ILLINOIS
NATURAL
HISTORY
SURVEY

Non-native Fishes Inhabiting the Streams and Lakes of Illinois

Christopher A. Laird and Lawrence M. Page
Center for Biodiversity
Illinois Natural History Survey

Illinois Natural History Survey Bulletin
Volume 35, Article 1
March 1996

Illinois Natural History Survey, Lorin I. Nevling, Chief
A Division of the Illinois Department of Natural Resources

A catalog of the publications of the Illinois Natural History Survey is available without charge from the address below. A price list and an order blank are included with the catalog.

Illinois Natural History Survey
Distribution Center
Natural Resources Building
607 East Peabody Drive
Champaign, Illinois 61820

Citation:
Laird, C.A., and L.M. Page. 1996. Non-native fishes inhabiting the streams and lakes of Illinois. Illinois Natural History Survey Bulletin 35(1):1-51.

Editor: Thomas E. Rice

US ISSN 0073-4918

Printed by Authority of the State of Illinois
(X41259-2M-3-96)

Contents

Acknowledgments

Illustrations on pages 7, 10, 11, 13, and 15 are reprinted from *The Fishes of Illinois* (Smith 1979). We are indebted to Craig W. Ronto for the additional illustrations; to Dan Sallee for first suggesting the project to us and reviewing the manuscript; to Brooks M. Burr for allowing access to records in the Fish Collection of Southern Illinois University at Carbondale and reviewing the manuscript; to Richard E. Sparks, J. Ellen Marsden, and Robert J. Maher for information on the distribution of exotic fishes in Illinois; and to Thomas E. Rice for improving the manuscript.

Introduction

At the turn of the century, only one non-native* species of fish, the common carp, was established in Illinois (Forbes and Richardson 1908). In contrast, by 1979, six non-native fishes were reproducing in Illinois (Smith 1979) and, in 1996, only 17 years later, seven more non-native fishes have become established (Table 1). In addition to these 13 species, 9 non-native fishes are periodically stocked in Illinois or stray into the state from nearby states where they are stocked (Table 1).

Because several of these fishes only recently have become introduced or are expanding their ranges in Illinois, they are not familiar to most residents of the state. The keys and descriptions in this publication are intended to assist in the identification and monitoring of the impacts of these 22 species. Also included for each species is a brief summary of its ecological and life history characteristics, and a discussion of its Illinois distribution. Additional information can be found in accounts by Smith (1979) and by Burr (1991), who reviewed various aspects of recent changes in the fish fauna of Illinois.

*A non-native species is defined as one that did not occur in Illinois historically; an established non-native is one that now lives and reproduces in Illinois waters as a result of human influence. Two species, the white catfish *(Ameiurus catus)* and the Rio Grande cichlid *(Cichlasoma cyanoguttatum)*, were once considered established but are no longer thought to be reproducing in Illinois (Smith 1979; Burr 1991).

Table 1. Non-native fishes in Illinois.

Species established by 1979	Additional species established by 1996	Other species periodically released in Illinois or nearby states
sea lamprey, *Petromyzon marinus*	grass carp, *Ctenopharyngodon idella*	silver carp, *Hypophthalmichthys molotrix*
alewife, *Alosa pseudoharengus*	bighead carp, *Hypophthalmichthys nobilis*	rudd, *Scardinius erythrophthalmus*
threadfin shad, *Dorosoma petenense*	Oriental weatherfish, *Misgurnus anguillicaudatus*	rainbow trout, *Oncorhynchus mykiss*
rainbow smelt, *Osmerus mordax*	inland silverside, *Menidia beryllina*	coho salmon, *Oncorhynchus kisutch*
common carp, *Cyprinus carpio*	threespine stickleback, *Gasterosteus aculeatus*	chinook salmon, *Oncorhynchus tshawytscha*
goldfish, *Carassius auratus*	white perch, *Morone americana*	pink salmon, *Oncorhynchus gorbuscha*
	round goby, *Neogobius melanostomus*	brown trout, *Salmo trutta*
		Atlantic salmon, *Salmo salar*
		striped bass, *Morone saxatilis*

Environmental Impacts of Non-native Fishes

None of the introduced fishes has enhanced the plight of a native species or a natural aquatic ecosystem in Illinois and, thus, none can be said to have had a beneficial environmental impact. Instead most, and perhaps all, can be shown to have had negative environmental impacts.

Perhaps best known is the negative impact of the parasitic sea lamprey on native fishes of Lake Michigan. The sea lamprey was introduced from Atlantic Slope drainages into Lake Michigan in the 1930s and led to dramatic declines in the native, commercially valuable lake trout and other salmonids. Another familiar example of environmental degradation caused by an introduced species was the pollution of Lake Michigan beaches by the massive die-offs of alewives, another introduced Atlantic Slope species, in the 1960s.

Environmental damage caused by other introduced species is less visible and less known but perhaps only because the extent of their damage has yet to be understood. Non-native species compete with related or ecologically similar native species for food, spawning areas, and other limited resources. For example, the bighead carp and silver carp, only recently introduced into North America from Eurasia, feed on plankton, food of the larvae of all native fishes and all native mussels. If these two species of carp become common in Illinois, they may significantly reduce populations of native species by limiting successful reproduction.

Non-native species may alter the habitat in ways that make it unsuitable for native species. For example, the common carp, another transplant from Eurasia, destroys vegetation and increases water turbidity by rooting in the substrate, causing a loss of habitat for species requiring vegetation and clear water. The grass carp was brought to North America from Asia to feed on plants in farm ponds and other water bodies where an abundance of vegetation is considered a problem. However, populations of many native stream- and lake-inhabiting plants already are being depleted because of excessive siltation resulting from poor agricultural practices and the use of herbicides. Silt smothers the plants, and herbicides poison them. In addition to the lamentable loss of the vegetation itself, many fishes and other aquatic animals are dependent on aquatic plants as places to hide, to spawn, and to find food. Several fishes now extirpated from Illinois, and several threatened and endangered fishes (e.g., the bigeye chub, bigeye shiner, starhead topminnow, and banded killifish) are those that are strongly dependent upon vegetation for survival, and it is apparent that their loss is due at least in part to the loss of aquatic vegetation. The grass carp is going to make their survival in Illinois even more difficult. Many species of waterfowl are heavily dependent on aquatic vegetation for food, and their habitats also are negatively affected by the common and grass carps.

Non-native fishes can have negative impacts by feeding on native species. For example, two recent arrivals in Illinois, the threespine stickleback and the round goby, are known to feed on the eggs and larvae of fishes, including sport fishes. The various species of Pacific salmon being stocked in Lake Michigan, and the striped bass, occasionally stocked in southern Illinois, are acquired because they are large sport fishes of interest to anglers. However, as adults they feed on native fishes, including threatened and endangered species and native species also considered desirable as sport fishes, such as sunfishes and basses.

Even introductions considered from economic and recreational perspectives to be successful carry with them environmental and economic tradeoffs. Introductions rarely fulfill the hyperbole that accompanies them, and most damage the environment or result in an economic cost, or both. While the number of non-native species has been increasing in Illinois, the number of native fishes has declined from 187 species at the turn of the century (Forbes and Richardson 1908) to only 174 today. The loss of 13 species was due to a large number of factors relating to environmental degradation, probably including the introductions of exotic fishes. The general environmental impact of each introduced species is discussed in the next section.

Four of the 13 established non-native fishes—sea lamprey, alewife, threespine stickleback, and white perch—reached Illinois accidentally as the result of the Welland Canal, built in the 1820s to bypass Niagara Falls and connect Lake Ontario with Lake Erie. Two established species, the goldfish and Oriental weatherfish, escaped accidentally from ponds or were released by aquarists. One species, the round goby, arrived accidentally in the same manner as the zebra mussel *(Dreissena polymorpha)—in* ship bilge water. The remaining six species were brought to Illinois deliberately in an effort to improve fishing: common carp, grass carp, bighead carp, threadfin shad, rainbow smelt, and inland silverside. The six salmonids in Lake Michigan also have been stocked there in an effort to improve fishing.

The Identification of Non-native Fishes Found in Illinois

Keys are provided for the identification of non-native fishes found in Illinois. A key to the families of fishes appears first and leads the reader to the page where a key to species of a particular family is found. The family key includes native as well as introduced families. The keys to species include native species that are related or are similar in appearance and likely to be confused with introduced species. The keys are written as supplements to keys published in Smith's (1979) *The Fishes of Illinois*, and some parts of Smith's keys are reprinted verbatim. Non-native fishes can be identified with the following keys; however, if you suspect that the fish you are attempting to identify is a native species, you should consult Smith (1979). Species names in bold print are those of non-native fishes established or commonly found in Illinois; family names in bold print are those families that contain established or stocked species.

For some identifications, it will be best to begin with the family key and work your way through to the species. However, if you know from past experience that the fish you are working with is one of a few species (e.g., a shad), you can begin with a key to species.

Diagnostic counts given are those that are useful in separating closely related species. Lateral-scale counts (often referred to elsewhere as lateral-line scale counts) refer to the number of scales along the lateral line if the lateral line is present and complete, or along the mid-side if the lateral line is absent or incomplete. Maximum and common lengths are total (rather than standard) lengths.

Key to Families of Fishes Found in Illinois

(Those families in bold print contain non-native species)

1. Mouth without jaws; pectoral and pelvic fins absent; 7 gill openings on each side (lampreys) .... **Petromyzontidae** (p. 7)
   Mouth with jaws; pectoral fins always present, pelvic fins usually present; 1 gill opening on each side of head 2

2. Dorsal fin single (i.e., of soft rays only) and extending more than half of body length; anterior nostrils tubular 3
   Dorsal fin single or double (2 fins, first with spines); if single, extending much less than half of body length; anterior nostrils not tubular 4

3. Dorsal, caudal, and anal fins continuous; scales tiny, deeply imbedded; body snakelike (eels) .... Anguillidae
   Dorsal, caudal, and anal fins not continuous; scales large; body stout, more fishlike (bowfins)................................. Amiidae

4. Caudal fin heterocercal (vertebral column flexed upward into caudal fin) 5
   Caudal fin homocercal (vertebral column not flexed upward into caudal fin) 7

5. Caudal fin rounded; snout a bony, strongly toothed beak; body completely covered with scales (gars) .... Lepisosteidae
   Caudal fin forked; snout not a bony, strongly toothed beak; body not completely scaled 6

6. Snout long and paddle-shaped; without bony scutes (paddlefishes) . . . . Polyodontidae
   Snout conical or shovel-shaped; large bony scutes on head and along back and sides (sturgeons)........................ Acipenseridae

7. One set of paired fins (pectorals); eyes very small (cavefishes) . . . . . . Amblyopsidae
   Two sets of paired fins (pectorals and pelvics); eyes variable 8

8. Adipose (unrayed fatty) fin present 9
   No adipose fin 12

9. Large barbels present around mouth (catfishes) .... Ictaluridae
   No barbels 10

10. First 1 or 2 rays of dorsal and anal fms spiny; scales strongly ctenoid and rough to the touch; small, rather translucent fishes (trout-perches) .... Percopsidae
    All fin rays soft; scales cycloid and smooth to the touch; usually large, darkly pigmented fishes 11

11. No pelvic axillary process; lower jaw strongly projecting beyond upper; usually 70 or fewer scales in lateral line; conspicuously enlarged teeth on jaws and tongue (smelts) .... **Osmeridae** (p. 23)
    Axillary process at base of pelvic fin; jaws equal or lower jaw slightly projecting; usually more than 70 scales in lateral line; teeth not conspicuously enlarged (trout, salmon, whitefishes) .... **................................. Salmonidae** (p. 25)

12. Body elongate; 5 pairs of barbels around mouth (loaches) .... **Cobitidae** (p. 22)
    Body variable; 1 pair, a single, or no barbels around mouth 13

13. Conspicuous median barbel near tip of chin; dorsal and anal fins each with 60 or more rays (codfishes) .... Gadidae
    No median barbel near tip of chin; dorsal and anal fins each with fewer than 35 rays **14**

14. Anus between gill membranes (except in small young, which have anus farther back, but well in front of anal fin) (pirate perches) .... Aphredoderidae
    Anus situated just in front of anal fin . . . 15

15. Anterior dorsal fin represented by 2 to 9 spines not connected, or barely connected to one another by membranes (sticklebacks) .... **Gasterosteidae** (p. 34)
    Dorsal fin without isolated, unconnected spines 16

16. One dorsal fin with no more than 3 spiny rays 17
    One or 2 dorsal fins; if 1, anterior portion with more than 3 spiny rays 25

17. Dorsal fin with large stout spine (goldfish and introduced carp species) .... **................................ Cyprinidae (p.** 13)
    Dorsal fin without sharp spine 18

18. Head scaleless 19
    Head partly or entirely scaled 22

19. Axillary process at base of pelvic fin; conspicuous adipose eyelid 20
    No pelvic axillary process; no adipose eyelid 21

20. Midline of belly with sawtoothed edge; dorsal fin base situated well anterior to anal fin base; lateral line absent (herrings, shads) .... **Clupeidae** (p. 9)
    Midline of belly without sawtoothed edge; dorsal fin base situated partly or entirely over anal fin base; lateral line present (mooneyes) . ... Hiodontidae

21. Lips thickened, striate, and papillose (except in buffalos); anal fin usually situated posteriorly, its adpressed rays reaching, or almost reaching, caudal fin base; 10 or more dorsal rays (except in creek chubsucker, which has a sucking mouth and no lateral line) (suckers) . . . . Catostomidae
    Lips thin (except in suckermouth minnow); anal fin usually situated farther forward, its adpressed rays far short of caudal fin base; 9 or fewer dorsal rays (minnows). . ... **Cyprinidae (p. 13)**

22. Caudal fin forked; snout duckbeak-like; jaws with large canine teeth; scales small, more than 90 in lateral series (pikes) . . . . Esocidae
    Caudal fin rounded; snout not duckbeak-like; jaws without canine teeth; scales large, fewer than 50 in lateral series . . 23

23. Mouth terminal; no groove between snout and upper lip; pelvic fins originate closer to caudal fin base than to tip of snout (mudminnows) .... Umbridae
    Mouth upturned; upper lip separated from snout by deep groove; pelvic fins closer to tip of snout than to caudal fin base 24

24. Body with bars or stripes; anal fin of male without elongated anterior rays and not modified as an intromittent organ; body with bars or stripes (topminnows) .... Fundulidae (previously Cyprinodontidae)
    Body without bars or stripes; anal fin of male with elongated anterior rays and modified as an intromittent organ; body without bars or stripes (mosquitofishes) .... Poeciliidae

25. Pelvic fins fused to one another (gobies) . . .. **Gobiidae** (p. 40)
    Pelvic fins separate 26

26. Body unscaled; 4 or fewer pelvic rays (sculpins) .... Cottidae
    Body scaled; 5 or more pelvic rays 27

27. Large gap between small anterior and large posterior dorsal fins; origin of pelvic fin well behind origin of pectoral fin (silversides) .... **Atherinidae** (p. 33)
    Dorsal fins continuous or separated by narrow gap; origin of pelvic fin under or slightly behind origin of pectoral fin 28

28. Lateral line extends to end of caudal fin; base of first dorsal fin about half as long as base of second dorsal fin (drums) . . . . Sciaenidae
Lateral line, if present, not continued to end of caudal fin; base of first dorsal fin more than half length of second dorsal fin base 29

29. Three or more anal spines; body deep and slab-sided 30
One or 2 anal spines; body usually more or less fusiform (perches and darters) .... Percidae

30. Large spine on rear edge of gill cover; sawtoothed edge on preopercle (temperate basses) .... **Moronidae** (p. 36)
No spine on gill cover; smooth-edged preopercle (sunfishes) . . . . Centrarchidae

Petromyzontidae

Key to adult lampreys

1. Prominent black mottling on body and fins; 2 dorsal fins separated at base; to 120 cm (47 in.) (sea lamprey) .... **Petromyzon marinus**
No prominent dark mottling (body dark olive above, light below); slightly notched dorsal fin or 2 dorsal fins joined at base; to 39 cm (15.5 in.) .... native lampreys

***Petromyzon marinus, sea* lamprey**
Figure 1

Origin and Range

The sea lamprey is native to the Atlantic Ocean and Lake Ontario. The 1820 construction of the Welland Canal allowed this and other migratory fishes to bypass Niagara Falls and move from Lake Ontario to the western Great Lakes. The sea lamprey was first found in Illinois in 1936 attached to a lake trout from Lake Michigan (Hubbs and Pope 1937). Sea lampreys were so abundant in Lake Michigan during the 1940s and 1950s that they caused serious damage to the fishing industry (Shetter 1949). During the 1960s the sea lamprey population was reduced, at least in part, through the use of a chemical pesticide that kills lamprey larvae. This species is still present in Lake Michigan, but in reduced numbers.

Biology

The life history of the sea lamprey was described in detail by Applegate (1950). Great Lakes sea lampreys leave their lake only during the spawning season. Newly transformed adults migrate to deep, offshore areas of the lake during fall, winter, and early spring and remain until late summer, when they move to shallow water. They remain in shallow water until the next spring, when upstream migration occurs (Applegate 1950). Mature adults stop feeding prior to migration, and the digestive system atrophies. Adults die after spawning; consequently, the adult sea lamprey lives for 1-1.5 years.

Lampreys can travel long distances, commonly moving between lakes. One tagged individual was recaptured 628 km (393 mi) from its point of release (Moore et al. 1974). Sea lampreys are known to attach to the hulls of ships, further facilitating their movement. The habitat of the stream-dwelling ammocoetes consists of shallow areas with a sand/silt substrate for the first two years and deeper areas of the stream with a silt and detritus-covered bottom after two years (Manion and McLain 1971). Ammocoetes burrow into the substrate and filter feed, with only the oral hood protruding from the substrate (Applegate 1950). Diet consists of diatoms shortly after hatching and filamentous green algae, detritus, pollen, diatoms, desmids, and protozoans as ammocoetes (Creaser and Hann 1929). Adults are parasitic and feed by attaching to other fishes with the oral sucking disk, rasping a wound into the host and consuming body fluids. A secretion from the buccal glands helps prevent blood coagulation in the host and digests muscle to the point that it can be ingested by the lamprey (Scott and Crossman 1973). There is some evidence that fishes with soft scales, such as the lake trout, are preferred to those with harder scales.

Spawning usually occurs from May to July. Migration begins once the water temperature in the stream reaches 4.4°C (40°F), and sea lampreys may be present at the spawning site for 6-8 weeks before spawning activity begins. Migration ends when the lampreys reach shallow areas with a gravel substrate and strong current. Upstream runs can be as long as 181 km (121 mi), but are usually considerably shorter (Norman 1979). Spawning activity begins when water reaches a temperature of 10°C (50°F) and peaks at 16°C (61°F). Prior to spawning, a circular nest is constructed by removal of gravel with the sucking disk. The nest is usually constructed in a riffle or at its upstream margin in water that is 38-61 cm deep (15-24 in.) (Scott and Crossman 1973). Early in the season the male begins the construction but later, when males are more scarce, the female may initiate nest construction activity (Applegate 1950). Most nests are about 45 cm X 40 cm (17.7 in. X 15.7 in.), but often they are so close together that they are effectively joined and can extend for several meters (Manion and McLain 1971). During the spawning act the female attaches her sucking disk to a rock at the upstream end of the nest, the male attaches his sucking disk to her back, slightly behind the head, and wraps his body around her. The female vibrates while eggs and milt are released (Scott and Crossman 1973). Spawning continues for 16-48 hours, during which 20-40 eggs are released at intervals of 1-10 minutes (Applegate 1950). Most matings consist of one male and one female that remain paired throughout the spawning period, but other combinations, especially of multiple females with one male, are observed later in the season when males are outnumbered by females (Applegate 1950). The adhesive eggs are carried to the downstream end of the nest and covered by sand and gravel, which are stirred up by additional nest-building activities of the adults. The number of eggs released per female ranges from 24,000 to 107,000 (Becker 1983) and averages of 62,870 and 68,599 have been reported (Vladykov 1951; Manion 1972). Average numbers of larvae found in nests utilized by one pair of adults ranged from 2,627 to 4,029 (Manion 1968).

Eggs range from 0.8 to 1.3 mm in diameter and hatch in 11-14 days. The ammocoete stage is usually reached after 17-33 days (Manion and McLain 1971). Ammocoetes are typically found in areas with a soft substrate at least 10 cm (4 in.) thick (Applegate 1950). A study on the Big Garlic River in Michigan reported the following lengths at each age for larval lampreys: 1.3 cm (0.5 in.) at year 0, 3.9 cm (1.5 in.) at year 1, 6.3

cm (2.5 in.) at year 2, 8.0 cm (3.1 in.) at year 3, 9.2 cm (3.6 in.) at year 4, and 10.7 cm (4.2 in.) at year 5 (Manion and McLain 1971). Growth was considerably slower after this point with a size of 12.9 cm (5.1 in.) at 12 years (Manion and Smith 1978). Low ammocoete density and increasing stream size were both positively correlated with faster growth. Some movement took place before metamorphosis, but several ammocoetes had not moved more than a few meters in 5 years. Transformation of larvae into adults can begin in as few as 5 years (Manion and McLain 1971), although Stauffer (1962) found a minimum of 7 years. In the Garlic River some ammocoetes had not metamorphosed after 17 years (Becker 1983). Newly transformed adults range in length from 9.5 to 24.3 cm (3.7-9.6 in.) (Applegate et al. 1961) and average 14.0 cm (5.5 in.) (Manion and Stauffer 1970). The maximum size of the sea lamprey is 120 cm (47 in.); adults commonly reach 50 cm (20 in.).

Diagnostic Counts

Usually 66-75 trunk myomeres; 2 supraorbital teeth; usually 2-2-2-2 lateral circumoral teeth; 8-10 posterior circumoral teeth; 7-8 infraoral teeth.

Expansion

It is unlikely that the range of the sea lamprey in Illinois will expand beyond Lake Michigan.

Impact on Illinois

The sea lamprey contributed to a major decline in several native salmonids in Lake Michigan, especially the lake trout, *Salvelinus namaycush*, and the cisco, *Core gonus artedii.* Populations of native fishes, as well as the Lake Michigan commercial fishing industry, may never recover to prelamprey levels. Presently the sea lamprey population is controlled through the use of chemical pesticides that have varying effects on other organisms. The walleye, *Stizostedion vitreum*, is almost as susceptible to the most common lampricide (3-triflouromethyl-4-nitrophenol [TFM]) as is the sea lamprey (Becker 1983). Lieffers (1990) found that 88% of invertebrate populations sampled decreased in number after the application of TFM, although they seemed to recover within a few months. Bills and Johnson (1992) showed that the toxicity of TFM increased with decreasing pH, possibly resulting in mortality of nontarget species. The continued control of the sea lamprey, while necessary, will probably have detrimental effects on other organisms.

Clupeidae

Key to herrings and shads

1. Last ray of dorsal fin not elongated; pectoral fin not extending to pelvic fin origin; 18 or fewer anal rays 2
   Last ray of dorsal fin of adult elongated into a filament; pectoral fin extending posteriorly to or beyond pelvic fin origin; 19 or more anal rays 4

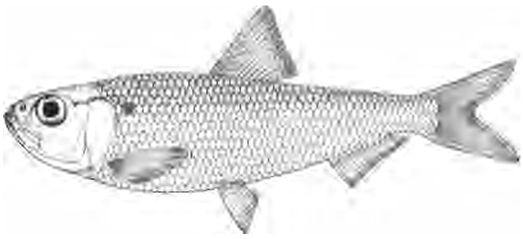
2. Lower jaw projecting far beyond snout; 20-24 rakers on lower limb of first gill arch (skipjack herring) .... *Alosa chrysochloris*
   Lower jaw equal to or projecting only slightly beyond snout; 39 or more rakers on lower limb of first gill arch 3

3. Cheek decidedly deeper than long; 42-48 rakers on lower limb of first gill arch; no jaw teeth (Alabama shad) .... *Alosa alabamae*
   Cheek longer than deep; 39-41 rakers on lower limb of first gill arch; teeth on lower jaw (alewife) .... ***Alosa pseudoharengus***

4. Terminal mouth; rounded snout; 40-48 lateral scales; 17-27 anal rays (threadfin shad) .... ***Dorosoma petenense***
   Subterminal mouth; blunt snout; 52-70 lateral scales; 25-36 anal rays (gizzard shad) .... *Dorosoma cepedianum*

***Alosa pseudoharengus*, alewife**

Figure 2



Origin and Range

The alewife is native to the Atlantic Ocean and streams of the Atlantic coast of North America. This species was found in Lake Michigan in 1949 and became extremely abundant there in the 1950s and 1960s after populations of native predators had been severely reduced by the sea lamprey. The alewife population declined subsequent to the introduction of several large predaceous salmon and trout into Lake Michigan. Presently, alewives are common in Lake Michigan but are not as abundant as they were during the 1950s. This species is not found elsewhere in Illinois.

Biology

Alewives are anadromous in their native range, but Illinois populations reproduce in the main body of Lake Michigan. Anadromous populations form schools that usually remain close to the natal estuary (Mansueti and Hardy 1967). Both anadromous and landlocked populations inhabit open water during most of the year. Alewives remain offshore during the day and move to shallower water at night. Threinen (1958) observed schools of alewives in Lake Michigan that were 4.5-6 m (15-20 ft) in diameter containing 5,000-6,000 individuals. Graham (1957) described schooling behavior of Lake Ontario alewives while inshore. He observed a "roller-coaster" movement in which the school undulates from the surface to the bottom and back, often breaking the surface. "Milling" behavior occurs when the school forms a circle, usually at an indentation of the shoreline or an isolated object in the water.

Lake Michigan studies indicate that zooplankton, especially copepods and cladocerans, compose the diet of juveniles and adults found at depths less than 9.1 m (30 ft) (Morsell and Norden 1968; Norden 1968). Adults found at greater depths fed mostly on the amphipod genus *Pontoporeia* (Morsell and Norden 1968). Scales have been found in the stomachs of alewives as well as the eggs of conspecifics and other species (Edsall 1964; Morsell and Norden 1968). Schools of alewives have been observed feeding on insects at the surface at dusk in Lake Ontario (Graham 1957), and Odell (1934) observed alewives leaping from the water to catch insects.

Movement towards spawning grounds usually begins in late April or early May. In Lake Michigan, spawning has been reported as early as June 24 (Edsall 1964) and as late as August 24 (Norden 1967). Spawning occurs at night over sand or gravel (Scott and Crossman 1973). Water depth ranges from a few inches (Rothschild 1962) to 10 ft (Edsall 1964). Spawning usually occurs in sluggish water but has been observed in fast water over gravel (Greeley 1935). During the spawning act, two or more fish swim in tight circles with their sides touching while spiraling upward towards the surface and then down again (Edsall 1964). Most adults leave the spawning area soon after spawning (Graham 1956). Fecundity was estimated to range from 10,000 to 12,000 for landlocked females (Odell 1934) and from 60,000 to 100,000 for anadromous females (Scott and Crossman 1973). From a Michigan spawning, Edsall (1964) reported consumption of large numbers of eggs by spottail shiners *(Notropis hudsonius)* and juvenile alewives. Bigelow and Welsh (1925) reported swarms of young white perch following spawning alewives and devouring the eggs.

Mansueti and Hardy (1967) described the development of eggs and fry. They reported fertilized eggs of 0.94-1.25 mm in diameter and an incubation time of 3-5 days at 20°C (68°F). Male alewives mature earlier and die earlier than females (Becker 1983). In Lake Ontario, Graham (1956) found females up to 8 years old, but no males older than 5 years were collected. Norden (1967) reported the following mean total lengths for Lake Michigan alewives: 13.9 cm (5.5 in.) at 1 year, 15.8 cm

(6.2 in.) at 2 years, 17.3 cm (6.8 in.) at 3 years, and 19.3 cm (7.6 in.) at 4+ years. Most alewives first reproduce at 2 or 3 years.

The alewife is known to undergo periodic population die-offs in the Great Lakes. The causes of these die-offs are not entirely clear. Most authors attribute the die-offs to intolerance of changing temperatures (Graham 1956; Becker 1983). Hoar (1952) suggested that alewives may lose osmotic control in fresh water as a result of an exhausted thyroid mechanism. Smith (1968) suggested that the alewife cannot tolerate the cold temperatures of the Great Lakes during the winter. The maximum size of the alewife is 38.1 cm (15 in.) but Great Lakes individuals seldom exceed 20 cm (7.9 in.).

Diagnostic Counts

39-41 rakers on lower limb of first gill arch; 12-16 dorsal rays; 15-19 anal rays.

Expansion

The distribution of alewives in Illinois is not expected to expand beyond Lake Michigan.

Impact on Illinois

In the late 1960s, massive die-offs of alewives occurred causing nuisance conditions near the shores of the lake. Alewives have contributed to the decline of several native planktivorous salmonids of Lake Michigan and are believed to have adversely affected populations of other fishes as well, including the emerald shiner *(Notropis atherinoides)* and the yellow perch *(Perca flavescens)*. The alewife is commercially harvested in northern Lake Michigan on a small scale for use as fertilizer and pet food (Becker 1983).

***Dorosoma petenense*, threadfin shad**

Figure 3

Origin and Range

The threadfin shad is native to the streams of the southern U.S., Mexico, and Central America. It was introduced to several Tennessee Valley Authority reservoirs during the 1940s and 1950s and later to many of the large reservoirs of the southwestern U.S. This species spread north and was first found in Illinois in 1957 (Smith 1979). By 1979 it was established and commonly captured in the Ohio River and was present in other streams in extreme southern Illinois. In recent years the threadfin shad has spread further and has been captured from several sites on the Illinois River, sometimes in high numbers (Rip Sparks, pers. comm.).

Biology

The threadfin shad is an open-water filter feeder and often feeds in large schools over sand or mud. The schools are often composed only of one year-class of fish (Berry et al. 1956). Threadfin shad are usually found in schools over deep water, but small schools and individuals are sometimes found near the shore. Threadfin shad are sensitive to low temperatures, and population die-offs often occur after a temperature drop. Laboratory experiments indicate that schools begin to break up and feeding activity decreases at temperatures below 9°C (48.2°F); a temperature of 4°C (39.2°F) is fatal (Griffith 1978).

Algae is an important component of the diet of threadfin shad with studies reporting that it averages 16.4-54.1% of the diet (Haskell 1959; Miller 1967). In an Arkansas study, Miller (1967) found that the animal portion of the diet (45.9%) consisted of all major groups of plankton as well as dipteran larvae and adult insects. The diets of young-of-the-year and age-I individuals were the same and no evidence of selective feeding was found. However, Kimsey (1958) did find selectivity for the eggs of the gulf croaker *(Bairdiella icistius)* in a coastal California study. In an Arizona study, crustaceans composed 7.5% of the diet (Haskell 1959). In addition to pelagic feeding, the threadfin shad commonly feeds from the bottom as evidenced by the presence of mud, sand, and bits of wood in the gut of most individuals collected (Miller 1967; Haskell 1959). Haskell (1959) found algae to be the most common food item during the winter and animal matter prevalent in the diet during the spring and summer. Foods reported only in small quantities include filamentous algae, blue-green algae, eggs of invertebrates, and aquatic nematodes (Haskell 1959).

Threadfin shad usually spawn from early April to August at water temperatures of 14.4-27.2°C (60-81°F). Johnson (1971) reported different spawning peaks for different year-classes of fish in an Arizona reservoir study. Age 3 and 4 fish became ripe on April 1 and peaked on April 10, age 2 fish became ripe on April 25 and peaked during early May, and age 1 fish became ripe during mid-April and peaked in late May. Spawning begins at dawn and terminates shortly after sunrise. In Tennessee, spawning usually took place between 5:30 and 7:30 a.m. (McLean et al. 1982). Johnson also reported that older shad may sometimes spawn more than once during a season, but that age 0 threadfin shad did not spawn. Some have suggested that age 0 fish may spawn late in the season (Berry et al. 1956; Smith 1979). Lambou (1965) and Kimsey (1964) observed spawning of threadfin shad in Louisiana and California. They reported one or more females swimming in a loose school with several males in attendance. This group swam near the surface and rushed rapidly to an object projecting above the water, or slightly below the surface, and released gametes. The shad often break the surface of the water as the adhesive eggs are released. Eggs adhere to submerged plants, pilings, and other objects. Berry et al. (1956) reported evidence of occasional mass-spawning mortality. This was not associated with temperature fluctuations and does not seem to be typical. Kimsey (1964) reported mortality of threadfin shad that spawned near shore resulting from some of them being stranded during spawning activities. Johnson (1971) found an average of 2,308 eggs per gram of ovary and estimated average fecundity for each year class. Estimated averages range from 923 to 1,616 for age 1 fish and 1,616 to 3,924 for age 2 fish. Up to 25,000 eggs per female were reported from an Arkansas reservoir (Kilambi and Baglin 1969). Some females may be able to spawn more than once per season causing yearly fecundity estimates to be too low. Johnson (1971) also found some individuals whose gonads were filled with fatty tissue and gender was indeterminable. This phenomenon was more common in large individuals with about 77.3% of the fish over 9.9 cm (3.9 in.) having fatty tissue in the gonads.

Eggs are 0.75 mm in diameter. Laboratory studies show a maximum incubation temperature of 34.2°C (93.5°F) and a minimum of 15°C (59°F) (Hubbs and Bryan 1974). Threadfin shad generally do not live longer than 4 years and most do not live longer than 2 years. Johnson (1970) found that most of the largest fish were females, resulting from higher male mortality rather than faster female growth. Sexual maturity may sometimes be reached in less than 1 year (Smith 1979), although most researchers found no evidence of this. Maximum size is 23 cm (9 in.); adults seldom exceed 13 cm (5 in.) in fresh water and 19 cm (7.5 in.) in salt water.

Diagnostic Counts

40-48 lateral scales; 10-14 dorsal rays; 17-27 anal rays.

Expansion

Threadfin shad have infiltrated the large rivers of the southern half of the state and are present in the Illinois River. Their intolerance of cold probably will prevent them from becoming common in northern Illinois.

Impact on Illinois

Threadfin shad often are stocked in reservoirs as forage for large predators. This species feeds on plankton and is very prolific, giving it the potential to deplete populations of plankton. Other plankton-feeding fishes, including the larvae of all native fishes, can be adversely affected.

Cyprinidae

Key to introduced minnows and the golden shiner, which is similar in appearance to the rudd.

1. Dorsal fin long, 15-21 rays 2
   Dorsal fin short, 8-11 rays 3

2. Conspicuous barbels around mouth; 32-37 lateral scales (common carp) .... ***Cyprinus carpio***
   No barbels; 26-30 lateral scales (goldfish) . . .. ***Carassius auratus***

3. Keel between anal and pelvic fin bases . . . 4
   No ventral keel (grass carp) . ... ***Ctenopharyngodon idella***

4. More than 85 lateral scales 5
   Fewer than 55 lateral scales 6

5. Ventral keel extending from anus to isthmus between gill covers; gill rakers fused into porous plate; sides of body plain (silver carp) . . . . ***Hypophthalmichthys molotrix***
   Ventral keel extending from anus to pelvic fin base; gill rakers comblike; sides of body covered with small dark blotches (bighead carp) .... ***Hypophthalmichthys nobilis***

6. No scales on keel; clear to orange fins; no black on tail; usually 7-9 dorsal rays; 11-14 anal rays; 17-19 rakers on first gill arch; pharyngeal teeth 0,5-5,0 (golden shiner) .... *Notemigonus crysoleucas*
   Scaled keel; red fins; anterior portion of caudal fin with black rays; usually 9-11 dorsal rays; 10-11 anal rays; 10-13 rakers on first gill arch; pharyngeal teeth 3,5-5,3 (rudd) . . . ***Scardinius erythrophthalmus***

Cyprinus carpio, common carp
Figure 4

Origin and Range

Native to Eurasia, the common carp first arrived in North America in 1831 and is now widely distributed. It was distributed throughout Illinois by the time of Forbes and Richardson's (1908) survey of Illinois fishes and was described as abundant in all parts of the state by Smith (1979). It remains common in most areas of Illinois.

Biology

The common carp is an omnivorous benthic feeder that is most abundant over silt or clay, often near vegetation. It can be found in almost any type of habitat but prefers warm sluggish waters of streams and lakes. Common carp are very tolerant of high turbidity and low oxygen levels. This species is able to utilize atmospheric oxygen (MacKay 1963) and is often one of the few species able to persist in highly degraded streams.

Common carp feed most heavily at 20°C (68°F) and almost cease to feed below 8°C (46.4°F) (Muus and Dahlstrom 1971). Common carp frequently forage by sucking up bottom ooze and expelling it to expose food items (Moyle 1976), thereby increasing the turbidity of waters that they inhabit. The diet consists of a variety of foods including insect adults and larvae, crustaceans, mollusks, fishes, bottom ooze, worms, and plant material. The proportions of these foods in the diet vary among populations. For most populations insect larvae and other benthic invertebrates are the principal components of the diet. Plant matter was reported to compose as much as 43.5% of the diet in a New Mexico study (Jester 1974) and as little as 2.8% of the diet in a study conducted in Wisconsin (Pearse 1918). Other components vary in the diet depending on environmental availability. A recent report documented the presence of large quantities of lake trout eggs and zebra mussels in the stomachs of common carp captured near a breakwater at the southern end of Lake Michigan (Marsden 1993).

In Illinois, spawning takes place from spring to early summer (Smith 1979). Swee and McCrimmon (1966) reported on reproductive biology in Ontario. Spawning begins when water temperature reaches about 17°C (62.6°F) and ceases when water reaches 26°C (78.8°F) (Scott and Crossman 1973). Common carp congregate in large numbers and spawn in shallow water, often with the backs of large individuals protruding from the surface. In Illinois spawning frequently takes place in flooded cornfields (Sigler 1958). From one to several males attend each female as she broadcasts her eggs over the substrate (Becker 1983). The eggs are adhesive and become attached to vegetation and debris found in the spawning area. Females produce enormous numbers of eggs, which may account for as much as one-third of the female's weight (Muus and Dahlstrom 1971). Swee and McCrimmon (1966) reported a range of 36,000 eggs, from an age 4 female of 39.4 cm (15.5 in.) to 2,208,000 eggs in an age 16 female of 85.1 cm (33.5 in.) and 10.1 kg (22.3 lb).

The 1-mm diameter eggs hatch in about 5 days (Swee and McCrimmon 1966) and, in Illinois, young attain a length of around 13 cm (5.1 in.) by the late fall of their first year (Smith 1979). Becker (1983) reported the following total length estimates at each age, based on scale annuli of individuals captured from the Wisconsin River: 30.4 cm (12 in.) at 2 years, 40.4 cm (15.9 in.) at 3 years, 49.0 cm (19.3 in.) at 4 years, 54.3 cm (21.4 in.) at 5 years, 58.4 cm (23.0 in.) at 6 years, 62.2 cm (24.5 in.) at 7 years, 64.3 cm (25.3 in.) at 8 years, 66.7 cm (26.3 in.) at 9 years, 69.5 cm (27.4 in.) at 10 years, 74.6 cm (29.4 in.) at 11 years, and 76.1 cm (30.0 in.) at 12 years. Sexual maturity occurs at 3-4 years for males and at 4-5 years for females (McCrimmon 1968). McCrimmon also noted that common carp can live for more than 20 years in North America. Muus and Dahlstrom (1971) report a life span of up to 40 years. Maximum size is 122 cm (48 in.); adults commonly exceed 77 cm (30 in.).

Diagnostic Counts

32-38 lateral scales; 17-21 dorsal rays; 5-6 anal rays; pharyngeal teeth 1,1,3-3,1,1.

Expansion

The distribution and abundance of common carp in Illinois is not expected to change in the near future.

Impact on Illinois

Common carp have been present in Illinois since the earliest surveys, making their effects on native species difficult to determine. Common carp tend to destroy vegetation and increase water turbidity by dislodging plants and rooting around in the substrate, causing a deterioration of habitat for species requiring vegetation and clear water. This species attains a large size and has become an important commercial food species in Illinois; however, it may have done so at the expense of ecologically similar native species, such as carpsuckers and buffalos.

Carassius auratus, goldfish

Figure 5

Origin and Range

Native to eastern Asia, the goldfish was introduced into North America as early as the late 1600s (Page and Burr 1991) and had become established in Illinois' rivers by the time Nelson (1876) conducted his survey of Illinois fishes. Smith (1979) reported it to be most abundant in the Illinois River and its Chicago-area headwaters and sporadically distributed elsewhere in the state. The goldfish remains common in Illinois only in the upper Illinois River system.

Biology

The goldfish prefers vegetated pools, but its high tolerance of turbidity and pollution has enabled it to survive in some of the degraded streams and canals of the Chicago region, where few other species persist. Trautman (1957) described the goldfish as similar to the common carp ecologically, but less tolerant of cold water, turbidity, siltation, and pollution, and more dependent on submerged vegetation. Goldfish usually remain near the bottoms of the pools or ponds that they inhabit, but occasionally school at the surface. The species is omnivorous, relying mostly on plants for food (Robison and Buchanan 1990) but also consuming worms and other benthic invertebrates.

Goldfish begin to spawn when the water temperature reaches about 15.6°C (60°F). The season lasts from late March to August, and most activity occurs during the mornings of sunny days. Each female is accompanied by two or more males as she broadcasts her adhesive eggs over aquatic plants and submerged tree roots (Scott and Crossman 1973). The males follow closely, fertilizing the eggs as they are released. Webster (1942a) described females leaping from the water and being "wildly" chased by males. This species has a prolonged spawning season with each female releasing eggs 3-10 times at 8-10 day intervals (Mansueti and Hardy 1967). Females release 2,000-4,000 eggs at once and the ovaries may hold from 160,000 to 380,000 eggs (Muus and Dahlstrom 1971). Berg (1964) and Muus and Dahlstrom (1971) discuss populations of *C. auratus* in Asia and Europe that consist only of females. The eggs of these goldfish are stimulated to develop by the sperm of other carp species, but receive no genetic information from the sperm. The resulting fry are all female goldfish.

Mansueti and Hardy (1967) and Battle (1940) described the development of eggs and larvae. Eggs hatch 3-10 days after fertilization, depending on the water temperature (Mansueti and Hardy 1967). Goldfish total lengths were reported by Becker (1983) as 12.0 cm (4.8 in.) at 1 year, 15.1 cm (6.0 in.) at 2 years, and 18.8 cm (7.4 in.) at 3 years. Experimental data indicate that goldfish produce a substance that increases the rate of growth in conspecifics (Lagler et al. 1977), and Swigle (1956) reported the presence of a secretion that represses reproduction in overcrowded populations. Goldfish typically live 6-7 years. Maximum size is 44.7 cm (17.6 in.); adults commonly reach 33.0 cm (13.0 in.).

Diagnostic Counts

15-21 dorsal fin rays; 5-7 anal fin rays; 25-31 lateral scales; pharyngeal teeth 0,4-4,0.

Expansion

Goldfish appear to be unable to compete with native Illinois fishes and became established only in severely disturbed areas of Illinois where native species have disappeared. The distribution of the goldfish in Illinois will increase or decrease depending on the future condition of our streams.

Impact on Illinois

Goldfish have little impact on other Illinois fishes because they are common only in areas that are so severely degraded that few other species are present.

Ctenopharyngodon idella, grass carp
Figure 6

Origin and Range

The grass carp is native to eastern Asia. It was introduced to North America as a biological control for aquatic vegetation in the early 1960s. From its point of introduction in Arkansas it has now spread or been introduced to at least 34 states. The first collection in Illinois was in 1971 (Greenfield 1973) and Smith (1979) reported its presence in the Mississippi River as far north as Pike County. Today grass carp are reproducing in Illinois (Raibley et al. 1995) and occur sporadically in the southern half of the Illinois portion of the Mississippi River, the southern half of the Illinois River, Lake Michigan and the Chicago River in Cook County, the Cache River in Alexander/Pulaski counties, the Big Muddy River in Jackson County, Clear Creek in Alexander County, and the Kaskaskia River in Clinton County.

Biology

Greenfield (1973) and Stanley et al. (1978) provided reviews of literature and summaries of most aspects of the life history of the grass carp. The species inhabits quiet waters including lakes, ponds, and pools and backwaters of large rivers. It usually prefers shallow water but moves into deeper areas as water temperature decreases (Nixon and Miller 1978). Grass carp can withstand temperatures from 0 to 35°C (32-95°F) (Stevenson 1965) and are very tolerant of low oxygen levels and high salinity.

The grass carp is a voracious feeder capable of consuming 40% of its body weight each day (Omarov 1970). While this species is primarily herbivorous, conflicting reports have been made on its food preferences. Nikolskii (1956) reported a diet of rotifers, crustaceans, and midge larvae until 3.0 cm is reached and suggested that the grass carp is almost exclusively herbivorous once it reaches that size. Hickling (1966) also contended that the grass carp becomes totally herbivorous, despite the results of his research. He reported data showing that the gut length to total length ratio does not change as body size increases, that the gut is only 2.25 times the length of the fish (which is much shorter than would be expected from an exclusively herbivorous fish), and that only about half of the plant material consumed is digested. The conclusion that a switch from omnivory to almost exclusive herbivory was contradicted by Lin (1935) in a study conducted on a grass carp population in China. In addition to macrophytes, Lin reported a diet that included small fishes, earthworms, silkworm pupae, other insects, and other nonplant foods. Grass carp have been caught by hook-and-line fishermen and with trotlines baited with small fishes (Pflieger 1978). Stevenson (1965) reported fingerlings feeding heavily on worms and zooplankton in ponds, even when algae and commercial food were available. However, in a different pond study in which benthic invertebrates and zooplankton were numerous, grass carp fingerlings fed almost exclusively on macrophytes (Colle et al. 1978). In a pond containing several other fish species, grass carp fed primarily on vegetation, despite the availability of insects (Kilgen and Smitherman 1971). Tang (1970) suggested that when macrophyte levels are low or when competition for other foods is low, the diet shifts away from macrophytes. The stomach contents of six large individuals from the streams of Missouri consisted mostly of filamentous algae, but also included parts of terrestrial vascular plants (Pflieger 1978).

Grass carp migrate upstream towards spawning grounds as water becomes warmer. Reported minimum water temperatures required for spawning range from 15°C (Aliev 1976) to 20°C (Nikolskii 1956). In China, native populations spawn from April to mid-August, but activity is heaviest from May to mid-June (Greenfield 1973). Fecundity can be very high. Berg (1964) reported a 7-year-old, 7.4 kg (16.3 lb) female that contained 816,000 eggs. Behavior during spawning in natural populations has not been described. Spawning generally takes place in large, turbid lowland rivers. However, in Missouri larvae were found as far as 8 km (5 mi) upstream from the mouths of two small streams (41 m [135 ft] and 42.2 m [138 ft] wide) (Brown and Coon 1991). Brown and Coon felt it unlikely that the larvae could have swum or been washed this distance from the Missouri River, suggesting that these smaller streams might be suitable for grass carp spawning. Spawning is usually initiated by a large rise in water level. Spawning may occur in the absence of a rise in water level. Temperature changes, turbidity changes, and other environmental factors may be capable of initiating spawning (Stanley et al. 1978). Grass carp generally spawn in turbid water, which probably reduces predation of eggs. Leslie et al. (1982) reported very high levels of egg predation in an experiment conducted in a clear Florida stream.

Grass carp eggs are semipelagic and require flowing water to prevent sinking and dying. Varying figures have been reported for minimum current velocity required for egg incubation. Several authors report 0.6m/s as the lowest speed that will allow successful reproduction in natural populations (Stanley et al. 1978). A Florida study indicates that unfertilized eggs may be successfully transported downstream in as little as 0.23m/s (Leslie et al. 1982). Incubation time varies with water temperature and ranges from 60 hours at 17.0°C (62.6°F) to 18 hours at 28.0°C (82.4°F) (Stanley et al. 1978). Larvae enter still water soon after hatching and begin to actively feed after 2-4 days (Vinogradov and Erokhina 1967). Juveniles prefer quiet water, usually a lake, reservoir, or stream pool. Adults and juveniles are known to move long distances, as evidenced by the short time between the release of grass carp in Arkansas and their appearance in large numbers in the Missouri River (Pflieger 1978). Growth is rapid in ponds, and grass carp can attain a size of 8.0 cm (3.1 in.) and .004 kg (.009 lb) at 6 months, 12.0 cm (4.7 in.) and .021 kg (.046 lb) at 9 months, 28.0 cm (11.0 in.) and .372 kg (.829 lb) at 12 months, and 50.0 cm (19.7 in.) and 1.816 kg (4.000 lb) at 18 months (Stevenson 1965). Eighteen wild-caught specimens from Missouri averaged 6.9 kg (15.2 lb) at 2-3 years of age, 3.5 kg (7.7 lb) at 3-4 years of age, and 5.4 kg (11.9 lb) at 4-5 years of age (Pflieger 1978). These individuals were probably hatchery escapees and their unusual growth pattern is most likely due to varying conditions under captivity and upon first entering natural waters. Hickling (1962) reported age and size at maturity for several locations: 8-10 years and 2.7-3.8 kg (5.9-8.4 lb) in Russia, 4 years and 6 kg (13.2 lb) in southern China, 5-8 years and 8-10 kg (17.6-22.0 lb) in Israel, and 10-14 months and 2-5 kg (4.4-11 lb) in Malaysia. The grass carp attains a maximum size of 1.5 m (59 in.) and 32 kg (70.4 lb); adults commonly reach 76 cm (30 in.).

Diagnostic Counts

34-45 lateral scales; 7-9 dorsal rays; 8-10 anal rays; pharyngeal teeth 2,5-4,2 or 2,4-4,2.

Expansion

The grass carp is known to reproduce in the Mississippi River drainage (Conner et al. 1980; Brown and Coon 1991), including the Illinois and Mississippi rivers in Illinois (Raibley et al. 1995). This species is found sporadically throughout Illinois and is likely to become more numerous and widespread, especially in large rivers.

Impact on Illinois

Although a large species, the feeding habits of the grass carp make it unsuitable for sport fishing. Grass carp are commonly caught by commercial fishermen in the large rivers of the southern part of the state. It is not known how common the grass carp will become and, thus, its future importance as a source of food for humans is unknown. Because it feeds on aquatic plants, the grass carp has the potential to destroy habitats that are important to many native species, including threatened and endangered species. The blacknose shiner *(Notropis heterolepis),* pugnose shiner *(Notropis anogenus),* Iowa darter *(Etheostoma exile),* and other threatened or endangered species are dependent on aquatic plants for cover from predators; substrate for prey, such as aquatic insects; and as spawning substrate. Other organisms that rely on aquatic plants, such as waterfowl, also will be negatively affected by the alteration of vegetated aquatic habitats by grass carp.

Hypophthalmichthys molotrix, silver carp

Figure 7

Origin and Range

This fish and the similar bighead carp are native to the large lowland rivers of eastern Asia. The silver carp was introduced into Arkansas in 1973 (Henderson 1976). It spread through the state and by the early 1980s Arkansas' commercial fishermen were catching this species from the Mississippi River (Carter and Beadles 1983). Smith (1979) made no mention of silver carp in Illinois, but today commercial fishermen frequently catch the species in the Mississippi River. Documented collections exist from Illinois portions of the Mississippi River drainage in Alexander, Monroe, and Jackson counties.

Biology

The silver carp is an open-water filter feeder typically found in large, slow portions of large rivers. During the winter silver carp aggregate in large numbers in deep river pools (Berg 1964). Henderson (1976) discussed diet and feeding of the silver carp, and much of the following summary is taken from him. The gill rakers of the silver carp are fused into a porous plate allowing particles as small as 41.tm to be filtered from the water. Organisms 40-50gm in size have been collected from the gut, but larger items are reduced in size by the pharyngeal teeth, which grind food against a cartilaginous plate. The diet consists almost exclusively of plankton, the majority of which is phytoplankton. Copious quantities are consumed daily with feeding heaviest in the early morning (Omarov 1970). The gut is long, with reports of it being slightly longer than 3-5 times (Henderson 1976) to 12 times the length of the fish (Nikolskii 1956). Food passes through the gut quickly, with estimates as low as 4 hours, indicating that the gut could be filled and evacuated six times in a 24-hour period (Omarov 1970). Much of the food passes through undigested.

No wild spawning of the silver carp has been described from North America. Robison and Buchanan (1990) described the spawning conditions of the silver carp as similar to those of the bighead carp, which spawns when water rises after heavy rains (Berry and Low 1970) at temperatures ranging from 18.3 to 26°C (65.0-78.8°F) (Chang 1966). Spawning occurs in large rivers or side channels. The current must be sufficient to keep the semibuoyant eggs from sinking and dying. In China, spawning begins in late May or early June and continues for 8-10 weeks (Bogaevskii in Berg 1964). Reproductive ability is reached during the sixth year of life, and individual fecundity ranges from 467,000 to 542,000 eggs (Bogaevskii in Berg 1964). It was previously believed that neither the bighead nor silver carp could reproduce in North American rivers; however, there is now evidence of bighead carp reproduction in the Mississippi drainage. Reproductive requirements are similar for the bighead and silver carp, indicating that silver carp may also have the potential to successfully spawn in the Mississippi River. However, no evidence for spawning yet exists.

Eggs of the closely related bighead carp are about 1.5 mm in diameter when released and quickly absorb water and swell until the diameter is about 5 mm (Jennings 1988). Weights at several year classes were reported by Bogaevskii (in Berg 1964) as follows: 3.0 kg (6.6 lb) at 5 years, 3.6 kg (7.9 lb) at 6 years, 4.1 kg (9.0 lb) at 7 years, 4.4 kg (9.7 lb) at 8 years, and 4.9 kg (10.8 lb) at 9 years. Faster growth has been reported, with weights of 18-23 kg (39.6-50.6 lb) reached in 4-5 years (Henderson 1979). Sexual maturity occurs during the sixth year of life in Asia, and this species can live for 20 years. The silver carp sometimes exceeds 1 m in length and can exceed 27.3 kg (60 lb), although it does not commonly exceed 9 kg (20 lb).

Diagnostic Counts

95-103 lateral scales; 12-13 anal rays; 8 dorsal rays; pharyngeal teeth 0,4-4,0.

Expansion

Although not yet known to reproduce in Illinois, given the recent expansion of its range the silver carp is likely to become established in Illinois and occupy large rivers throughout the state.

Impact on Illinois

The silver carp has some potential as a food fish because of its large size, rapid growth, and acceptable flavor, and it also has been used in Arkansas for removal of excessive algae from waste water (Henderson 1977). The impact of this species on aquatic ecosystems is not yet known and is highly dependent on the extent to which its population increases. It has the potential to do enormous damage to populations of native organisms because it feeds on plankton, the same food consumed by larval fishes and native mussels.

Hypophthalmichthys nobilis, bighead carp

Figure 8

Origin and Range

Like the closely related silver carp, the bighead carp is native to Asia and was introduced into Arkansas in the early 1970s for use as an aquaculture species (Henderson 1976; Jennings 1988). It has been collected in Illinois from the Mississippi River in Henderson, Hancock, Calhoun, and Madison counties; the Illinois River in Mason, Schuyler, and Fulton counties; the Big Muddy River in Jackson and Union counties; the Cache River in Alexander County; the Kaskaskia River in Washington County; and the Kankakee River in Kankakee County. In addition to these records, bighead carp have been taken by fishermen snagging for paddlefish near Mississippi River Lock and Dam #21 and are commonly captured there by commercial fishermen (Robert Maher, pers. comm.).

Biology

Jennings (1988) described most aspects of the life history of this species. Bighead carp are typically found in quiet waters of large rivers, lakes, and reservoirs. Larval and juvenile bighead carp seek out vegetated areas that have little or no current. The gill rakers of the bighead carp are enlarged at the distal ends, forming an almost solid filtering surface (Henderson 1977). Zooplankton are the major component of the diet but phytoplankton and detritus become important when zooplankton levels are low (Danchenko 1970; Lazareva et al. 1977). Also, pieces of terrestrial and aquatic insects have been observed in the gut of bighead carp (Henderson 1976). This species has no real stomach and it can be inferred that it must feed almost continuously (Henderson 1976).

Spawning migrations upstream to faster water are usually triggered by rising water levels. In China the spawning season usually lasts from April to June and peaks in May (Chang 1966). Chang (1966) recorded data for several years of spawning on the Yangtze River of China. He found a temperature range of 18.3-23.5°C (65.0-74.3°F), water lever increases of 40-140 cm (15.7-55.1 in.), and water velocities of 0.78-2.26 m/s (2.6-7.4 ft/s) to be associated with spawning. The water was very turbid and spawning took place at the surface. Dah-Shu (1957) reported spawning below the surface. Sukhanova (1966) reported a range in fecundity of 478,000 to 549,000 eggs, but up to 1,100,000 were produced by one individual (Chang 1966). The eggs are semibuoyant and require current to keep them from sinking and dying.

Eggs are about 1.5 mm in diameter when deposited but they absorb water until the diameter is about 5 mm (Jennings 1988). Eggs hatch about 1 day after fertilization in water temperatures of 22-26°C (72-79°F) (Sukhanova 1966). Shortly after hatching larvae seek out quiet waters near the shore. Krzywosz et al. (1977) reported the following estimated average lengths for each year class for bighead carp that were raised in ponds for 3 years and then released into Lake Dgal Wielki in Poland: 12.5 cm (4.9 in.) at 1 year, 24.2 cm (9.5 in.) at 2 years, 39.2 cm (15.4 in.) at 3 years, 50.3 cm (19.8 in.) at 4 years, 58.0 cm (22.8 in.) at 5 years, 66.7 cm (26.3 in.) at 6 years, and 71.6 cm (28.2 in.) at 7 years. Bighead carp typically weigh 0.75-1.5 kg (1.65-3.3 lb) at 2 years of age, and 3-4 kg (6.6-8.8 lb) at 3 years of age. Maturity has been reported as early as 2 years and as late as 10 years with males of most populations reaching maturity a year earlier than females (Jennings 1988). Bighead carp have been known to reach a length of 1.5 m (4.9 ft) and a weight of 40 kg (88 lb). This species commonly reaches 75 cm (29.5 in.) and 18 kg (40 lb).

Diagnostic Counts

85-100 lateral scales; 13-14 anal rays; 8-9 dorsal rays; pharyngeal teeth 0,4-4,0.

Expansion

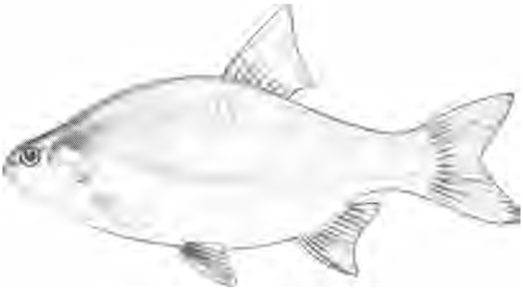
Young-of-the-year have been collected in Illinois (Burr and Warren 1993), suggesting that the bighead carp is established in the state. It is likely to become common in the large rivers of Illinois.

Impact on Illinois

The bighead carp has a better flavor than the silver carp and is more likely to be used for food (Robison and Buchanan 1990). It has been used for removal of excessive algae and nutrients from waste water in some areas (Henderson 1977) and, thus, may offer some environmental benefits. However, because bighead carp are planktivorous and attain a large size, they have the potential to deplete populations of zooplankton. A reduced availability of plankton can lead to reductions in populations of native species that rely on plankton for food, including all larval fishes, certain adult fishes (e. g., shad, paddlefish), and native mussels.

***Scardinius erythrophthalmus*, rudd**

Figure 9



Origin and Range

Native to Eurasia, this minnow was introduced to the U.S. as early as 1897 (Bean 1897, 1903; Hubbs 1921), but until recently populations were established only in Maine and New York (Courtenay et al. 1986). The rudd has now been reported in 13 other states, including Illinois, and is being raised in Oklahoma (Pigg and Pham 1990). Recent Illinois captures result from the distribution of the rudd as a bait minnow by the Arkansas fish farming industry (Burkhead and Williams 1991). The rudd has been found in bait shops at Carlyle Lake in Clinton County (Brooks Burr, pers. comm.) This species has been collected from northern Illinois in Grundy, Kendall, Lake, and Will counties.

Biology

The rudd is most often found in sluggish, vegetated waters of lakes and rivers, but is also known to occur in brackish water. Berg (1964) reported a population that reproduces in the saline Aral Sea. It can tolerate very low levels of dissolved oxygen, but is sensitive to pollution (Lelek 1987). The rudd is generally found in upper portions of the water column, where it is reported by Wheeler (1969) to feed on surface and terrestrial insects and midwater crustaceans. He contends that young rudd consume small amounts of plant material and that adults are wholly carnivorous. However, Lelek (1987) reported a larger percentage of plant matter in the diet of adults, and Muus and Dahlstrom (1971) described consumption of the leaves of submerged macrophytes as well as benthic invertebrates.

In Europe, the rudd spawns from April to June and usually begins when the water temperature reaches 18°C (64°F) (Wheeler 1969). The spawning season is often prolonged and eggs can be laid in two batches. In some populations gravid females can be found with their 3-4-week-old fry (Kiselevich 1926). Breeding males become more brightly colored than usual and develop tubercles on the head. During spawning small groups or pairs of rudd form and the female broadcasts the eggs over submerged aquatic vegetation. In a river near the Black Sea fecundity ranged from 96,000 to 232,000 eggs per female (Berg 1964). In Europe the rudd is known to spawn in association with other cyprinid species, often resulting in hybrid offspring (Muus and Dahlstrom 1971). No reproduction has been documented in Illinois.

Eggs are about 1.5 mm in diameter upon release and hatch in 3-14 days depending on the water temperature. The eggs are very adhesive and become attached to plants. The alevins are 4.5 mm upon hatching and remain attached to vegetation until the yolk sac is consumed (Wheeler 1969). Berg (1964) reported growth of rudd from three different populations. Average standard lengths ranged from 5.9-6.8 cm (2.3-2.7 in.) at 1 year, 9.5-11.5 cm (3.7-4.5 in.) at 2 years, 12.7-16.3 cm (5.0-6.4 in.) at 3 years, 17.2-19.5 cm (6.8-7.7 in.) at 4 years, and 21.4-23.0 cm (8.4-9.1 in.) at 5 years. Sexual maturity is usually reached during the third year of life. This species can live for more than 10 years. It attains a maximum length of 48.0 cm (19 in.), and adults commonly reach a length of 25.0 cm (10 in.).

Diagnostic Counts

36-45 lateral scales; usually 9-11 dorsal rays; 10-11 anal rays; 10-13 rakers on first gill arch; pharyngeal teeth 3,5-5,3.

Expansion

This species is being marketed as a bait minnow and could be found anywhere in the state. There is no evidence of reproduction in Illinois, but it seems likely that the species will become established if it continues to be used as bait.

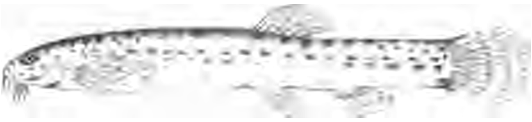
Impact on Illinois

If the rudd becomes established in Illinois, it will compete with native minnows and thereby alter our aquatic ecosystems. Although the rudd has been touted as a hardy bait minnow and as potential forage for piscivorous sport fishes (Burkhead and Williams 1991), there is no evidence that the rudd fulfills these needs better than native minnows.

Cobitidae

The only cobitid in Illinois is the introduced Oriental weatherfish.

Misgurnus anguillicaudatus,
Oriental weatherfish
Figure 10



Origin and Range

The Oriental weatherfish is native to Asia and presumably was released in Illinois waters by home aquarists. This species was first collected in Illinois in 1987. Presently the range of this species in Illinois is Lake Michigan and contiguous streams in Cook County.

Biology

The life history of the Oriental weatherfish was summarized by Okada (1959-1960) and much of the following description is taken from his work. The Oriental weatherfish inhabits soft-bottomed areas of stream backwaters, swamps, and lakes. It tolerates low oxygen levels by ingesting air and absorbing oxygen through a vascularized gut epithelium as the air passes through the alimentary canal. The Oriental weatherfish is nocturnal and usually remains buried in the substrate during the day. The diet is chiefly mollusks, but various other benthic invertebrates as well as occasional plant matter are consumed. Early free-swimming larvae feed on plant matter.

In its native range the Oriental weatherfish spawns from April to June. Most activity occurs in the morning (Okada 1959-1960). The following description of spawning is taken from Breder and Rosen (1966). During spawning the male places his left pelvic fin above and over the right pelvic fin of the female and wraps his tail around her. During the spawn he attaches his mouth to hers. While the female slowly moves forward, eggs are released in groups of 20-50. Eggs may be scattered on the substrate near the bases of plants or on the plants themselves (Okada 1959-1960). Females may produce as many as 150,000 eggs during a spawn (Sterba 1966).

The reddish eggs of the Oriental weatherfish are 1.3-1.4 mm in diameter (Okada 1959-1960). Incubation time varies with 1-2 days reported at a temperature of 23-25°C (73.4-77°F) (Okada 1959-1960) and 8-10 days reported at a temperature of 21.1°C (70°F) (Breder and Rosen 1966). About 25 days after hatching, the young are fairly well developed and can be found in the same habitat as the adults. This species attains a maximum size of about 30 cm (11.8 in.).

Diagnostic Counts

10 barbels around mouth; 7-8 anal rays; 9 dorsal rays; 6-7 pelvic rays.

Expansion

The Oriental weatherfish reproduces in Illinois, but it is difficult to predict how abundant and widespread it will become. Although it is possible that it will spread throughout the state, introductions of this species elsewhere in North America—in California, Michigan, and Idaho—have resulted only in localized populations (Page and Burr 1991).

Impact on Illinois

If the Oriental weatherfish remains confined to extreme northeastern Illinois, it is unlikely to have much impact on native species. If it becomes more abundant or spreads to other areas, it could reduce populations of native species it preys upon.

Osmeridae

The only osmerid in Illinois is the introduced rainbow smelt.

Osmerus mordax, **rainbow smelt**
Figure 11

Origin and Range

The rainbow smelt is native to Arctic and temperate regions of the northern hemisphere. Rainbow smelt became established in Lake Michigan as the result of an introduction in Crystal Lake, Michigan, in 1912 (Hubbs and Lagler 1941). When Smith (1979) published his survey of Illinois, the rainbow smelt was common in Lake Michigan and occasionally strayed into the Illinois River system. Today it remains common in Illinois waters of Lake Michigan and inhabits the Illinois, Ohio, Wabash, and Mississippi rivers (Mayden et al. 1987; Burr 1991).

Biology

The rainbow smelt is a schooling marine, estuarine, and inland species. Marine populations are seldom found far from shore. In the Great Lakes rainbow smelt show a seasonal pattern of movement, probably associated with spawning activity and temperature changes (Wells 1968). Young are usually found in midwater in areas less than 18.3 m (60 ft) deep (Dryer 1966; Ferguson 1965). In southeastern Lake Michigan, adults are known to move into waters of less than 18.3 m (60 ft) but they avoid the warm water near the shore (Wells 1968). However, some authors have reported much deeper summer depths. Wells (1968) reported rainbow smelt common at 64 m (210 ft) and sporadic down to 91.4 m (300 ft) in northern Lake Michigan. Daly and Wiegert (1958) reported summer depths down to 61 m (200 ft), and Dryer (1966) reported smelt inhabiting water of 36.6-89.6 m (120-294 ft) during the summer in Lake Superior.

Marine populations of rainbow smelt feed primarily on shrimp, annelid worms, and young fishes (Bigelow and Schroeder 1953). In the Great Lakes, most studies indicate that the opossum shrimp *(Mysis relicta)* is the most important component of the diet (Schneberger 1936; Baldwin 1950; O'Gorman 1979; Scott and Crossman 1973) although piscivory has also been noted, with alewives (O'Gorman 1979), minnows (Creaser 1925; Gordon 1961), sculpins (Schneberger 1936), and smelt (Schneberger 1936) making important contributions to the diet. In Lake Erie the volume of fish in the diet ranged from 5.3% in the spring to 95.7% during the fall (Price 1963). It was hypothesized that the low utilization of fish in the spring was due to the abundance of invertebrate prey. Price also found that fishes were taken only by smelt greater than 12.7 cm (5.0 in.) in length. Food in Crystal Lake during the summer consisted almost exclusively of emerald shiners *(Notropis atherinoides)* (Creaser 1925). Mayflies are important seasonally (Baldwin 1950; Gordon 1961).

In the fall and winter of 1942-1943, a massive die-off of smelt occurred in Lakes Michigan and Huron (Van Oosten 1947). The cause was a communicable viral or bacterial pathogen. Populations recovered to their former abundance after about 5 years. The rainbow smelt is tolerant of suspended sediments (Chaisson 1993) and is known to contain antifreeze proteins that lower the freezing point of the serum (Ewart and Fletcher 1989). In some eastern lakes the rainbow smelt is heavily preyed on by Atlantic salmon, composing more than 95% of its winter diet by volume (Sayers et al. 1989).

Spawning occurs in the spring for about 2 weeks, during which adults congregate and broadcast their adhesive eggs over the substrate (Smith 1979). Spawning begins at a water temperature of about 4.4°C (40°F) (Daly and Wiegert 1958). The following description of the spawning behavior of rainbow smelt in

Crystal Lake, Michigan, is a summary of Creaser (1925). In early April the smelt began to run up Cold Creek while there was still ice on much of the lake. The portion of the river used for spawning was clear, fast, not more than 76 cm (30 in.) deep, and ran over gravel and sand. Most of the spawning smelt entered the stream at dusk and returned to the lake as dawn approached, although some remained in the creek in dark places under a bridge or projecting shelves of ice. Many gulls gathered to feed upon the smelt. The upstream migration was short with few smelt moving more than 120 m (400 ft) upstream. So many smelt tried to enter the stream that the bottom could not be seen and many were unable to enter. Those that were unable to enter the stream spawned over the gravel-bottomed mouth of the creek. Smelt ate little while spawning. The males and females became covered with breeding tubercles and were sometimes observed vibrating against each other. The smelt were tightly packed together in the stream and released eggs at random. The day after a spawning run, eggs could be collected up and down the length of the stream.

A Lake Huron study indicated that runs are heaviest in streams with rapid current at the mouth (Baldwin 1950). Langois (1935) provided a second description of the spawning run in Cold Creek that was similar to that of Creaser (1925) in all respects except the positions of the males and females during the release of eggs and milt. He described a female swaying in the current with five attendant males, each holding a position slightly downstream of the female. The female released clusters of eggs as she swayed in the current and these drifted downstream where they were presumably fertilized by the males. Hoover (1936) studied an inland population in New Hampshire. He reported that the male assumes a position anterior and dorsal to the female and violently drives her to the bottom or toward shore. Males attended females in ratios similar to the sex ratio in the stream. No more than 50 of the strongly adhesive eggs were ever released at once. Bailey (1964) found that males outnumber females on the spawning area at the beginning of the run, but that females outnumber males towards the end of the run.

Rainbow smelt normally spawn in streams but they also spawn on the shores of lakes (Lievense 1954; Rupp 1959). Rupp (1965) reported that smelt gather in shallow water near shore as night approaches and form a tight school. Eggs were released seemingly with little attention to substrate type. Many of the eggs were destroyed by the action of waves and changes in the level of the lake. Rainbow smelt spawn from age 2 to age 5 (Creaser 1925). In Lake Superior, average fecundity for fishes ranging from 18.5 to 23.4 cm in size (7.3-8.8 in.) was 31,338 eggs (Bailey 1964). McKenzie (1964) reported a range of 8,500 eggs from a 12.7 cm (5.0 in.) smelt to 69,600 from a 20.9 cm (8.2 in.) individual. Grout (1983) reported the collection of two hermaphroditic individuals, but he was unable to determine whether they were capable of reproduction.

Eggs average 0.9 mm in diameter. Hatching occurs in 8 days at a temperature of 15°C (59°F) (Cooper 1978) and in about 29 days at 6-7°C (42.8-44.6°F) (McKenzie 1964). Females grow faster than males and have an increasingly larger average size than males after 2 years of age (Bailey 1964). Growth in Green Bay, Wisconsin, was reported by Schneberger (1936) with the following average lengths at each year: 17.8 cm (7.0 in.) at 2 years, 25.4 cm (10.0 in.) at 3 years, 30.5 cm (12.0 in.) at 4 years, and 35.6 cm (14.0 in.) at 5 years of age. Females also live longer than males based on their dominance of the 5- and 6-year-old age classes (Bailey 1964). Bailey (1964) found that in Lake Superior 40.7% of 2-year-old males were sexually mature but that only 17.7% of the females were mature at 2 years. All individuals of both sexes were mature at 3 years. Males reached maturity at a shorter average length, but the smallest mature individual was 12.7-13.2 cm (5.0-5.2 in.) for both sexes (Bailey 1964). Maximum adult size is 33 cm (13 in.); adults commonly reach 20 cm (8 in.).

Diagnostic Counts

62-72 lateral scales; 11-16 anal rays; usually 28-32 rakers on first gill arch.

Expansion

Rainbow smelt reproduce in Lake Michigan and will probably remain common there. In winter samples from the Mississippi River the rainbow smelt is sometimes the most abundant species (Brooks Burr, pers. comm.). However, it has not been collected in late summer and probably does not reproduce in the Illinois portion of the river. Rainbow smelt are expected to be only sporadically encountered in the large rivers of Illinois.

Impact on Illinois

In Lake Michigan the rainbow smelt may have played a role in the declines of some of the native whitefishes. Anderson and Smith (1971) attributed the decline of the lake herring *(Coregonus artedii)* to competition from the rainbow smelt at the larval stage. If the rainbow smelt becomes common in Illinois rivers, it will compete with native species for food and prey on small fishes. It may serve as food for large fishes. The rainbow smelt is not harvested commercially in Illinois but is favored by many recreational fishermen (Becker 1983).

Salmonidae

Key to trouts and salmons

1. Mouth of adult white inside; usually 10-12 branchiostegal rays 2
   Mouth of adult black inside; usually 12-19 branchiostegal rays 6

2. Black or brown spots on light body; fewer than 160 lateral scales 3
   Light spots (occasionally red) on dark body; more than 160 lateral scales 5

3. Usually 9 anal rays; adults with x-shaped spots on side; vomerine teeth little developed, those on the shaft of the bone few and deciduous (Atlantic salmon) . . . . ***Salmo salar***
   Usually 10-13 anal rays; side usually with round spots; vomerine teeth well developed, those on the shaft of the bone numerous, persistent, and arranged in 1 zigzag or 2 alternating rows 4

4. Few large black or brown spots on body, few or none on caudal fin; reddish spots more or less strongly developed (often surrounded by light border); adipose fin orange or red-orange, without dark margin or spots; no pink to rose stripe along side of body (brown trout) . . .. ***Salmo trutta***
   Many small black or brown spots on body and caudal fin; no red spots; adipose fin olive, with black margin or spots; broad pink to rose stripe along side of body (rainbow trout) . . ***Oncorhynchus mykiss***

5. Caudal fin little forked; red spots on body; lower fins each with black stripe near leading edge; 9-12 gill rakers; mandibular pores usually 7-8 on each side (brook trout) .... *Salvelinus fontinalis*
   Caudal fin strongly forked; no red spots on body; lower fins without black stripe; 12-14 gill rakers; mandibular pores usually 9 or 10 on each side (lake trout) .... *Salvelinus namaycush*

6. 147-205 lateral scales; large black spots on back and both lobes of caudal fin, largest as large as eye; 24-35 rakers on first gill arch; breeding male with distinct humpback (pink salmon) .... ***Oncorhynchus gorbuscha***
   112-165 lateral scales; small dark spots on back and caudal fin, largest as large as pupil of eye; 16-26 rakers on first gill arch; breeding males without humpback 7

7. Entire mouth, including gums, black; 14-19 anal rays; 140-185 pyloric caeca; small black spots on both lobes of caudal fin (chinook salmon) .... ***Oncorhynchus tshawytscha***
   Gums whitish; 11-15 anal rays; 45-114 pyloric caeca; small black spots, when present on caudal fin, on upper fin only (coho salmon) . . ***Oncorhynchus kisutch***

Salmo salar, Atlantic salmon

Figure 12

Origin and Range

Atlantic salmon are native to the northeastern coastal drainages of North America, Lake Ontario, and Atlantic coastal areas of Europe. Many natural landlocked populations occurred in Europe and eastern North America, including one in Lake Ontario. Unfortunately, Atlantic salmon were extirpated from Lake Ontario before 1900 and repeated efforts to re-establish the species in the lake have failed. Presently, natural and introduced landlocked populations exist in several lakes in eastern Canada and the northeastern U.S. Atlantic salmon have been widely stocked outside their native range but have rarely become established. In Illinois they have been found only in the lower Mississippi River (Burr 1991).

Biology

Most of the following information on the biology of the Atlantic salmon is taken from Scott and Crossman (1973) and Smith (1985). Atlantic salmon are typically anadromous and spawn in gravel-bottomed streams. They migrate up streams in the spring and summer, but do not spawn until October or November. Members of landlocked lake populations move into streams during early fall. A female constructs a nest by turning sideways and beating her caudal fin to fan out a depression (redd) in the substrate. While the female constructs the redd, a male defends the female and nest from other males. When the female is ready to spawn she positions herself in the bottom of the redd, the male moves next to her, and eggs and milt are released. The female then begins a new redd immediately upstream of the old one, covering the fertilized eggs with newly displaced gravel. This process is repeated until the female has deposited all of her eggs. Females deposit about 700 eggs/pound of body weight. Adults often survive spawning and return to the ocean or lake. Atlantic salmon may spawn more than once.

Atlantic salmon eggs range from 5 to 7 mm in diameter and hatch in about **110** days depending on the water temperature. After hatching the young remain buried in the gravel until the yolk sac is absorbed, usually in May or June. Growth in the stream is slow, and after 2-3 years the young are 13-15 cm (5-6 in.). At this time the young move downstream to the ocean or lake, where they usually spend 1-2 years before spawning. Atlantic salmon generally do not live longer than 9 years, although some populations are believed to have a slightly longer life span. Adult Atlantic salmon feed on fish and crustaceans in the sea, but they do not feed during spawning runs. Young rely mostly on aquatic insects, with terrestrial insects playing a smaller role in the diet. Anadromous Atlantic salmon are typically larger than those in lake populations, with adults averaging around 4.5 kg (10 lb) and 1.4 kg (3 lb), respectively. The maximum length is 140 cm (55 in.); adults commonly reach 61 cm (24 in.).

Diagnostic Counts

Usually 12 branchiostegal rays; 11 dorsal rays; 109-121 lateral scales; 8-11 anal rays; young have 8-11 narrow parr marks.

Expansion

This species is not reproducing in Illinois and is not likely to become established.

Impact on Illinois

This species is too rare in Illinois to have an ecological impact.

Salmo trutta, brown trout

Figure 13

Origin and Range

The brown trout is native to Europe, western Asia, and northern Africa. It has been stocked heavily throughout the world, including Lake Michigan and northern Illinois. Reproduction may have occurred in Piscasaw Creek in the northern part of the state.

Biology

The extensive literature on this species was summarized by Carlander (1969), Becker (1983), Moyle (1976), and Scott and Crossman (1973). Much of the following information is taken from them. Brown trout are best suited to cool, medium to large rivers with a gravel or rocky substrate; however, they are more tolerant of high temperatures and turbidity than are other trout species. Brown trout can tolerate temperatures as high as 26°C (78°F) for short periods of time, but optimal temperatures range from 7-19°C (45-66°F). In the Great Lakes, brown trout are usually found near shore in water less than 15 m (49 ft) deep. The diet of young brown trout consists mostly of aquatic invertebrates during the winter and terrestrial invertebrates and worms during the summer Larger individuals become increasingly piscivorous with increased size; fishes compose about 70% of the diet in the largest individuals.

Most populations of brown trout spawn between October and December in water from 2 to 13°C (35-55°F). Spawning usually takes place in fast, gravel-bottomed streams. The female uses her caudal fin to construct a nest in the substrate, which is guarded by one male. When the female is ready to spawn she enters the nest, the male moves alongside her, and gametes are released. After the spawn the female immediately begins to beat her caudal fin above the gravel just upstream of the nest to simultaneously cover the fertilized eggs and begin construction of a new nest. This process is repeated many times until the female has released all of her eggs, usually from 400 to 21,000. Brown trout do not die after spawning and can spawn for several years. In the Great Lakes, spawning can occur on rocky areas near shore as documented by Eddy and Underhill (1974) in Lake Superior and by Daly (1968) in Lake Michigan.

The amber-colored eggs are 4-5 mm in diameter and hatch in 48 days at 1.9°C (35°F) and in 33-36 days at 11.1-11.2°C (52°F) (Aver 1982). Fry begin feeding 3-6 weeks after hatching. Growth is usually rapid. In southern Wisconsin, brown trout are known to attain a length of 30.5 cm (12 in.) and sexual maturity at an age of 20 months. While males in some populations are mature before 2 years of age, maturity usually occurs after the second or third year. In Lake Michigan, brown trout released at 20 cm (8 in.) and 1 year of age reached 44.5 cm (17.5 in.) at 2 years of age and 54.6 cm (21.5 in.) after their second growing season in the lake (Daly 1968). Maximum size is 103 cm (40.5 in.); adults commonly reach 38 cm (15 in.).

Diagnostic Counts

Usually 10 branchiostegal rays; 9 dorsal rays; 120-130 lateral scales; 10-12 anal rays; young have 9-14 short narrow parr marks.

Expansion

Brown trout are highly valued as game fish and have at times been heavily stocked in Illinois; however, there is little suitable habitat and the species does not reproduce.

Impact on Illinois

Brown trout are insufficiently common in Illinois to affect other species. Neither the brown trout nor any of the other introduced salmonids are being commercially harvested in Illinois, but a considerable sport fishery has developed for them.

***Oncorhynchus mykiss*, rainbow trout**

Figure 14

Origin and Range

Rainbow trout are native to the western coast of North America and have been widely introduced throughout the world. This anadromous species has been stocked repeatedly in Lake Michigan and several northern Illinois streams. Rainbow trout also have been stocked in some central and southern Illinois reservoirs and are known to have reproduced in Devil's Kitchen Lake, a reservoir in Williamson County (Brooks Burr, pers. comm.).

Biology

Scott and Crossman (1973) and Moyle (1976) described the life history of this species in detail, and most of the following information is taken from them. Rainbow trout usually are found in streams with cool, clear water and a rocky substrate. Lakes and reservoirs that are deep enough to remain cool on the bottom throughout the summer also provide suitable habitat. In streams, feeding territories are established, and food consists mostly of drift organisms in the summer and benthic invertebrates during winter. However, in lakes and reservoirs, feeding territories have not been observed, and diet consists mostly of benthic invertebrates with fishes being increasingly important in the diet of large individuals. Feeding is heaviest around dusk. In Lake Taneycomo in Missouri, 90% of the diet consisted of amphipods (Pflieger 1975). Optimum temperature range is 13-21°C (55-70°F).

Rainbow trout usually spawn in the spring, most commonly between April and June. However, in the Great Lakes, spawning is known to begin as early as December, and at high altitudes in western regions it may take place as late as August. Spawning occurs over gravel riffles in which a female constructs a nest by beating her caudal fin above the substrate to dig a nest (redd). Males compete for females, and a male defends a female and her nest from intrusion by other males. During the spawn the female enters the nest and remains in the center while one or two males assume parallel positions and press against her as gametes are released. The female then enlarges the nest on the upstream side, covering the eggs with gravel. Individual females dig and spawn in several nests, often with the same male. Each female may deposit from 200 to 12,000 eggs. Unlike the Pacific salmon species, rainbow trout do not die after spawning and may spawn during subsequent years. During spawning, the temperature is usually 10-15°C (50-60°F). There is little evidence that successful reproduction occurs in areas other than rocky streams.

Eggs are 3-5 mm in diameter and usually hatch in 4-7 days. Fry commence feeding in approximately 15 days. Progeny of lake residents may immediately return to the lake, but have been known to spend up to 3 years in the stream. Growth is most rapid in reservoirs and lakes but varies considerably depending on habitat conditions and on the origin of the population in question. Males can be sexually mature as small as 13 cm (5 in.) and at 1 year of age. However, both sexes usually reach sexual maturity after 3-5 years. Life expectancy of Great Lakes rainbow trout seems to be 6-8 years. Rainbow trout reach a maximum of 114 cm (45 in.) in length; adults commonly reach 38 cm (15 in.).

Diagnostic Counts

115-130 lateral scales; 10-12 dorsal rays; 8-12 anal rays; young have 5-10 widely spaced, short oval parr marks.

Expansion

Rainbow trout are established in upper Lake Michigan and sometimes stray into Illinois waters. However, little suitable habitat for this species exists in Illinois, and the rainbow trout is not expected to become established.

Impact on Illinois

The rainbow trout is popular as a sport fish wherever it is stocked in Illinois. It rarely reproduces in the state and does not become common enough in Illinois streams to have a serious effect on native species.

***Oncorhynchus gorbuscha*, pink salmon**

Figure 15

Origin and Range

The pink salmon is native to the northwestern coast of North America and the northeastern coast of Asia, including Japan and Korea. Pink salmon now found in the Great Lakes result from a 1956 stocking of about 20,000 surplus fingerlings into the Current River, a tributary to Lake Superior (Parsons 1973). The eggs were brought from the Skeena River, British Columbia, and raised in the Port Arthur Fish Hatchery on Thunder Bay, Ontario, in an attempt to establish spawning runs in the Hudson Bay drainage (Schumacher and Eddy 1960). By 1969, pink salmon had spread through most of Lake Superior and had been found in Lake Huron (Parsons 1973). By 1975 the species had spread through northern Lake Huron and northern Lake Michigan (Wagner 1976). Pink salmon have not been stocked in Illinois, but strays from northern Lake Michigan are sometimes collected in the Illinois portion of the lake.

Biology

A detailed account of pink salmon life history was given by Heard (1991), and most of the following information is taken from him and Scott and Crossman (1973). In the Great Lakes pink salmon are usually found in open water near the surface (Becker 1983). Pink salmon seldom feed in streams either as adults or as newly hatched fry. Adults feed mostly on pelagic macrocrustaceans, with fish playing increasingly important roles as they increase in size. Opossum shrimp, amphipods, and copepods are important dietary components in the Great Lakes. Fry and adults feed and migrate in schools.

In native North American populations, migration to streams and estuaries occurs from July to September, although it begins in June in some Asian populations (Takagi et al. 1981). Spawning begins at a temperature of about 10°C (50°F) and peaks at 16°C (61°F) . The distance of the upstream migration is generally smaller for the pink salmon than for other Pacific salmon species, often no more than 64 km (40 mi). Spawning sometimes occurs in the intertidal areas of small rivers. Prior to spawning, male pink salmon develop a large hump on the back and the mouth becomes a strongly hooked kype. Both sexes undergo atrophy of the alimentary canal and digestive organs, thickening of the skin, and color changes. These changes take 4-6 weeks, during which the fish remain in deeper pools of streams or in estuaries before migrating upstream. Spawning beds are usually gravel riffles. The female constructs a redd by beating her tail above the gravel in the manner of other salmon and trout. When the female is ready to spawn she enters the nest and is joined by one or several males, and gametes are released. Males often spawn with more than one female. Eggs are covered by further nest construction upstream of the fertilized eggs. Females carry 1,200-1,900 eggs. Adults usually die shortly after spawning is completed; however, the female guards the eggs from other females as long as she lives.

Eggs are about 6 mm in diameter and hatch from December to February, depending on the water temperature. The fry remain under the gravel until the yolk sac is absorbed, usually in April or early May. Pink salmon fry migrate to estuaries immediately upon absorption of the yolk sac. They usually do not feed in fresh water, but remain in an estuary to feed for several months before migrating to the open sea. Pink salmon generally live for 2 years, but adults at 3 years of age have been reported. Since this 2-year life cycle is fixed, odd-year and even-year spawning populations in the same stream are reproductively isolated and are usually distinguishable genetically. Some streams have spawning runs only every other year.

The Great Lakes population of pink salmon is the only one known to complete its life history entirely in fresh water and shows more variation than its anadromous counterparts. While most aspects of biology are very similar to those displayed by anadromous populations, Great Lakes individuals show lower fecundity, smaller adult size, and more variable age at maturity, presumably related to less favorable growing conditions. The originally established population in Lake Superior spawned only during odd years, but later an even-year population developed from age-3, odd-year spawners. Pink salmon have a smaller adult size than other Pacific salmon species with a maximum of 76 cm (30 in.); adults commonly reach 51 cm (20 in.).

Diagnostic Counts

169-198 lateral scales; 10-16 dorsal rays; 13-19 anal rays; young lack parr marks.

Expansion

This species is present in Illinois only as stragglers from northern Lake Michigan and is not expected to reproduce in Illinois nor to invade new areas.

Impact on Illinois

The pink salmon is too rare in Illinois to have an important impact on other species.

Oncorhynchus tshawytscha, chinook salmon

Figure 16

Origin and Range

The chinook salmon is native to the northwestern coast of North America and the northeastern coast of Asia. It was introduced into Lake Michigan in 1967 by the Michigan Department of Conservation (Smith 1979). Today the chinook salmon is fairly common in Lake Michigan but must be continuously stocked to maintain a population.

Biology

Healey (1991) discussed the biology of the chinook salmon in detail and the following information is taken from his work and that of Scott and Crossman (1973). Newly emerged chinook fry are usually associated with the stream edge and woody cover, but as they increase in size they move to areas with a higher water velocity. Those that remain in the natal stream feed mostly on terrestrial invertebrates at the surface, but benthic and midwater feeding also occur. When fry first emerge from the gravel they feed in schools, but those that remain in the stream soon establish feeding territories. Large chinook young do not become piscivorous in streams as the young of coho salmon do. Those young that migrate downstream to the estuary or lake feed mostly on midges and other insects. Fishes make up about 97% of the diet of adults at sea, with squid and other invertebrates making up the other 3%. Optimal temperature range for fry is 12-14°C (53.6-57.2°F) and they cannot tolerate temperatures higher than 25.1°C (77.2°F) (Brett 1952).

Chinook salmon spawning may take place at almost any time of the year, and many streams have more than one run each year. However, in most rivers spawning activity occurs from late summer to late fall. Spawning may take place anywhere from just upstream of tidal influence to as far as 3,200 km (2,000 mi) upstream (Major et al. 1978). Spawning beds can be found in small shallow creeks (Vronskiy 1972) as well as main channels of large rivers (Chapman 1943; Hallock et al. 1957). Spawning usually occurs in much larger rivers than those used by other Pacific salmon. The depth at which the spawning bed is found also varies considerably, ranging from a minimum of 5 cm (2 in.) to an estimated maximum of 7 m (23 ft). As with other salmon, the female constructs the redd. A dominant male usually defends each female and redd, and satellite males often are present. During spawning the female and dominant male enter the nest, and eggs and sperm are released. Satellite males frequently dash into the nest and release gametes. The female deposits the eggs in clumps during spawning, and each clump is buried in a pit and covered with gravel displaced by the construction of the next spawning pit. A female usually deposits 4 or 5 egg clumps during the spawn. The total number of eggs deposited by a female ranges from 2,000 to 17,000. Females remain to defend the redd after spawning and may do so for as long as 25 days, although death may occur as soon as 4 days after the start of spawning activity. Members of Great Lakes populations sometimes spawn on shoals within the lake instead of ascending a stream.

The eggs of chinook salmon are 6-7 mm in diameter and incubate for 30-150 days, largely dependent on water temperature. Above 17°C (63°F), young suffer retarded growth and increased mortality (Davidson and Hutchinson 1938). The fry spend 2-3 weeks in the gravel until the yolk sac is absorbed. They may proceed to the estuary after only a few weeks in the natal stream, although many remain for up to 2 years. In anadromous populations most adults spend 2-3 years at sea, although spawning adults up to 9 years of age have been reported. Stocked chinook salmon in Lake Michigan have a 4-year life span (Becker 1983). Chinook salmon are the largest of the introduced salmon species and growth in Lake Michigan is rapid. Daly (1971) reported average lengths for each year class: 25.4 cm (10 in.) at 1 year; 63.5 cm (25 in.) at 2 years; 86.4 cm (34 in.) at 3 years; 102 cm (40 in.) at 4 years. The largest reported chinook salmon was a 147 cm (58 in.), 57.2 kg (126 lb) individual captured in Alaska; adults often reach 91 cm (36 in.).

Diagnostic Counts

130-165 lateral scales; 10-14 dorsal rays; 14-19 anal rays; young have 6-12 large parr marks.

Expansion

The chinook salmon does not reproduce in Illinois but does reproduce in the tributaries of northern Lake Michigan where it is more common. Chinook salmon are not expected to be found in Illinois outside Lake Michigan.

Impact on Illinois

The chinook salmon aids in the control of the introduced alewife and is a popular sport fish. Like other introduced Pacific salmonids, the chinook salmon has the potential to compete with the lake trout and other native species.

Oncorhynchus kisutch, coho salmon
Figure 17

Origin and Range

Coho salmon are native to the western coast of North America and the northeastern coast of Asia. This species was first introduced to Lake Michigan in 1967 as a sport fish and to control the alewife population. It is not found in Illinois outside Lake Michigan.

Biology

The following account is based on the work of Moyle (1976) and Scott and Crossman (1973), and the comprehensive review of the species by Sandercock (1991). Freshwater habitat for young coho salmon consists of medium-sized pools and quiet stream margins where feeding territories are established. The territory size increases with fish size and the number of suitable territories in a stream limits the abundance of coho. Young coho salmon are visual predators feeding mostly in the water column and at the surface, and are reported to jump from the water to capture low-flying insects. Insects are the principal component of the diet until about 1 year of age, at which time fishes become increasingly important. Fry of other salmon species often are consumed. Marine invertebrates are the most common food items when coho salmon first leave the streams, but adult coho become more piscivorous until fishes are about 80% of the diet.

In most populations, spawning takes place from November to January, but occurs from early September to early October in the Great Lakes. Water temperature is usually 7.2-15.6°C (45-60°F) during spawning migrations (Reiser and Bjornn 1979). Coho salmon migrate further upstream than pink salmon, but not as far as chinook salmon. Coho usually do not migrate more than 238 km (150 mi) upstream (Godfrey 1965), but a known spawning area in Alaska is 1,830 km (1,152 mi) from the Pacific Ocean (McPhail and Lindsey 1970). Coho salmon usually spawn in small streams that often have a width of 1 m or less. While small streams with a gravel bottom are preferred, coho salmon are the most tolerant of variable spawning conditions and sometimes spawn over sand or silt and in a wide variety of stream sizes. Prior to spawning, male coho salmon develop enlarged jaws and teeth, often to the extent that the mouth can no longer be closed. The jaws of females also become enlarged but to a lesser extent than those of males. When the spawning grounds are reached, the female selects a nest site, which she defends from other females. The female constructs the nest (redd) by beating her tail above the substrate to lift gravel and silt into the water column, where it is carried downstream. Several males can be in attendance, but usually a dominant male will attempt to drive others away. When the female is ready to spawn, she enters the nest and inserts her anal fin into the substrate. The dominant male assumes a parallel position and gametes are released. Satellite males often rush in and deposit sperm. As in other salmon species, after spawning the female immediately begins construction of a new nest upstream of the old one, thereby covering the fertilized eggs with gravel. Females produce 2,000-5,000 eggs. Males continue to exhibit courting behavior until they are too weak to maintain a position in the current. Females may guard the fertilized eggs until death, but sometimes the post-spawn female will continue digging motions even though the new nests are shallow and nonfunctional. Males and females usually die within 2 weeks of spawning.

Eggs of Pacific populations range from 4.5-6.0 mm in diameter, but in Lake Ontario they range from 6.6 to 7.1 mm. Hatching occurs anywhere from 35 to 115 days after fertilization, depending on the temperature. After hatching, fry remain in the gravel until the yolk sac is gone, usually 2-3 weeks. Upon leaving the redd, they feed in schools for a short time before establishing feeding territories. Coho young remain in the stream for 1-2 years, after which they migrate to the lake or ocean. Most smolts (juvenile salmon) are about 10 cm (4 in.) when they migrate to open water. Usually about 18 months are spent in the lake or ocean, although some males return after only one season. Spawning migration to streams other than the natal stream is more common in the Great Lakes than in anadromous populations, where about 85% of the individuals return to their natal streams. Maximum size is 98 cm (38.5 in.); adults commonly reach 53 cm (21 in.).

Diagnostic Counts

121-148 lateral scales; 9-12 dorsal rays; 12-17 anal rays; young have 8-10 narrow parr marks.

Expansion

Coho salmon are established in Michigan waters of Lake Michigan. No reproduction occurs in Illinois, but strays from northern parts of the lake are found in Illinois. Coho salmon are by far the most common introduced salmonid in Lake Michigan (Tom Trudeau, pers. comm.). They are not expected to be encountered in Illinois streams.

Impact on Illinois

Like the chinook salmon, the coho salmon aids in the control of the introduced alewife and is a popular sport fish. It also has the potential to compete with the lake trout and other native species.

Atherinidae

Key to silversides

1. Long beaklike snout (1.5 times eye diameter); first dorsal fin origin above anal fin origin; 74-87 lateral scales; 22-25 anal rays (brook silverside) .... *Labidesthes sicculus*

   No beaklike snout (snout length equal to eye diameter); first dorsal fin origin in front of anal fin origin; 36-44 lateral scales; usually 16-18 anal rays (inland silverside) .... ***Menidia beryllina***

***Menidia beryllina*, inland silverside**
Figure 18

Origin and Range

Primarily a marine and brackish water species native to the Atlantic and Gulf coasts of the U. S. and the lower Mississippi River, the inland silverside has been widely introduced as a forage species for game fish. Smith (1979) mentioned only that this species had been captured in Illinois. The inland silverside has been stocked in Lake Baldwin, Randolph/St. Clair counties; Lake of Egypt, Jackson/ Williamson counties; and Rend Lake, Franklin/ Jefferson counties. Collections from Illinois waters include those from the Cache River, Wabash River, lower Mississippi and Ohio rivers, and from the Kankakee River system in Will County.

Biology

The inland silverside is usually found in large schools near the surface of sand-bottomed, clear, quiet waters. It is often found in shallow water during the day but retreats to deeper water at night (Hubbs 1982). It is a visual feeder and has been reported to feed most heavily shortly after sunrise (Elston and Bachen 1976); however, Hubbs (1982) reported more nighttime feeding. In a California study, the diet consisted mostly of zooplankton with *Ceriodaphnia* sp., *Daphnia pulex*, and emerging dipterans the most important items (Elston and Bachen 1976). During the winter and while spawning, little foraging occurs and growth is greatly reduced (Hubbs 1982).

Most of what is known about the spawning of the inland silverside in fresh water results from studies on Lake Texoma, which have been summarized by Hubbs (1982). Inland silversides begin to spawn in March or early April and continue until the water becomes too warm (about 30°C [86°F1), usually in late June or July (Hubbs and Bailey 1977). Females produce clutches daily throughout the breeding season, each with a weight of about *7.5%* that of the female (Hubbs 1976). Clutch size varies in Lake Texoma from 384 to 1,699 eggs, depending on the size of the female (Mense 1967).

Incubation time is 15 days at 18°C (64.4°F) but can be less than 5 days when the water is warmer (Hubbs et al. 1971). Upon hatching, young inland silversides are about 0.5 cm (0.2 in.) in length. Young can grow to a maximum of 7.0 cm (2.8 in.) by the end of the breeding season in late July (Hubbs and Dean 1979). Growth of young-of-the-year is density dependent and is fastest after years with a high winter mortality (Hubbs and Dean 1979). Females are known to become reproductive at sizes as small as 4.8 cm (1.9 in.), and young-of-the-year sometimes reproduce during the same breeding season in which they were spawned (Hubbs 1982). Most individuals die after their first year of life. Mense (1967) and Hubbs et al. (1971) noted a disparity in the mortality of males and females during the spawning season and attributed the difference to the differing habitat preferences of the sexes. Hubbs et al. (1971) attributed the higher mortality of males to their preference for vegetated areas, where silverside integument damage could occur and centrarchid predators were more common. Inland silversides can reach 15 cm (6 in.) in length.

Diagnostic Counts

36-44 lateral scales; 15-20 anal rays; 4-5 spines in first dorsal fin; 8-10 rays in second dorsal fin.

Expansion

Reproduction of this species in Illinois is likely to occur in light of its abundance in the Ohio River. It is increasing its range in the Mississippi River drainage south of Illinois (Robison and Buchanan 1990), and individuals collected from the extreme southern tip of Illinois are probably a result of this expansion. In other states, stocked inland silversides have become established and abundant and will probably do so in Illinois.

Impact on Illinois

The inland silverside appears to have had little effect on other Illinois species. If the inland silverside becomes abundant in Illinois, it may compete in some bodies of water with native species by depleting populations of invertebrates, such as crustaceans and insects.

Gasterosteidae

Key to species of sticklebacks

1. Three dorsal spines, the last very short; large bony plates on side (threespine stickleback) . . . *Gasterosteus aculeatus*
   Five to 12 short dorsal spines; no bony plates on side 2

2. Four to 6 dorsal spines; no bony keel on caudal peduncle (brook stickleback)........ .... *Culea inconstans*
   Seven to 12 (usually 9) dorsal spines; bony keel on caudal peduncle (ninespine stickleback) .... *Pun gitius pungitius*

Gasterosteus aculeatus,
threespine stickleback
Figure 19

Origin and Range

The threespine stickleback has a circumpolar distribution in the Northern Hemisphere and is increasing its range in the Great Lakes region. It is native to the St. Lawrence River and as far west as Lake Ontario, but not in the more western Great Lakes (Wootton 1984). The first collections from Illinois were made in Cook and Lake counties in 1988 (Johnston 1991). Since then, several more collections have been made in these two counties, but none from other Illinois counties.

Biology

The biology of the threespine stickleback was discussed in detail by Wootton (1984). Threespine sticklebacks are found in sluggish waters of lakes, ponds, large lowland rivers, estuaries, and marine coastlines. Most populations reside in an estuary or the ocean when not engaged in spawning activities (Scott and Crossman 1973). Freshwater populations usually inhabit shallow vegetated water (Moyle 1976; Scott and Crossman 1973), although large numbers of individuals are sometimes encountered in deep water (Okada 1959-1960; Greenbank and Nelson 1958) and at the surface far from shore (Wootton 1984; Greenbank and Nelson 1958). All populations spawn in fresh water in shallow, soft-bottomed areas.

Threespine sticklebacks are visual feeders (Wootton 1976) and feed chiefly on microcrustaceans and insect larvae (Wootton 1984). However, essentially any food may be consumed including algae (Wootton 1984) and the eggs and fry of fish and conspecifics (Scott and Crossman 1973).

Spawning in fresh water populations usually occurs from April to the end of July, beginning when water reaches a temperature of 14°C (57°F) (Wheeler 1969). The territorial males prefer to build nests in sheltered areas, even though rooted vegetation is not required as in other stickleback species (Wootton 1984). The tube-shaped nest is formed when the male makes a depression in the substrate and completes the tube with algae, twigs, and other pieces of debris, which are held together by an adhesive secretion produced in the male's kidney (Scott and Crossman 1973). The male then attempts to attract females with a courtship "dance" that varies from swimming about rapidly to mere side-to-side head movements (McPhail and Lindsey 1970). If the female is willing to spawn in the male's nest, she assumes a vertical head-up position after which the male swims back to the nest. The male pokes his snout into the entrance of the nest, presumably enticing the female to enter. If she is ready to spawn, she enters and deposits eggs (McPhail and Lindsey 1970). Females may spawn more than once, and a nest may be visited by several females. Wootton (1971) discussed the raiding of nests by other males. He described raiding in which a male would lose breeding colors and make very short runs toward another male's nest, resting on the substrate between runs. When the resident male detected the raider before it reached the nest the raider was almost invariably driven off, but when it reached the nest it usually succeeded in carrying off eggs or nest material. Males that were already engaged in courtship activities were never observed to raid the nests of other males. Wootton suggested that this raiding behavior is a result of food and nest-building material shortages. Kynard (1979) reported a mean clutch size of 96 eggs and an average of 1,000 eggs in each nest. After eggs are deposited, males remain with the nest to fan and guard the eggs. Males guard the fry for 1-9 days after the eggs hatch (Wootton 1984).

The 1.5-2.0 mm eggs hatch in 15-20 days at 10°C (50°F) (Wootton 1984) and in 5-6 days at 21°C (70°F) (Kynard 1978). Fry range from 4.2 to 5.0 mm upon hatching (Kuntz and Radcliffe 1917; Jones and Hynes 1950). After the first year, individuals from freshwater populations are usually from 3.0 to 4.4 cm (1.2-1.7 in.) and individuals from anadromous populations are around 6.0 cm (2.4 in.) (Wootton 1984). Individuals in most populations mature after 1 year and have a maximum life span of 3 years. Maximum size is about 7.6 cm (3 in.) in freshwater populations and about 10.0 cm (4 in.) in anadromous populations.

Diagnostic Counts

2-4 (usually 3) dorsal spines; pelvic fin with 1 spine and 1 ray.

Expansion

The threespine stickleback reproduces in Illinois waters of Lake Michigan. This species will probably increase in abundance in the Lake Michigan area but is unlikely to infiltrate other areas of the state.

Impact on Illinois

In some areas this species is an important forage fish for salmonids and fish-eating birds and, if its abundance increases, it might play this role in Illinois as well. However, it is known to prey on the eggs of other fishes and may have a negative impact on native species. It also may compete with native sticklebacks for food and other resources.

Moronidae

Key to temperate basses

1. No dark stripes along side of body (young have interrupted dark lines, bars on side); body deepest under first dorsal fin (white perch) .... *Morone americana*
   Dark stripes along side of body; body deepest between dorsal fins 2

2. Black stripes on silver-yellow side; stripes broken and offset on lower side; second anal spine about as long as third; no teeth on tongue (yellow bass) .... *Morone mississippiensis*
   Gray stripes on silver-white side; stripes not offset on lower side; second anal spine distinctly shorter than third; teeth on rear of tongue.. 3

3. Deep body strongly arched behind head; to 45 cm (18 in.) in total length (white bass) .... *Morone chrysops**
   Smoothly arched dorsal profile; to 2 m (79 in.) in total length (striped bass) .... *Morone saxatilis**

*Hybridization between the white bass and striped bass is common. Hybrids are morphologically intermediate between the two species.

Morone americana, **white perch**

Figure 20

Origin and Range

In recent years the white perch has invaded the western Great Lakes from its native range of Lake Ontario and the Atlantic Slope drainages of northern North America. By 1988 the white perch had reached the Illinois waters of Lake Michigan, and a specimen was captured at Belmont Harbor in Chicago (Savitz et al. 1989). Recently, white perch have been captured in the Calumet River system, the Illinois River, and in the Mississippi River drainage in extreme southern Illinois.

Biology

Detailed information on the life history of the white perch was given by Mansueti (1961, 1964). The white perch is a semianadromous schooling species found principally in brackish water but many populations complete their life histories in lakes and reservoirs. Coastal populations migrate from estuaries into shallow streams to spawn during the spring. The winter is passed in deep water.

White perch spend the day in deeper water and enter shallow water at night to feed (Webster 1942b). From Chesapeake Bay collections, Hildebrand and Schroeder (1928) reported a diet of annelids, amphipods, isopods, copepods, and insect larvae in individuals smaller than 10 cm (4 in.) with fishes increasingly important as food as individuals increase in size. Freshwater studies indicate that insects, microcrustaceans, fishes, and crayfishes are the most important components of the diet (Reid 1972; Schaeffer and Margraf 1986; Smith 1947). Schaeffer and Margraf (1986) reported a seasonal shift to consumption of gizzard shad *(Dorosoma cepedianum)* as young-of-the-year became available in late summer and fall. White perch feeding on the eggs of other fishes has been reported (Bigelow and Welsh 1925; Webster 1942a; Schaeffer and Margraf 1986). A Maine population showed a dietary shift with individuals under 20.1 cm (8 in.) consuming mostly insects; those from 20.1-28.0 cm (8-11 in.) feeding equally on fishes, insects, and crayfishes; and individuals longer than 28 cm (11 in.) feeding chiefly on crayfishes (Reid 1972).

Spawning in white perch takes place from May to July. Hildebrand and Schroeder (1928) reported the capture of 10 ripe males and 3 ripe females during December 1915, but no other evidence of winter reproduction has been reported. Males are first to arrive at the spawning grounds and outnumber females there throughout the season, although females outnumber males away from the spawning areas (Mansueti 1961). Spawning temperatures range from 11-15°C (52-59°F) (Sheri and Power 1968). Foster (1918) estimated that 10% of the population was ripe at the height of the season with the percentage decreasing towards the beginning and end of the season. Spawning takes place in shallow water over a variety of substrates. Males and females seem to release gametes at random (Scott and Crossman 1973). The eggs are adhesive and become attached to the substrate and submerged objects. Individual fecundity ranges from 5,200-250,000 eggs and increases with increasing fish length, although there is a great deal of variation in number of eggs produced per gram of body weight (Sheri and Power 1968).

The 0.73 mm (.03 in.) eggs hatch in 6 days at 10.6-11.9°C (51-53°F) (Hildebrand and Schroeder 1928), but can hatch in as little as 30 hours at 20°C (68°F) (Scott and Crossman 1973). Larvae and eggs are not sensitive to high levels of suspended sediments (Morgan et al. 1983).

Growth is rapid during the first 2 years and slows greatly thereafter. St. Pierre and Davis (1972) found more rapid growth in females than males until age 5, possibly due to earlier maturation in males. St. Pierre and Davis (1972) found the following average lengths from the James River of Virginia: 7.6 cm (3.0 in.) at 1 year, 12.0 cm (4.7 in.) at 2 years, 14.9 cm (5.9 in.) at 3 years, 17.2 cm (6.8 in.) at 4 years, 18.9 cm (7.4 in.) at 5 years, 20.4 cm (8.0 in.) at 6 years, 22.0 cm (8.7 in.) at 7 years, 23.6 cm (9.3 in.) at 8 years, 25.3 cm (10.0 in.) at 9 years, and 26.2 cm (10.3 in.) at 10 years. Similar values were reported from the York River in Virginia (St. Pierre and Davis 1972) and the Patuxent River in Maryland (Mansueti 1961). Mansueti (1961) found an inverse relationship between population density and growth, and first-year growth was negatively related to spring rainfall. In Lake Ontario about 8% of males were mature after 1 year and all were mature at 2 years, while about 6% of the females were mature after 1 year, 76% were mature at 2 years, and all were mature at 3 years (Sheri and Power 1968). Males can mature at lengths near 8.0 cm (3.15 in.) while females begin at lengths near 9.0 cm (3.5 in.) (Mansueti 1961).

Females appear to live longer than males (Mansueti 1961; St. Pierre and Davis 1972; Sheri and Power 1968), although Wallace (1971) found the opposite result. St. Pierre and Davis (1972) suggested the preponderance of females among older fish might be attributable to sex reversal. In Lake Ontario, females outnumbered males at all age classes with an increasing disparity in older fish, suggesting higher mortality for males (Sheri and Power 1968). The oldest recorded white perch was 17 years old but in most populations the maximum age is about 10 years, with females living longer than males. Maximum size is 58 cm (23 in.); adults rarely exceed 24 cm (9.5 in.).

Diagnostic Counts

9 spines in first dorsal fin; 1 spine and 11-14 rays in second dorsal fin; 3 anal spines; 9-10 anal rays.

Expansion

The white perch is reproducing in Illinois and rapidly expanding its range. It is likely to become statewide in distribution.

Impact on Illinois

White perch are considered game fish in some areas, and the species may be promoted as a sport fish in Illinois. The effect of the species on Illinois ecosystems depends largely on its abundance. If it becomes common in Illinois, it is likely to compete with two closely related native sport fishes, the white bass and yellow bass.

***Morone saxatilis*, striped bass**

Figure 21

Origin and Range

The striped bass is an anadromous species native to the eastern coast of North America, where it inhabits marine and coastal waters, estuaries, and large rivers. This widely introduced species first appeared in Illinois in 1974 as an escapee from impoundments in western Kentucky, where it had been established (Smith 1979). Today, striped bass are regularly captured from the lower Mississippi and Ohio rivers and several captures have been reported from the Illinois River.

Biology

All aspects of striped bass biology were summarized by Setzler et al. (1980). Most studies indicate a high degree of piscivory in striped bass once the juvenile stage is reached (Hildebrand and Schroeder 1928; Manooch 1973; Hollis 1952; Trent and Hassler 1966); however, invertebrates are consumed in large quantities when they are abundant and fish are scarce or difficult to catch (Schaefer 1970; Rulifson and McKenna 1987). Most studies indicate that soft-rayed fishes, especially clupeids, are the most commonly consumed prey of striped bass in marine (Manooch 1973) and freshwater habitats (Ware 1971; Stevens 1958; Trent and Hassler 1966). The most commonly consumed invertebrates are crabs, shrimp, and amphipods (Manooch 1973). Fry feed on invertebrates, especially copepods and cladocerans (Harrell et al. 1977). Juveniles feed on fish (Hollis 1952; Manooch 1973) and whatever invertebrates are most available (Rulifson and McKenna 1987). Stevens (1958) found that striped bass in the Santee-Cooper Reservoir of South Carolina fed almost entirely on gizzard shad *(Dorosoma cepedianum)* and threadfin shad *(Dorosoma petenense)* except in the spring, when they shifted to mayflies. Seasonal diet shifts can result from differential prey availability (Hollis 1952). Bigelow and Schroeder (1953) observed that striped bass tend to focus on one abundant prey item and ignore others.

Manooch (1973) found that while prey that are about 20% of the bass' length are preferred, individuals up to 60% of the predator's length are sometimes eaten. Most feeding takes place at night (Bigelow and Schroeder 1953).

Spawning usually takes place in rapids in fast-water streams. Individuals from anadromous populations tend to move far enough upstream to be well above the tidal influence (Scott and Crossman 1973). Some females return to the stream from which they were spawned but males do not (Chapman 1989). VanCleve (1945) and Hassler (1958) suggested that spawning success is dependent upon river flow, with high flow yielding better reproductive success. Spawning takes place near the surface (Raney 1952; Hildebrand and Schroeder 1928) where a female may be surrounded by many males (Merriman 1941). Eggs are broadcast into the current. The season begins in mid-February in Florida and runs until July in Canada (Setzler et al. 1980).

Spawning usually begins when water temperature reaches about 14.4°C (58°F) and peaks at temperatures from 15.6-18.3°C (60-65°F). Feeding ceases during spawning. Eggs and larvae can survive at temperatures ranging from 13-24°C (55-75°F) (Albrecht 1964). Female fecundity estimates range from 14,000 (Raney 1952) to 40,507,500 (Jackson and Tiller 1952).

Eggs are normally 1.2 mm in diameter when released into the water, but they soon increase in size until the diameter is about 3.6 mm. Eggs hatch in 70-74 hours at 14.4-15.6°C (58-60°F), 48 hours at 19.4°C (67°F), and 30 hours at 21.7-22.2°C (71-72°F) (Bigelow and Schroeder 1953). Eggs are semibuoyant and require a current of about 30.5 cm/s (1 foot/s) to remain suspended in the water column (Albrecht 1964). Larvae and eggs do not seem to be sensitive to high levels of suspended sediment (Morgan et al. 1983); however, those that sink to the bottom have a greatly reduced probability of hatching. Eggs seem to survive best at moderate levels of salinity, such as those that might be encountered in an estuary (Albrecht 1964). Feeding usually begins about the sixth day after hatching (Harrell et al. 1977). In Chesapeake Bay young tend to remain in the natal estuary until the age of 2 years (Chapman 1989). Striped bass begin to school early in life and do so until they attain large sizes at which time they forage singly or in small groups (Bigelow and Schroeder 1953).

Growth was measured in individuals collected from the Roanoke River of North Carolina by Trent and Hassler (1968). Average fork length for males was 42.4 cm (16.7 in.) at 3 years of age, 46.4 cm (18.3 in.) at 4 years, and 50.3 cm (19.8 in.) at 5 years. Females averaged 51.3 cm (20.2 in.) at 4 years, 54.4 cm (21.4 in.) at 5 years, and 60.2 cm (23.7 in.) at 6 years. Sexual maturity is often reached at an earlier age by males and is reached more rapidly in both sexes at higher water temperatures. Almost all males are mature at 2 years in most populations (Ware 1971; Raney 1954) but age at maturity varies more for females. Lewis (1962) found that females began to mature at 3 years in the Roanoke River, North Carolina, and Jackson and Tiller (1952) found that they began to mature at 4 years in the Chesapeake Bay; however, Bason (1971) found that no females were mature before their fifth year. Minimum lengths at maturity are 43.2 cm (17 in.) for females (Clark 1968) and 17.4 cm (6.9 in.) for males (Raney 1952). Females live longer than males. Few males exceed 11 years of age (Setzler et al. 1980), but a female from Rhode Island was estimated to be 29-31 years old (Merriman 1941). Striped bass can become very large with weights up to 56.8 kg (125 lb) reported; they often reach lengths above 76 cm (30 in.) and have been reported up to 2 m (79 in.).

Hermaphroditism has been reported for Oregon populations of the striped bass that originated from the California population established in the late 1800s (Morgan and Gerlach 1950; Schultz 1931; Moser et al. 1983). Young hermaphrodites have functional sperm and immature ovaries; older hermaphrodites have functional ovaries.

Diagnostic Counts

9 spines in first dorsal fin; 1 spine and 11-14 rays in second dorsal fin; 3 anal spines; 9-13 (usually 11) anal rays.

Expansion

Illinois reproduction of striped bass occurs in the Ohio River where young have been collected in large numbers (Brooks Burr, pers. comm.). Reproduction in other Illinois rivers has not been documented, but the potential exists for this species to become established in large rivers statewide.

Impact on Illinois

Striped bass attain a very large size and are highly sought game fish. However, their predation on other fishes, including other game species and threatened and endangered species, could have undesirable effects on native fish communities. Presently, striped bass are not common enough in Illinois to be an important game fish or to have caused noticeable effects on other aquatic ecosystems.

Gobiidae

The only goby established in Illinois is the introduced round goby.

***Neogobius melanostomus*, round** goby
Figure 22

Origin and Range

The round goby is native to the Black and Caspian seas and their drainages. It was collected in 1990 in the St. Clair River, Michigan, and was first collected in Illinois in 1993 in the Calumet River drainage. It is now established and rapidly spreading north and east along the shores of Lake Michigan. It is not known whether the Illinois population is derived from the one in the St. Clair River or if it was transported here directly from Europe in the ballast water of a ship.

Biology

Throughout most of the year, the round goby occurs in rocky inshore areas of the Black and Caspian seas but overwinters in deeper water (Miller 1986). Round gobies are benthic and are capable of attaching themselves to hard surfaces with their fused pelvic fins that are modified into a suctorial disc. The diet comprises mostly bivalves, amphipods, and polychaetes; midges, small fishes, and fish eggs also are consumed (Jude et al. 1992).

Spawning usually occurs in May and June (Berg 1964). The following information was taken largely from Jude et al. (1992). Individuals spawn up to six times each season, about every 18-20 days. The adhesive eggs are deposited between rocks (Breder and Rosen 1966) and guarded by the male. Fecundity ranges from 328 to 5,221 eggs per female, with the average near 1,000 (Berg 1964). Eggs are large, measuring about 3.9 x 2.2 mm (Jude et al. 1992).

Round gobies can become mature at 1 year of age (Berg 1964). Males commonly reach 18 cm (7.1 in.) and females typically reach 14 cm (5.5 in.). The maximum size is about 30 cm (11.8 in.).

Diagnostic Counts

49-55 lateral scales; 5-6 dorsal spines; 16-17 dorsal rays; 18-19 pectoral rays; 6 pelvic rays; 11-13 anal rays.

Expansion

Since its first collection in Illinois in 1993, this species has become abundant in some areas. It is found in large numbers in the southwestern portion of Lake Michigan in Illinois. Its ability to survive in Illinois rivers is unknown, but it often ascends rivers in its native range and has survived in the St. Clair River of Michigan and the Calumet River of Illinois.

Impact on Illinois

The round goby is a benthic species known to eat eggs and young fish and is thought to have caused reductions of native sculpins in the St. Clair River. In Illinois it will probably have a detrimental effect on native sculpins and possibly on other native benthic species. On the positive side, the round goby is known to have caused localized reductions in zebra mussel populations in Lake Michigan (E. Marsden, pers. comm) This species is commercially important in its native range where it is harvested for human consumption.

Literature Cited

Albrecht, A.B. 1964. Some observations on factors associated with survival of striped bass eggs and larvae. Calif. Fish. Game 50:100-113.

Aliev, D.S. 1976. The role of phytophagous fishes in the reconstruction of commercial fish fauna and the biological improvement of water. J. Ichthyol. (USSR) 16:216-229.

Anderson, E.D., and L.L. Smith. 1971. Factors affecting abundance of Lake Herring *(Core gonus artedii* Lesueur) in western Lake Superior. Trans. Am. Fish. Soc. 100:691-707.

Applegate, V.C. 1950. Natural history of the sea lamprey, *Petromyzon marinus,* in Lake Michigan. U.S. Fish Wildl. Serv. Spec. Rep. Fish. No. 55. 237 pp.

Applegate, V.C., J.H. Howell, J.W. Moffett, B.G.H. Johnson, and M.A. Smith. 1961. Use of 3-triflouromethyl-4-nitophenol as a selective sea lamprey larvicide. Gr. Lakes Fish. Comm. Tech. Rep. 1. 35 pp.

Aver, N.A. 1982. Family Salmonidae, trouts. Pages 80-145 *in* N.A. Aver, ed. Identification of larval fishes of the Great Lakes Basin, with an emphasis on the Lake Michigan drainage. Gr. Lakes Fish. Comm Spec. Pub. 82-83. Ann Arbor.

Bailey, M.M. 1964. Age, growth, maturity, and sex composition of the American smelt, *Osmerus mordax* (Mitchill), of western Lake Superior. Trans. Am. Fish. Soc. 93:382-395.

Baldwin, N.S. 1950. The American smelt, *Osmerus mordax* (Mitchill), of South Bay, Manitoulin Island, Lake Huron. Trans. Am. Fish. Soc. 78:176-180.

Bason, W.H. 1971. Ecology and early life history of the striped bass, *Morone saxatilis,* in the Delaware estuary. Ichthyol. Assoc. Bull. 4. 122 pp.

Battle, H.I. 1940. The embryology and larval development of the goldfish *(Carassius auratus* L.) from Lake Erie Ohio J. Sci. 40:82-93.

Bean, T.H. 1897. Notes upon New York fishes received at the New York Aquarium, 1895-1897. Bull. Am. Mus. Nat. Hist. 9:327-375.

Bean, T.H. 1903. Catalogue of the fishes of New York. N.Y. State Bull. 278, Albany.

Becker, G.C. 1983. Fishes of Wisconsin. University of Wisconsin Press, Madison. xii + 1052 pp.

Berg, L.S. 1964. Freshwater fishes of the U.S.S.R. and adjacent countries. 4th ed. Vol. 2. Israel Program for Scientific Translations, Jerusalem 496 pp.

Berry, F.H., M.T. Huish, and H. Moody. 1956. Spawning mortality of the threadfin shad, *Dorosoma petenense* (Günther), in Florida. Copeia 1956:192.

Berry, P.Y., and M.P. Low. 1970. Comparative studies on some aspects of the morphology and histology of *Ctenopharyngodon idellus, Aristichthys nobilis* and their hybrid (Cyprinidae). Copeia 1970:708-726.

Bigelow, H.B., and W.C. Schroeder. 1953. Fishes of the Gulf of Maine. U.S. Fish and Wildl. Serv. Fish. Bull. 53. vii + 577 pp.

Bigelow, H.B., and W.W. Welsh. 1925. Fishes of the Gulf of Maine. U.S. Bur. Fish. Bull. 40. Part 1. 567 pp.

Bills, T.D., and D.A. Johnson. 1992. Effect of pH on the toxicity of TFM to sea lamprey larvae and nontarget species during a stream treatment. Gr. Lakes Fish. Comm. Tech. Rep. 57:7-19.

Breder, C.M., Jr., and D.E. Rosen. 1966. Modes of reproduction in fishes. Natural History Press, Garden City, New York. xv + 941 pp.

Brett, J.R. 1952. Temperature tolerance in young Pacific salmon, genus *Oncorhynchus.* J. Fish. Res. Board Can. 9:265-323.

Brown, D.J., and T.G. Coon. 1991. Grass carp larvae in the lower Missouri River and its tributaries. N. Am. J. Fish. Manage. 11:62-66.

Burkhead, N.M., and J.D. Williams. 1991. An intergeneric hybrid of a native minnow, the golden shiner, and an exotic minnow, the rudd. Trans. Am. Fish. Soc. 120:781-795.

Burr, B.M. 1991. The fishes of Illinois: an overview of a dynamic fauna. Pages 417-427 *in* L.M. Page and M. R. Jeffords, eds. Our living heritage: the biological resources of Illinois. Ill. Nat. Hist. Surv. Bull. 34.

Burr, B.M., and M.L. Warren, Jr. 1993. Fishes of the Big Muddy River drainage with emphasis on historical changes. Pages 186-209 *in* L.W. Hesse, C.B. Stalnaker, N.G. Benson, and J.R. Zuboy, eds. Proceedings of the Symposium on Restoration Planning for the Rivers of the Mississippi River Ecosystem. Natl. Biol. Surv. Biol. Rep. 19.

Carlander, K.D. 1969. Handbook of freshwater fishery biology. Vol. 1. Iowa State Univ. Press, Ames. 752 pp.

Carter, F.A., and J.K. Beadles. 1983. Range extension of the silver carp, *Hypophthalmichthys molotrix.* Proc. Ark. Acad. Sci. 37:80.

Chaisson, A.G. 1993. The effects of suspended sediment on rainbow smelt *(Osmerus mordax):* a laboratory investigation. Can. J. Zool. 71:2419-2424.

Chang, Y.F. 1966. Culture of freshwater fish in China. *In* E.O. Gangstad, ed. 1980. Chinese fish culture. Report 1. Technical report A-79. Aquatic plant control research program. (Translated by T.S.Y. Koo, 1980). Washington, D.C.: U.S. Army Waterways Experiment Station.

Chapman, R.W. 1989. Spatial and temporal variation of mitochondrial DNA haplotype frequencies in the striped bass *(Morone saxatilis)* 1982 year class. Copeia 1989:344-348.

Chapman, W.M. 1943. The spawning of chinook salmon in the main Columbia River. Copeia 1943:168-170.

Clark, J.R. 1968. Seasonal movements of striped bass contingents of Long Island Sound and the New York Bight. Trans. Am. Fish. Soc. 97:320-343.

Colle, D.E., J.V. Shireman, and R.W. Rottmann. 1978. Food selection by grass carp fingerlings in a vegetated pond. Trans. Am. Fish. Soc. 107:149-152.

Conner, J.V., R.P. Gallagher, and M.F. Chatry. 1980. Larval evidence for natural reproduction of the grass carp *Ctenopharyngodon idella* in the lower Mississippi River. U.S. Fish and Wildl. Serv. Biol. Serv. Program, FWS/OBS-80/43:1-19.

Cooper, J.E. 1978. Identification of eggs, larvae and juveniles of the rainbow smelt, *Osmerus mordax,* with comparison to larval alewife, *Alosa pseudoharengus,* and gizzard shad, *Dorosoma cepedianum.* Trans. Amer. Fish. Soc. 107:56-62.

Courtenay, W.R., Jr., D.A. Hensley, J.N. Taylor, and J.A. McCann. 1986. Distribution of exotic fish in North America. Pages 675-698 *in* C.H. Hocutt and E.O. Wiley, eds. The zoogeography of North American freshwater fishes. Wiley and Sons, New York. xiii + 866 pp.

Creaser, C.W. 1925. The establishment of the Atlantic smelt in the upper waters of the Great Lakes. Pap. Mich. Acad. Sci. Arts Lett. 5:405-423.

Creaser, C.W., and C.S. Hann. 1929. The food of larval lampreys. Pap. Mich. Soc. Arts Lett. 10:433-437.

Dah-Shu, L. 1957. The method of cultivation of grass carp, black carp, silver carp and bighead carp. (Translated from Chinese by Language Services Branch, U.S. Department of Commerce, Washington, D.C.) China: Aquatic Biology Research Institute, Academica Sinica. 90 pp.

Daly, R.I. 1968. Progress report of fish management on Lake Michigan. Wis. Dep. Nat. Resour. Bur. Fish Manage., Oshkosh. 18 pp.

Daly, R.I. 1971. Chinook: the big one. Wis. Conserv. Bull. 36:22-23.

Daly, R.I., and W. Wiegert. 1958. The smelt are running! Wis. Conserv. Bull. 23(3):14-15.

Danchenko, E.V. 1970. The role of zooplankton in food of second year grass carp and bighead reared jointly with carp in ponds of the Sinyukhinskiy fish farm in Krasnodarsk Province. (Translated from Russian). Pages 53-60 *in* Materials from a scientific conference on intensive fisheries exploitation of the inland waters of northern Caucasus, Kradnodar.

Davidson, F.A., and S.J. Hutchinson. 1938. The geographic distribution and environmental limitations of the Pacific salmon (genus *Oncorhynchus).* U. S. Dep. Commer. Bur. Fish. Bull. 48:667-692.

Dryer, W.R. 1966. Bathymetric distribution of fish in the Apostle Islands region, Lake Superior. Trans. Am. Fish. Soc. 95:248-259.

Eddy, S., and J.C. Underhill. 1974. Northern fishes. Univ. Minn. Press, Minneapolis. 414 pp.

Edsall, T.A. 1964. Feeding by three species of fishes on the eggs of spawning alewives. Copeia 1964:226-227.

Elston, R., and B. Bachen. 1976. Diel feeding cycle and some effects of light on feeding intensity of the Mississippi silverside, *Menidia audens*, in Clear Lake, California. Trans. Am. Fish. Soc. 105:84-88.

Ewart, K.V., and G.L. Fletcher. 1989. Isolation and characterization of antifreeze proteins from smelt *(Osmerus mordax)* and Atlantic herring *(Clupea harengus harengus).* Can. J. Zool. 68:1652-1658.

Ferguson, R.G. 1965. Bathymetric distribution of American smelt, *Osmerus mordax*, in Lake Erie. Gr. Lakes Res. Div. Univ. Mich. Pub. 13:47-60.

Forbes, S.A., and R.E. Richardson. 1908. The fishes of Illinois. Ill. State Lab. Nat. Hist. cxxxvi + 357 pp.

Foster, F.J. 1918. White perch notes and method of propagation. Trans. Am. Fish. Soc. 48:160-165.

Godfrey, H. 1965. Coho salmon in offshore waters. Pages 1-39 *in* Salmon of the North Pacific Ocean. Part IX. Coho, chinook, masu salmon in offshore waters. Int. North Pac. Fish. Comm. Bull. 16.

Gordon, W.C. 1961. Food of the American smelt in Saginaw Bay, Lake Huron. Trans. Am. Fish. Soc. 90:439-443.

Graham, J.J. 1956. Observations on the alewife, *Pomolobus pseudoharengus* (Wilson), in fresh water. Tor. Univ. Biol. Ser. 62. 43 pp. Publ. of the Ont. Fish. Res. Lab. no. LXXIV.

Graham, J.J. 1957. Some observations on the schooling movements of the alewife in Lake Ontario. Can. Field Nat. 71:115-116.

Greeley, J.R. 1935. Fish of the watershed, with annotated list. Pages 63-101 *in* A biological survey of the Mohawk-Hudson watershed. Suppl. to 24th Ann. Rep., Conserv. Dept., State of New York (1934).

Greenbank, J , and P.R. Nelson. 1958. Life history of the threespine stickleback *Gasterosteus aculeatus* Linnaeus in Karluk Lake and Bare Lake, Kodiak Island, Alaska. U.S. Fish. Wildl. Serv. Bull. 153. 59:537-559.

Greenfield, D.W. 1973. An evaluation of the advisability of the release of the grass carp, *Ctenopharyngodon idella*, into the natural waters of the United States. Trans. Ill. State Acad. Sci. 66:47-53.

Griffith, J.S. 1978. Effects of low temperature on the survival and behavior of threadfin shad, *Dorosoma petenense*. Trans. Am. Fish. Soc. 107:63-70.

Grout, D.E. 1983. A case of hermaphroditism in the rainbow smelt, *Osmerus mordax*. Copeia 1983:812-813.

Hallock, R.J., D.H. Fry, Jr., and D.A. LaFaunce. 1957. The use of wire fyke traps to estimate the runs of adult salmon and steelhead in the Sacramento River, California. Calif. Fish Game 43:271-298.

Harrell, R.M., H.A. Loyacano, and J.D. Bayless. 1977. Zooplankton availability and feeding selectivity of fingerling striped bass. Ga. J. of Sci. 35:129-135.

Haskell, W.L. 1959. Diet of the Mississippi threadfin shad, *Dorosoma petenense atchafalayae*, in Arizona. Copeia 1959:298-302.

Hassler, W.W. 1958. The striped bass in relation to the multiple use of the Roanoke River, North Carolina. Trans. 23d N. Am. Wildl. Conf. 378-391.

Healey, M.C. 1991. Life history of the chinook salmon *(Oncorhynchus tshawytscha)*. Pages 313-393 *in* C. Groot and L. Margolis, eds. Pacific salmon life histories. Univ. of British Columbia, Vancouver.

Heard, W.W. 1991. Life history of the pink salmon *(Oncorhynchus gorbuscha)*. Pages 121-230 *in* C. Groot and L. Margolis, eds. Pacific salmon life histories. Univ. of British Columbia, Vancouver.

Henderson, S. 1976. Observations of the bighead and silver carp and their possible application in pond fish culture. Ark. Game and Fish Comm., Little Rock. 18 pp.

Henderson, S. 1977. An evaluation of filter feeding fishes for water quality improvement. Ark. Game and Fish Comm., Little Rock. 26 pp.

Henderson, S. 1979. Utilization of silver and bighead carp for water quality improvement. Ark. Game and Fish Comm., Little Rock. 32 pp.

Hickling, C.F. 1962. Fish culture. Faber and Faber, London. 295 pp.

Hickling, C.F. 1966. On the feeding process in the white amur, *Ctenopharyngodon idella*. J. Zool. 148:408-419.

Hildebrand, S.F., and W.C. Schroeder. 1928. Fishes of Chesapeake Bay. U.S. Bur. of Fish. Bull. 43. 366 pp.

Hoar, W.S. 1952. Thyroid function in some anadromous and landlocked teleosts. Trans. R. Soc. Can. 46:39-53.

Hollis, E.H. 1952. Variations in the feeding habits of striped bass, *Roccus saxatilis* (Walbaum), in Chesapeake Bay. Bull. Bingham Oceanogr. Collect. Yale Univ. 14:111-131.

Hoover, E.E. 1936. The spawning activities of freshwater smelt, with special reference to sex-ratio. Copeia 1936:85-91.

Hubbs, C.L. 1921. Geographical variation of *Notemigonus crysoleucas*, an American minnow. Trans. Ill. State Acad. Sci. 11:147-151.

Hubbs, C.L., and T.E.B. Pope. 1937. The spread of the sea lamprey through the Great Lakes. Trans. Am. Fish. Soc. 66:172-176.

Hubbs, C.L., and K.F. Lagler. 1941. Guide to the fishes of the Great Lakes and tributary waters. Cranbrook Inst. of Sci. Bull. 18. 100 pp.

Hubbs, C. 1976. The diel reproductive pattern and fecundity of *Menidia audens.* Copeia 1976:386-388.

Hubbs, C. 1982. Life history dynamics of *Menidia beryllina* from Lake Texoma. Am. Midl. Nat. 107:1-12.

Hubbs, C., H.B. Sharp, and J.F. Schneider. 1971. Developmental rates of *Menidia audens* with notes on salt tolerance. Trans. Am. Fish. Soc. 100:603-610.

Hubbs, C., and C. Bryan. 1974. Maximum incubation temperature of the threadfin shad, *Dorosoma petenense.* Trans. Am. Fish. Soc. 103:36-371.

Hubbs, C., and H.H. Bailey. 1977. Effects of temperature on termination of breeding season of *Menidia audens.* Southwest. Nat. 22:544-547.

Hubbs, C., and S.M. Dean. 1979. Growth and reproductive responses of *Menidia beryllina* (Atherinidae) inhabiting Lake Texoma. Southwest. Nat. 24:546-549.

Jackson, H.W., and R.E. Tiller. 1952. Preliminary observations on spawning potential in the striped bass, *Roccus saxatilis* (Walbaum). Md. Bd. Nat. Res. Dept. Resour. and Educ. No. 93. 16 pp.

Jennings, D.P. 1988. Bighead carp *(Hypophthalmichthys nobilis):* a biological synopsis. U.S. Fish. Wild. Serv. Biol. Rep. 88(29). 35 pp.

Jester, D.B. 1974. Life history, ecology, and management of the carp, *Cyprinus carpio* Linnaeus, in Elephant Butte Lake. N.M. State Univ. Exp. Stn. Res. Rep. No. 261. 111 pp.

Johnson, J.E. 1970. Age, growth, and population dynamics of threadfin shad, *Dorosoma petenense* (Günther), in central Arizona reservoirs. Trans. Am. Fish. Soc. 99:739-753.

Johnson, J.E. 1971. Maturity and fecundity of threadfin shad, *Dorosoma petenense* (Gunther), in central Arizona reservoirs. Trans. Am. Fish. Soc. 100:74-85.

Johnston, C.E. 1991. Discovery of the threespine stickleback *(Gasterosteus aculeatus)* (Pisces: Gasterosteidae) in Lake Michigan drainage, Illinois. Trans. Ill. State Acad. Sci. 84:173.

Jones, J.M., and H.B.N. Hynes. 1950. The age and growth of *Gasterosteus aculeatus, Pygosteus pungitius* and *Spinachia vulgaris,* as shown by their otoliths. J. Anim. Ecol. 19:59-73.

Jude, D.J., R.H. Reider, and G.R. Smith. 1992. •Establishment of Gobiidae in the Great Lakes Basin. Can. J. Fish. Aquat. Sci. 49:416-421.

Kilambi, R.V., and R.E. Baglin, Jr. 1969. Fecundity of the threadfin shad, *Dorosoma petenense,* in Beaver and Bull Shoals reservoirs. Trans. Am. Fish. Soc. 98:320-322.

Kilgen, R.H., and R.O. Smitherman. 1971. Food habits of the white amur stocked in ponds alone and in combination with other species. Progr. Fish-Cult. 33:123-127.

Kimsey, J.B. 195'8. Possible effects of introducing threadfin shad *(Dorosoma petenense)* into the Sacramento-San Joaquin Delta. Calif. Inland Fish. Admin. Rep. 58-16.21 pp.

Kimsey, J.B. 1964. Spawning of threadfin shad, *Dorosoma petenense,* at low water temperatures. Calif. Fish and Game 50:58.

Kiselevich, K.A. 1926. Volgo-kaspiiski rybolovnyi raion, ego osobennosti i prichiny bogatstva ryboi [Volgo-Caspian fishing region: its characteristics and factors determining its fish wealth]. Astrakhan, 1926. 48 pp.

Krzywosz, T., W. Bialokoz, and E. Brylinski. 1977. Wzrost tolpygi pstrej *(Aristichthys nobilis)* Rich. W Diel Wielki Jeriorze (Growth of the bighead carp A. *nobilis* in Lake Dgal Wielki). Rocz. Nauk. Roln. Ser. H. Rybactwo 98:103-115.

Kuntz, A., and L. Radcliffe. 1917. Notes on the embryology and larval development of twelve teleostean fishes. Bull. U.S. Bur. Fish. 35, 1915-16, doc. 849:87-134.

Kynard, B.E. 1979. Breeding behavior of a lacustrine population of threespine sticklebacks *(Gasterosteus aculeatus* L.). Copeia 1979(3):525-528.

Lagler, K.F., J.E. Bardach, R.R. Miller, and D.R.M. Passino. 1977. Ichthyology. 2nd ed. John Wiley and Sons, New York. xv + 506 pp.

Lambou, V.W. 1965. Observations on size distribution and spawning behavior of threadfin shad. Trans. Am. Fish. Soc. 94:385-386.

Langois, T.H. 1935. Notes on the spawning habits of the Atlantic smelt. Copeia 1935: 141-142.

Lazareva, L.P., M.O. Omarva, and A.N. Lezina. 1977. Feeding and growth of the bighead in the waters of Dagestan-USSR. (Engl. Transl. Vopr. Ikhtiol.) J. Ichthyol. 17:65-71.

Lelek, A. 1987. Threatened fishes of Europe. The freshwater fishes of Europe, Vol. 9. AULA-Verlag, Weisbaden. 343 pp.

Leslie, A.J., Jr., J.M. VanDyke, and L.E. Nall. 1982. Current velocity for transport of grass carp eggs. Trans. Am. Fish. Soc. 111:99-101.

Lewis, R.M. 1962. Sexual maturity as determined from ovum diameters in striped bass from North Carolina. Trans. Am. Fish. Soc. 91:279-282.

Lieffers, H.J. 1990. Effects of the lampricide 3-triflouromethyl-4-nitrophenol on macroinvertebrate populations in a small stream. Gr. Lakes Fish. Comm. Tech. Rep. No. 55. 26 pp.

Lievense, S.J. 1954. Spawning of the American smelt, *Osmerus mordax,* in Crystal Lake County, Michigan. Copeia 1954:232-233.

Lin, S.Y. 1935. Life history of Waan Ue, *Ctenopharyngodon idellus* (C. & V.). Lingnan Sci. J. 14:129-135.

MacKay, H.H. 1963. Fishes of Ontario. Ont. Dep. Lands For., Toronto. 300 pp.

Major, R.L., J. Ito, S. Ito, and H. Godfrey. 1978. Distribution and origin of chinook salmon *(Oncorhynchus tshawytscha)* in the Yakima River, Wash. Fish. Bull. (U.S.) 67:347-359.

Manion, P.J. 1968. Production of sea lamprey larvae from nests in two Lake Superior streams. Trans. Am. Fish. Soc. 97:484-486.

Manion, P.J. 1972. Fecundity of the sea lamprey *(Petromyzon marinus)* in Lake Superior. Trans. Am. Fish. Soc. 101:718-720.

Manion, P.J., and T.M. Stauffer. 1970. Metamorphosis of the landlocked sea lamprey, *Petromyzon marinus.* J. Can. Fish. Res. Board 27:1735-1746.

Manion, P.J., and A.L. McLain. 1971. Biology of larval sea lampreys *(Petromyzon marinus)* of the 1960 year class, isolated in the Big Garlic River, Michigan, 1960-1965. Gr. Lakes Fish. Comm. Tech. Rep. No. 16. 35pp.

Manion, P.J., and B.R. Smith. 1978. Biology of larval and metamorphosing sea lampreys, *Petromyzon marinus,* of the 1960 year class in the Big Garlic River, Michigan, part II, 1966-

72. Gr. Lakes Fish. Comm. Tech. Rep. 30. 35 pp.

Manooch, C.S. 1973. Food habits of yearling and adult striped bass, *Morone saxatilis* (Walbaum), from Ambermarle Sound, North Carolina. Chesapeake Sci. 14:73-86.

Mansueti, R.J. 1961. Movements, reproduction, and mortality of the white perch, *Roccus americanus,* in the Patuxent Estuary, Maryland. Chesapeake Sci. 2:142-205.

Mansueti, R.J. 1964. Eggs, larvae, and young of the white perch, *Roccus americanus,* with comments on its ecology in the estuary. Chesapeake Sci. 5:3-45.

Mansueti, A.J., and J. D. Hardy, Jr. 1967. Development of fishes of the Chesapeake Bay Region. Part 1. Nat. Res. Inst., Univ. Maryland. 202 pp.

Marsden, J.E. 1993. Lake trout spawning in Lake Michigan. Ill. Nat. Hist. Surv. Rep. 324:1-2.

Mayden, R.L., F.B. Cross, and O.T. Gorman. 1987. Distributional history of the rainbow smelt, *Osmerus mordax* (Salmoniformes: Osmeridae), in the Mississippi River basin. Copeia 1987:1051-1054.

McCrimmon, H.R. 1968. Carp in Canada. Fish Res. Board Can. Bull. 165. 93 pp.

McKenzie, R.A. 1964. Smelt life history and fishery in the Miramichi River, New Brunswick. Fish. Res. Board Can. Bull. 144:1-77.

McLean, R.B., P.T. Singley, D.M. Lodge, and R.A. Wallace. 1982. Synchronous spawning of threadfin shad. Copeia 1982:952-955.

McPhail, J.D., and C.C. Lindsey. 1970. Freshwater fishes of northwestern Canada and Alaska. Fish. Res. Board of Can. Bull. 173. 381 pp.

Mense, J.B. 1967. Ecology of the Mississippi silverside, *Menidia audens* Hay, in Lake Texoma. Okla. Dept. Wildl. Cons. Fish. Res. Lab. Bull. 6:1-32.

Merriman, D. 1941. Studies on the striped bass *(Roccus saxatilis)* of the Atlantic Coast. U.S. Fish. Wildl. Serv. Fish. Bull. 50:1-177.

Miller, P.J. 1986. Gobiidae. Pages 1019-1095 *in* P.J.P. Whitehead, M.L. Bauchot, J.C. Hureau, J. Nielson, and E. Tortonese, eds. Fishes of the northeast Atlantic and Mediterranean. Vol. III. UNESCO, Paris.

Miller, R.V. 1967. Food of the threadfin shad, *Dorosoma petenense*, in Lake Chicot, Arkansas. Trans. Am. Fish. Soc. 96:243-246.

Moore, H.H., F.H. Dahl, and A.K. Lamsa. 1974. Movement and recapture of parasitic-phase sea lampreys *(Petromyzon marinus)* tagged in the St. Mary's River and Lakes Huron and Michigan, 1963-67. Gr. Lakes Fish. Comm. Tech. Rep. No. 27. 19 pp.

Morgan, A.R., and A.R. Gerlach. 1950. Striped bass studies on Coos Bay, Oregon, in 1949 and 1950. Oreg. Fish Comm. Contrib. 14. 31 pp.

Morgan, R.P., II, V.J. Rasin, and L.A. Noe. 1983. Sediment effects on eggs and larvae of striped bass and white perch. Trans. Am. Fish. Soc. 112:220-224.

Morsell, J.W., and C.R. Norden. 1968. Morphology and food habits of the larval alewife, *Alosa pseudoharengus* (Wilson), in Lake Michigan. Proc. 11th Conf. Gr. Lakes Res. 1968:96-102.

Moser, M., J. Whipple, J. Sakanari, and C. Reilly. 1983. Protandrous hermaphroditism in striped bass from Coos Bay, Oregon. Trans. Am. Fish. Soc. 112:567-569.

Moyle, P.B. 1976. Inland fishes of California. University of California Press, Berkeley. viii + 405 pp.

Muus, B.J., and P. Dahlstrom. 1971. Freshwater fish of Britain and Europe. Collins, London. 222 pp.

Nelson, E.W. 1876. A partial catalogue of the fishes of Illinois. Ill. State Lab. Nat. Hist. Bull. 1:33-52.

Nikolskii, G.V. 1956. Fishes of the Amur Basin. Results of the Amur ichthyological expedition 1945-1959. (in Russian). Akad. Nauk. USSR, Moscow. 551pp.

Nixon, D.E., and R.L. Miller. 1978. Movements of grass carp, *Ctenopharyngodon idella,* in an open reservoir system as determined by underwater telemetry. Trans. Am. Fish. Soc. 107:146-148.

Norden, C.R. 1967. Age, growth and fecundity of the alewife, *Alosa pseudoharengus* (Wilson), in Lake Michigan. Trans. Am. Fish. Soc. 96:387-393.

Norden, C.R. 1968. Morphology and food habits of the larval alewife, *Alosa pseudoharengus* (Wilson), in Lake Michigan. Proc. 11th. Conf. Gr. Lakes Res. 1968:103-110.

Norman, R.H. 1979. Distribution and ecology of lampreys in the lower peninsula of Michigan, 1957-75. Gr. Lakes Fish. Comm Tech. Rep. 33. 55 pp.

Odell, T.T. 1934. The life history and ecological relations of the alewife *(Pomolobus pseudoharengus* [Wilson]), in Seneca Lake, New York. Trans. Am. Fish. Soc. 64:118-126.

O'Gorman, R. 1979. Predation by rainbow smelt *(Osmerus mordax)* on young-of-the-year alewives *(Alosa pseudoharengus)* in the Great Lakes. Prog. Fish. Cult. 36:233-234.

Okada, Y. 1959-1960. Studies of the freshwater fishes of Japan. Prefectural University of Mie Tsu, Mie Prefecture, Japan. 860 pp.

Omarov, M.O. 1970. The daily food consumption of the silver carp *[Hypophthalmichthys molotrix* (Val.)]. J. Ichthyol. 10:425-426.

Page, L.M., and B.M. Burr. 1991. A field guide to freshwater fishes of North America north of Mexico. The Peterson Field Guide Series, Houghton Mifflin Co., Boston. xii + 432 pp.

Parsons, J.W. 1973. History of salmon in the Great Lakes, 1850-1970. U.S. Bur. Sport Fish. Wildl. Tech. Paper no. 68. 80 pp.

Pearse, A.S. 1918. The food of the shore fishes of certain Wisconsin lakes. Bull. U.S. Bur. Fish. 37:253-272.

Pflieger, W.F. 1975. Fishes of Missouri. Missouri Department of Conservation, Jefferson City. viii + 343 pp.

Pflieger, W.F. 1978. Distribution and status of the grass carp *(Ctenopharyngodon idella)* in Missouri streams. Trans. Am. Fish. Soc. 107:113-118.

Pigg, J., and T. Pham. 1990. The rudd, *Scardinius erythrophthalmus,* a new fish in Oklahoma waters. Proc. Okla. Acad. Sci. 70:37.

Price, J.W. 1963. A study of the food habits of some Lake Erie fish. Bull. Ohio Biol. Surv., New Ser. 2. 89 pp.

Raibley, P.T., D. Blodgett, and R.E. Sparks. 1995. Evidence of grass carp *(Ctenopharyngodon idella)* reproduction in the Illinois and upper Mississippi Rivers. J. Freshwater Ecol. 10:65-74.

Raney, E.C. 1952. The life history of the striped bass, *Roccus saxatilis* (Walbaum). Bull. Bingham Oceanogr. Collect. 14:5-97.

Raney, E.C. 1954. The striped bass in New York water. Conservationist 8:14-17.

Reid, W. F., Jr. 1972. Utilization of the crayfish *Orconectes limosus* as forage by white perch *(Morone americana)* in a Maine Lake. Trans. Am. Fish. Soc. 101:608-612.

Reiser, D.W., and C. Bjornn. 1979. Influence of forest and rangeland management on anadromous fish habitat in the western United States and Canada. Part 1. Habitat requirements of anadromous salmonids. U.S. Forest Serv. Gen. Tech. Rep. PNW-96. 54 pp.

Robison, H.W., and T.M. Buchanan. 1990. Fishes of Arkansas. University of Arkansas Press, Fayetteville. 536 pp.

Rothschild, B.J. 1962. The life history of the alewife, *Alosa pseudoharengus* (Wilson) in Cayuga Lake, New York. Ph.D. Thesis, Cornell Univ. 113 pp.

Rulifson, R.A., and S.A. McKenna. 1987. Food of striped bass in the Upper Bay of Fundy, Canada. Trans. Am. Fish. Soc. 116:119-122.

Rupp, R.S. 1959. Variation in the life history of the American smelt in inland waters of Maine. Trans. Am. Fish. Soc. 88:241-252.

Rupp, R.S. 1965. Shore-spawning and survival of eggs of the American smelt. Trans. Am. Fish. Soc. 94:160-168.

Sandercock, F.K. 1991. Life history of coho salmon *(Oncorhynchus kisutch).* Pages 397-445 *in* C. Groot and L. Margolis, eds. Pacific salmon life histories. Univ. of British Columbia, Vancouver.

Savitz, J., C. Aiello, and C.L. Bardygula. 1989. The first record of the white perch *(Morone americana)* in Illinois waters of Lake Michigan. Trans. Ill. Acad. Sci. 82:57-58.

Sayers, R.E., Jr., J.R. Moring, P.R. Johnson, and S.A. Roy. 1989. Importance of rainbow melt in the winter diet of landlocked Atlantic salmon in four Maine lakes. N. Am. J. Fish. Manage. 9:298-302.

Schaefer, R.H. 1970. Feeding habits of striped bass from surf waters of Long Island. N. Y. Fish Game J. 15:117-118.

Schaeffer, LS., and F.J. Margraf. 1986. Food of white perch *(Morone americana)* and potential for competition with yellow perch *(Perca flavescens)* in Lake Erie. Ohio J. Sci. 86:26-29.

Schneberger, E. 1936. The biological and economic importance of the smelt in Green Bay. Trans. Am. Fish. Soc. 66:139-142.

Schultz, L.P. 1931. Hermaphroditism in the striped bass. Copeia 1931:64.

Schumacher, R.E., and S. Eddy. 1960. The appearance of pink salmon, *Onchorhynchus gorbuscha* (Walbaum), in Lake Superior. Trans. Am. Fish. Soc. 89:371-373.

Scott, W.B., and E.J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Board Can. Bull. 184, Ottawa. xviii + 966 pp.

Setzler, E.M., W.R. Boynton, K.V. Wood, H.H. Zion, L. Lubbers, N.K. Mountford, P. Frere, L. Tucker, and J.A. Mihursky. 1980. Synopsis of biological data on striped bass, *Morone saxatilis* (Walbaum). Nat. Oceanic and Atmos. Admin. Tech. Rep. Nat. Mar. Fish. Serv. 433. 69 pp.

Sheri, A.N., and G. Power. 1968. Reproduction of white perch, *Roccus americanus*, in the Bay of Quinte, Lake Ontario. J. Fish. Res. Board Can. 25:2225-2230.

Shetter, D.S. 1949. A brief history of the sea lamprey problem in Michigan waters. Trans. Am. Fish. Soc. 76:160-176.

Sigler, W.F. 1958. The ecology and use of carp in Utah. Utah Agric. Exp. Stn. Bull. 405:1-63.

Smith, C.L. 1985. The inland fishes of New York State. New York Department of Environmental Conservation, Albany. 522 pp.

Smith, M.W. 1947. Food of killifish and white perch in relation to supply. J. Fish. Res. Board. Can. 7:22-34.

Smith, P.W. 1979. The fishes of Illinois. University of Illinois Press, Urbana. 314 pp.

Smith, S.H. 1968. The alewife. Limnos 1:12-20.

St. Pierre, R.A., and J. Davis. 1972. Age, growth, and mortality of the white perch, *Morone americana,* in the James and York rivers, Virginia. Chesapeake Sci. 13:272-281.

Stanley, J.C., W.W. Miley II, and D.L. Sutton. 1978. Reproductive requirements and likelihood for naturalization of escaped grass carp in the United States. Trans. Am. Fish. Soc. 107:119-128.

Stauffer, T.M. 1962. Duration of larval life of sea lampreys in Carp Lake River, Michigan. Trans. Am. Fish. Soc. 91:422-423.

Sterba, G. 1966. Freshwater fishes of the world. Studia Vistat. Ltd. London. 877 pp.

Stevens, R.E. 1958. The striped bass of the Santee-Cooper Reservoir. Proc. 11th Annu. Conf. Southeast. Assoc. Game Fish Comm. 1957:253-264.

Stevenson, J.H. 1965. Observations on grass carp in Arkansas. Progr. Fish.-Cult. 27:203-206.

Sukhanova, Ad. 1966. Development of the bighead *Aristichthys nobilis.* Vopr. Ikhtiol. 6:39.

Swee, U.B., and H.R. McCrimmon 1966. Reproductive biology of the carp, *Cyprinus carpio* L., in Lake St. Lawrence, Ontario. Trans. Am. Fish. Soc. 95:372-380.

Swigle, H.S. 1956. A repressive factor controlling reproduction in fishes. Oceanogr. Zool. Proc. 8th Pacific Sci. Congr. 3a (1953):856-871.

Takagi, K., K.V. Aro, A.C. Hartt, and M.B. Dell. 1981. Distribution and origin of pink salmon *(Oncorhynchus gorbuscha)* in offshore waters of the North Pacific Ocean. Int. North Pac. Fish. Comm. Bull. 40. 195 pp.

Tang, Y.A. 1970. Evaluation of balance between fishes and available fish foods in multispecies fish culture ponds in Taiwan. Trans. Am. Fish. Soc. 99:708-718.

Threinen, C.W. 1958. Life history, ecology and management of the alewife. Wis. Conserv. Dep. Pub. 223. 8 pp.

Trautman, M.B. 1957. The fishes of Ohio. Ohio State Univ. Press, Columbus. 683 pp.

Trent, L., and W.W. Hassler. 1966. Feeding behavior of adult striped bass, *Roccus saxatilis,* in relation to stages of sexual maturity. Chesapeake Sci. 7:189-192.

Trent, L., and W.W. Hassler. 1968. Gill net selection, migration, size and age composition, sex ratio, harvest efficiency, and management of striped bass in the Roanoke River, North Carolina. Chesapeake Sci. 9:217-232.

VanCleve, R. 1945. A preliminary report on the fishery resources of California in relation to the Central Valley project. Calif. Fish Game 31:35-52.

Van Oosten, J. 1947. Mortality of smelt, *Osmerus mordax* (Mitchill), in Lakes Huron and Michigan during the fall and winter of 1942-1943. Trans. Am. Fish. Soc. 74:310-337.

Vinogradov, V.K., and L.V. Erokhina. 1967. Effect of temperature on the embryonic development of herbivorous fish. (in Russian). Tr. Vses. Nauchno-Issled. Inst. Prud. Rybn. Khoz. 15:70-76.

Vladykov, V.D. 1951. Fecundity of Quebec lampreys. Can. Fish Cult. 10:1-14.

Vronskiy, B.B. 1972. Reproduction biology of the Kamchatka River chinook salmon *[Oncorhynchus tshawytscha* (Walbaum)]. J. Ichthyol. 12:259-273.

Wagner, W.C. 1976. Pink salmon in Michigan tributaries of the Great Lakes, 1975. Mich. Dep. Nat. Resour., Marquette Fish. Res. Stn. 3 pp.

Wallace, D.C. 1971. Age, growth, year class strength, and survival rates of the white perch, *Morone americana* (Gmelin), in the Delaware River in the vicinity of Artificial Island. Chesapeake Sci. 12:205-218.

Ware, F.J. 1971. Some early life history of Florida's inland striped bass, *Morone saxatilis.* Proc. 24th Annu. Conf. Southeast. Assoc. Game Fish Comm. 1970:439-447.

Webster, D.A. 1942a. The life histories of some Connecticut fishes. Pages 122-127 *in* A fishery survey of some Connecticut lakes. Bull. Conn. State Geol. Nat. Hist. Surv. 63.

Webster, D.A. 1942b. Food progression in young white perch, *Morone americana*, (Gmelin) from Bantam Lake, Connecticut. Trans. Am. Fish. Soc. 72:136-144.

Wells, L. 1968. Seasonal depth distribution of fish in southeastern Lake Michigan. U.S. Fish and Wildl. Serv. Fish. Bull. 67:1-15.

Wheeler, A. 1969. The fishes of the British Isles and north-west Europe. Michigan State Univ. Press, East Lansing. xvii + 613 pp.

Wootton, R.J. 1971. A note on the nest-raiding behavior of male sticklebacks. Can. J. Zool. 49:960-962.

Wootton, R.J. 1976. The biology of the sticklebacks. Academic Press, London. 387 pp.

Wootton, R.J. 1984. A functional biology of sticklebacks. University of California Press, Berkeley. 265 pp.