. Lawrence, Ontario, carp with respect to age, weight, and total length.

Eggs may hatch in 3 to 20 days, depending on water temperature. Newly-hatched larvae average 5.2 mm in total length, and at first, live on the contents of their yolk sacs. After a few days, however, as their fins develop, they start to feed on zooplankton. By the end of their first week, most fry

TABLE 1. Relative fecundity of 56 female carp from Lake St. Lawrence, Ontario, with respect to age, weight, and total length (from Swee and McCrimmon 1966).

Age	Number of fish	Average total length (mm)	Average weight (kg)	Average number of eggs per female
IV	5	419	1.07	56,463
V	13	475	1.56	223,150
VI	11	510	1.93	326,385
VII	3	576	2.92	664,350
VIII	5	613	3.81	979,687
IX	6	642	4.67	854,300
X	5	667	5.01	930,000
XI	6	700	5.68	1,127,500
XV	1	787	11.06	1,851,000
XVI	1	851	10.10	2,208,000

move into beds of emergent or submergent vegetation where they remain until they are from 7 to 10 cm in total length and fairly secure from predation. They range from 98 to 113 mm in total length and from 14 to 21 g in weight by their twelfth week. Swee and McCrimmon (1966) and Jester (1974) have detailed carp behavior and spawning conditions.

Nursery areas for all species in Lake Huron are located in bays with large areas of shallow water (less than 9.2 m) with rivers or streams flowing into them and infrequent or no upwellings. Important rearing grounds for fish larvae in the western part of the lake include St. Martin, Thunder, and Saginaw Bays, and the area around the Les Cheneaux Island (O'Gorman pers. comm.). In the area of Ludington on Lake Michigan carp spawn in marshes of the Pere Marquette River. This area has been depleted recently because of low lake levels (Liston pers. comm.). Presumably, similar spawning areas are used throughout the Great Lakes region.

Survival

Survival of a hatch of carp is influenced by a number of factors, including amount and type of vegetation and food supply in the area, time of year when eggs are spawned, and natural enemies (Frey 1940). Young carp probably fall prey to a variety of predaceous fishes and birds, but wary, thick-scaled adults likely have few enemies. In Pathfinder Reservoir, Wyoming, carp reach 100-160 mm after one year of growth, after which they probably have a very low rate of mortality due to predation (Wichers 1976).

Hoffman (1967) reports algae, fungi, and invertebrates as parasites of carp. Parasites of Lake Erie carp populations (Bangham and Hunter 1936) and those in the South Bay of Lake Huron (Bangham 1955) have been investigated. These fish are usually free of parasites, however, and carry mainly gill flukes or external forms (Bangham and Adams 1954). Comparatively few diseases are fatal to carp (Sigler 1958). (It should be noted that proper cooking of dressed fish insures that parasites are harmless to man.)

Marked similarity in the relative abundance of various year classes in Lakes Monona, Waubesa, Kegonsa, and Wingra suggests that some broad environmental control may determine the rate of survival of a hatch of carp (Frey 1940). An exceptionally abundant year class was produced in the Des Moines River, Iowa, during a year of low stable water levels (Rehder 1959), whereas carp did not spawn in numbers in Oliver Lake, Indiana, in 1947, probably because of changeable spring weather (Gerking 1950). Wichers (1976) studied a population which was evidently limited by density-dependent competition factors (e.g. food and habitat limitations) between young-of-that-year and older carp.

Production of carp young may be extremely erratic. There seems to be little apparent correlation between the population of brood fish and the strength of resulting year classes; strong year classes can be traced through a fishery for several years (Mraz and Cooper 1957). In the Madison lakes there was a large surviving hatch in 1931, almost no survival in 1932 and 1933, an increase in 1934 and 1935, and a tremendous hatch and survival in 1936; in fact, the 1936 year class comprised more than 90% of the 453,592 kg (1,000 lb x 10^3) removal of carp from each lake during 1938 and 1939 (Frey, 1940). Similarly, the carp population in Pathfinder Reservoir, Wyoming, was found to consist primarily (at least 90%) of individuals from three strong year classes (1962, 1970 and 1971) (Wichers 1976). Schoffman (1942) noted that age groups

IV, V, VI, VII, and VIII represented 72% of the Reelfoot Lake, Tennessee, population. Although spawning is observed in most years, yearling fish are uncommon and a successful year class is produced only occasionally in Clear Lake, Iowa (Bulkley et al. 1976). Buck et al. (1970) measured variation in carp production in replicate ponds and suggest that carrying capacity in ponds is less stable than commonly believed, that no environmental factor (e.g. basin fertility) maintains a dominant continuous influence, and that production is controlled by a new assortment or combination of factors in each new season.

It may sometimes be possible to predict a strong year class. Wichers (1976) suggests that the production of a strong surviving year class in Pathfinder Reservoir requires both average or better than average spawning conditions, and excess available food and habitat due to either inundation of new shoreline or significant decrease in the previous standing crop of carp. Intensive commercial harvest of older fish has been observed to be followed by abundant year class the following year. Wichers (1976) refers to Ocean Lake, Wyoming, studies of the production of carp and effects of simulated harvest of commercial species. Effects of commercial harvest on the carp population structure are potentially significant to the development of a fishery. The percentage survival of adult carp is said to exceed that of largemouth bass, bluegill and black crappie (Mraz and Cooper 1957). Mean survival and cumulative mortality rates have been computed for various carp populations (Neess et al. 1957, Jester 1974). However, there are essentially no data on these parameters for Great Lakes carp populations.

Age and Growth

Jester (1974) found both scales and opercular bones useful in determining age and computing growth of carp in Elephant Butte Lake, New Mexico. Although scale formation relative to growth and development has been investigated (McCrimmon and Swee 1967), in some cases there appears to be less variation in opercular bone-body length relationships than in scale-body length ratios (McConnell 1951, Rehder 1959). Fin spine cross sections have been used to determine the age of carp in Wyoming because neither scales nor opercles were satisfactory (Wichers 1976).

In the wild, carp seldom live longer than 12-15 yr or exceed 80 cm in standard length and 9 kg in weight. In Elephant Butte Lake the computed mean life span was approximately 1.3 yr (Jester 1974). Carp have been recorded as living as long as 47 yr in captivity.

Carp average 0.45-1.36 kg in weight although 2.27-4.54 kg are not uncommon. The largest recorded carp weighed 39.9 kg (Pretoria, South Africa), and the largest from North America weighed 26.9 kg (Iowa). Commercial fishermen give maximum lengths of 1.0-1.2 m and weights of 18.1-27.2 kg; in Lake Erie and the Bay of Quinte they generally obtain weights of 13.6-18.81 kg. Carp may range from 7 to 36 cm in standard length during their first summer of life, but average from 10 to 15 cm. They may double in length during their second year and add 10-12 cm during each following year. Growth tends to slow down after the fourth or fifth year. Schoffman (1942) found that the annual increment of growth in weight in Reelfoot Lake, Tennessee, increased progressively during the first 14 summers of life. Total length: standard length ratios did not decrease progressively with increase in length of carp in the lake. Johnson (1970) caught few carp heavier than 1 kg in Roosevelt Lake, Arizona, yet Canyon Lake, just downstream on the same river, contained carp averaging 3-5 kg. Thus, as with sizes of various carp populations marked variation occurs in growth rate.

Length-weight relationships determined from several carp populations are presented in Table 2. There is commonly no significant difference in growth between males and females (Gerking 1950, Jester 1974, Wichers 1976). Jester (1974) measured a grand mean condition factor, K_{TL} = 1.23 for carp in Elephant Butte Lake and discusses condition as it relates to sex, length, and age of carp and to season. Condition factors in the Madison lakes are minimal in early summer after spawning (Frey 1940). In the Des Moines River, Iowa, they are highest in midsummer, the time of high water level (Rehder 1959).

Estimated age composition and mean lengths and weights by age of male and female carp collected from Saginaw Bay in the spring of 1976 by commercial seine are reported in Table 3. Table 4 provides the length-frequency distribution data of this catch. Similarly, the age-frequency distribution of

TABLE 2. Length-weight relationship of carp populations from various locations.

Length-weight relationship	Location	Reference
$W = 1.44 \times 10^{-5} L^{3.0042}$	nearshore areas of western Lake Erie (1970)	Parkhurst 1971
$W = 1.58 \times 10^{-4} L^{2.624}$	Lake Oliver, Indiana	Gerking 1950
$\text{Log } W = -5.16310 + 3.11902 \text{ Log } L$	Pathfinder Reservoir, Wyoming (1975)	Wichers 1976
$\text{Log } W = -4.62025 + 2.87981 \text{ Log } L$	Elephant Butte Lake, NM	Jester 1974
$\text{Log } W = -5.55070 + 3.26009 \text{ Log } L$	Pathfinder Reservoir, Wyoming (1974)	Wichers 1976

TABLE 3. Estimated age composition (n=155) and mean lengths and weights by age of male (n=63) and female (n=85) carp collected from Saginaw Bay in the spring of 1976 by commercial seine.

Age	Total	Percent of total catch	CPE*	Mean length (mm) (male)	Mean length (mm) (female)	Mean weight (kg) (male)	Mean weight (kg) (female)
II	4	2.58	2.00				
III	1	0.65	0.50	259		0.23	
IV	5	3.23	2.50	414		0.85	
V	6	3.87	3.00	468	478	1.24	1.56
VI	15	9.72	7.54	487	508	1.47	1.74
VII	11	7.19	5.57	497	563	1.45	2.61
VIII	9	5.90	4.57	515	553	1.62	2.50
IX	15	9.95	7.71	555	560	2.20	2.58
X	88	56.91	44.11	632	668	3.34	4.82

carp collected in the spring of 1976 is given in Table 5. These data (Tables 3-5) were obtained from Michigan Department of Natural Resources index station catch records provided by Patriarche (pers. comm.). Mean length and condition factor at the end of the growing season and mean annual growth rate for carp collected from Lake Erie near the Monroe Power Plant during 1970 through 1975 are reported by Lavis and Cole (1976). Calculated lengths to each annulus for carp from the nearshore areas of the western part of the lake during 1970 are presented in Table 6.

McCrimmon (1968) discusses age and growth of carp as determined primarily from studies in Ontario lakes. Rates vary with the summer water temperature, length of the growing season, and food availability. Carp are active at

TABLE 4. Length-frequency distribution of carp collected by commercial seine from Saginaw Bay in the spring of 1976.

Size group (mm)	Total catch	Size group (mm)	Total catch
178	1	508	10
203	1	533	15
229	2	559	18
254	1	584	14
279	0	610	14
305	0	635	14
330	0	660	11
356	1	686	7
381	0	711	8
406	2	737	7
432	5	762	1
457	7	787	1
483	12	813	3

temperatures from 4 to 34° C, although the optimum temperature for growth seems to be about 24° C. Rates are generally lowest in rivers and highest in rich weedy lakes. Extremely favorable food conditions allow rapid and intensive growth of young fish (Janković 1975). In ponds under intensive commercial production, population densities appear to control growth (suppressed at higher densities) through accumulation of excretory wastes or other substances (Carlander 1969) or for other unknown reasons (Minckley

TABLE 5. Age-frequency distribution of carp collected by commercial seine from Saginaw Bay in the spring of 1976.

Size group (mm)	Total per size group	Total per size group per age								
		II	III	IV	V	VI	VII	VIII	IX	X
178	1	1								
203	1	1								
229	2	2								
254	1		1							
356	1			1						
406	2			2						
432	5			2	1	2				
457	7				3	3	1			
483	12				1	6	3	2		
508	10				1	3	4	1	1	
533	14					1	2	2	6	3
559	18							4	6	8
584	14								2	12
610	14									14
635	14						1			13
660	11									11
686	7									7
711	7									7
737	6									6
762	1									1
787	1									1
813	4									4
914	1									1

Table 6. Calculated lengths to each annulus for carp from the nearshore areas of western Lake Erie during 1970 (from Parkhurst 1971).

Age	Number	Length at capture (mm)	1	2	3	4	5	6	7	8	9	10	11	12	13
I	29	249	129												
II	26	301	87	259											
III	41	336	111	239	315										
IV	47	410	107	244	334	404									
V	42	454	126	279	364	417	451								
VI	43	491	119	277	372	423	460	487							
VII	23	510	121	291	383	429	464	488	508						
VIII	24	545	147	297	388	439	474	508	527	542					
IX	11	557	123	268	369	435	478	506	525	542	552				
X	4	618	141	321	421	472	504	531	560	578	593	610			
XI	2	638	127	278	416	456	478	528	555	568	583	613	625		
XIII	2	662	128	334	403	414	499	544	554	581	590	615	637	650	655
Weighted Means															
Age		Length at capture													
4.8		423.0	118	268	358	423	464	498	525	550	573	612	631	650	655
Increment percent of growth			118	150	89	56	36	28	20	16	12	17	19	13	5

Calculated weights (g) for:

24 281 669 1108- 1468 1805 2106 2409 2647 3364 3756 4024 4098

1973). McConnell (1951) attributed a decrease in growth rate at any year of life for successive age groups in Utah to a gradual change in the environment. Increase in weight may also be highly variable. Young-of-the-year carp tend to grow faster than most fishes native to North American waters. Frey (1940) found evidence of progressive growth compensation, reducing the amount of total variation, in carp populations in the Madison lakes; each year after the first the small fish tended to grow more than the large fish.

Wichers (1976) traced the growth history of the strong 1962 year class in Pathfinder Reservoir to the time when they were caught, June 1975. Growth was greatly accelerated in 1969 and moderate in 1970, corresponding to a significant increase in the area covered by the reservoir. Wichers (1976) believed that complete age:growth data for all age classes from the reservoir would be impossible to obtain because approximately 90% of the population consisted of individuals from three strong year classes. This phenomenon may occur in, and complicate growth analyses of, Great Lakes carp populations.

There is evidence that commercial fishing in lakes may determine the age composition of carp populations (Janković 1975). Studies of the effects of fishing on age structure could help insure the introduction of protection measures and the advancement of fisheries by correlating the fishing, recruiting, and mortality of the population. With an increase in harvesting effort and yield, animal populations that are being harvested for sustained yield may take longer to recover from environmentally imposed disturbances (Beddington and May 1977).

Food and Feeding

Carp may feed almost any hour, day or night, usually over fine sediments where current is reduced and weeds are present. Carp generally feed in very shallow areas only during early morning or evening. Cold water results in a discontinuation of feeding. In the Madison lakes, carp were observed with food in their digesive tracts from April when the water temperature was 5° C to December when it was 3° C (Frey 1940). Rate of digestion experiments indicate that in water temperatures of 9.4° C or warmer, carp digest stomach contents within 24 hr (Moen 1953). Kevern (1966) found that food was retained for 22 to 50 hr at 12.5° C, and 16 to 25 hr at 20° C.

Typically, carp root around on silty bottoms, stirring up aquatic insects which they then pick out of the water. They often take silt up into their mouths, spit it out, and then pick out suspended organisms. In this way they may increase water turbidity and uproot aquatic plants which provide cover and food for other fishes and food for waterfowl.

Newly-hatched carp feed on entomstracans, rotifers, small insects, and phytoplankton. Carp larvae fed heavily on Bosmina and Alona in Clear Lake, Iowa (Bulkley et al. 1976). As they increase in size, they begin to feed on benthic insect larvae, and then on most available bottom invertebrates by the end of their first summer.

Data from analyses of 687 stomachs of carp from 14 northwestern Iowa lakes indicate that adults feed predominantly on animal material. Aquatic insect larvae, small crustaceans, and snails made up the bulk of the animal food during the summer periods; the winter food of carp was 100% animal material, with small crustaceans and midge larvae of about equal importance (Moen 1953).

In Buckeye Lake, Ohio, carp consumed 51.5% crustaceans (chiefly Cladocera) and 36.5% insects (midge larvae and adults) (Ewers and Boesel 1935). However, Minckley (1973) notes that carp rarely feed on other fishes when small, even though they sometimes raid nests for eggs. Earthworms and other terrestrial insects have been found to comprise most of their food during floods (Rehder 1959).

Whereas some investigators hold that carp do not depend on vegetation or rootlets except for deposition of eggs, Berner (1951) and Jester (1974) found mostly plant material in carp stomachs. On the average, algae and detritus made up over 85% of the diet of carp from White Oak Lake, Tennessee (Kevern 1966), and Des Moines River carp feed mostly (78%) on seeds and other plant material (Rehder 1959). Rooted aquatic plants are heavily eaten in the Madison lakes (Frey 1940). Small animals attached to the plants are probably of nutritional value.

Bulkley et al. (1976) observed food selection and shifting by carp, not only in relation to abundance of the food organisms, but also to other fish species present as well. Even though carp vary their feeding habits somewhat with abundance and seasonal occurrence of the types of food, it may become increasingly difficult for lakes to support the same number of carp as the increase in age and require more food per individual (Frey 1940).

Movement

Adult carp usually aggregate to overwinter in deeper waters of lakes and streams and move into shallow water to spawn and feed as the temperatures increase in springtime. They seek shelter in deeper holes when alarmed, and spread rapidly during floods. Infertile and cold water may be an ecological barrier to carp (Sigler 1955). The northward extension of carp into Manitoba and Saskatchewan, and approximate rates of invasion ranging from 32.2 to 64.4 km per year were reported by Atton (1959). Sigler (1958) discusses the invasion ability of carp, that is, their ability to establish and maintain themselves in the face of competition, and reviews the movement of carp populations as governed by water temperature, natural wariness, spawning activity, and migrating tendencies.

DISTRIBUTION AND ABUNDANCE

The first complete U.S. statistical survey of the Great Lakes fisheries was made in 1879, with subsequent intermittent canvasses until 1913. Since then, surveys have been conducted each year (Buettner 1968). Supply, demand and operational costs have affected production estimates, and modifications and changes in fishery regulations have disrupted the continuity of these records. In addition, carp populations may easily be underestimated when shallow waters are not sampled (Schumacher and Eschmeyer 1943), as has been the case in the Great Lakes. Discretion must be used in interpreting these data (Hile 1962). A summary of carp production from 1892 to 1977 in Lakes Erie, St. Clair, Huron, and Michigan is presented in Appendix A. Appendix B lists the grand total, U.S. total, and Michigan total production of carp in the Great Lakes from 1892 to 1977. Corresponding tables of values compiled for all species from the Great Lakes are presented in respective Appendices C and D for comparison. Summaries were compiled from U.S. commercial fishery statistics prepared by Baldwin and Saalfeld (1962), Statistics and Market News Division (1969-1973) and the Great Lakes Fishery Commission (1970, 1976).

Peterson and Drews (1957) discuss early trends in harvest and value of carp from Michigan waters of the Great Lakes. There were probably no overall trends in landings from 1945 to 1970, and present abundance is much greater than the landings indicate (Great Lakes Basin Commission 1975). Ballert (1975) estimates that carp ranked second in the U.S. commercial catch of 1971-1975, with 3,305,509 kg (7,287 lb x 10^3), 2,491,538 kg (5,493 x 10^3), 2,898,092 kg (6,389 x 10^3), 3,201,546 kg (7,058 lb x 10^3), and 3,053,856 kg (6,733 lb x 10^3) respectively in 1971, 1972, 1973, 1974 and 1975. However, it is very difficult, if not impossible, to accurately estimate the maximum sustainable yield of carp from the Great Lakes at this time.

Monroe and Sandusky Bay (Lake Erie), Saginaw Bay (Lake Huron), and Green Bay (Lake Michigan) support by far the largest portion of the Great Lakes carp fishery (Buettner pers. comm.). Carp production and value by port for these areas in 1975 and 1976 were obtained from the U.S. Fish and Wildlife Service (Ann Arbor, Michigan) and are presented in Tables 7 through 9. A summary prepared from Great Lakes Fishery Laboratory data of U.S. Great Lakes commercial carp production in 1976 by the Great Lakes Fish Commission (1977) indicates that total landings and value, and those from Michigan waters, were as presented in Table 10.

TABLE 7. Carp production (number) and value (dollar) by port in the Monroe and Sandusky Bay area of Lake Erie in 1975 and 1976.

Port	1975		1976	
	Number	Value	Number	Value
Michigan waters:				
Monroe	439,204	21,749	450,908	40,204
Luna Pier			36,500	1,240
Total	439,204	21,749	487,408	41,444
Ohio waters:				
Inland waters	232,800	17,270	766	48
Toledo	742,041	51,232	587,016	20,452
Port Clinton	1,134,637	70,118	1,115,240	72,408
Kelleys Island	42	2	110,665	6,972
Marblehead and Limpert	655,237	44,875	804,644	49,645
Huron	6,140	289	7,227	324
Vermilion	6,752	312	8,664	387
Lorain	1,693	86	116	5
Fairport			39	2
Ashtabula	12	0	174	7
Total	2,779,354	184,184	2,634,551	160,250

TABLE 8. Carp production (number) and value (dollar) by port in the Saginaw Bay area of Lake Huron in 1975 and 1976.

Port	1975		1976	
	Number	Value	Number	Value
AuGres	47,748	3,387	61,596	4,585
Bay Port	140,562	7,067	133,954	7,303
Detour Village	12	1	20	1
Linwood	74,818	5,717	57,500	3,894
Pinconning	167,581	14,057	87,856	7,132
Sebawaing	20	1	-	-
Standish	198,342	20,872	375,098	40,242
Total	629,083	51,102	716,024	63,157

TABLE 9. Carp production (number) and value (dollar) by port in the Green Bay area of Lake Michigan in 1975 and 1976.

Port	1975 Number	1975 Value	1976 Number	1976 Value
Wisconsin waters:				
Marinette	8	0	12	0
Peshtigo	103,939	5,892	3	0
Oconto	6,850	443	55,293	3,724
Pensaukee	84,081	672	48,645	788
Little Suamico	17,500	1,050	-	-
Suamico	34,035	870	1,459	11
Green Bay	1,883,448	76,549	525,849	11,447
Dyckesville	4	0	-	-
Little Sturgeon	558,548	28,155	43,135	2,585
Sturgeon Bay	179,548	9,671	73,185	7,111
Ellison Bay	459	11	129	6
Gills Rock	473	16	633	24
Baileys Harbor	73	1	55	1
Sheboygan	-	-	9	0
Total	2,879,908	123,968	748,407	25,697

TABLE 10. U.S. Great Lakes total and Michigan commercial carp landings (kg) and value (dollar) in 1976 (prepared by the Great Lakes Fishery Commission, 1977).

	Total		Michigan	
	kg x 10^3 (lbs x 10^3)	Dollars	kg x 10^3 (lbs x 10^3)	Dollars
Lake Erie	1,425.0 (3,141.7)	203,560	221.1 (487.4)	41,444
Lake Huron			324.8 (716.0)	63,157
Lake Michigan	339.6 (748.7)	25,700	82 (181)	-
Lake Superior	247 (545)	-	7 (15)	-
Great Lakes Total	2,092.0 (4,612.0)	292,600		

HARVEST AND MANAGEMENT CONSIDERATIONS

Production/effective effort by gear in 1975 and 1976 for areas of Lakes Erie (Monroe and Sandusky Bay), Huron (Saginaw Bay), and Michigan (Green Bay) as determined from data obtained from the U.S. Fish and Wildlife Service (Ann Arbor, Michigan) are presented in respective Tables 11, 12 and 13. Units of effort are as described by Hile (1962), except for the haul seine which was changed from one haul of 100-rod seine to one haul of a 1000-ft seine in 1974. Unfortunately, Michigan Department of Natural Resources index station catch data do not represent carp abundance because sampling stations are generally located in deeper offshore waters. Limited data from those catches in Lake Erie (gill and trap net) and Lake St. Clair (trap net) are reported in Tables 14 and 15, respectively.

Carp was the fifth most abundant species collected in Lake Erie trawl catches (1,333 kg) during Bowman's (1974) study; more than 85% came from the western basin, and from waters 7.3-11.0 m in depth. Based on a mean of the

TABLE 11. Production/effective effort by gear for the Monroe and Sandusky Bay areas of Lake Erie in 1975 and 1976.

	Ohio		Michigan	
Gear	1975	1976	1975	1976
2" gill net	719/104	14/3	-	-
shallow trap net	95,837/4,135	112,703/4,372	4,489/139	4,995/91
seine	2,171,689/3,307	2,171,096/3,441	434,715/461	482,413/401
pound net	964/13	-	-	-
set hooks	517/9	64/3	-	-

TABLE 12. Production/effective effort by gear for the Saginaw Bay area of Lake Huron in 1975 and 1976.

Gear	Michigan 1975	Michigan 1976
7" gill net	250,694/1,361	343,366/2,244
shallow trap net	145,707/4,438	160,007/3,977
seine	232,118/361	212,543/380
set hooks	-	88/13

Table 13. Production/effective effort by gear for the Green By area of Lake Michigan in 1975 and 1976.

Gear	Wisconsin 1975	Wisconsin 1976	Michigan 1975	Michigan 1976
2" gill net	784/64	206/19	-	-
3" gill net	171,000/53			
4" gill net	2,484/173	68/8	-	-
7" gill net	501,474/772	170,487/359		
fyke net	45,300/840	43,200/1,539		
seine	2,055,975/469	484,600/115		
pound net	228/7	-	10/15	96/14
otter trawl	84,006/320	48,645/308	-	-

Table 14. Lake Erie gill net (spring, 1975) and trap net (21 April to 28 May, 1978) catch summaries.

Size group (mm)	Gill net*	Trap net**
152		1
178	3	3
203	4	6
229	14	7
254	36	2
279	40	4
305	29	4
330	30	7
356	27	9
381	22	5
406	22	9
432	13	3
457	8	11
483	11	13
508	1	7
533	6	6
559	2	2
584	4	1
610	5	5
635		2
660		0
686		0
762		1
Total no. measured	227	108
Total weight (kg)	184	
Total catch	391	239
Catch per unit effort	18.10	5.09

* 1000 ft. effort
** 47 units of effort at 3 - 5.5 m

TABLE 15. Lake St. Clair trap net catch data.

Size group (mm)	North Channel 25 Oct - 31 Nov 1977, 3-3.4 m	Middle of Anchor Bay 27 May - 31 June 1977, 3-3.4 m
381	-	1
406	1	1
432	1	6
457	3	6
483	5	7
508	6	8
533	4	5
559	4	5
584	7	4
610	4	5
635	3	5
660	4	2
686	1	2
711	1	3
737	0	2
762	-	1
787	1	0
838	-	1
Total measured	45	64
Total weight (kg)	227	499
Total catch*	533	241
Catch per unit effort*	12.11	5.13

* North Channel, Fall 1976: Total Catch: 331 kg
CPUnE: 30.09

Middle of Anchor Bay, Spring, 1976: Total Catch: 486 kg
CPUnE: 9.92

past 63 yrs, recent carp landings in Ohio waters of Lake Erie have been above average; production is greatest in the area from Toledo to Huron (District 1) and in Sandusky Bay (District 4) (Ohio Department of Natural Resources, 1977). Seines are particularly effective in District 1 and trap nets in District 4. Seines accounted for 97% of the Ohio Lake Erie commercial harvest of carp in 1977 (Scholl 1978). However, gill nets were superior to seines and trawls for harvesting carp from Elephant Butte Lake, New Mexico (Jester 1974).

Buettner (1975) determined the average carp production in Lakes Erie, Huron, Michigan, and Superior based on 1970-1974 production figures. For Michigan waters of Lake Erie (District 1), 111,584 kg (246 lbs x 10^3) were collected by seine (April-August, October and December). In 1973, 15,876 kg (35 lbs x 10^3) were collected by trap net (April-June).

In Lake Huron, carp accounted for 77.8% of the total trawl catch in lower Saginaw Bay in 1963 (U.S. Department of Interior 1968). Potagannissing Bay is said to support such a large carp population that reduced competition from these animals could allow the smallmouth bass population to increase (Tack pers. comm.). Michigan waters of Lake Huron (District 4) in 1970-74 yielded 270,795 kg (597 lbs x 10^3) by 7-inch gill net collections (January-November), 102,512 kg (226 lbs x 10^3) by seine (May-June and November-December), and 81,193 kg (179 lbs x 10^3) by trap net (August-October) (Buettner 1975). A large proportion of carp harvested in Michigan comes from Saginaw Bay. Exceptionally good catches can be made with both standard monitoring trawls and extra-large mesh (8-9 inch) gill nets (U.S. Department of the Interior 1968). Carp comprise a substantial portion of the commercial catch from Green Bay and Lake Winnebago, Wisconsin (Wells and McLain 1973). They were the fourth most abundant species by weight landed by trawl from Green Bay in 1963-1965, particularly from south of Peshtigo Point at depths from 9.1 to 27.4 m (Reigle 1969).

Wells and Mclain (1973) note that carp are taken in nearly all shallow water areas of Lake Michigan, particularly the southeastern portion. However, very few carp appear in gill net catches at either Lake Huron proper or Lake Michigan index station sites (Patriarche pers. comm.). Carp have been taken by gill net in shallow areas near Ludington, Michigan, but very few have been collected from 1972 to the present (Liston pers. comm.). For the 1970-1974 period, Buettner (1975) determined that carp production in Lakes Michigan and Superior was negligible.

Carp are easily harvested in the spring and early summer when they migrate into shallow water. Kelly (pers. comm.) has suggested that the purse seine, which can be used over sand, mud, or gravel bottoms up to 33.5 m in depth, would be particularly effective in a carp spawning area. Winter movement of carp into deep water could interfere with year-round operation of the fishery but because they aggregate to overwinter, ultrasonic transmitters could be used to locate large concentrations. For instance, commercial fishermen, advised of two locations of carp concentrations, harvested 46,400 kg from Lake Mendota, Wisconsin (Johnsen and Hasler 1977). Scanning sonar has been used with moderate success to separate populations of carp, buffalo, and sheepshead. The length of the fishery season might thus be extended if similar techiques were used in the Great Lakes.

Alternatively, power plants have been observed to "attract" fish, and thereby could reduce time spent searching for carp. Heated water discharges may provide an environment which could allow these fish to remain in an area and be harvested throughout the year. Surveys made in 1968-1973 indicate that carp were definitely "attracted" by the warm waters of the heated discharge at the Palisades Nuclear Power Plant site on Lake Michigan (Patriarche 1975). Similarly, they were "attracted" to the discharge canal at the Monroe Power Plant site on Lake Erie at all times during the year (Lavis and Cole 1976). This tendency probably does not change from season to season or from day to night (Neill and Magnuson 1974), and could minimize the effort needed to harvest this presently underutilized species from such areas (Lavis and Cole 1976). Power plants can cause mortality because of thermal, mechanical, and biocidal effects (Marcy 1975), but the extent of this is not known.

Considering their traditionally low market value, landings of carp are generally dictated by market demand, or lack of it, rather than by their abundance or availability to the market. Trap net fisherman, particularly in western Lake Erie, indicate that increased harvest would be very possible were there a market for the product. Lack of a viable market thus limits, and in fact discourages, investment in the fishery.

The development of mechanical meat-bone separators, or deboners, could facilitate product development and increase the value of carp offered on the market as minced fish. Although progress has been made in food science technology (Iredale and Shaykewich 1973, Iredale et al. 1974, Iredale and York 1976), a serious marketing effort is still needed to create consumer demand for underutilized species. Financial resources for research and technological development are small, and funds necessary for conversion or modification of processing facilities are scarce. In view of costs (processing, transportation, etc.) it may be advisable at this time to concentrate on developing local markets. Marketing studies must address the problem of reliability of consumer response and the stability of fish production. In addition, there may be a problem with contaminants, particularly PCBs, although conclusive data are not readily available (Wright pers. comm.). Table 16 provides a summary of 1975 analyses for several Great Lakes contaminants.

There are many problems associated with the commercial harvest of carp, only a few of which have been considered here (see also Dawson _et al_. 1975). The fact that there are no reliable means to assess the Great Lakes carp stocks is particularly significant. In Minnesota, rough fish are removed both by state crews and by private commercial fishermen operating under contract or permit, and records are kept of the volume produced by removal operations. Records of commercial harvest and sales of carp are also available from Wisconsin.

However, weather, market prices, and species availability all are involved in addition to abundance in determining the amount of fish removal from a given lake in a given year, so available data are questionable for use in determining

TABLE 16. Summary of analyses for contaminants (ppm) of carp from Lakes Erie and Huron (Michigan Department of Agriculture 1975).

Zone	Size (No.)	DDT	PCB	Mercury
Lake Huron				
District 4	<5 lbs. (3)	0.11	0.93	0.07
	>5 lbs. (5)	0.39±0.06	2.00±0.57	0.06±0.00
District 5	<5 lbs. (10)	0.22±0.18	0.92±0.86	0.16±0.09
	>5 lbs. (2)	0.72	2.75	0.08
Lake Erie				
Monroe	<5 lbs. (11)	0.13±0.11	3.17±1.95	0.21±0.11
	>5 lbs. (1)	0.24	3.90	0.41

annual yield. And stock assessment in the Great Lakes is far more complicated than in smaller lakes. Past records, by month and by gear, of carp production and effective effort in areas of concerted effort to capture this species are available and may provide some relative indication of potential harvest. Conservative quotas might be set initially from historical yield data and these could be refined once a fishery became active. More accurate information on many aspects of the biology and ecology of the Great Lakes carp population (e.g. natural mortality and predation rates, reproductive success, modifications for specific Great Lakes problems and fish interactions, and changes in mortality rates once fish became vulnerable to the fishery), is needed before reliable estimates of the size and status of carp stocks in the Great Lakes can be made. Given present information, any expansion of the carp fishery should only be made slowly and with caution.

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APPENDIX A. Production (lbs x 10^3) of carp from 1892 to 1977 in Lakes Erie, St. Clair, Huron, and Michigan.

	Lake Erie			Lake St. Clair connecting waters	Lake Huron		Lake Michigan		
Year	Ohio	Mich.	Total	Michigan	Saginaw Bay	Mich.	Wisconsin	Mich.	Total
1892	–	20	–						
1893	–	–	636				–	–	2
1894	–	226	–				–	–	–
1895	–	–	–				–	–	–
1896	–	–	–				–	–	–
1897	–	–	–				–	–	–
1898	–	–	–				–	–	–
1899	3417	195	3634		–	6	6	9	25
1900	–	–	–		–	–	–	–	–
1901	–	–	–		–	–	–	–	–
1902	–	–	–		–	–	–	–	–
1903	3058	437	3547		–	37	37	4	535
1904	–	–	–		–	–	–	–	–
1905	–	–	–	680	–	–	–	–	–
1906	–	–	–	190	–	–	–	–	–
1907	–	–	–	–	–	–	–	–	–
1908	7140	1684	8893	237	–	407	407	4	483

(continued)

APPENDIX A (continued)

Year	Lake Erie			Lake St. Clair connecting waters	Lake Huron		Lake Michigan		
	Ohio	Mich.	Total	Michigan	Saginaw Bay	Mich.	Wisconsin	Mich.	Total
1909	-	-	-	-	-	-	-	-	-
1910	-	-	-	-	-	-	-	-	-
1911	-	-	-	-	-	-	-	4	-
1912	-	718	-	-	-	176	-	49	-
1913	1266	384	-	-	-	375	-	6	-
1914	6284	5590	12024	-	-	14	-	-	-
1915	7250	2186	9615	550	-	516	-	9	-
1916	4631	1138	1138	-	-	-	-		-
1917	4314	1404	1404	85	-	1145	244	2	247
1918	2978	1152	1152	-	633	643	-	5	-
1919	2047	876	876	-	1104	1109	-	7	-
1920	2331	1685	1685	-	813	1721	-	5	-
1921	4815	1661	1661	-	845	857	-	4	-
1922	1892	1914	1914	260	1038	1169	744	6	749
1923	1882	1236	1236	-	296	297	-	7	-
1924	394	833	833	-	467	497	-	7	-
1925	1097	1201	1201	-	396	427	-	12	-

(continued)

APPENDIX A (continued)

	Lake Erie			Lake St. Clair connecting waters	Lake Huron		Lake Michigan		
Year	Ohio	Mich.	Total	Michigan	Saginaw Bay	Mich.	Wisconsin	Mich.	Total
1926	3001	1150	1150	-	349	414	-	7	-
1927	734	960	960	-	1892	1939	-	6	-
1928	341	681	681	-	255	283	-	11	-
1929	467	511	511	-	387	390	602	5	608
1930	1243	631	631	-	808	868	479	10	491
1931	1459	931	931	-	848	875	818	11	831
1932	1790	1093	1093	-	1002	1011	252	29	284
1933	1284	779	779	-	960	960	885	31	919
1934	1062	527	527	-	1007	1007	1309	9	1320
1935	1279	658	658	-	1033	1033	1027	22	1054
1936	2005	679	2687	-	732	770	1435	47	1486
1937	1544	577	2153	-	959	978	1901	24	1925
1938	1458	709	2209	-	609	631	1829	41	1873
1939	1843	586	2445	112	638	739	1601	81	1689
1940	2016	461	2486	121	514	644	1877	96	1979
1941	1895	655	2555	184	634	669	1902	148	2057
1942	1678	764	2448	75	581	753	1638	92	1745

(continued)

APPENDIX A (continued)

Year	Lake Erie			Lake St. Clair connecting waters	Lake Huron		Lake Michigan		
	Ohio	Mich.	Total	Michigan	Saginaw Bay	Mich.	Wisconsin	Mich.	Total
1943	1625	598	2232	53	1085	1243	1459	36	1511
1944	1327	599	1932	125	832	1151	1162	32	1217
1945	1668	484	2153	144	2145	2370	1768	48	1832
1946	1340	539	1881	148	1462	1669	1194	73	1273
1947	1309	444	1755	73	1232	1327	975	55	1032
1948	1059	534	1596	186	1345	1459	1032	63	1095
1949	1678	555	2234	205	859	952	1321	38	1361
1950	1406	465	1879	193	984	1181	1115	21	1146
1951	1559	672	2231	87	1439	1677	1112	23	1136
1952	2108	893	3002	25	1398	1637	1069	36	1106
1953*	1793	1183	2976	55	1154	1361	1098*	19	1117
1954	2618	1138	3756	92	1262	1432	1330	13	1344
1955	2407	900	3308	67	1273	1373	1847	9	1856
1956	2713	711	3425	107	1164	1218	1822	29	1851
1957	3146	620	3768	160	1267	1309	2032	9	2041
1958	3880	997	4880	185	2186	2212	1227	15	1242
1959	2966	1042	4015	119	1211	1304	1923	14	1937

* From 1953 on, over 95% of the Lake Michigan catch has been from Green Bay.

(continued)

APPENDIX A (continued)

	Lake Erie			Lake St. Clair connecting waters	Lake Huron		Lake Michigan		
Year	Ohio	Mich.	Total	Michigan	Saginaw Bay	Mich.	Wisconsin	Mich.	Total
1960	3229	1341	4572	136	1285	1333	1382	24	1416
1961	3398	1298	4699	37	1401	1437	1801	41	1842
1962	3487	1276	4763	-	1558	1638	1200	2	1206
1963	2504	833	3338	-	1536	1647	1251	27	1277
1964	2274	636	2909	8	938	1003	1305	14	1320
1965	2384	806	3191	-	1384	1425	2006	10	2016
1966	2773	929	3702	-	769	832	2711	2	2714
1967	2556	485	3043	-	866	972	2531	1	2542
1968	2335	348	2683	-	1011	1016	2328	9	2352
1969	2587	432	3020	-	1258	1298	2118	1	2119
1970	3042	332	3401	-	1224	1224	1928	2	1935
1971	3262	115	3378	-	1387	1388	2463	1	2465
1972	2987	261	3251	-	888	888	1324	1	1326
1973	2136	254	2393	-	766	766	3208	3	3211
1974	2779	330	3110	-	684	684	3244	*	3244
1975	2779	439	3221	-	629	629	2880	*	2880
1976	2634	487	3142	-	716	716	748	*	749
1977	2752	354	3108	-	787	787	527	*	527

APPENDIX B. Grand total, U.S. total, and Michigan total production (lbs x 10^3) of carp in the Great Lakes from 1892 to 1977.

Year	Grand Total	U.S. Total	Michigan Total
1892			20
1893		638	
1894			226
1895			
1896			
1897			
1898			
1899		3666	204
1900			
1901			
1902			
1903		4123	441
1904			
1905			
1906			
1907			
1908		9788	1688
1909			
1910			
1911			4
1912	185	176	767
1913	425	376	390
1914	13529	12039	5590
1915	11175	10132	2195
1916	6910	5860	1139
1917	8268	7193	1406
1918	5684	4815	1800
1919	4682	4073	1985
1920	6396	5823	3410

(continued)

APPENDIX B (continued)

Year	Grand Total	U.S. Total	Michigan Total
1921	7907	7416	2523
1922	6262	5837	3088
1923	4221	3773	1541
1924	2197	1779	1316
1925	3092	2767	1640
1926	4927	4636	1571
1927	3981	3655	2905
1928	1735	1332	974
1929	2374	2005	906
1930	3721	3283	1509
1931	4702	4145	1817
1932	4882	4262	2133
1933	4671	3964	1781
1934	4711	3969	1559
1935	4936	4107	1759
1936	5530	4956	1496
1937	5680	5142	1579
1938	5419	4848	1381
1939	6411	5790	1406
1940	6428	5873	1201
1941	5866	5375	1472
1942	5493	4998	1609
1943	5601	5051	1849
1944	4762	4316	1782
1945	6839	6460	2902
1946	5265	4839	2281
1947	4468	4130	1825
1948	4567	4171	2056
1949	4974	4568	1546
1950	4776	4209	1667
1951	5537	5054	2372
1952	6283	5759	2566
1953	6148	5467	2562

(continued)

APPENDIX B (continued)

Year	Grand Total	U.S. Total	Michigan Total
1954	7236	6543	2583
1955	7234	6547	2282
1956	7583	6503	1958
1957	7828	7128	1938
1958	9027	8344	3224
1959	8246	6782	2360
1960	8027	7343	2698
1961	8636	8027	2776
1962	8100	7646	2915
1963	7000	6298	2507
1964	5770	5271	1653
1965	7153	6652	2240
1966	7725	7263	1762
1967	7126	6579	1458
1968	6688	6100	1373
1969	7340	6507	1731
1970	7142	6582	1558
1971	7830	7288	1503
1972	6052	5493	1150
1973	6948	6389	1023
1974	7546	7054	1014
1975	7265	6732	1068
1976	5130	4612	1203
1977	4800	4424	1141

APPENDIX C. U.S. and Michigan production (lbs x 10^3) of all species from 1879 to 1977 in the Great Lakes.

	U.S. Total*					Michigan Total				
Year	Ontario	Erie	Huron	Mich.	Superior	Erie	Huron Proper	Saginaw Bay	Mich.	Superior
1879	3640	29087	7205	23142	3817			7205		
1880										
1881										
1882										
1883										
1884										
1885	2398	51457	11457	23485	8826			11457		
1886										
1887										
1888										
1889	2692	63563	15429	26007	7884			15429		
1890	3446	65224	10330	26434	6116			10330		
1891			12702				12702			
1892			11776	28039			11776			
1893	928	43136	14816	40723	7979		14816			
1894			14677	42728			14677			
1895			14670	38212			14670			
1896			13541	47004			13541			

(continued)

APPENDIX C (continued)

	U.S. Total*					Michigan Total				
Year	Ontario	Erie	Huron	Mich.	Superior	Erie	Huron Proper	Saginaw Bay	Mich.	Superior
1897	921	35954	12393	39634	6028		12393			
1898			13448				13448			
1899	2310	58912	14320	37547	6335		14320			
1900			14151				14151			
1901			16813				16813			
1902			20003				20003			
1903	1073	23937	18566	36623	13986		18566			
1904			17989				17989			
1905			16895				16895			
1906			16860				16860			
1907			17821				17821			
1908	817	42466	13075	47356	9601		13075			
1909										
1910										
1911				26493						
1912			13876	24814			13876			
1913	208		11258	27091	10173		11258			
1914	296	54144	8291	28201	12475		8291			

(continued)

APPENDIX C (continued)

	U.S. Total*					Michigan Total				
Year	Ontario	Erie	Huron	Mich.	Superior	Erie	Huron Proper	Saginaw Bay	Mich.	Superior
1915	384	59773	10245	31642	9543		10245			
1916	344	41195	17212	21984	8350		17212			
1917	628	43649	12577	31674	9911		12577			
1918	464	51479	14977	27708	11553		14977			
1919	544	35165	15242	23922	10527		15242			
1920	330	32232	11541	19999	9066		11541			
1921	1914	46717	9607	21978	7525		9607			
1922	965	40898	13279	19394	6571		13279			
1923	841	44377	10102	15380	7585		10102			
1924	993	40273	8877	18316	9510		8877			
1925	446	26644	12600	21341	12555		12600			
1926	788	25057	13128	20494	13715		13128			
1927	698	23795	15706	23679	15630		15706			
1928	854	19762	9993	17998	13420		9993			
1929	948	18646	8829	26186	16565		3525	5304		
1930	682	29584	15317	26962	14867		5931	9386		
1931	442	34800	16467	24374	11258		6793	9674		
1932	521	33761	15414	19305	10369		6176	9238		

(continued)

APPENDIX C (continued)

	U.S. Total*					Michigan Total				
Year	Ontario	Erie	Huron	Mich.	Superior	Erie	Huron Proper	Saginaw Bay	Mich.	Superior
1933	527	25120	13471	21002	10631	1422	6544	6927	6516	
1934	717	32098	14390	26055	17620		6605	7785	8252	
1935	770	36749	13640	24432	17872	1130	6269	7371	9659	6189
1936	601	26925	12734	24478	16008	1078	5066	7668	8612	6548
1937	618	27619	11844	25602	16012	998	4343	7501	9380	6183
1938	690	28663	12033	24101	14856	1219	4588	7446	10266	5192
1939	1456	28663	13333	22448	16783	1251	4133	9200	8425	5857
1940	1359	22944	9012	22601	20672	1042	2624	6387	9201	6789
1941	597	22063	8727	22931	22111	1124	2385	6342	9843	8438
1942	325	24131	8466	21413	19228	1321	2369	6097	8738	7754
1943	395	27115	8610	22175	18372	1261	2197	6412	8768	7061
1944	400	28837	6433	19252	19245	1158	2215	4217	6829	7691
1945	492	28631	7475	22090	18725	1157	2216	5259	9080	6248
1946	384	29121	7147	22392	17848	1426	1670	5478	9048	6538
1947	464	19818	8034	24958	14987	1191	2838	5197	10452	5868
1948	386	26502	8838	27023	19221	1248	3614	5223	12799	7253
1949	351	34249	5580	25573	17730	1178	1917	3663	11900	6876
1950	189	23982	5073	27078	12584	1136	1537	3536	12223	4721

(continued)

APPENDIX C (continued)

	U.S. Total*					Michigan Total				
Year	Ontario	Erie	Huron	Mich.	Superior	Erie	Huron Proper	Saginaw Bay	Mich.	Superior
1951	498	20921	5521	27648	14035	1183	1399	4123	12898	5418
1952	668	25351	6118	32061	15465	1395	1397	4721	15875	5844
1953	196	27347	5498	28834	13650	1800	1328	4169	13068	4647
1954	311	28340	5421	30291	15385	1770	1080	4341	14239	5801
1955	233	26796	4561	30036	13581	1505	958	3603	13964	5408
1956	180	30744	3635	30798	13591	1347	834	2801	14207	5437
1957	206	29706	3341	27223	13565	1259	807	2535	11655	6222
1958	263	22575	5094	27771	13194	1757	1550	3545	12177	6459
1959	226	22433	5041	20808	14956	1570	2408	2633	8154	7558
1960	256	21258	6338	24311	13771	1901	3376	2962	9135	7647
1961	351	19563	6918	25559	14749	1921	3987	2931	7344	8352
1962	233	19660	5880	23475	12602	1838	3281	2599	7584	6819
1963	233	17238	5206	21021	12125	1334	2488	2718	6382	7404
1964	267	13354	4095	26201	9642	1128	1747	2348	8563	5976
1965	217	13524	4674	26994	8748	1257	1789	2885	8337	5481
1966	237	12698	3769	42764	8285	1389	1212	2557	11522	4604
1967	284	11615	3212	58951	7895	1052	799	2412	20966	3991
1968	342	11920	2678	45810	6574	778	484	2194	17412	3084

(continued)

APPENDIX C (continued)

	U.S. Total*					Michigan Total				
Year	Ontario	Erie	Huron	Mich.	Superior	Erie	Huron Proper	Saginaw Bay	Mich.	Superior
1969	294	11050	2897	47489	5239	744	480	2417	15416	2891
1970	333	9546	2411	53090	5009	420	183	2227	16197	2141
1971	305	8842	2815	44680	6182	173	201	2614	10113	2492
1972	282	7920	1984	43771	4471	366	277	1706	11684	2017
1973	300	8281	1942	50708	5426	371	152	1789	11540	2028
1974	324	9826	1718	59598	5524	374	256	1462	11105	2144
1975	233	8484	1858	45348	4735	501	381	1477	7588	2062
1976	194	9054	2160	48369	5878	618	460	1700	9503	1650
1977	207	9682	2069	55473	4505	471	410	1659	7515	1520

*Reported catch from New York waters of Lake Ontario; New York, Pennsylvania, Ohio, and Michigan waters of Lake Erie; Michigan waters of Lake Huron; Wisconsin, Michigan, Illinois, and Indiana waters of Lake Michigan; Wisconsin and Michigan waters of Green Bay; and Wisconsin, Michigan, and Minnesota waters of Lake Superior.

APPENDIX D. Grand total, U.S. total, and Michigan total production (lbs x 10^3) of all species in the Great Lakes from 1879 to 1977.

Year	Grand Total	U.S. Total	Michigan Total
1879	76238	66891	7205
1885	121290	97623	11457
1889	143937	115575	15429
1890	140196	111550	10330
1891		12702	12702
1892		39815	11776
1893	134211	107582	14816
1894		57405	14677
1895		52882	14670
1896		60545	13541
1897	115470	94930	12393
1898	145530	13448	13448
1899		119424	14320
1900		14151	14151
1901		16813	16813
1902		20003	20003
1903	113023	94185	18566
1904		17989	17989
1905		16895	16895
1906		16860	16860
1907		17821	17821
1908	137789	113315	13075
1909			
1910			
1911		26493	
1912		38690	13876
1913		48730	11258
1914	135138	103407	8291
1915	149865	111587	10245
1916	121987	89085	17212
1917	135237	97439	12577

(continued)

APPENDIX D. (continued)

Year	Grand Total	U.S. Total	Michigan Total
1918	145367	106181	14977
1919	115947	73168	11651
1920	104848	73168	11541
1921	117625	87741	9607
1922	113127	81107	13279
1923	112433	78285	10102
1924	112461	77969	8877
1925	100050	73586	12600
1926	97900	73182	13128
1927	107354	79508	15706
1928	89040	62027	9993
1929	98388	71210	8829
1930	115745	87412	15317
1931	114423	87341	16467
1932	104313	89675	15414
1933	94449	70751	21409
1934	116144	90880	22642
1935	116137	87011	30618
1936	118363	90570	28972
1937	111099	81001	28405
1938	108216	79299	28711
1939	110193	82683	28866
1940	98355	76588	26043
1941	97365	76429	28132
1942	94228	73563	26279
1943	101227	76667	25699
1944	99312	74167	22110
1945	105541	77413	23960
1946	104000	76919	24160
1947	87466	68261	25446

(continued)

APPENDIX D. (continued)

Year	Grand Total	U.S. Total	Michigan Total
1948	105108	81968	30137
1949	111144	83483	25534
1950	95408	68906	23153
1951	92771	68623	25021
1952	110017	79663	29232
1953	112473	75525	25012
1954	119614	79748	27231
1955	113769	75207	25146
1956	131165	78948	24636
1957	117783	74041	22478
1958	107303	68897	25488
1959	103562	63464	22323
1960	103854	65934	25021
1961	112508	67140	24535
1962	115386	61850	22121
1963	99818	55823	20326
1964	87604	53559	19762
1965	97736	54157	19749
1966	115539	67726	21284
1967	126793	81957	29220
1968	114543	67324	23952
1969	122548	66969	21948
1970	110556	70389	21169
1971	100930	62824	15593
1972	97210	58428	16051
1973	114919	66657	15881
1974	125353	76990	15341
1975	101087	60658	12009
1976	102055	65655	13931
1977	118000	71936	11575