Asian Carps of the Genus *Hypophthalmichthys* (Pisces, Cyprinidae) — A Biological Synopsis and Environmental Risk Assessment

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Introduction

Carps of the family Cyprinidae, the largest family of freshwater fishes in the world (Nelson 1994), have long been introduced beyond their native ranges, a practice that continues today. Although carps have been introduced for several centuries, the widespread introduction of the genus *Hypophthalmichthys*, the bigheaded carps, is a relatively recent phenomenon. All three recognized species of *Hypophthalmichthys—H. nobilis*, in North America referred to as Bighead Carp; *H. molitrix*; Silver Carp; and *H. harmandi*, Largescale Silver Carp—are native to fresh waters of eastern Asia. Largescale Silver Carp have been introduced elsewhere in west-central Asia as a hybrid with Silver Carp but are not known to have been brought to North America. Both Bighead and Silver carps have been introduced to many countries, including the United States, for uses in aquaculture production of food fishes and biological control of plankton in aquaculture ponds, reservoirs, and sewage treatment lagoons.

Bighead and Silver carps were first imported into the United States in the early 1970s. Soon after, both species were being used in research projects and were stocked into wastewater treatment lagoons and aquaculture ponds in several states without regard to their potential effects on the ecosystems to which they were introduced or on the species inhabiting them. Bighead and Silver carps escaped confinement during flood events and are now well established with reproducing populations in much of the Mississippi River Basin. The introduced range of both carps in the United States continues to grow. Based on the climate where these fishes are native, Bighead and Silver carps might eventually be found in many of the flowing waters of the United States.

The escape of Bighead and Silver carps during evaluation as phytoplankton biological control organisms in commercial aquaculture ponds and sewage treatment facilities has left a legacy that could affect native fish populations within the Mississippi River Basin for decades to come. Populations of these carps in parts of the Mississippi River Basin appear to be increasing exponentially. If food resources become limiting, Bighead and Silver carps may compete with native planktivorous fishes, like Gizzard Shad, *Dorosoma cepedianum*, Bigmouth Buffalo, *Ictiobus cyprinellus*, and Paddlefish, *Polyodon spathula*. In addition to continuing to spread farther in the Mississippi River Basin by natural spread, the spread of Bighead and Silver carps could be aided by transportation of fishes caught for live bait, by livehaulers, the live seafood industry, and by those practicing prayer animal releases (practiced as a form of prayer by those whom believe that merits can be accrued by freeing captive animals into the wild).

Although Silver Carp are not known to be cultured for marketing purposes in the United States now, Bighead Carp continue to be cultured in some states. Markets exist for live Bighead Carp in ethnic markets in the United States and southern Canada requiring transport in live haul trucks. Silver Carp have not been as prominent in the live food fish trade as Bighead Carp because they are not available from aquaculture and because they are more fragile to handle and transport alive. However, wild-caught Silver and Bighead carps are occasionally encountered in live markets.

The purpose of this document is to present a summary of the biology and distribution of the three species of *Hypophthalmichthys*. For each species, information is included as follows:

(1) taxonomy and distinguishing characteristics; (2) native range; (3) habitat preferences; (4) migrations and local movements; (5) biology and natural history (including temperature and salinity tolerances, reproductive biology, feeding habits, growth rate and longevity, and response to physical stimuli); (6) diseases and parasites; (7) human uses of *Hypophthalmichthys* (including harvest from reservoirs and other water bodies, culture, control of algae, removal of excess nutrients, and production and growth of other fishes); (8) history of introductions around the world and the United States; (9) potential range in the United States; (10) population and distribution control measures; and (11) state regulations.

Although most of the information in this document is supported by citations from peer-reviewed scientific literature, we have relied on personal observations and personal communications for some information, particularly the biology of Bighead and Silver carps in the United States. A variety of biological research is in progress on these fishes in the Mississippi River Basin, but much of the information from this research has not yet been vetted through peer-reviewed journals. We have minimized reliance on unpublished information to the greatest extent possible.

Also included is an evaluation of the organism risk potential of each species of *Hypophthalmichthys* in the United States using the Generic Nonindigenous Aquatic Organisms Risk Analysis Review Process. This risk assessment process uses both the probability of establishment and the consequences of establishment to determine the overall organism risk potential in the United States. This document is limited to the ecological effects and consequences of *Hypophthalmichthys* in the wild. The economic benefits of the continued culture and marketing of *Hypophthalmichthys* are beyond the scope of this document and are being evaluated by the U.S. Fish and Wildlife Service. Department of Fisheries and Oceans is also conducting a risk assessment on Asian carps of the genera *Ctenopharyngodon*, *Hypophthalmichthys*, and *Mylopharyngodon* in Canada.

Although we provide some discussion on the culture of these carps, we do not treat it in detail. For further information on the culture methods of Bighead and Silver carps, see Chen et al. 1969; Pagan-Font and Zimet 1979; Chung et al. 1980; Tsuchiya 1980; Rothbard 1981; Dupree and Huner 1984; Jhingran and Pullin 1985; Jennings 1988; Li and Mathias 1994; Li and Senlin 1995; Opuszynski and Shireman 1995; and Xie 2003.

Genus and Species Description and Distinguishing Characteristics

Genus: *Hypophthalmichthys* (Bleeker 1860)

The genus *Hypophthalmichthys* Bleeker 1860 first appeared in a key without any included species. A type of the genus was established by subsequent designation (Bleeker 1863). The genus is valid as *Hypophthalmichthys* Bleeker 1860 in the family Cyprinidae (Eschmeyer 2003).

Two species of the genus *Hypophthalmichthys*—Bighead and Silver carps—were originally described as species of the genus *Leuciscus*. They were subsequently placed in the genus *Hypophthalmichthys* where they remained until Oshima (1919) described the genus *Aristichthys* for the Bighead Carp. Morphological characters used by Oshima (1919) to distinguish *Aristichthys* from *Hypophthalmichthys* included differences in gill raker morphology, position of the abdominal keel, and pharyngeal dentition. Recognition of the genus *Aristichthys* was not universal, which resulted in the Bighead Carp being variously placed in one of the two genera, *Aristichthys* and *Hypophthalmichthys*, until the late 1970s. Gosline (1978) reported the tri-lobed gas bladder as evidence of a common ancestry for *Hypophthalmichthys* and *Aristichthys*. However, the gas bladder of *Aristichthys* and *Hypophthalmichthys* typically consist of two chambers. The confusion in this characteristic state is because of a constriction of the gas bladder, which is variously developed and has been erroneously interpreted as a third chamber (Howes 1981). The number of chambers in the gas bladder varies widely among unrelated groups of cyprinids and has no value in indicating a common ancestry (Howes 1981). A phylogenetic analysis conducted by Howes (1981) concluded that the species of bigheaded carps share unique derived morphological characteristics and consequently belong to the same genus, *Hypophthalmichthys*. A third species, the Largescale Silver Carp, *H. harmandi*, was later described as a species of *Hypophthalmichthys*.

Diagnostic Characteristics

Species of the genus *Hypophthalmichthys* are characterized by a stout body, large head, massive opercles with relief structures, head and opercles scaleless, gill membranes broadly joined across the isthmus, snout bluntly rounded, mouth terminal with thin lips, lower jaw slightly protruding, barbels absent, and jaws without teeth. The eye is small, located far forward below angle of the jaw, and projects downward. Scales are small, cycloid, and cover the entire body, and lateral line is complete. The dorsal fin originates posterior to the pelvic fin insertion, typically has fewer than nine branched rays and lacks an osseous spine. The anal fin typically has more than 10 branched rays. Pharyngeal teeth are typically in one row, four on each side, masticatory surface sole-shaped. The intestine is long and convoluted.

Species: Bighead Carp, *Hypophthalmichthys nobilis* (Richardson 1845)

The Bighead Carp was originally described as *Leuciscus nobilis* Richardson 1845. The holotype is from Canton, China, and is in the British Museum of Natural History (BMNH catalog number 1968.3.11.4; Eschmeyer 2003). There are no recognized subspecies of *Hypophthalmichthys nobilis* (Eschmeyer 2003).

Taxonomic treatment of *Hypophthalmichthys nobilis* has been inconsistent during the past century. Oshima (1919) established the genus *Aristichthys* exclusively for the species *nobilis*. However, based on a phylogenetic analysis, Howes (1981) concluded that the two species, *H. nobilis* and *H. molitrix*, share several unique characteristics and referred both species to the genus *Hypophthalmichthys*.

Diagnostic Characteristics

The Bighead Carp is deep-bodied, spindle-shaped, moderately compressed, with a smooth keel between the anal and pelvic fins that does not extend anterior of the base of the pelvic fins (Fig. 1). Head and mouth of the Bighead Carp are disproportionately large. The premaxillary and protruding mandible form rigid bony lips. Coloration of the body is dark gray above and cream-colored below with dark gray to black irregular blotches on the back and sides. This color pattern develops when the fish is about 2 months old. The blotched or mottled pattern is often lost in turbid water (Duane C. Chapman [DCC], personal observation). Scales are small, cycloid, lateral line complete, strongly convex ventrally, continuing posteriorly along middle of caudal peduncle, with about 98 to 100 scales. Scale rows above lateral line 26-28, and scale rows below lateral line 16-19. Dorsal and anal fins are without spines. The number of dorsal fin rays is typically 8, anal fin 12-14, pelvic fin rays 8-9, pectoral fin rays 17-19, which extend posteriorly beyond the origin of the pelvic fins. Pharyngeal teeth are in a single row, four on each arch. They have a spoon-like shape with the grinding surface shallowly concave. The grinding surfaces of the pharyngeal teeth of the Bighead Carp differ from those of the Silver Carp, which have fine striations (Chu et al. 1935, in Yokote 1956) that are visible with magnification. Gill rakers are long and slender, rays closely set, with many membranous septa (Fig. 2). The intestine is long and highly convoluted. Cremer and Smitherman (1980) reported intestinal length to be 2.4-4.5 times total length (mean of 3.3 times total length). Large individuals may reach a weight of 40 kg (Baltadgi 1979).

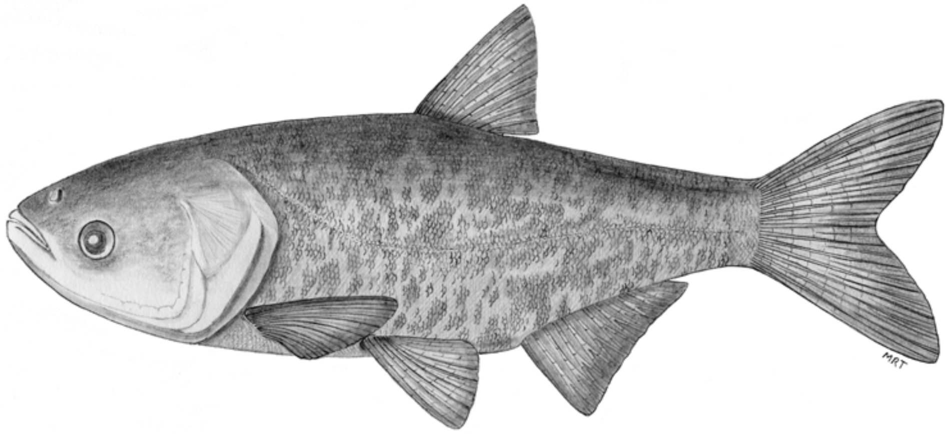

Figure 1. Bighead Carp, *Hypophthalmichthys nobilis*. Southern Illinois University-Carbondale catalog number 23919, 207 mm standard length, from Washington County, Illinois. Other common names frequently applied to Bighead Carp include Bighead and Bigheaded Carp. Illustration by Matt Thomas.

Bighead Carp can be distinguished from all native North American cyprinids, except the Golden Shiner, *Notemigonus crysoleucas*, by the presence of a well-developed ventral keel that extends from the vent anteriorly to the base of the pelvic fins. It can be distinguished from the Golden Shiner in having small scales (lateral line scales range from 98 to 100) compared to the Golden Shiner that has larger lateral line scales (39-51). Additionally, Bighead Carp have four pharyngeal teeth per side in a single row whereas Golden Shiners have five teeth per side in a single row.

Of the nine established nonindigenous cyprinids in North America, Bighead Carp is most similar to Silver Carp. However, Bighead Carp have long, thin gill rakers that are not fused (Fig.

2) which contrast sharply to the long, thin gill rakers that are fused to form a sponge-like apparatus in the Silver Carp. Additionally, the ventral keel of Bighead Carp extends from the vent anteriorly to the base of the pelvic fins whereas the keel of Silver Carp extends from the vent anteriorly to the anterior portion of the breast, almost to the junction of the gill membranes. The relative length of the pectoral fin is another character useful in distinguishing these two species. In observations of more than 100 fish of each species, the overlap of the pelvic fin to the pectoral fin was always greater in Bighead Carp than in Silver Carp (DCC, unpublished data). When pressed against the body, the pectoral fin of the Bighead Carp extended well beyond the origin of the pelvic fin base, overlapping 16% to 42% of the length of the pelvic fin. The pectoral fin of the Silver Carp either did not overlap the origin of the pelvic fin, or it overlapped <10% of the length of the pectoral fin. Bighead Carp can also usually be distinguished from Silver Carp by its mottled sides (compared to the uniformly silvery sides of Silver Carp). The eyes of both Bighead and Silver carps are situated low on the head, but the eyes of Bighead Carp differ from those of Silver Carp by facing ventrally and forward (Fig. 3).

Figure 2. A gill arch (*left*) and a gill arch segment (*right*) of a Bighead Carp, *Hypophthalmichthys nobilis*. Gill filaments are shown on the outside margin and the long, straight gill rakers are on the inner margin of the arch. The segment was cut from the center of another arch and illustrates the bifurcation of the gill rakers on each gill arch. Photo by Doug Hardesty.

Species: Silver Carp, *Hypophthalmichthys molitrix* (Valenciennes 1844)

The Silver Carp was originally described as *Leuciscus molitrix* Valenciennes 1844 in Cuvier and Valenciennes 1844. There are no type specimens known (Eschmeyer 2003).

Diagnostic Characteristics

The Silver Carp is deep-bodied, spindle-shaped, laterally compressed with a well-developed keeled abdomen that extends from the throat to the vent (Fig. 4). The keel is scaled anteriorly, but is scaleless posteriorly. Adult coloration is typically gray-black dorsally, upper

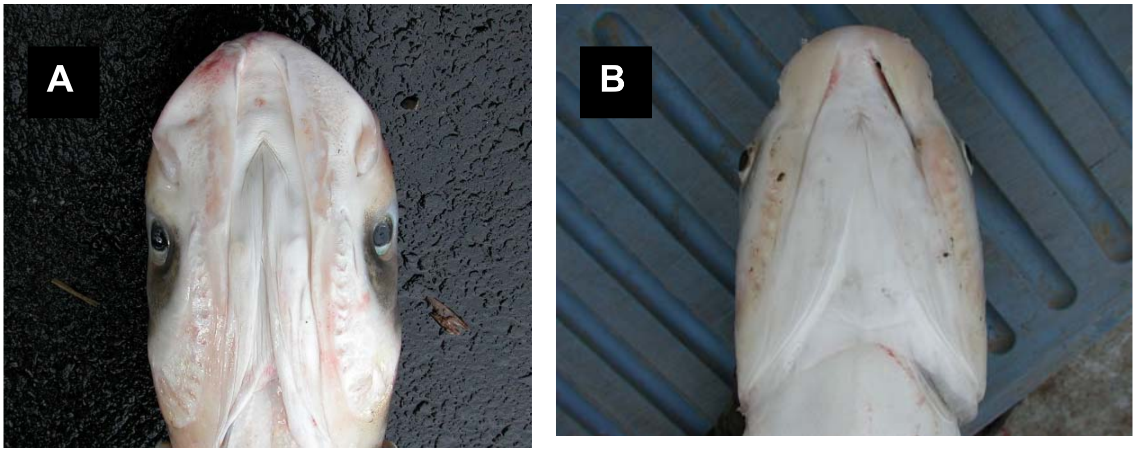

Figure 3. Ventral views of the head of (*A*) Bighead Carp (*Hypophthalmichthys nobilis* and (*B*) Silver Carp (*H. molitrix*). Notice the more ventral orientation of the eyes of Bighead Carp compared with those of Silver Carp. Photographs provided by the U.S. Geological Survey.

sides olivaceous grading to silver laterally and ventrally. Lower jaw has a small tubercle, and the upper jaw is slightly notched. The scales are small, cycloid, lateral line scale counts typically range from 85 to 108, 29-30 scales above the lateral line, and scales below the lateral line 16-17. Fins are dark and without true spines; however, in larger individuals the anterior ray of the pectoral fins is thickened, stiff and is finely serrated posteriorly. The dorsal fin typically has three unbranched and seven branched rays; anal fin with two or three unbranched and 11-15 branched fin rays. The intestine is long and convoluted with many loops. Smitherman and Cremer (1980) reported intestine length to be 3.5-7.3 times total length (mean of 5.0 times total length). Large individuals reach over 1.2 m (Kamilov and Salikhov 1996) and 50 kg (Billard 1997).

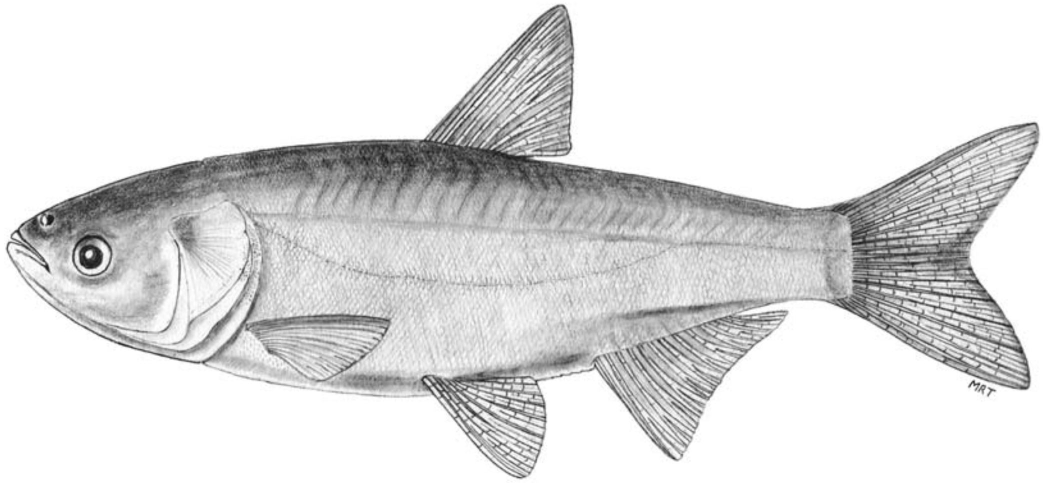

Figure 4. Silver Carp, *Hypophthalmichthys molitrix*. Southern Illinois University-Carbondale catalog number 23044, 289 mm standard length, from Alexander County, Illinois. Illustration by Matt Thomas.

The gill rakers of Silver Carp are unique and form a highly specialized filtering apparatus. Gill rakers are in two separate rows on each gill arch, forming a v-shaped cavity between them (Yokote 1956). Gill rakers are extremely thin, with the length being 200 times the width at the tip. Each row is united into a continuous band by a mucous membrane making the upper part of the gill rakers distinguishable, but the lower portions of the gill rakers are fused into two thick spongy structures running along the anterior margin of each gill arch (Fig. 5). The inside of the v-shaped cavity formed between these two structures is extremely smooth, with microscopic pores. The exit pores on the outside of the v-shaped structure (visible when lifting the operculum) are much larger, and appear spongelike. Pharyngeal teeth are similar to those of the Bighead Carp (except for those of Silver Carp having striations visible under magnification); formula is 4-4 and the teeth are long and bluntly rounded, and slightly concave on the grinding surface.

Figure 5. A gill arch (*left*) and a gill arch segment (*right*) of a Silver Carp, *Hypophthalmichthys molitrix*. Gill filaments are shown on the outside margin and the fused, sponge-like gill rakers are on the inner margin of the arch. The segment was cut from the center of another arch, and illustrates the bifurcation of the gill rakers on each gill arch. Photograph by Doug Hardesty.

Silver Carp can be distinguished from all native North American cyprinids except the Golden Shiner by the presence of a well-developed ventral keel. It can be distinguished from the Golden Shiner in having very small scales (lateral line scales range from 85 to 108) compared to the Golden Shiner that typically has larger lateral line scales (39-51). Additionally, Silver Carp have only four pharyngeal teeth per side in a single row while the Golden Shiner has five on each side in a single row. Small Silver Carp (15 to 150 cm total length) may resemble shad, but can be distinguished by the presence of a lateral line and usually less than 14 anal rays compared to shad (*Dorosoma* species) which have no lateral line and more than 16 anal rays.

Of the nine established nonindigenous cyprinids, the Silver Carp is most similar to Bighead Carp. The Silver Carp has long, thin gill rakers that are fused to form a sponge-like apparatus (Fig. 5) whereas gill rakers of the Bighead Carp are long, thin rakers that are not fused. Additionally, the ventral keel of Silver Carp extends from the vent to the anterior portion of the ventral median line, almost to the junction of the gill membranes whereas the keel of the Bighead Carp extends forward only to the base of the pelvic fins. Another characteristic useful in distinguishing these two species is the pectoral fin length. When pressed against the body, the pectoral fin of the Silver Carp generally does not extend past the base of the pelvic fin (Fig. 4), although it sometimes may overlap up to 10% of the length of the pelvic fin (DCC, unpublished data). The pectoral fin of the Bighead Carp always extends well beyond the base of the pelvic fin. Silver Carp do not have the mottling that is often seen in Bighead Carp.

Species: Largescale Silver Carp, *Hypophthalmichthys harmandi* (Sauvage 1884)

The Largescale Silver Carp was originally described in the genus *Hypophthalmichthys*. The holotype is from Hanoi, Vietnam, and is in the Muséum National d'Histoire Naturelle (MNHN catalog number 1884-0075; Eschmeyer 2003).

There are no recognized subspecies of *Hypophthalmichthys harmandi*, although some authors (e.g., Mai 1978) treated this fish as a subspecies of Silver Carp. Silver Carp were introduced into Vietnam beginning in 1958 (Chaudhuri 1968) and subsequently hybridized with Largescale Silver Carp (Chan and Fan 1988). This factor may have contributed to Mai's (1978) interpretation of the hybrid as a subspecies of Silver Carp. Other common names used for this species include Southern Silver Carp, Vietnamese Carp, and Harmandi Silver Carp.

Diagnostic Characteristics

The Largescale Silver Carp is deeper bodied than the Silver Carp (Fig. 6). Like the Bighead and Silver carps, this fish is spindle-shaped, laterally compressed but somewhat wider dorsally than Silver Carp, with a well-developed keel from beneath the pelvic fin to the vent. The snout is broad and short. The upper jaw does not extend to beneath the anterior margin of the eye. The interorbital space is broadly convex. Gill rakers are intertwined with each other with a sponge-like base and the anterior portion forming a thin membrane. Pharyngeal tooth formula is 4-4. A well-developed spiral branchial apparatus is present. Scales are cycloid and somewhat larger than those in Silver Carp. The lateral line is complete, bending dowconward, extending through the middle of the caudal peduncle, with 78-88 scales. There are 21 to 23 scale rows above the lateral line and 11 below. There are 27-31 scales around the caudal peduncle. The dorsal fin contains three unbranched and seven branched rays. The anal fin has 3 unbranched and 15 branched rays. Gas bladder large, with two chambers; the anterior chamber is large and the posterior one is cone-shaped. Body coloration is silver-white, the dorsal portion brownish-gray. Fin coloration is pale white-gray. Large individuals may reach a weight of 30 kg (Chen 1998).

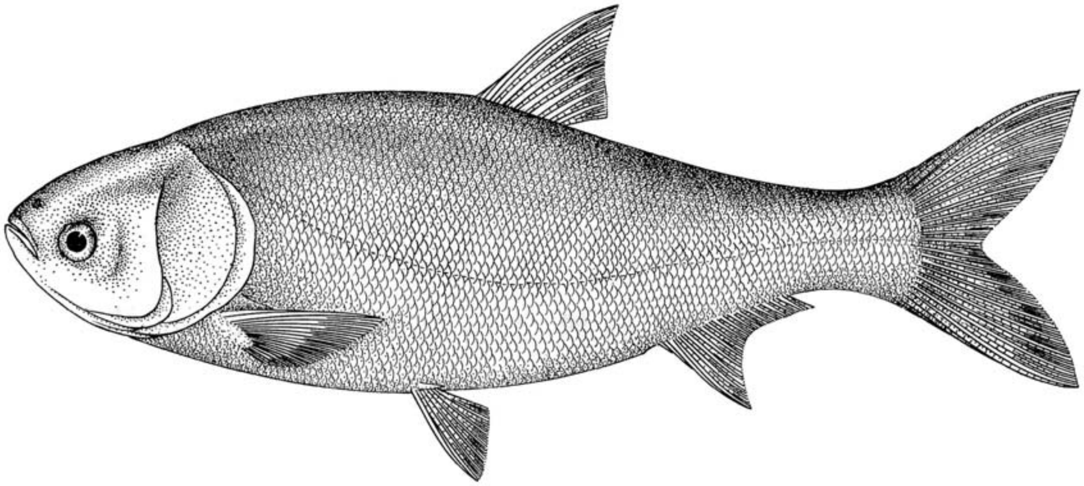

Figure 6. Largescale Silver Carp, *Hypophthalmichthys harmandi*. Taken from Chen et al. (1998).

The Largescale Silver Carp is morphologically most similar to the Silver Carp. Presently there are no known introductions of this species in the open waters of the United States. If they were present, the same characteristics used to distinguish Silver Carp from native North American cyprinids and Bighead Carp (presented above) would also differentiate the Largescale Silver Carp. Relatively larger scale size of the Largescale Silver Carp is the most reliable characteristic to distinguish it from Silver Carp. The number of scales along the lateral line of the Largescale Silver Carp range from 77 to 88 compared to the Silver Carp with 85 to 108. Scale rows above the lateral line in Largescale Silver Carp range from 21 to 23 compared to 29 to 30 in the Silver Carp. There is also a difference in the number of scale rows below the lateral line. Largescale Silver Carp usually have 11 rows compared to 16 or 17 rows in the Silver Carp.

Hybrids of *Hypophthalmichthys* spp.

Hybridization between closely related species of cyprinids (e.g., species of *Hypophthalmichthys*) is not unusual (Schwartz 1981). Silver Carp are known to hybridize and to produce viable offspring with both Bighead and Largescale Silver carps (Chan and Fan 1988; Mia et al. 2002). We found no literature confirming hybridization between Largescale Silver Carp and Bighead Carp, but it seems probable that they would hybridize. Hybrids of Silver and Bighead carps are often used in aquaculture because Bighead Carp produce insufficient milt late in the season (Mia et al. 2002). Both crosses (Bighead Carp × Silver Carp and the reciprocal cross) are diploid and are fertile (Brummett et al. 1988). Hybrids of Bighead and Silver carps often strongly resemble one or the other of the parent species. The inadvertent use of hybrids or backcrosses as brood stock and the resultant introgression has been identified as a problem in aquaculture in Asia (Kohinoor et al. 2002). Scientists should be aware of the presence of hybrids when performing research on wild *Hypophthalmichthys*. Hybrids of Bighead and Silver carps are known in the wild in China, but they are rare and usually attributed to escapement from aquaculture (B. Yi, Institute of Hydrobiology, Wuhan, China, personal communication, 2004). Mair (2003) argues against the use of hybrid Bighead Carp × Silver Carp in culture in Asia because they might escape and contaminate wild stocks, causing introgression. Such hybrids, however, are common in parts of the United States and are not likely to be the result of escapement of artificially induced hybrids because neither Silver Carp nor *Hypophthalmichthys* hybrids are in use in aquaculture in the United States. Five percent of the adult *Hypophthalmichthys* caught by DCC in the lower Missouri River in summer 2004 were hybrids. Reciprocal hybrid crosses, (male Bighead Carp × Silver Carp and the reciprocal cross) were confirmed by genetic analysis. The presence of large numbers of wild-spawned hybrids implies that Bighead and Silver carps often spawn in the same place at the same time in U.S. waters.

Hybridization between closely related cyprinid fishes occurs most commonly where a species has been introduced (Wheeler 1969). Wheeler (1969) further remarked that hybridization between cyprinids typically occurs when members of related species share similar spawning habitat, behavior, and season because of the loss of environmental cues that inhibit hybridization behavior. The effect of introgression between the two species is unknown, but it follows that eventually pure strains of each species may become rare. This has occurred in other groups of fishes when multiple species of closely related species are introduced (e.g., tilapias in the southwestern United States). Balon (1992) reported an intergeneric hybrid between two cyprinid fishes from the Danube River—the Zährte, *Vimba vimba*, and the Silver Bream, *Blicca bjoerkna*. He believed that dams constructed on the Danube River had interrupted reproductive isolation between these fishes, resulting in hybridization. Although Makeeva (1972) had moderate success in artificially producing hybrids of *Hypophthalmichthys* spp. and Common Carp (*Cyprinus carpio*), the spawning locations and behaviors of the two genera are so different that production of wild hybrids would be unlikely.

Bighead and Silver carps can be easily distinguished from each other by the distinctive morphology of their gill rakers. The gill rakers of hybrids are generally intermediate in their development between the two species, but usually appear more similar to one of the parental species. In one form, the gill rakers appear more like those of Bighead Carp, but will be clubbed or wavy, sometimes with small branches (Fig. 7). In the form that appears more like the gill rakers of Silver Carp, the gill rakers are incompletely fused, giving a ragged appearance (Fig. 8). In this form, the gill rakers can usually be separated with a light touch, unlike with the filtration apparatus of pure Silver Carp. Like most hybrid fishes, many characteristics are intermediate between the parental species. These include the ratios of head or gut length to body length, and the length of the extension of the pectoral fin past the insertion of the pelvic fin. A meristic guide that should aid in the identification of hybrids is now in development by DCC.

Native Range

Bighead Carp

The Bighead Carp is native to eastern China, eastern Siberia, and extreme North Korea (Fig. 9). It occurs in rivers of eastern Siberia (mouths of the Tumannaya and Razdolnaya rivers of the Primorsky District, Russia, south of the Amur [Heilongjiang] River, along the China, Russia, and North Korea borders; Shedko 2001), southward in rivers of the North China Plain

Figure 7. Gill rakers of a hybrid Bighead × Silver Carp. The gill rakers shown here are not fused together (more similar to those of a Bighead Carp, *Hypophthalmichthys nobilis*, than a Silver Carp, *H. molitrix*) but they are wavy and appear deformed. Photograph courtesy of U.S. Geological Survey.

Figure 8. Gill rakers of a hybrid Bighead × Silver Carp. The gill rakers shown here are fused together (more similar to those of a Silver Carp, *Hypophthalmichys molitrix*, than a Bighead Carp, *H. nobilis*) but the edges are ragged and the gill rakers can be separated with slight pressure. Photograph courtesy of U.S. Geological Survey.

including the Yellow (Huanghe) River and Yangtze (Changjiang) Rivers and southern China including the Pearl (Zhujiang) River. The native range of Bighead Carp has been reported to be 47º to 24ºN (Hseih 1973; Shedko 2001). Nevertheless, Chen et al. (1998) reported a range of 47° (Amur River Basin, where it is an introduced species [Krykhtin 1972]), to approximately 21°N (Hainan Island), another introduction (Chen 1998). The actual native range of this species may never be determined accurately because this species has been widely introduced in eastern Asia (Zhen-Yu and Yan 2002).

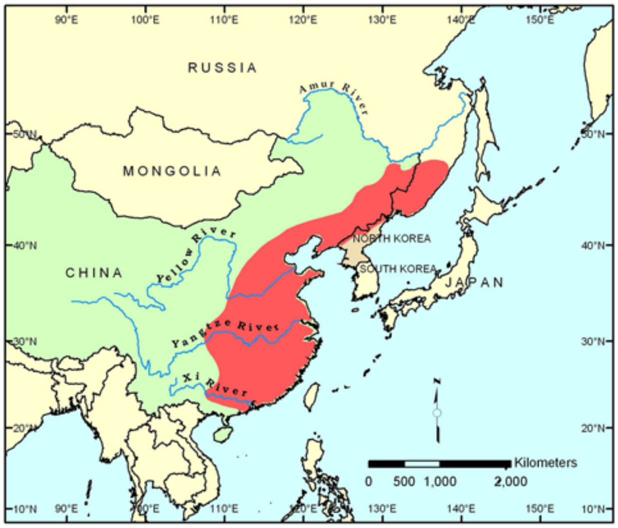

Figure 9. Native range of Bighead Carp, *Hypophthalmichthys nobilis*, indicated in red. After Fan (1990).

Mean annual air temperature in the native range of Bighead Carp ranges from –4ºC (Manchurian Plain region) to 24ºC in southern China (Hseih 1973). During the coolest month (January), air temperature ranges from -30ºC or below and in the northern areas to 40ºC in southern China during the warmest month (July).

Bighead Carp occur in rivers, lakes, and reservoirs, but are reported to require rivers for spawning (Jennings 1988; Robison and Buchanan 1988; Opuszynski and Shireman 1995). In their native China, Bighead and Silver carps comprise more than 60% of the total catch from reservoirs. The total catch of all fish species from Chinese reservoirs in 1998 was 1,294,000 metric tons (Huang et al. 2001).

Silver Carp

Kamilov and Komrakova (1999) reported the Silver Carp to be endemic to the large rivers of southern Asia, eastern China, and far eastern Russia that flow into the Pacific Ocean (Fig. 10). Others stated that the Silver Carp is native to large lakes and rivers of China, northern Vietnam, and Siberia ranging from 21º N to 54º N latitude (Laird and Page 1996; Xie and Chen 2001; Froese and Pauly 2004). Reports of this species from northern Vietnam are probably based on introduced populations.

Konradt (1965) stated that the Amur River is the northern boundary of the distribution of Silver Carp. The Amur River is in northeastern Asia and is about 4,355 km in length including the Arguan and Kerulean rivers (Nico et al. 2005), and it divides northeastern China from far eastern Russia through part of its course (Nico et al. 2005). Gorbach and Krykhtin (1989) stated that Silver Carp are widely distributed in the Amur River Basin and they collected Silver Carp in northern Malmyzh, 655 km upstream from Nikolayevsk, which is at the mouth of the Amur River. They also collected Silver Carp in the central Amur River near northern Leninskoye, 1,170 km upstream of Nikolayevsk. According to Nikol'skiy (1956), Silver Carp occur in the Amur River between the lower reaches of the estuary and the village of Kumara, slightly above Blagoveschchensk. Berg (1964) stated that Silver Carp are native to the Amur River from

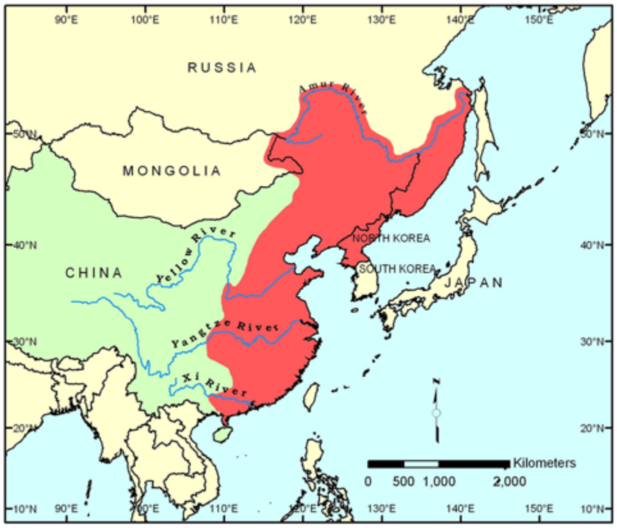

Figure 10. Native range of Silver Carp, *Hypophthalmichthys molitrix*, indicated in red. After Fan (1990).

Blagoveschchensk and farther downstream, and that they remained abundant as far as the lower reaches. He also reported that Silver Carp are native to Lake Khanka and the lower reaches of the Zeya and Amglluy rivers. Dulma (1973) reported that Silver Carp inhabit lakes Boyr and Boyan in the Mongolian part of the upper Amur River Basin (Karasev 1978).

Gorbach and Krykhtin (1989) stated that the chief spawning grounds in the Amur River are on the Amurzet-Petrovskoe section, 125-400 km above Khabarovsk. They also reported that Silver Carp spawn in the lowlands of the Sungari (Songhuajiang) River extending up to 200 km from the mouth and in the Sungari River-influenced waters of the Amur River. Dobriyal (1988) and Payusova and Tselikova (1981) noted that Silver Carp are native in the Yangtze River Basin in China. Dobriyal (1988) reported that Silver Carp are native in the West River Basin as well as in the Kwangsi and Kwangtung river basins in south and central China. They are also native in the Liao River south to Guangzhou, China (Berg 1964). Silver Carp is an introduced species on Hainan Island (Pearl River Fisheries Research Institute 1991; Chen 1998). Thus, the native range of Silver Carp extends from approximately 22°N to 54°N in eastern Asia. The actual native range, however, may never be ascertained because Silver Carp have been widely introduced in eastern Asia (M. Kottelat, Cornol, Switzerland, personal communication, 2004).

Silver Carp occur in rivers, lakes, and reservoirs, but are reported to require rivers for spawning (Jennings 1988; Robison and Buchanan 1988; Opuszynski and Shireman 1995). In their native China, Bighead and Silver carps comprise more than 60% of the total catch from reservoirs. The total catch of all fish species from Chinese reservoirs in 1998 was 1,294,000 metric tons (Huang et al. 2001).

Largescale Silver Carp

The Largescale Silver Carp is native to the Nandujiang River of northern Hainan Island, China (Chen 1998) and is present in the Songtao Reservoir (10,000 ha) in Hainan (Pearl River Fisheries Research Institute 1991; Chen 1998; Li 2001). Largescale Silver Carp are also native to the Red (Hong Ha) River of northern Vietnam (Pellegrin 1934; Chen 1998; Fig. 11) and are present in the Thac Ba (18,000 ha) and Nui Coc (2,000 ha) reservoirs (Ngo and Luu 2001). The species does not occur naturally on the Chinese mainland and, to our knowledge no introductions have been reported there. Native range of Largescale Silver Carp is subtropical to tropical (21-22º N), making it the southernmost fish of the genus. In culture, Largescale Silver Carp are known to hybridize with introduced Silver Carp in northern Vietnam and to some extent in the Red River (Chan and Fan 1988). Chen (1998) did not report hybrids from Hainan.

Figure 11. Native range of Largescale Silver Carp, *Hypophthalmichthys harmandi*, indicated in red. Based on native range descriptions in Pearl River Fisheries Research Institute (1991) and Chen (1998).

Habitats, Migrations, and Local Movements

Bighead Carp

In their native range, Bighead Carp are primarily creatures of large rivers and associated floodplain lakes (Yi et al. 1988b). They have been introduced widely to ponds, lakes, reservoirs, and large canals where they exist and grow well, although reproduction and recruitment is probably rare without access to an appropriate riverine environment for spawning. Successful spawning of Bighead Carp in a reservoir in Taiwan (Tang 1960) and in the Kara Kum Canal, Turkmenistan (Aliev 1976), however, indicate that spawning in additional habitat types is possible. Nikolsky (1963) and Chang (1966) reported that adult Bighead Carp generally remained in river channels, reservoirs, or lakes, except during spawning periods when they moved to areas of rapids. Little information is available concerning the ecology and habitat of wild juvenile Bighead Carp past the larval stage. Young-of-year and juvenile Bighead Carp on the Yangtze River are thought to migrate to floodplain lakes (Yi et al. 1988b). Abdusamadov

(1987) reported that, in the Terek Region of Russia, Bighead Carp fingerlings migrated into the coastal areas of the Caspian Sea.

In a telemetry study (2002–2004) on the Missouri River, DCC (unpublished data) found that adult Bighead Carp primarily used low velocity habitats behind wing dikes (rock structures extending from shore into the navigation channel) and also extensively used tributaries of the Missouri River, particularly the sections of the tributaries that cross the floodplain. These segments are often deep and generally have low velocity except during periods of local rainfall. Bighead Carp often moved between the Missouri River and a tributary multiple times. The water depth at 90% of adult Bighead Carp locations was 3 m deep or more. Adult Bighead Carp strongly preferred spur dikes (dikes at right angles to the flow) to L-head dikes (dikes shaped like an "L" with one arm extending from the bank at right angle to the flow and the other arm extending downstream). L-head dikes create an environment more protected from the fast-moving portion of the river, but the pools behind L-head dikes are often shallower than those behind spur dikes. Tagged adult Bighead Carp did not use sandbar areas without associated wing dikes.

The Long Term Resource Monitoring Program (LTRMP) is a Federally managed program mandated to monitor populations of fishes and other taxa in the Upper Mississippi River System (UMRS). This program samples fish in five reaches of the Upper Mississippi River (Navigation Pools 4, 8, 13, and 26, and Open River at Cape Girardeau, Missouri) and one reach on the Illinois River (La Grange Pool, Illinois). The LTRMP collected Bighead Carp (1991-2004) from a variety of habitats in Navigation Pool 26 and the Open River at Cape Girardeau, Missouri, in the Mississippi River, and La Grange Pool, Illinois, in the Illinois River. Three habitats—contiguous backwaters, main channel borders, and side channel borders—were sampled at all pools and a total of 1,059 Bighead Carp were collected. The subadult/adult-size class (*n*=266) of Bighead Carp did not show a preference for any of the habitats (Fig. 12). Bighead Carp of all sizes collected in the UMRS for the LTRMP were strongly associated with slow-moving waters (97% in water flowing ≤0.3 m/s); data obtained from the fishery database browser at http://www.umesc.usgs.gov/data_library/fisheries/fish1_query.shtml).

Because the invasion of Bighead Carp into the Mississippi River Basin is recent and ongoing, information regarding the habitat use of juvenile Bighead Carp is not yet available in peer-reviewed literature. Therefore, we must rely on reports from biologists encountering juvenile Bighead Carp in the field to gain an understanding of habitat use by this life stage. Table 1 presents a summary of responses from field biologists sampling juvenile Bighead and Silver carps in 2004. Although not conclusive, responding biologists reported juvenile Bighead Carp from similar habitats, low velocity and off-channel habitats, in the Missouri, Mississippi, Wabash, and Lower Ohio rivers. Similarly, more juvenile (100-500 mm) Bighead Carp collected for the LTRMP were found in contiguous backwaters than in the main channel or side channel borders (Fig. 12).

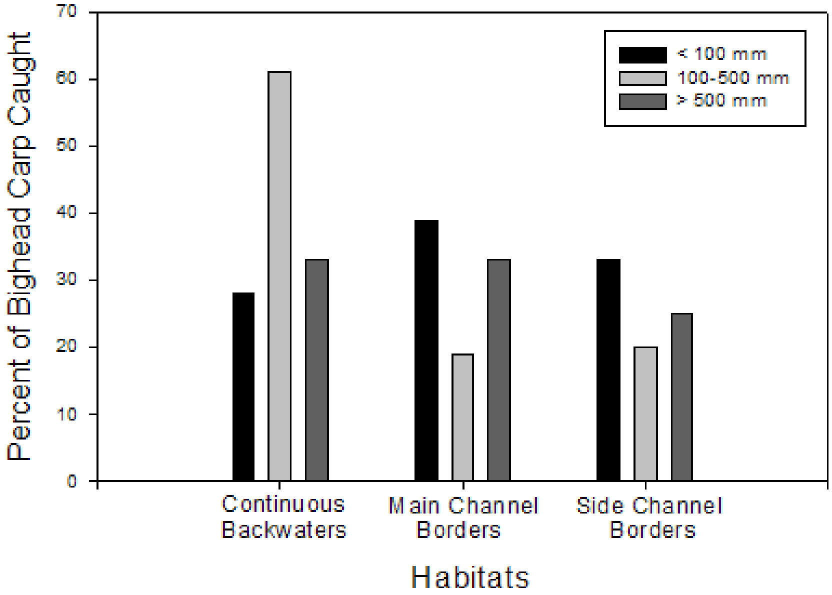

Figure 12. Percentage of young-of-year (< 100 mm), juvenile (100-500 mm), and subadult/adult (>500 mm) Bighead Carp, *Hypophthalmichthys nobilis* (*n*=1,059) collected from various habitats in Navigation Pools 4, 8, 13, and 26, and Open Reach at Cape Girardeau, Missouri, in the Mississippi River, and La Grange Pool, Illinois, in the Illinois River, parts of the Upper Mississippi River System for the Long Term Resource Monitoring Program from 1991 to 2004.

Table 1. Rivers and habitats of juvenile Bighead and Silver carps collected in the United States in 2004. "Contact" is the field biologist who provided the information.

Location	Habitat	Contact
Missouri River	Low velocity, off-channel habitats associated with inside-bend sandbars, and areas of flooded vegetation	A. Starostka (U.S. Fish and Wildlife Service, Columbia, Missouri)
Missouri and Illinois rivers	Floodplain wetlands and backwaters	D. Chapman (U.S. Geological Survey, Columbia, Missouri)
Low order tributaries of the Mississippi River	Low gradient portions where the tributary crosses the floodplain	R. Maher (Illinois Department of Natural Resources, Brighton, Illinois)
Middle Mississippi River	Backwaters and in low velocity areas behind wing dikes, sand bars, or closing structures	N. Caswell (U.S. Fish and Wildlife Service, Marion, Illinois)
Wabash and Lower Ohio rivers	Low or no flow sites	L. Frankland (Illinois Department of Natural Resources, Fairfield, Illinois)

Migrations and movements of Bighead Carp are believed to be associated with reproductive and feeding behaviors. As summarized by Jennings (1988) from other references, adults in their native habitat remained in the river channel until the water levels rise; migrated upstream to spawn, and then moved on to floodplain lakes. After hatching, larvae may migrate from the nursery areas up and down the main river channel, seeking refuge in vegetation as well as feeding grounds. Data from an ongoing study conducted by DCC using telemetry and depth-temperature archival tag implanted in the fish indicate that Bighead Carp in the Missouri River are active in the winter, with activity slowing at <4ºC and little movement occurring at temperatures below 2ºC. In that study, Bighead Carp often used tributaries of the Missouri River, especially the deeper, lower velocity portion of the tributary that crosses the Missouri River floodplain. Tributary use was highest in the winter. Bighead Carp often moved back and forth between tributaries multiple times, apparently because of changes in hydrology and river conditions, but generally did not travel long distances (ranges of <15 km) except during periods of high water, when some fish moved long distances upriver, sometimes exceeding 80 km, probably for spawning migrations.

Silver Carp

Silver Carp naturally occur in a variety of freshwater habitats including large rivers and warmwater ponds, lakes, and backwaters that receive flooding or are otherwise connected to large rivers (Berg 1964; Kaul and Rishi 1993; Finley 1999). They also have been introduced widely to ponds, lakes, reservoirs, and canals where they grow well, but probably cannot spawn and recruit without access to an appropriate riverine habitat. Silver Carp prefer open areas (Abdusamadov 1987) and eutrophic zones (Robison and Buchanan 1988) of standing or slow-flowing waters (Berg 1964; Rasmussen 2002) and occupy the upper and middle layers of the water column (FAO 1980; Shetty et al. 1989). In its natural range, mature Silver Carp migrate from lower river reaches and connected lakes to areas with swift currents in the spring for breeding (Berg 1964; Konradt 1965), often to river mouth areas (Berg 1964). Eggs and larvae drift downstream to floodplain zones (Froese and Pauly 2004). After moving to areas with rapids during high water stages to spawn, adult Silver Carp typically return to main channels, reservoirs, or lakes (Nikolsky 1963; Chang 1966). As juvenile Silver Carp approach maturity, they begin migrating to spawning grounds. For example, juvenile Silver Carp were found to feed for 4-5 years in lower reaches of the Amur River before gradually migrating up the Amur River. Two years later, they reached the Malmyzh region after traversing 500 km. They then ascended an additional year before arriving at the main spawning grounds (Gorbach and Krykhtin 1989).

In the United States, data from an ongoing telemetry study by DCC indicate that adult Silver Carp in the lower Missouri River, like Bighead Carp, usually used low velocity areas behind wing dikes, especially areas more than 3 m deep. Silver Carp also preferred spur dikes to wing dikes, did not use sandbars unassociated with wing dikes, and only used undiked outside bend habitats when moving between locations. Silver Carp in the Missouri River occupied primarily low velocity water >3 m deep in all months of the year. Silver Carp also used low velocity sections of Missouri River tributaries. Adult Silver Carp aggregate in pool habitats to overwinter (Berg 1964; Abdusamadov 1987; Gorbach and Krykhtin 1989). Preliminary data from telemetry and depth-temperature archival tags implanted in the fish (by DCC) indicate that Silver Carp in the Missouri River are active in winter, with activity slowing at <4ºC and little movement occurring at temperatures below 2ºC. Silver Carp differed from Bighead Carp in that Silver Carp used tributaries much less than Bighead Carp and used them mostly in summer, rather than winter.

Sampling of the UMRS for the LTRMP (1992-2004) resulted in the collection of 846 Silver Carp from contiguous backwaters, main channel borders, and side channel borders of Navigation Pool 26 and the Open River at Cape Girardeau, Missouri, in the Mississippi River, and La Grange Pool, Illinois, in the Illinois River. Of the 100 subadult/adult Silver Carp collected by the LTRMP, more were collected from side channel borders than from main channel borders and contiguous backwaters (Fig. 13). More than 95% of Silver Carp were caught in water with a current ≤0.3 m/s and more than 70% were in water ≤1 m in depth (data obtained from fishery database browser at http://www.umesc.usgs.gov/data_library/fisheries/fish1_query.html).

Little information also exists on the ecology of wild Silver Carp in the fingerling stage. Yi et al. (1988b) and Wang et al. (2003a) reported that large lakes connected to rivers often serve as nursery areas for Silver Carp. Abdusamadov (1987) reported that juvenile Silver Carp typically remain in the floodplain and in backwater habitats whereas adults are typically found in main channels of rivers, and in the Terek Region of Russia, juvenile Silver Carp migrated into coastal areas of the Caspian Sea.

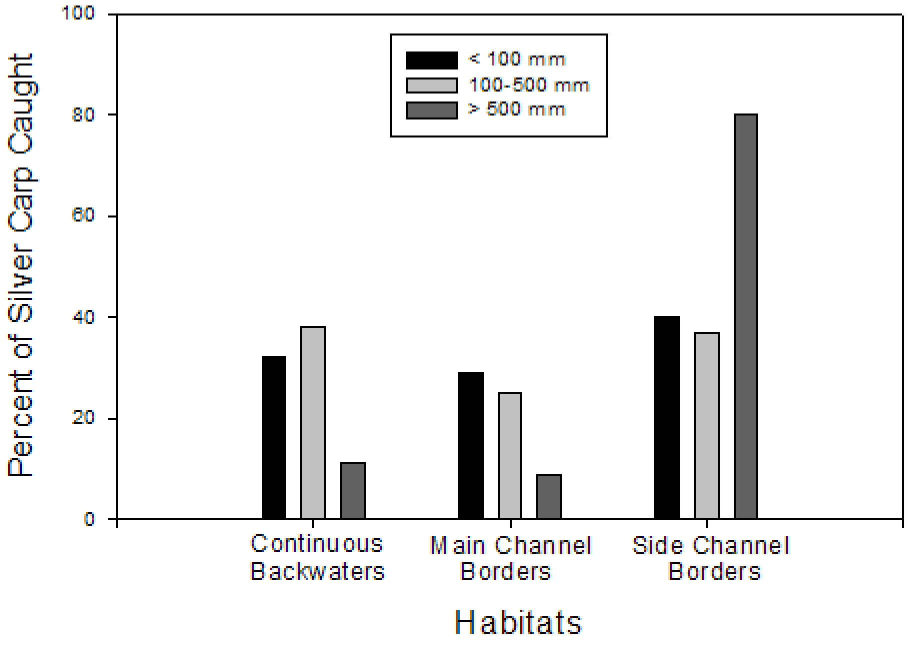

Figure 13 Percentage of young-of-year (< 100 mm), juvenile (100-500 mm), and subadult/adult (>500 mm) Silver Carp, *Hypophthalmichthys molitrix*, (*n*=846) collected from various habitats in Navigation Pools 4, 8, 13, and 26, and Open River at Cape Girardeau, Missouri, in the Mississippi River, and La Grange Pool, Illinois, in the Illinois River, parts of the Upper Mississippi River System for the Long Term Resource Monitoring Program from 1992 to 2004.

A lack of information is available in peer-reviewed literature about the habitat use of juvenile Silver Carp in the United States because the invasion is recent and ongoing. Williamson and Garvey (*in press*), however, report an abundance of young-of-year Silver Carp in the backwaters of the middle Mississippi River. Some of the field biologists encountering juvenile Silver Carp in 2004 reported collecting this life stage in low velocity and off-channel habitats in the Missouri, Mississippi, Wabash, and lower Ohio rivers (Table 1). Young-of-year (<100 mm) and juvenile (100-500 mm) Silver Carp collected for the LTRMP (1992-2004) were found in similar proportions between main channel borders, side channel borders, and contiguous backwaters (Fig. 13).

Largescale Silver Carp

Largescale Silver Carp prefer slow-moving, plankton-rich open waters. This species is a nocturnal feeder and remains in deeper waters during daylight hours (Pearl River Fisheries Research Institute 1991). Chen (1998) noted that migrations into flowing water are associated with spawning behavior. He also noted that Largescale Silver Carp typically reside in slow-moving, open waters. The only information we found on local movements involved diurnal feeding movements of this species.

Biology and Natural History

Temperature Tolerance

Bighead Carp

Bighead Carp can tolerate extremes in water temperature, from cold temperate to tropical. In their native range in China, Bighead Carp spawn at different temperatures: in the Yangtze River, from 26 to 30°C in 1957 to a range of 18.3 to 23.5°C in 1953 and 1954 (Chang 1966) and as low as 18°C in the Han River (Chunsheng et al. 1980). Russian waters provide several other examples of temperature tolerance: in the delta region of the Lower Volga River, 3- to 4-day-old larvae were caught in early June 1972, and the water temperature at the time of spawning could not have been higher than 14-15°C according to calculations by Opuszynski and Shireman (1995). Negonovskaya (1980) reported that in the lakes of Russia's Pskov Region, the most active feeding activity occurs at 20-22°C, Bighead Carp fingerlings continued minimal feeding levels at 10°C and survived (albeit did not feed or respond to external stimuli) at temperatures as low as 5°C. In studies with archival tags implanted in adult Bighead Carp in the Missouri River in 2003 and 2004, DCC (unpublished data) found that the fish were inactive below 2°C, but that fish were usually active at temperatures above 4°C, and sometimes moved to the surface at night. DCC sometimes collected adult Bighead Carp with full guts at temperatures lower than 4°C, but gut evacuation rates in Bighead Carp at these temperatures are not known.

Experiments with thermal preferences conducted in Texas (Bettoli et al. 1985) indicated that young Bighead Carp (56-73 mm) acclimated to 23.0ºC selected a mean temperature of 25.4ºC. Their critical thermal maximum appeared to be 38.8ºC, and a preferred temperature range of 25.0 to 26.9ºC in the laboratory has been reported (Bettoli et al. 1985). We found no documentation of lower water temperature lethal limits. Nevertheless, the presence of Bighead Carp in rivers and reservoirs in the Manchurian Plain that remain frozen 4 to 6 months out of the year suggests that the species is quite cold tolerant.

Also significant is the finding that annual temperature fluctuations, which are characteristic in the natural range of Chinese carps, are not necessarily needed for natural reproduction. In the Pampanga River Basin of the Philippines, for example, where natural spawning occurs, the temperature does not change appreciably during the year. The average range in monthly air temperature is from 25.9 to 19.6°C (Opuszynski and Shireman 1995).

Silver Carp

As with Bighead Carp, the water temperature range at which larval Silver Carp can exist is broad: 16-40°C (Tripathi 1989), with optimum temperature reported as 26-30 (Panov and Khromov 1970, in Radenko and Alimov 1992), 39 (Opuszynski et al. 1989), and 33.5°C (Radenko and Alimov 1992). The ultimate upper lethal temperature of larval Silver Carp (aged 3 to 28 days) was 43.5-46.5°C (Opuszynski et al. 1989). Silver Carp are quite tolerant to low water temperatures. In Alberta, Canada, Silver Carp successfully overwinter in ponds that are near 0ºC from around the beginning of November through the end of April (B. MacKay, Alberta Department of Agriculture, Food and Rural Development, Lethbridge, Alberta, personal communication, 2004). Silver Carp are known to feed at water temperatures of 10 to 19°C in Israel (Leventer 1979, in Wrigley et al. 1988). When the water temperature dropped below 15°C, appetite of Silver Carp was reduced, and below 8-10°C, feeding almost ceased (FAO 1980; Tripathi 1989). In the Missouri River, Silver Carp caught by DCC sometimes had full guts at temperatures lower than 4°C. Bialokoz and Krzywosz (1981) found that gut evacuation rate of Silver Carp at 4°C was 108 hours. At water temperatures below 18°C or higher than 31°C, rates of ovulation and hatching of Silver Carp have been reported to be low with high rates of abnormal embryonic development (FAO 1980). Water temperatures for maximum growth of Silver Carp have been reported to be 24-31°C (Mahboob and Sheri 1997) and 30-34°C (Javed 1988, in Mahboob and Sheri 1997). Presence of this species in the Amur River Basin and absence of Bighead Carp (except where introduced) from that basin, suggests that the Silver Carp may be more cold tolerant than Bighead Carp.

Largescale Silver Carp

Although we found no information on temperature tolerance, the native range of this species (21-22º N) indicates that it is a subtropical to tropical species and may be intolerant of temperate climates. Nevertheless, hybrids between this species and Silver Carp are established in the middle Syr Dar'ya River (ca. 44-46º N) in Kazakstan (Payusova and Shubnikova 1986; Salikhov and Kamilov 1995), a clear indication that the hybrids are tolerant of a temperate climate.

Salinity Tolerance

Bighead Carp

Several studies have indicated that Bighead Carp can survive within a limited range of low salinities. Chervinski (1980) found that adult Bighead Carp, when transferred from fresh water to saltwater, were able to adjust to 15-20‰ saltwater concentrations. Fish that were kept in water at these concentrations for an additional 2 weeks remained alive. Fermin (1990) and Garcia et al. (1999) conducted studies of Bighead Carp fry in Laguna Lake, Philippines, which undergoes an annual intrusion of seawater. They concluded that Bighead Carp fry possess some degree of osmoregulatory capability, allowing them to survive and grow following direct exposure to a range of low salinities. In the Terek Region of Russia, Bighead Carp larvae and fingerlings migrate into the coastal areas of the Caspian Sea (salinity = 6-12‰), where they remain until reaching sexual maturity (Abdusamadov 1987).

Research has been conducted on salinity tolerances of Bighead Carp fry in the Philippines (Garcia et al. 1999). Most Bighead Carp culture in the Philippines occurs in Laguna Lake in lakeshore hatcheries of the 89,000-ha lake. During the dry season (March-June), seawater from Manila Bay enters the lake through the Pasig River. Bighead Carp fry were exposed to seawater for 96 hours at 11, 18, and 35 days post-hatch. There was 98.3% to 100% survival of all fry at salinities of 0% and 2‰. At a salinity of 4‰, all 11-day-old fry died but 98.9% of 18-day-old fry and 100% of 35-day-old fry survived. Only 56.7% of 18-day-old fry and 100% of 35-day-old fry survived at 6‰, and at 8‰ only 25% of the 35-day-old fry survived. At salinities above 2‰, food intake, absorption, and conversion efficiencies were reduced, slowing growth rate. Thus, the ability of Bighead Carp fry to osmoregulate increased with age and 6‰ appeared to be the critical maximum salinity.

Silver Carp

According to the FAO (1972), Silver Carp is a freshwater species that can live in slightly brackish waters. However, as in Bighead Carp, a limited range of salinity tolerances has been reported for this species. Zang et al. (1989) reported that Silver Carp fingerlings could withstand, at most, water at 1.5‰ salinity whereas Zabka (1983) bred Silver Carp in water with a salinity of 2.5‰. Waller (1985) also reported that salinity should be maintained below 4‰ to produce Silver Carp. Falk (1986) found that Silver Carp reared in water at 5.1‰ salinity increased in weight from 1.3 to 8.8 g/individual in 32 days. Tripathi (1989) reported that fry and fingerlings have a tolerance of 7.5‰ to 12.0‰ salinity. Abdusamadov (1987) reported that larvae and fingerlings of Silver Carp migrate into the coastal areas of the Caspian Sea where the salinity is 6‰ to 12‰, where they remain until reaching sexual maturity. Verbal reports of Silver Carp in low salinity backwater bays along the Gulf Coast of Louisiana have not been confirmed.

Largescale Silver Carp

No information was found on the salinity tolerance of Largescale Silver Carp. Considering that this species is most closely related to Silver Carp with which it hybridizes, its salinity tolerance is probably similar to that of Silver Carp.

Reproductive Biology

Fecundity

Bighead Carp

Bighead Carp have a notably high fecundity rate. Fertility of Bighead Carp increases with age and body weight and is directly related to growth rate (Verigin et al. 1990). In Russian waters, females spawning for the first time had an average stripped fecundity of 280,000 eggs (Vinogradov et al. 1966) whereas older spawners gave 478,000 to 549,000 eggs (Abdusamadov 1987). In the Terek Region of the Caspian Basin, absolute individual fecundity of introduced Bighead Carp ranged from 316,300 to 1,860,800 eggs (Sukhanova 1966). In the Yangtze River, China, fecundity of Bighead Carp weighing 18.5 kg (42 lbs) was 1.1 million eggs (Chang 1966). Fecundity of Bighead Carp from the lower Missouri River collected in 1998-1999 ranged from 11,588 to 769,964, with an average of 226,213 eggs (Schrank and Guy 2002).

High fecundity in fishes is usually accompanied by high mortality in early life stages and low fecundity with parental care or protection and lower mortality. However, as noted by de Iongh and Van Zon (1993), predation may be less intense in a nonnative habitat, giving a highly fecund nonindigenous fish such as the Bighead Carp an advantage over species with lower fecundity. Welcomme (1988) suggested this mechanism to explain the successful establishment of Common Carp beyond its native range.

Silver Carp

Fecundity of Silver Carp, like that of Bighead Carp, is high and well studied. Estimates of fecundity have differed among geographic regions and the size of fish examined: 315,000-1,340,500 eggs per female (for a 62 cm, 4.2 kg, and a 82 cm, 9.3 kg fish; Abdusamadov 1987), 299,000-5,400,000 eggs per female (Kamilov and Salikhov 1996), 145,000-2,000,000 eggs per female for fish 3.18-8.51 kg (Alikunhi et al. 1963, in Singh 1989), and 597,000-4,329,600 eggs per female for fish 6.4-12.1 kg (Singh 1989). Total fecundity of six Silver Carp from the middle Mississippi River in 2003 ranged from 57,283 to 328,538 (Williamson and Garvey, *in press*). As in other fishes, fecundity of Silver Carp increases with body size (Kamilov and Salikhov 1996). Dobriyal (1988) reports a linear relation between body length and fecundity and between body length and ovary weight. Kamilov and Komrakova (1999) found no significant association between relative fecundity and length or weight.

Largescale Silver Carp

We found no specific information regarding the fecundity of Largescale Silver Carp in the literature but expect fecundity would be similar to that of Silver Carp.

Sexual Maturity and Mating Behavior

Bighead Carp

Henderson (1979b) reported that sexual maturity of Bighead Carp was reached at 3 or 4 years, but Chang (1966), Huet (1970), and Bardach et al. (1972) noted that age at maturity varied significantly with environmental and climatic conditions. In southern China, for example, Bighead Carp males, usually maturing 1 year earlier than females (Jennings 1988), reached sexual maturity at 2 to 3 years; in central China, at 3 to 4 years; and in northeast China, at 5 to 6 years (Kuronuma 1968). Woynarovich and Horváth (1980) recorded the average age of Bighead Carp at first maturity in temperate climates to be 6 to 8 years, compared with 3 to 4 years in subtropical and tropical climates. A similar discrepancy existed for the average size of these fish at first maturity: in temperate climates, Bighead Carp matured at an average weight of 5 to 10 kg and 70 to 80 cm, and at a smaller size—an average of 3 to 7 kg—in subtropical and tropical climates (Woynarovich and Horváth 1980).

Mating activity of Bighead Carp generally takes place at the surface (Chang 1966) with males actively chasing females and sometimes leaping out of the water. Usually more than two males follow one female; like other carps, the Bighead Carp is promiscuous (Jennings 1988; Opuszynski and Shireman 1995). A male often prods its head against the belly of a female, sometimes causing both fish to flip over, swim upside down, and ultimately cast the eggs and milt into the air (Chang 1966). In an intensive 5-year study of 1,700 km of the Yangtze River, Yi et al. (1988b) found that Bighead and Silver carps used 36 specific spawning sites. The spawning sites were used by both species.

Silver Carp

Like male Bighead Carp, male Silver Carp usually mature 1 year earlier than females (Kuronuma 1968), and the age at which this species reaches sexual maturity was variable across systems. In the rivers of south China, Silver Carp matured at 3 to 4 years whereas further north in the Yangtze River, they did not mature until age 4 (Konradt 1965). Silver Carp matured even later in the Amur River (Makeeva 1963, in Konradt 1965), and not until at least age 5 for those raised in southern regions of the former USSR (Konradt 1965). All Silver Carp collected by Kamilov and Komrakova (1999) from Uzbekistan were mature at 4 years. Abdusamadov (1987) reported Silver Carp spawning at age 4 to 8 years in the Terek Region of the Caspian Basin. Berg (1964) stated that Silver Carp were mature by their sixth year of life, presumably in the former USSR. Kuronuma (1968) found that Silver Carp matured at 2 to 5 kg and 2 to 3 years in southern China, at 4 to 5 years in central China, and at 5 to 6 years in northern China.

Maturation rate of Silver Carp, as in Bighead Carp, has been found to be related to water temperature, requiring 1,000 degree days at 15°C and 500 degree days at 30°C (Jhingran and

Pullin 1985, in Laws and Weisburd 1990). In Guangxi, China, with a growing period of 12 months and water temperatures averaging 27.2°C, Silver Carp matured in 2 years; in Guangdong, China, with a 11-month growing season and average water temperature of 25°C, they matured in 2 to 4 years; in Jiangsu, China, with an 8-month growing season and water temperature of 24°C, they matured in 3 to 4 years, and in the Amur River with a 5.5-month growing season and average water temperature of 20.2°C, they matured in 5 to 6 years (FAO 1980). In the natural climatic conditions of Uzbekistan, gonadal development and growth of Silver Carp are positively correlated. Growth rate of Silver Carp in the first year of life is the determining factor for age of sexual maturation (Kamilov 1987). They have matured in farm ponds of Uzbekistan at 3 years when they have attained 17 cm and 100-120 g in the first year of life (Kamilov 1987).

When Silver Carp are ready to spawn, ripples have been seen on the water surface from spawners chasing each other. About 40 to 80 minutes later, males and females ascended close to the water surface, chasing each other and shedding eggs and sperm (Kuronuma 1968). Yi et al. (1988b) found that Silver Carp repeatedly used discrete spawning sites within the Yangtze River, and enumerated the number of sites. Thirty-six sites, used for Bighead and Silver carps for spawning, were found in 1,700 km of river.

Largescale Silver Carp

Largescale Silver Carp reach sexual maturity at a younger age than Bighead or Silver Carp. Pearl River Fisheries Research Institute (1991) and Chen (1998) reported that females reach maturity in 2 years and males in 1 year. No information was found on mating behavior other than spawning typically occurs in rivers during rains or floods in May and June, although spawning may be postponed until mid-August (Pearl River Fisheries Research Institute 1991; Chen 1998).

Spawning

Bighead Carp

In Asia, Bighead Carp generally spawn between April and June, peaking in late May (Chang 1966; Verigin et al. 1978). Spawning of Bighead Carp is initiated by rising water levels following the heavy rains that occur in the spring or, in China, during the monsoon season (Jennings 1988; Pflieger 1997). Yi et al. (1988b) found that eggs were collected mostly on the rising hydrograph, as opposed to after the peak. Bighead Carp migrate upstream to spawning grounds (Verigin et al. 1978). In an ongoing telemetry study, DCC has tracked Bighead Carp traveling long distances upriver, sometimes exceeding 80 km during periods of high water.

Spawning grounds of Bighead Carp are characterized by rapidly flowing (current velocity of 0.6 to 2.3 m/s) turbid water, 18-30°C, with suspended solids and a visibility of 10 to 15 cm (Chang 1966; Verigin et al. 1978). These sites are commonly found where there is a mixing of water, such as at a confluence of rivers, among the rocks of rapids, or behind sandbars, stonebeds, or islands (Breder and Rosen 1966; Chang 1966; Huet 1970). Chang (1966) documented these environmental conditions in his studies of Bighead Carp spawning sites in the Yangtze, Pearl, and Hwai river systems in their native China.

Although Asian and European populations of Bighead Carp have been studied extensively, the spawning characteristics and early life history of this species in North American river ecosystems have yet to be well documented. Nevertheless, results of preliminary studies of Bighead Carp in the United States indicate parallels in spawning conditions and behavior to populations in Asia and Europe. A study by Schrank et al. (2001), for example, found that increased water discharge and a temperature of 22°C initiated spawning of Bighead Carp in the lower Missouri River—similar to results reported from Asian literature.

When *Hypophthalmichthys* are introduced to a new environment, however, their reproductive requirements may undergo substantial changes (Opuszynski and Shireman 1995). For example, the successful spawning of three Chinese carps (Grass [*Ctenopharyngodon idella*], Silver, and Bighead carps) in the Kara Kum Canal, Turkmenistan, contradicts the belief that a rise in the water level is a basic precondition to spawning. The Kara Kum Canal is probably the only known example of natural reproduction of Asian carps in a human-made channel. Although it flows rapidly (0.9 to 1.2 m/s) and is turbid with suspended material from the Amu Dar'ya River, the water level in the canal is more or less stable and not subjected to substantial fluctuations in the spring-summer period when spawning occurs (Aliev 1976). Also, Tang (1960) reported that Bighead Carp spawned in a reservoir in Taiwan, but the details are unclear.

Silver Carp

In the Terek Region of the Caspian Basin, Abdusamadov (1987) reported the spawning migration of introduced Silver Carp started during the last 2 weeks of May and continued until the beginning of July. Other timings reported for Silver Carp vary slightly: mid-May through mid-June spawning in Arkansas (Freeze and Crawford 1983); May through July in the Terek River (Abdusamadov 1987); June through the end of July or the beginning of August in the Amur River where this species is native (Krykhtin and Gorbach 1981; Gorbach and Krykhtin 1989); late May or early June through June in Uzbekistan (Kamilov 1987), where it probably lasts for 8 to 10 weeks (Berg 1964); in April-July in its native China (Dobriyal 1988); and in June-July in Japan (Dobriyal 1988). Water temperatures reported during Silver Carp spawning include 18-19 (Abdusamadov 1987) and 22-26°C (Kaul and Rishi 1993). The introduced Silver Carp spawning grounds in the Syr Dar'ya River have been found to vary from year-to-year and be influenced by flood intensity and current velocity (Kamilov and Salikhov 1996). Large lakes connected to rivers often serve as nursery areas for Silver Carp (e.g., Poyang Lake, in the middle basin of the Yangtze River; Wang et al. 2003a).

As in Bighead Carp, Silver Carp often spawn after a sharp rise in the water level associated with the spring freshet (Verigin 1979). Krykhtin and Gorbach (1981) suggested that associating spawning with a rise in water level is adaptive because this decreases the possibility of egg mortality and helps larvae to enter floodwaters rich in the food they need, at the commencement of exogenous feeding. Konradt (1965) offered that the timing of spawning is determined by water level changes and that temperature plays a subordinate role. Jankovic (1992) believed that suspended alluvium (1.2 kg/m^3) was more important for successful spawning than water level increase. It is unclear if homing behavior exists in Silver Carp (Wang et al. 2003a).

Because Silver Carp eggs, like those of Bighead Carp, are semi-buoyant, spawning typically occurs in water of sufficient flow to keep the eggs from sinking to the bottom and dying (Laird and Page 1996). Reported current velocities required for successful spawning range from 0.3 to 3.0 m/s (Chang 1966; Holĉík 1976; Krykhtin and Gorbach 1981; Kamilov and Salikhov 1996). Abdusamadov (1987) found most eggs in the main river channel at current velocities 1.1-1.9 m/s. Total quantity of heat required for reproduction of Silver Carp is 2,685 degree days on average (Abdusamadov 1987). Silver Carp are known to spawn in one reservoir, the Gobindsagar Reservoir, in Himachal Pradesh, India (Sehgal 1989, 1999).

In the Amur River, specimens occur with asynchronous vitellogenesis indicating that the same female may spawn twice during one growing season (Makeeva 1963, in Konradt 1965). There is less information on the spawning activities of Silver Carp in the United States than for Bighead Carp.

Bighead and Silver Carps

As described above, Bighead and Silver carps are known to spawn in the spring and early summer after a rise in water levels. There are also several indications of spawning by Bighead and Silver carps in the wild in late summer or early fall in the United States. These indications are recent and most have not yet been reported in peer-reviewed literature. Therefore, we rely on personal communications and unpublished data to convey the early indications that Bighead and Silver carps have a prolonged spawning period in the United States.

Pflieger (1997) reported collecting a 7.6 cm (age 0) Bighead Carp in mid-August and a 2.5-cm (age 0) Bighead Carp in mid-September in the Missouri River, suggesting an extended spawning period or multiple spawning. Rasmussen (2002) noted multiple size classes of young-of-year *Hypophthalmichthys* in the Upper Mississippi River backwaters in 1999 and 2000. Diana Papoulias (U.S. Geological Survey, Columbia, Missouri, unpublished data), using histological analysis, found females and males of Bighead and Silver carps at late reproductive stages (V and VI) as late as October in 2003 and 2004. Kerry Reeves (U.S. Geological Survey Cooperative Fish and Wildlife Research Unit, University of Missouri, Columbia, Missouri, unpublished data) collected *Hypophthalmichthys* larvae from the lower Missouri River in late August or early to mid-September each year from 2002 to 2004. On October 3, 2004, young-of-year Silver Carp measuring 27 to 37mm were caught in floodplain wetlands of the lower Missouri River (A. Starostka, U.S. Fish and Wildlife Service Field Research Office, Columbia, Missouri, unpublished data). These wetlands had been connected to the river by overbank floods on August 31 and September 1, 2004. Silver Carp collected in July on the same wetland were more than 100 mm total length, evidently the result of spawns in spring 2004. Schrank and Guy (2002) found bimodal distribution of intraovarian egg diameters from Bighead Carp in the lower Missouri River. Taken together, these data provide strong evidence that *Hypophthalmichthys* in the United States have a potential spawning season that extends into late summer and early fall.

Largescale Silver Carp

In its native range (Red River, northern Vietnam, and Nandujiang River of Hainan), Largescale Silver Carp is reported to typically spawn in May and June, although spawning may be delayed until mid-August. Rains or floods stimulate spawning migrations into rivers (Pearl River Fisheries Research Institute 1991; Chen 1998). No additional information was found on the spawning habits of Largescale Silver Carp. Because Largescale Silver and Silver carps are closely related, we presume that spawning requirements are similar to those of Silver Carp.

Early Development

Bighead Carp

During spawning, eggs are released by Bighead Carp in rapids of rivers, on the downstream sides of sandbars, and in currents around islands (Jennings 1988). The eggs are semi-buoyant and must remain suspended in the water column by the turbulence of the moving water in order to hatch (Soin and Sukhanova 1972; Yi et al. 1988b; Pflieger 1997). Nevertheless, in 2004, many Bighead Carp eggs were inadvertently collected while sampling bedload sediment in a side channel of the Missouri River (DCC, unpublished data). They were held at room temperature in unaerated and unagitated plastic bags of water and sediment where they hatched and survived for 4 days, at which time they were sacrificed.

Soin and Sukhanova (1972) and Yi et al. (1988a) described the eggs, larvae, and fry of Bighead, Silver, Black (*Mylopharyngodon piceus*), and Grass carps. Yi et al. (1988a) provided elegant sketches of the eggs and larvae at small incremental changes in development. The water-hardened eggs of Bighead Carp were larger than those of Silver and Grass carps, usually ranging in size between 5.7 and 6.2 mm, but rarely as small as 4.9 mm. Fresh, unpreserved eggs of *Hypophthalmichthys* were clear in color, unlike those of Grass Carp with a slight yellow tint. Table 2 provides data on myomere counts that can be used to differentiate between the larvae of Bighead, Silver, Grass, and Black carps. Further diagnostic characteristics including pigmentation, fin shape, and morphometric differences of these carps at different larval stages can be found in Yi et al. (1988a).

Table 2. Myomere counts in three stages in the larval development of Bighead (*Hypophthalmichthys nobilis*), Silver (*H. molitrix*), Grass (*Ctenopharyngodon idella*), and Black carps (*Mylopharyngodon piceus*). Anterior = number of myomeres anterior to caudal fin, not including myomere directly under leading edge. Posterior = number of myomeres between anterior and vent, including myomere directly over vent. Translated from Yi et al. (1988a).

Species	Immediately posthatch				At first appearance of gas bladder				After two chambers of gas bladder visible			
	Trunk section		Caudal section	Total	Trunk section		Caudal section	Total	Trunk section		Caudal section	Total
	Anterior	Posterior			Anterior	Posterior			Anterior	Posterior		
Bighead Carp	6	17	15	38	8	15	16	39	11	12	16	39
Silver Carp	6	19	14	39	8	17	15	40	10	15	15	40
Grass Carp	8	22	13	43	9	21	15	45	12	18	15	45
Black Carp	7	19	14	40	9	17	15	41	11	15	15	41

In large river ecosystems, an increase in discharge coupled with rising water temperature provides good conditions for larval fish that depend on floodplains for development (Galat et al. 1996). One day after fertilization, if spawning occurs during periods of rising water level, the eggs and hatching Bighead Carp larvae are carried downstream to flooded lakes, creeks, and channels that serve as nursery areas (Nikolsky 1963; Huet 1970). Currents may carry larvae to quieter waters such as creeks, lakes, reservoirs, or flooded areas that become nursery areas (Nikolsky 1963). Under conditions of falling water levels, larvae migrate away from river channels to vegetated calm waters (Nikolsky 1963; Chang 1966). Nikolsky (1963) reported that if eggs and larvae descend during periods of falling water, the larvae actively migrate to nursery areas, out of the main channel, to seek refuge in vegetation and feeding grounds. Such behavior has not been studied in the United States.

Incubation of Bighead Carp eggs in soft water can cause premature and poor survival of the larvae (Chaudhuri 1979). The outer membranes of fertilized Bighead Carp eggs absorb water and swells rapidly. If the incubating medium has a lower ionic concentration than the egg, premature bursting of the egg from excessive water absorption may occur (Gonzal et al. 1987). Poor survival of Bighead Carp because of soft water has been a problem for fish farmers (Chaudhuri 1979). Although we found no information specific to Bighead Carp, a study examining the effect of water hardness on the survival of Silver Carp eggs (Gonzal et al. 1987) found that a water hardness of 300-500 mg/L calcium carbonate was optimal for the successful hatching of Silver Carp.

Silver Carp

Silver Carp also produce semi-buoyant eggs released during periods of flooding that are carried by currents through the hatching stage (Laird and Page 1996). Currents bring larvae to slow-flowing backwaters, creeks, reservoirs, or other flooded areas that become nursery areas (Nikolsky 1963). Gorbach and Krykhtin (1989) found that eggs and larvae of Silver Carp can be carried more than 500 km downstream from spawning grounds. Krykhtin and Gorbach (1981) stated that minimum flow requirements and developmental period to exogenous feeding necessitates >100 km of channel for successful reproduction of Silver Carp.

Soin and Sukhanova (1972) and Yi et al. (1988a) described the eggs and larvae of Silver Carp. The water-hardened eggs of Silver Carp ranged in diameter from 4.9 to 5.6 mm, similar to eggs of Grass Carp but smaller than those of Bighead Carp. Fresh eggs of Silver Carp were clear and could be distinguished from Grass Carp eggs that had a yellow tinge. Table 2 provides data on myomere counts than can be used to differentiate between the larvae of Bighead, Silver, Grass, and Black carps. Further diagnostic characteristics including pigmentation, fin shape, and morphometrics differences of these carps at different larval stages can be found in Yi et al. (1988a).

When incubated in soft water, eggs of Silver Carp can hatch or burst prematurely (Chaudhuri 1979). If the incubating medium has a lower ionic concentration than the egg, premature bursting occurs from excess water absorption. Highest hatching rates (22-29%) were reported at water hardness of 300, 400, and 500 mg/L calcium carbonate whereas low hatching rates (3-5%) were observed at 100 and 200 mg/L calcium carbonate (Gonzal et al. 1987).

Optimum total hardness was 382 mg/L calcium carbonate for hatchability and 423 mg/L for larval viability (Gonzal et al. 1987). Water softness is unlikely to limit reproduction of Bighead and Silver carps within the central United States where the water is usually hard, but may be important in some areas where *Hypophthalmichthys* are not yet established, for example, certain tributaries of the Great Lakes.

Largescale Silver Carp

No specific information was found. Nevertheless, because this species is most closely related to Silver Carp, early development of this species is probably similar.

Feeding Habits

Bighead Carp

Most literature cites the Bighead Carp as being predominantly zooplanktivorous (Borutskiy 1973; Lazareva et al. 1977; Cremer and Smitherman 1980; Burke et al. 1986; Dong and Li 1994), particularly when zooplankton biomass is high (Danchenko 1970; Lazareva et al. 1977). The youngest larvae (7-9 mm) have been found to eat primarily protozoa and zooplankton, including rotifers, the cladocerans *Bosmina* and young *Moina*, and copepod nauplii and copepodites (Chang 1966; Bardach et al. 1972; Marciak and Bogdan 1979). Ling (1967) found that 10-17 mm larvae consumed Cladocera. At lengths between 18 and 23 mm, larvae began to eat phytoplankton (mainly diatoms), and at 24 to 30 mm they readily consumed zooplankton and phytoplankton (Ling 1967). Lazareva et al. (1977) found that when zooplankton biomass was above 2 to 3 g/m^3, and the stocking rate was sufficiently low, that zooplankton constituted 14-25% of the food bolus weight of juvenile Bighead Carp. Borutskiy (1973) reported that adult Bighead Carp feed primarily on zooplankton in fish ponds in eastern regions of the former Soviet Union. Nikol'skiy and Aliyev (1974) reported that adult Bighead Carp in the Kara Kum Canal, former USSR, relied primarily on zooplankton (cladocerans, copepods, and to a lesser extent, rotifers) in the spring and early fall.

Larval, juvenile, and adult Bighead Carp exhibit highly opportunistic feeding habits, however, depending in part, on zooplankton abundance and biomass. Many studies have shown that when concentrations of zooplankton are low, Bighead Carp will switch to feeding on phytoplankton (blue-green algae, diatoms, and green algae). Lazareva et al. (1977) found that larval Bighead Carp in ponds with low zooplankton biomass switched from primarily zooplankton to phytoplankton (blue-green and euglenoid algae). They also reported a lower incidence of zooplankton in the stomachs of juvenile Bighead Carp from ponds with lower zooplankton biomass (0.7-5.5% of food bolus weight when zooplankton was 1 g/ m^3, increasing to 14-25% of food bolus weight at 2-3 g/ m^3 zooplankton). Nikol'skiy and Aliyev (1974), Danchenko (1970), Lazareva et al. (1977), and Burke et al. (1986) found that Bighead Carp fed primarily on zooplankton during May and June and switched to colonial algae in July and August, when standing stocks of algae were high and zooplankton was scarce. Bighead Carp sometimes consume large quantities of detritus, as well; other studies have found an average of 69.3% of their diets and as much as 87% to 97% of the weight of food they consumed was comprised of organic substances and mineral particles (Moskul 1977; Cremer and Smitherman 1980; Opuszynski 1981).

The feeding adaptability of Bighead Carp is related to the morphology of its comb-like gill rakers and epibranchial organ. Dong and Li (1994) described a large number of taste buds in the epithelium of the filtering organ, which may aid Bighead Carp in identifying areas with a high density of zooplankton. Food selectivity also depends on plankton density and particle size: if plankton biomass is sufficient (5 mg/L) and a size differential exists within the plankton community, the fish tend to selectively filter the larger food items. When plankton biomass has been sufficient, without a size differential, food selectivity has not been observed (Jennings 1988). Consumption of larger food particles, usually 50-100 µm but up to 3,000 µm, has been reported (Cremer and Smitherman 1980; Spataru et al. 1983; Opuszynski and Shireman 1991). Although the gape of Bighead Carp is large, foregut size may limit the particle size that can be consumed. Expansion of the foregut to accommodate larger particles appears to be limited by the structure of the pharyngeal teeth and the grinding plate (DCC, personal observation). Bighead Carp also ingest particles up to four times smaller than gill raker width, particularly in times of zooplankton scarcity (Opuszynski et al. 1991). Although the mechanism used for this small-particle food capture is not entirely clear, it is possible that a mucous coating on the gill rakers facilitates this by trapping smaller particles and aiding their passage to the esophagus (Jennings 1988).

Filter feeding by Bighead Carp influences the composition and size structure of the plankton community by reducing concentrations of zooplankton and large phytoplankters (Stone et al. 2000), although little research has been done on the effect of filter feeding by Bighead Carp on phyto- and zooplankton communities independent from that of Silver Carp. The combined stocking of Bighead and Silver carps has resulted in reduced cladocerans and copepods in a shallow, eutrophic lake in China where the fishes were not native (Yang et al. 1999), a decline in the abundance of cladocerans in a subtropical lake in China where the fishes were not native (Shao et al. 2001), cladocerans and copepods were severely reduced, and rotifers were reduced by more than 80% in a 0.8-ha pond in Colorado (Lieberman 1996).

There are two primary forms of filter-feeding in fishes: pump feeders and ram suspension feeders (Sanderson et al. 1994). Pump feeders (e.g., Gizzard Shad) use the buccal pump to push water through the filtering gill rakers (Sanderson et al. 2001). Lu and Xie (2001) considered Bighead Carp to be pump filter feeders. Dong and Li (1994) stated that juvenile Bighead Carp in aquaria functioned as pump filter feeders, and although they selected areas of high zooplankton abundance, they did not snap at individual prey or move towards individual zooplankters swimming in front of them. Ram suspension feeders (e.g., Paddlefish) hold their mouths open and swim through the water, forcing water through the filtering gill rakers (Sanderson et al. 1994). DCC has observed Bighead Carp in the field using a variety of feeding behaviors, including those resembling both types of filter feeding. Bighead Carp have been often observed hanging nearly vertically in the water with their heads toward the surface (Fig. 14), apparently using their buccal pump to feed on plankton or other food particles in the surface film or near the surface. Bighead Carp also exhibit ram feeding, or possibly a combination of ram suspension and pump feeding. In this behavior, the fish swims at a moderate speed in a mostly horizontal position holding their mouth open and forcing water through the gills, with intermittent gulps.

This behavior occurs below the surface or on the surface (Fig. 15). When Bighead Carp feed at or near the surface, the white lower lip forms a distinct crescent shape that is visible at a distance and very diagnostic of the presence of surface-feeding fish. Surface feeding by Bighead Carp has been observed in the Missouri River most often during the night and evening. Adult Bighead Carp have been observed taking larger food items into the mouth and blowing them out again repeatedly, apparently in an attempt to dislodge particles small enough to ingest. These observations are offered in the absence of available literature on feeding behavior of Bighead Carp. Bighead Carp may have other feeding behaviors in addition to these that have been observed, and the relative importance of different feeding behaviors is not known.

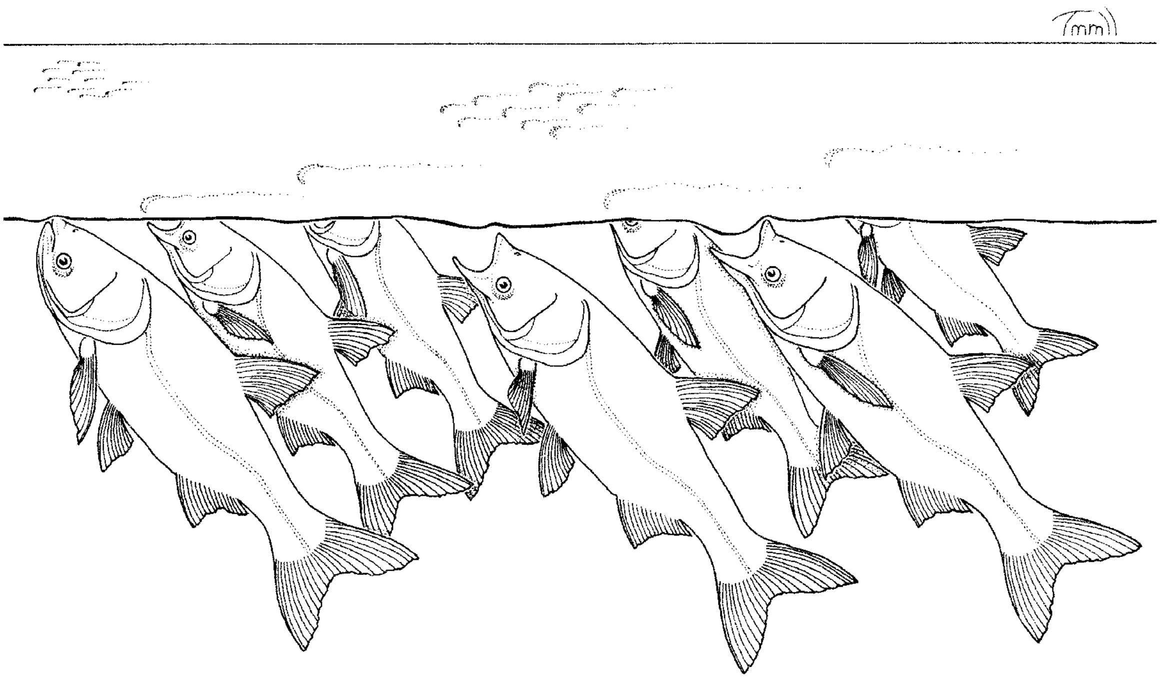

Figure 14. Bighead Carp, *Hypophthalmichthys nobilis*, pump-feeding at water surface. Illustration by Susan Trammell.

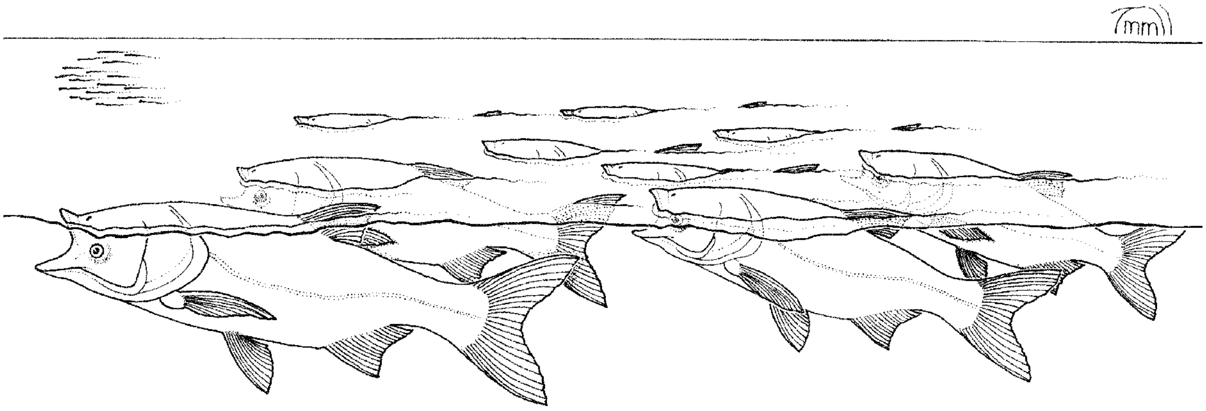

Figure 15. Bighead Carp, *Hypophthalmichthys nobilis*, ram feeding at the water surface. Illustration by Susan Trammell.

Although Bighead Carp are considered to be filter feeders, they can be caught with hook and line by using sweet smelling pasty baits that break down slowly (Hangzhou Rongchan Sporting Products Co., Ltd. 2003; Barth 2004), chunks of fish flesh (Angling Direct Holidays 2003), aquatic weeds, bread, potatoes, mollusks, and earthworms (Thai Fishing Guide Co., Ltd. 2004; Fig. 16). Sport angling for Bighead Carp generally relies on a "suspension method" in which dough bait is suspended in the water with tackle that facilitates hooking the fish, even though the bait is not consumed directly from the hook (Fig. 17).

Figure 16. Bighead Carp, *Hypophthalmichthys nobilis*, caught on hook and line, in Thailand. Photograph courtesy of Jean-Francois Helias, Fishing Adventures Thailand.

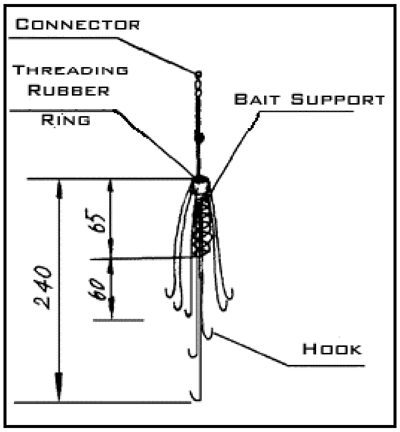

Figure 17. Tackle required for the 'suspension method' of sport angling for Bighead, *Hypophthalmichthys nobilis*, and Silver, *H. molitrix*, carps (modified from Hangzhou Rongchan Sporting Products Co., Ltd. 2003).

Bighead Carp in captivity have been reported to feed readily on pelleted trout food whereas Silver Carp will not (Shelton and Smitherman 1984). Bighead Carp also feed at a wide range of temperatures. In China, the optimum temperature for feeding was recorded as 20 to 30°C (Ling 1977); similarly, in small lakes of the former USSR, Negonovskaya (1980) found that Bighead Carp fed most actively at water temperatures of 20 to 22°C, but will continue levels of minimal feeding at 10°C. Preliminary research on the behavior of Bighead and Silver carps in the Missouri River indicates that the fish are active during cold weather and sometimes had full guts at water temperatures as low as 2.5°C (Chapman 2003), although gut evacuation rate is likely to be low at such low temperatures (Bialokoz and Krzywosz 1981).

While data pertaining to the consumption rate of Bighead Carp are limited, it is known that this fish, like other Asian carps, is a voracious feeder. Jennings (1988) noted that the daily ration (relation of total food weight taken in one day to the weight of the fish) for Bighead Carp was found to be 6.6% whereas Opuszynski and Shireman (1993) determined that the mean daily food ration of Bighead Carp ranged from 7.2% to 11.3% of fish body weight in ponds in Florida. Opuszynski et al. (1991) determined that the filtration rate ranged from 185 to 256 mL/h/g for 34- to 2,242-g fishes.

Silver Carp

Silver Carp consume plankton and other particles that are harvested by filtration, but can effectively filter and consume smaller particles than Bighead Carp (Table 3). They are thought to be pump filter feeders (Lu and Xie 2001). Silver Carp have gill rakers that are highly modified into a sponge-like filtering apparatus (Fig. 5; Jirasek et al. 1981). Ingested food is ground by blunt pharyngeal teeth against a cartilaginous plate (Robison and Buchanan 1988). They can remove smaller particles than would be expected based on the spaces between their gill rakers (Barthelmes 1977, in Adamek and Spittler 1984) because of an epibranchial organ (also called suprabranchial organ by some authors) that consolidates filtered materials by production of copious amounts of mucus (Spataru 1977). The epibranchial organ in Silver Carp is much smaller than that of the Bighead Carp. Silver Carp have been found to remove *Chlorella* (algae) at 3.2 μm (De-Shang and Shuang-Lin 1996), particles 4 μm (Omarov 1970), 5-10 μm (Kucklentz 1985), 10 μm, and larger (Smith 1989). Vörös et al. (1997) found that Silver Carp could not take in algae smaller than 10 μm based on comparison of gut contents with natural food assemblages. Cremer and Smitherman (1980) reported that food particles in the intestine were 8-100 μm, and Kaul and Rishi (1993) reported larval Silver Carp consumed particles 50-300 μm. Xie (1999) found 90-g Silver Carp removed particles 4.5-10 μm. Leventer and Teltsch (1990) found a maximum particle size of up to 100 μm. Spittler (1978) found that Silver Carp, 3-35 mg, chose particles 160-180 μm from a wide range offered. Silver Carp have been found to be ineffective at removing nannoplankton and picoplankton from the water (Sieburth et al. 1978). Although the gape of Silver Carp is large, foregut size may limit the particle size that can be consumed. Expansion of the foregut to accommodate larger particles appears to be limited by the structure of the pharyngeal teeth and the grinding plate (DCC, personal observation).

Many studies have found Silver Carp to feed primarily on phytoplankton (Ghosh et al. 1973; Cremer and Smitherman 1980; Kaushal et al. 1980; Spataru et al. 1983; Maheshwari et al. 1992). Ghosh et al. (1973), and Kirilenko and Chigrinzkaya (1983), and Vybornov (1989) considered Silver Carp to be important consumers of Cyanophyta (blue-green algae). Several studies have found that the cyanobacteria *Microcystis* may, depending on the season, constitute 20-98% of the food bolus of Silver Carp (Borutskiy 1973; Tarasova et al. 1977; Gorobets 1979; Tarasova 1979, in Kirilenko and Chigrinzkaya 1983; Shapiro 1985). Some controversy exists over whether Silver Carp can select certain taxa or particle sizes from the water that they filter.

Table 3. Comparison of the feeding habits of Bighead (*Hypophthalmichthys nobilis*) and Silver (*H. molitrix*) carps.

	Bighead carp	**Silver carp**
Type of feeder	Primarily a zooplanktivore, but highly opportunistic.	Primarily a phytoplanktivore, but highly opportunistic.
Food items consumed	Zooplankton; phytoplankton; detritus. Will bite on dough balls used as bait.	Phytoplankton; zooplankton; bacteria (planktonic and in aggregations); detritus. Can filter smaller particles than Bighead Carp. Will bite on bread paste and dough balls used as bait.
Morphological characteristics specific to feeding	Long, comb-like gill rakers coated with mucus to help trap smaller particles. Many taste buds on filtering organ aid detection of zooplankton.	Special filtering apparatus on gill bars allows removal of small particles. Suprabranchial organ consolidates ingested materials by producing large amounts of mucus.
Consumption rate	High; voracious feeder	High, but widely variable
Feeding temperatures	Most active at 20-22°C. Will continue levels of feeding at 10°C or as low as 2.5°C.	Most active at 15-30°C. Will continue feeding as low as 4°C. More cold-tolerant than Bighead Carp.
Ecological niche for feeding	Often at the water surface, but also feed throughout water column, including bottom.	Do not commonly feed at the surface.
Dietary overlap with indigenous species?	Yes	Yes

Cremer and Smitherman (1980) found phytoplankton in the guts of Silver Carp in the same proportion as in water samples, indicating no selectivity.

Efficiency of digestion of algae by Silver Carp has been found to vary by algal species: *Chloroella pyrenoidosa* 23%, *Scenedesmus obliquus* 22%, *Glenodinium* sp. 50%, *Pediastrum* sp. 48%, *Pandorin morum* 76%, pine pollen 91%, and *Brachionus calyciflorus* 100% (Dong et al. 1992). Xie (1999) suggested that the variable digestibility of algae is because of differential crushing of algae in the esophagus since little is lysed in the intestine. It has also been suggested that Silver Carp may not be able to meet energy requirements consuming phytoplankton alone (Bitterlich 1985c). Silver Carp fed only *Scenedesmus* showed 80% mortality after 5 weeks whereas those fed a mixed algae culture showed 25% mortality (Tarifeno-Silva et al. 1982). On the basis of stable carbon isotopes in fish muscle and algae and observations of stomach and intestinal contents, more than 90% of Silver Carp yield in the organically manured ponds was based on food webs originating with algal carbon (Schroeder et al. 1990). Miura and Wang (1985, in Leventer 1987) found 35% of the chlorophyll did not decompose in the digestive system and is excreted into the water.

Even though isotope techniques have indicated that Silver Carp digest green algae and cyanobacteria efficiently (Iwata 1976; Zhu and Deng 1983), whether Silver Carp are primarily phytoplanktivorous has been questioned. The gut fluids of Silver Carp lack cellulase, indicating difficulty in breaking down cellulose by means of enzymatic digestion (Ni and Chaing 1954, in Xie 1999; Bitterlich 1985a,b,c). As a result, a high proportion of algal cells in the hindgut or after excretion seem intact or remain live (e.g., Spataru 1977 observed live *Euglena* and *Phacus*, *Rotaria*, and *Brachionus*; Henebry et al. (1988) observed live *Chlamydomonas* in the hindgut or feces of Silver Carp). Not only are Silver Carp unable to obtain nutrition when algae passes through their system intact, but the growth of some algae is actually stimulated by passing through the intestine of the Silver Carp (Barthelmes 1977, in Adamek and Spittler 1984). Bitterlich (1985b) reported much undigested algal matter in the gut of Silver Carp, and differential digestion among algal taxa.

Filter feeding by Silver Carp has been shown to affect the abundance and structure of the phytoplankton community. The effect of filter feeding by Silver Carp on the biomass of phytoplankton appears inconsistent. Some studies (e.g., Kajak et al. 1975; Leventer 1987; Lieberman 1996; Lu et al. 2002) have shown that Silver Carp cause a decline in algal biomass. Others, however, have shown that algal biomass increases as a result of filter feeding by Silver Carp (e.g., Opuszynski 1981; Spataru et al. 1983; Milstein et al. 1985a). Regardless of their effect on the abundance of phytoplankton, studies have consistently shown that filter feeding by Silver Carp shifts the species composition of the phytoplankton community to smaller species (Kucklentz 1985; Leventer 1987; Milstein et al. 1988; Smith 1989; Costa-Pierce 1992; Laws and Weisburd 1990; Vörös et al. 1997).

Silver Carp also have been shown to consume zooplankton, especially when phytoplankton abundance is low (Spataru and Gophen 1985; Burke et al. 1986). Rotaria are important food for larval Silver Carp (Krykhtin and Gorbach 1981; Kouril et al. 1982). Dabrowski and Bardega (1984) found that from the third day of feeding, larval Silver Carp consumed zooplankton 300-400 µm. Sobolev (1970) found that Silver Carp fed on zooplankton at 2 weeks (12-14 mm), but that they switched to primarily phytoplankton after 18 days. Opuszynski (1979b) observed ontogenetic diet shift from being a general planktonic feeder to being selectively phytophagous in Lake Kinneret, Israel. Spataru and Gophen (1985) found that Silver Carp in Lake Kinneret consumed a high biomass of cyclopoid copepods and that zooplankton constituted 50% or more of Silver Carp diets in fall and winter. Domaizon et al. (2000) found zooplankton to be the major contributor to the diet of age 1+ Silver Carp (90.5% ingested biomass) whereas the diet of those 3+ years contained zooplankton (44.8% ingested biomass) and phytoplankton (55.2%). Using photosynthetic pigment ratios and photosynthetic rates of gut materials, Takamura et al. (1993) concluded that the occurrence of phaeophorbide *a* in feces of Silver Carp indicated consumption of herbivorous zooplankton, even though zooplankton was rarely observed in feces (perhaps because of rapid digestion; Bitterlich and Gnaiger 1984). Their results also showed that Silver Carp preferred Chlorococcales and Euglenophyceae over blue-green algae. These two types of phytoplankton, however, were observed in the feces of Silver Carp. Algae of these groups remained undigested and were still photosynthesizing after passage through the intestine. Gu et al. (1996) found using stable carbon and nitrogen isotope values that conventional diet analysis might have underestimated nutritional importance of zooplankton in Silver Carp because of their inability to determine dietary components incorporated into fish tissue and to determine dietary changes over time.

Filter feeding by Silver Carp has been shown to affect the structure and abundance of the zooplankton community. Studies have consistently shown that the presence of Silver Carp results in a zooplankton community dominated by smaller individuals. Fukushima et al. (1999), for instance, found that that the zooplankton community in Lake Kasumiguara (Japan) shifted toward smaller individual zooplankters in the presence of Silver Carp, regardless of fish density. In one of the two experiments, rotifers bloomed in the fishless enclosure and not in any of the different densities of fish. In enclosures in Lake Donghu, China, Lu et al. (2002) found that crustacean zooplankton biomass decreased with increasing fish biomass. They found that small-bodied crustacean zooplankton survived in the presence of fish, but large-bodied cladocerans and copepods were abundant only in enclosures without fish. Interestingly, they reported that calanoid copepods, which are evasive as adults, did not develop in enclosures with high densities of Silver Carp because of predation on nauplii. Domaizon and Devaux (1999) also found an inverse relation between Silver Carp density and zooplankton abundance. Many studies have attributed reduced abundance in zooplankton in response to the presence of Silver Carp (e.g., Milstein et al. 1985b; Burke et al. 1986; Wu et al. 1997; Radke and Kahl 2002). Silver Carp can also affect the population growth characteristics of zooplankters. Radke and Kahl (2002), for example, found that the presence of Silver Carp resulted in a rapid decline in the size and age at maturity of the cladoceran *Daphnia galeata*. The mechanism of the effect of Silver Carp on the zooplankton community has been debated. In a pond experiment, Burke et al. (1986) speculated that the reduction in zooplankton abundance in the presence of Silver Carp was due to competition for food resources (phytoplankton) because few zooplankters were found in the stomachs of Silver Carp. In another pond experiment, Milstein et al. (1985b) concluded that the relation between Silver Carp and the zooplankton community was complex—not only did Silver Carp prey on zooplankton, but they also competed with them for food resources.

Several studies have found that Silver Carp consume considerable amounts of bacteria, both planktonic and in aggregations (Kuznetsov 1978, 1980; Balasubramanian et al. 1993). Kuznetsov (1978) found that juvenile Silver Carp (6-10 g) consumed large quantities of bacterial aggregates, which were often surrounded by slime produced by the fish. Voropayev (1969) showed that Silver Carp filtered aggregates of bacteria ranging from 21 to 60 µm; Schroeder (1979) considered bacterial aggregates >37 µm to be a principal food for Silver Carp. Some authors have also found detritus in the intestine of Silver Carp (e.g., Bitterlich 1985c). Detritus has been reported to be >90% of Silver Carp diets in the Amur River in spring and 60-100% in fall (Borutskiy 1973, in Opuszynski 1981), 89-94% from Silver Carp in ponds (Borutskiy 1973), 90-99% (Vovk 1974), and >99% (Nabereznii et al. 1972). Large amounts of detritus in the intestine of Silver Carp suggested to Bitterlich (1985a) that these stomachless fish are omnivorous, not primarily herbivorous. Henebry et al. (1988) suggested that bacterial grown in the gut may be important in the nutrition of Silver Carp; bacteria increased in concentration between the foregut and midgut of the fish and decreased in concentration between the midgut and hindgut, indicating that bacteria were being grown and then digested.

Williamson (2004) found that Silver Carp from the middle Mississippi River selected for phytoplankton and against zooplankton in August and September 2003, but as phytoplankton abundance decreased, Silver Carp selected for zooplankton and against phytoplankton. He suggested that avoidance of zooplankton was driven by a high abundance of more difficult-to-capture copepods.

Although considered to be planktivorous in the literature, Silver Carp are successfully caught by hook and line using bread, bread paste waterproofed with salt-free butter and flavored with aromatic attractants such as "smelly" cheese, Aniseed oil, rotten bananas (Dias 2004), or sticky dough (Hangzhou Rongchan Sporting Products Co. Ltd. 2003) using specialized tackle (Fig. 17) and the "suspension method".

Silver Carp are thought to be pump filter feeders (Lu and Xie 2001). Dong and Li (1994) stated that juvenile Silver Carp in aquaria functioned as pump filter feeders, and although they selected areas of high zooplankton abundance, they did not snap at individual prey or move towards individual zooplankton swimming in front of them. Despite the fact that both Silver and Bighead carps are abundant in the lower Missouri River, DCC has often observed Bighead Carp feeding but has never observed Silver Carp feeding behavior in the wild. The reason is unclear, but may be because Silver Carp are more difficult to approach, or perhaps because they do not share the surface-feeding behaviors of Bighead Carp.

Food consumption rates estimated for Silver Carp have been quite variable. Fry at the smallest size class consumed up to 140% of their body weight daily, declining to just more than 30% by 63 mg and rising up to 63% for fingerlings 70-166 mg (Wang et al. 1989). According to Moskul (1977, in Leventer 1979), Silver Carp consumed about 20% of their body weight per day. Kuznetsov (1980) found that juvenile Silver Carp consumed 0.15-0.18 g/m^3 bacteria (dry weight) per 1 g of weight in water without algae and 0.09-0.23 g/m^3 per 1 g in water with algae. Bialokoz and Krzywosz (1981) estimated annual food consumption of adult Silver Carp to be 8.8 kg, with 90% of consumption occurring during the three warmest months in Paproteckie Lake, Poland. Balasubramanian et al. (1993) found that filtration rate increased with the size of Silver Carp. Smith (1989) found a maximum filtering rate of Silver Carp to be 18.25 L/hour/fish. Removal rate of food particles by Silver Carp decreases with increasing particle size (Dong and Li 1994). Dong et al. (1992) found suction volumes (mL/mouth) increased with fish size and water temperature: 0.28 mL at 15°C and 0.17 mL at 25°C for a 5.6-cm fish, and 1.14 mL at 15°C and 1.34 mL at 25°C for a 11-cm fish.

Evacuation rates have been estimated for a variety of sizes and ages of Silver Carp at different water temperatures. Using food labeling, Omarov (1970) estimated the time of food passage through the intestine of a 2-year old Silver Carp (320-370 g) to be 4 hours at 23°C and 4.23 mg/L dissolved oxygen. Bialokoz and Krzywosz (1981) estimated evacuation rates to be 10 hours at 22.6°C and 108 hours at 4.0°C. Henebry et al. (1988) found a food retention time for 20.7-25.7 cm Silver Carp of 4 to 5 hours at 28.5°C. Okoniewska and Kruger (1979, in Bialokoz and Krzywosz 1981) found that gut passage time for Silver Carp (200-500 g) fluctuated between 5.5 and 10.2 hours at 20 to 22°C. Alimentary tracts containing more food emptied 30% slower than those that were less full (Bialokoz and Krzywosz 1981).

Largescale Silver Carp

Pearl River Fisheries Research Institute (1991) and Chen (1998) noted that Largescale Silver Carp feed on phytoplankton. Because this species is most closely related to Silver Carp, their food and feeding habits are probably much the same. Chen (1998) reported that Largescale

Silver Carp are nocturnal feeders, remaining in deeper water during daylight hours. No other information on feeding habits of this species was found.

Growth Rate and Longevity

Bighead Carp

Age and growth of Bighead Carp remain somewhat poorly understood because aging of this species has met with varied success. Nuevo et al. (2004a) found otoliths and cleithra to be unsuitable structures for age determination of Bighead Carp from the Mississippi River. However, Morrision et al. (2004) successfully used otoliths and scales in the aging of Bighead Carp caught from Lake Erie. Accuracy of age assessment of known-age fish in the Nuevo et al. (2004a) study was 69% using pectoral ray cross sections and 78% using scales. Nuevo et al. (2004b), using the pectoral ray cross-section method, found that Bighead Carp grew rapidly in the Mississippi River, reaching 1 kg in weight by age 2. Given their rapid growth rates, high fecundity, adaptable feeding behavior, and tolerance of a variety of environmental conditions, one could conclude that Bighead Carp is a hardy species with the potential to reproduce and persist as large, fluctuating populations in U.S. rivers and lakes.

Bighead Carp are capable of amazingly fast growth rates. In fertile waters with temperatures above 13.9 ºC, Bighead Carp can attain 2.7 kg in less than 1 year (Waterman 1997). After reaching 0.45 to 0.68 kg, they can gain 0.45 kg or more per month (Stone et al. 2000), are capable of reaching 18 to 23 kg in 4 to 5 years (Henderson 1978), and can grow up to 1.5 m or more in length. Maximum weight of Bighead Carp is around 40 kg (Baltadgi 1979). The U.S. record is a 40.8-kg Bighead Carp that was caught in a Texas lake in 1999 (Howells 2001). In culture systems, Bighead Carp show a high growth potential and outperform Silver and Grass carps in terms of net production (Woynarovich 1968; Newton 1980; Opuszynski 1981).

Three-year-old Bighead Carp collected from the lower Missouri River in 1998-1999 averaged 550 mm in length; 5-year-old Bighead Carp averaged 700 mm (Schrank and Guy 2002). The growth of Bighead Carp in the lower Missouri River during this time peaked between 2 and 3 years of age, declining after age 3 (Schrank and Guy 2002). Mean back-calculated lengths of Bighead Carp from the lower Missouri River were larger than those of Bighead Carp from populations stocked into reservoirs in Poland (Schrank and Guy 2002; Fig. 18). Nuevo et al. (2004b) reported that fish of the same ages, collected from the Mississippi River in the same years, were much larger than those collected by Schrank and Guy (2002) from the Missouri River; 3-year-old fish from the Mississippi River ranged from 757 to 852 mm, and 5-year-old fish ranged from 807 to 909 mm.

Survival of Bighead Carp in aquaculture has been reported to be high. Maddox et al. (1978) studied productivity of Bighead Carp, Silver Carp, and tilapias in a polyculture system in the United States, and reported that Bighead Carp survival was 92% during the 52-day study. Newton et al. (1978) combined five species at the rates (per hectare) of 250 Bighead Carp (1.39 kg), 1,250 Silver Carp (566 g), 50 Grass Carp (542 g), 50 Largemouth Bass (*Micropterus salmoides*; 184 g), and 3,150 Channel Catfish (*Ictalurus punctatus*; 36 g) in a low-intensity polyculture system in the United States. They reported that Bighead Carp survival averaged

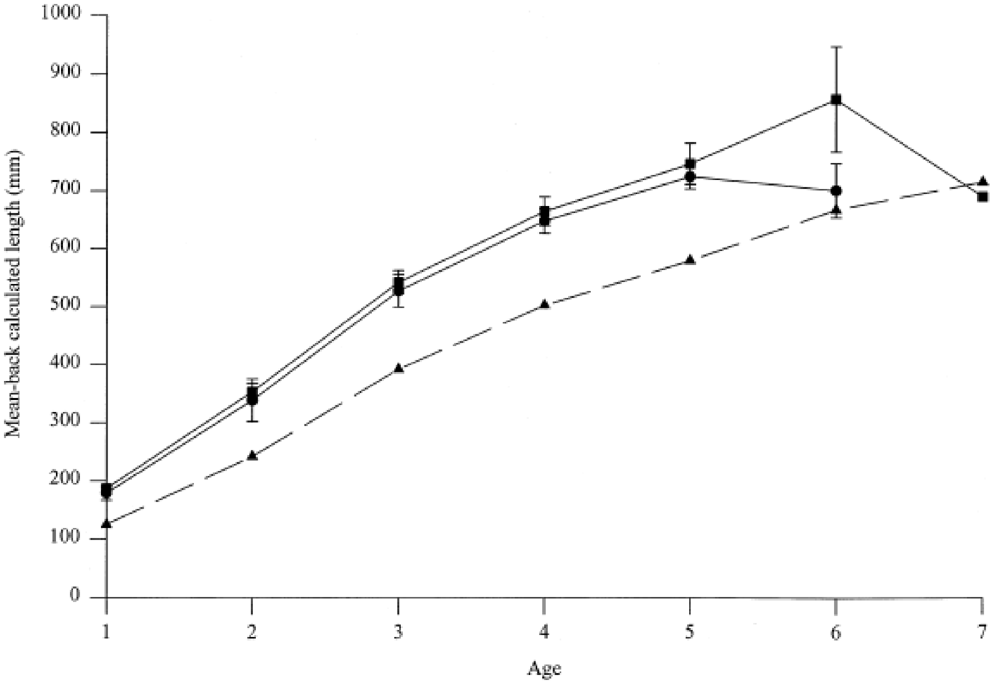

Figure. 18. Mean back calculated length (mm) by age using dorsal fin rays of male (*circles*) and female (*squares*) Bighead Carp (*Hypophthalmichthys nobilis*) collected in the lower Missouri River (May-August 1998, January-May 1999). Bars represent one standard error. Dashed line represents mean back calculated length of Bighead Carp stocked into lakes in Poland (Jennings 1988). Taken from Schrank and Guy (2002).

98% after 140 days. Green and Smitherman (1984) reported survival of Bighead Carp from eggs to larvae, with high quality spawn and normal incubation conditions, of not <70% to 80%. Furthermore, they reported survival of Bighead Carp fry stocked at 370,500 fry/ha to be 95% in ponds and 100% in tanks after 42 days.

As noted by Jennings (1988), there is a lack of specific information on longevity and mortality of naturalized or indigenous populations of Bighead Carp. Recently, the maximum age of Bighead Carp was reported to be 16 years (J. Yang, Kunming Institute of Zoology, Kunming, China, personal communication to P. Chen, Museum of Zoology, University of Kansas, 2004). The oldest Bighead Carp that have been aged in the United States, to our knowledge, was by Morrison et al. (2004). They aged two Bighead Carp that were caught from Lake Erie, Ontario, and reported that both fish were 8-10 years old, were in excellent health, and displayed recent growth at the time of capture. Because the biology of Grass Carp and that of Bighead Carp are similar, it is possible that the latter may have similar longevity. Although little is known about the longevity of Grass Carp, three specimens of Grass Carp were collected from Spiritwood Lake, North Dakota, in 2004 that must have been stocked into the lake by the North Dakota Department of Game and Fish in 1972, making these Grass Carp 32 to 33 years old (G. Van Eeckhout, North Dakota Department of Game and Fish, personal communication, 2004). These data suggest that Bighead Carp may be quite long lived.

Silver Carp

Like Bighead Carp, Silver Carp can grow quickly. In culture, the following growth rates have been reported: 1 kg in 55 days (Newton 1980), 1 kg in 5 months (Ghosh et al. 1973), a 17-fold increase in weight in 78 days for 7.6 cm Silver Carp (Stott and Buckley 1978), 5.4 kg in 1 year (Henderson 1979a), 2-2.5 kg in 2 years (Leventer 1987), and 18-23 kg at 4-5 years (Henderson 1979a). Silver Carp can also grow quickly in reservoirs and natural waters: 20+ kg in 5 years (Leventer 1987) in a wastewater reservoir. In Lake Kinneret, Israel, fish achieved 20 to 30 kg in 5 to 8 years (Leventer 1987). Kamilov and Salikhov (1996) reported Silver Carp up to a maximum total length of 1.26 m from the Syr Dar'ya River. Liang et al. (1999) grew six fish species in ponds for 2 years and found that Silver Carp had the highest increase in biomass (522 kg/ha/year). Net yield was 940 kg/ha; Silver Carp grew to marketable size (0.5-1.0 kg) in less than 1 year (Liang et al. 1999). In 2003, Silver Carp from the middle Mississippi River attained mean total lengths (back calculated from fin rays) of 318 mm by the end of the first year, and 650 mm by age 3 (Williamson and Garvey, *in press*).

Documented daily growth rates for Silver Carp include 0.003 g/day in mesocosm experiments (Starling 1993) and juveniles increased an average of 4.19 g/day (FAO 1980). At 400/ha in polyculture, Silver Carp grew 8.8 g/day (Leventer 1987), and grew 5.8 g/day in pen culture in reservoirs in Nepal (Rai 2000). During the first spring after they were stocked in Lake Kinneret, Israel, Silver Carp grew 4-5 g/day, and their growth rate increased to 8 g/day as temperature rose (Shefler and Reich 1977). During the next year when fish weighed 2+ kg, growth was about 10 g/day with some intervals at 15 g/day (Shefler and Reich 1977). The following percent increases have been reported: 6,000-9,000% in 180 days in Taiwan (Chien and Tsai 1985, in Smith 1994), 15,000% in 10 months in Taiwan (Sin and Chiu 1987, in Smith 1994); 11,000-15,000% in 12 months in Arkansas (Henderson 1983), and 2,000% in 6 months in Alabama (Cremer and Smitherman 1980, in Smith 1994). Silver Carp (age 1 through age 5) collected from the middle Mississippi River in 2003 grew substantially faster than those from Gobindsagar Reservoir, India, and those from the Amur River, Russia (Williamson and Garvey, *in press*).

Growth of Silver Carp is influenced primarily by food availability (Tripathi 1989; Hagiwara and Mitsch 1994, in Liang et al. 1999). However, Cremer and Smitherman (1980) found that growth of juvenile Silver Carp was not affected by phytoplankton densities in ponds and did not differ in ponds receiving fertilizer or feed (2.7 g/day for 159 days). Density dependent growth, however, has also been documented (Murty et al. 1978; Leventer 1987; Opuszynski 1980).

Shefler and Reich (1977) reported that Silver Carp did not cease growing in winter in Lake Kinneret, Israel. But Wrigley et al. (1988) found that Silver Carp decreased in weight during winter at a rate of 0.2-0.3% per day. Tripathi (1989) showed a weight loss of 21-32% in 30 days in Silver Carp (1.2-45.8 g) at 15-18°C, suggesting that overwintering of fry and fingerlings is more hazardous than that of juveniles and adults because of the higher metabolic rates of fry and fingerlings.

Survival of Silver Carp in aquaculture has been reported to be high. Ghosh et al. (1973) reported that Silver Carp cultured in ponds had almost 91% survival. Survival of Silver Carp at various stocking density rates (100,000-250,000/ha) was 74.4% to 99.3% (Murty et al. 1978) and 59.8% in a polyculture experiment (Liang et al. 1999). The annual mortality of Silver Carp in the middle Mississippi River, however, was lower than anticipated (64%) on the basis of literature values, given only limited commercial harvest of this species (Williamson and Garvey, *in press*).

Longevity data for Silver Carp are scarce largely because Silver Carp are difficult to age. It is clear from ponds with Silver Carp of known ages that one annulus forms on the scales in a year. Peculiarities of the scales of Silver Carp (the diffused expression of annuli) and opaque otoliths, however, make it difficult to use them for aging (Kamilov 1985). Sysoeva (1958, in Kamilov 1985) reported fan-shaped divergent circuli of the new year laid down after the annulus in all ages of Silver Carp from the Amur River. Aging of Silver Carp using other body parts has met with varied success. Johal et al. (2000) reported that the postcleithrum was a good aging structure for Silver Carp. Johal et al. (2001) stated that the body-cleithrum relation can be used for aging. Shefler and Reich (1977) reported aging Silver Carp using scales from the pectoral fin region. Kamilov (1985) found that the first ray of the pectoral fin, vertebrae, and pterygiophore of the first ray of the dorsal fin were suitable for aging whereas the operculum and otoliths were not.

Reports of maximum ages of Silver Carp indicate that the species is long lived. Kamilov and Salikhov (1996) found Silver Carp up to 10 years old in the Syr Dar'ya River in Uzbekistan, but this information probably applies to hybrids of Silver and Largescale Silver carps. Silver Carp in China have been reported to reach a maximum of 40 kg and live up to 15 years (J. Yang, Kunming Institute of Zoology, Kunming, China, personal communication to P. Chen, Museum of Zoology, University of Kansas, 2004). Berg (1964) reported that Silver Carp can reach an age of 20 years and that the 17+ year class dominated a particular catch. Because the biology of Grass Carp and that of Silver Carp are similar, it is possible that the latter may have similar longevity. Although little is known about the longevity of Grass Carp, three specimens of Grass Carp were collected from Spiritwood Lake, North Dakota, in 2004 that must have been stocked into the lake by the North Dakota Department of Game and Fish in 1972, making these Grass Carp 32 to 33 years (G. Van Eeckhout, North Dakota Department of Game and Fish, personal communication, 2004).

Largescale Silver Carp

Chan and Fan (1988) indicated that the Largescale Silver Carp has a slightly higher growth rate than Silver Carp and that the growth rate for hybrids between these two species is intermediate. They reported mean growth rate for 20 individuals each in culture in northern Vietnam as 511 g for Largescale Silver Carp and 370 g for Silver Carp in 1985. No information was found on longevity. Pearl River Fisheries Research Institute (1991) stated that a 1-year-old fish can reach 500 mm and weigh 3 kg; a 2-year-old fish, more than 600 mm and 6 kg; and a 3-year-old fish, 700 mm and 8 kg. Some large adults reach weights of 20 to 25 kg. Berg (1964) reported that Silver Carp can live 20 years. This suggests the possibility of a similar longevity in the closely related Largescale Silver Carp.

Response to Physical Stimuli

Over the past few years, Silver Carp have received considerable attention in the United States because of their physical and psychological impact on boaters. These fish become agitated by the sound and vibration of boat motors and react by leaping out of the water. Often they jump high into the air and hit boats and their passengers. Bighead Carp have also occasionally been reported to leap from the water in response to boat traffic, but this activity is either rare or possibly the reports are the result of misidentification of Silver Carp or hybrids of Silver and Bighead carps. Of hundreds of fishes that have leaped into the boat of one author (DCC), all of the fish have been Silver Carp or hybrid Bighead Carp × Silver Carp. Bighead Carp will occasionally leap a short distance out of the water when electrofished or when spawning.

Bighead Carp

Vinogradov (1979) described the Bighead Carp as a "quiet schooling fish, easily caught from lakes and reservoirs." U.S. Fish and Wildlife Service (2003) reported that Bighead Carp submerged at the sound of an outboard motor in the Missouri River below Gavins Point Dam, South Dakota and Nebraska. During a telemetry study in the Missouri River, DCC has had many opportunities to observe the behavioral responses of *Hypophthalmichthys* spp. to motor boats. Tagged Bighead Carp were sometimes observed to react strongly to the presence of a running outboard or even an electric trolling motor, requiring that locations of the fish be established through triangulation from a distance. Tagged Bighead Carp occasionally left a wing-dike pool when the research vessel entered.

DCC has observed that Bighead and Silver carps are susceptible to being driven by a boat or other noise-generating methods useful in their capture. Nevertheless, Bighead Carp are more lethargic than Silver Carp and do not often jump from the water. Bighead Carp are easily caught from culture ponds using a seine. Green and Smitherman (1984) found that 75% to 99% of Bighead Carp were caught from a pond with a single seine haul, compared to 38% for Silver Carp.

Silver Carp

Silver Carp is a pelagic, schooling species (Mukhamedova 1977). Man and Hodgkiss (1981) reported that they usually swim just beneath the water surface. However, winter data from archival tags implanted in Silver Carp by DCC in the Missouri River indicated that these fish generally stayed between 1 and 5 m deep and were rarely located near the bottom. Unlike Bighead Carp, Silver Carp in the Missouri River or its tributaries are rarely observed on the surface until disturbed. DCC has observed that once disturbed, Silver Carp often swim rapidly near the surface creating a characteristic large wake. Silver Carp regularly jump out of the water when disturbed (Tarifeno-Silva et al. 1982; Skelton 1993), particularly in response to outboard motors (Fig. 19). Brian Todd (Missouri Department of Conservation, Kirksville, Missouri, personal communication, 2003) stated that this response is more pronounced with higher RPMs and greater motor noise.

Figure 19. Jumping Silver Carp, *Hypophthalmichthys molitrix*. Photograph courtesy of R.D. Nelson, U.S. Department of Agriculture, Natural Resources Conservation Service, Lincoln, Nebraska.

Reports of large jumping Silver Carp seriously injuring boaters and water-skiers and severely damaging watercraft are becoming more frequent (Beattie 2002; Deardorff 2002; Kilborn 2002; Perea 2002; Lien 2003; Myhre 2003; Williams 2003). Occurrences of Silver Carp landing in boats and hitting boaters are commonplace. With boat speeds of more than 32 km/hour and fish that sometimes exceed 9 kg, results can be disastrous (Chapman 2003). One day of sampling fish in the Missouri River by DCC resulted in more than 100 kg of Silver Carp jumping into a research vessel. Fishery biologists working in areas with Silver Carp are often hit by jumping fish (Perea 2002; M. Pegg, Illinois Natural History Survey, Havana, Illinois, personal communication, 2003). As reported by Meersman (2004), boater Marcy Poplett was on the Illinois River in October 2003 on a personal watercraft when a Silver Carp struck her in the face. The impact knocked her off the watercraft and she fell, unconscious, into the river. She revived to find herself bleeding and then passed out a second time. A passing boater rescued her. Her injuries included a broken nose, concussion, injured back, black eye, and a broken foot.

In addition to personal injury, Silver Carp also cause property damage and leave a mess for boaters to clean. One author (DCC) has observed damage to recreational boats on the Missouri River, including a broken windshield and a broken Plexiglas faring. Other reports of damage from jumping Silver Carp include a broken generator (B. Canaday, Missouri Department of Conservation, Jefferson City, Missouri, personal communication, 2003), and broken radios and depth finders (M. Pegg, Illinois Natural History Survey, Havana, Illinois, personal communication, 2003). When a Silver Carp lands in a boat, even if it does not break anything of value, it leaves slime, scales, and feces for boaters to contend with. Some fisheries professionals, including one author (DCC), who work in areas where Silver Carp are common, have added screens or netting to their vessels to deflect carp and thus reduce injuries and equipment damage.

The specific dynamics of this behavior—the reason that boat motors prove to be such a strong stimulus for Silver Carp—have yet to be thoroughly investigated. It has been suggested that the jumping is a method of avoiding predators (Perea 2002), but this has not been proven.

While now widely publicized because of the magnitude of its effects, this behavior actually was recorded at least as early as 1928 when V.K. Soldatov reported that Silver Carp, frightened by the noise of his boat, would leap out of water and fall into the boat (Berg 1964). Clearly, the jumping behavior of Silver Carp presents a physical danger to recreational boaters and water-skiers. Injuries to humans from jumping fish will continue and may increase with Silver Carp populations, and human deaths may possibly occur. Risk to humans is highest when there are two boats, both moving at high speeds in the same direction (DCC, personal observation). At such speeds, Silver Carp jump out of the water behind the first boat, placing the following boat and its occupant(s) in jeopardy of being struck. Water-skiers face the same risk.

Silver Carp are difficult to capture from culture ponds with a seine because of their jumping behavior. Not only do Silver Carp escape the seine by jumping over it, but the large jumping fish create a hazardous situation for persons in or near the water (M. Freeze, Keo Fish Farm, Keo, Arkansas, personal communication, 2004).

Largescale Silver Carp

No information on the response of Largescale Silver Carp to physical stimuli was found. Because Chen (1998) noted that Largescale Silver Carp remain deep in the water column during daylight hours and swim toward the surface at night to feed on plankton may indicate that they are less prone to jumping than Silver Carp in response to sounds of boat engines during daytime.

Associated Diseases and Parasites

Bighead Carp

Originally compiled by Jennings (1988), Table 4 provides an updated, annotated list of disease-causing agents that reportedly infect Bighead Carp, mostly in high-density culture situations. Also from Jennings (1988) is a summary of Bauer et al.'s (1973) discussion of several of these diseases. The information provided is based on citations from the literature. We cannot verify the taxonomic accuracy of the organisms listed or discussed.

“White-skin disease” of Bighead Carp is caused by the bacterium *Pseudomonas dermoalba* and is recognized by a whitening of the skin at the base of the dorsal and caudal fins. Mortality results if the fish are not treated. The most infectious disease is caused by *Saprolegnia*, characterized by a cotton-like growth that develops on the epidermis as a result of the fish being stressed.

Bighead Carp are also susceptible to many diseases caused by parasitic protozoans. *Eimeria* sp. caused coccidial enteritis, a disease that is widespread in fish ponds in the Russian Federation and Hungary (Mólnar 1976). All developmental stages of this disease occur in any part of the gut, but intensive infection usually affects the foregut and midgut. The fish becomes sluggish and emaciated, the abdomen becomes soft and swollen, and yellowish strands of mucus,

Table 4. Disease-causing agents of Bighead Carp (*Hypophthalmichthys nobilis*).

Causative agent	Resulting disease; symptoms; other notes	References
BACTERIA		
Aeromonas hydrophila	Red sore disease; bacterial septicemia; hemolytic ascites disease. Raised, red lesions on the tips of fins, fin erosion, and ulcers on body	Hoole et al. (2001)
Edwardsiella sp.	Septicemia; bleeding on skin, fins, in mouth, and internal organs	Hoole et al. (2001)
Proteus rettgeri	Affects most of body, cutaneous subfusions and ulcerations localized on the caudal trunk area	Hoole et al. (2001)
Pseudomonas dermoalba	White-skin disease; whitening of skin at base of dorsal and caudal fins; death results if not treated	Bauer et al. (1973)
P. fluorescens	Septicemia; bleeding on skin, fins, in mouth, and internal organs of fish, accompanied by anemia	Petrinec et al. (1985), Hoole et al. (2001)
VIRUSES		
Rhabdovirus carpio	Spring viraemia of carp; systemic, acute, and highly contagious; typically occurs when water temperature <18°C; most common in spring	Hoole et al. (2001), Fijan (2002)
FUNGI		
Saprolegnia sp.	Infectious fungal disease; cotton-like growth on epidermis, develops because of stress	Bauer et al. (1973)
PROTOZOANS		
Apiosoma sp.	High numbers attached to skin and gills cause inflammation, necrosis, and ulceration	Migala (1978), Hoole et al. (2001)
Chilodonella sp.	Chilodoniasis; feeds on epithelial cells of skin and gills, causes skin to become tattered and vulnerable to bacteria; heavy infestations can be lethal. Highly pathogenic protozoan; can survive low temperatures (<5°C)	Musselius (1979), Hoole et al. (2001)
C. cypini		Migala (1978)
C. hexasticha		Migala (1978)
C. cucullulus		Migala (1978)
Cryptobia agitate	Cryptobiosis; infects gill filaments	Bykhovskaya-Pavlovskaya et al. (1964)
C. branchialis	Cryptobiosis; infects gill filaments, causes them to become abnormally red and eventually destroys them	Bauer et al. (1973)
Eimeria sinensis	Coccidiosis; intensive infection usually affects foregut and midgut; fish becomes sluggish and emaciated; abdomen softens and swells; widespread disease in fish ponds in Russia and Hungary	Bauer et al. (1973), Mólnar (1976), Musselius (1979)
E. cheni		
Frontonia acuminata		Migala (1978)
F. leucas		Migala (1978)
Glaucoma scintillans		Migala (1978)

Table 4. Continued.

Causative agent	Resulting disease; symptoms; other notes	References
Ichththyophthirius multifilis	Ich; parasitizes skin and gill epithelium; characterized by small white tubercles on body; lesions of cornea and blindness also may occur; often causes mass mortality in culture situations	Bauer et al. (1973), Anonymous (1978), Migala (1978); Musselius (1979)
Myxobolus pavlovskii	Parasitizes gill epithelium; cyst size and intensity increase with age (Czech Republic); infection most massive among Bighead Carp fry (Hungary)	Lucky (1978), Mólnar (1979)
Trichodina sp.	Trichodiniasis; caused by infusoria of genera *Dichodina, Dichodinella,* and *Dipailiella.* Infects skin and gills and inhibits circulation	Anonymous (1978), Migala (1978)
T. domevguei	Trichodiniasis; infestation on gills and skin. Slime covers skin-like fog, fins clamped, and denuded of tissue	Bauer et al. (1973), Migala (1978)
T. pediculus		Bauer et al. (1973), Migala (1978)
T. nigra		Bauer et al. (1973)
T. ovaliformis		Bykhovskaya-Pavlovskaya et al. (1964)
T. reticulata		Bauer et al. (1973), Migala (1978)
Trichodinella epizootica		Bauer et al. (1973), Migala (1978)
T. minuta	Infects gills	Bykhovskaya-Pavlovskaya et al. (1964)
Tripartiella bulbosa		Bauer et al. (1973), Musselius (1979)
T. lieni	Infects gills	Bykhovskaya-Pavlovskaya et al. (1964)
Trypanosoma aristichthysi	Infects blood	Bykhovskaya-Pavlovskaya et al. (1964)
TREMATODES		
Dactylogyrus aristichthys	Infects the gill filaments	Bauer et al. (1973), Migala (1978)
D. nobilis		Bauer et al. (1973)
D. spathaceum	Metacercariae parasitize the eyes	Bauer et al. (1973)
Posthodiplostomum sp.	Black-spot disease; larva infects the skin and subcutaneous tissue,	Bardach et al. (1972)
P. cuticola	depositing a black pigment around the cyst it forms in the skin	Bauer et al. (1973)
CESTODES		
Bothriocephalus acheilognathi	Asian carp tapeworm; swelling of intestines, mucus membrane damage, can parasitize fishes of several different families; dangerous parasite.	Bauer et al. (1973), Anonymous (1978), Musselius (1979)
Diagramma intenupta	Diagrammosis; parasitizes the body cavity; reported in culture situations in Russia	Musselius (1979)

Table 4. Continued.

Causative agent	Resulting disease; symptoms; other notes	References
Ligula intestinalis	Parasitizes the body cavity	Bauer et al. (1973)
COPEPODS		
Lernaea sp.	Attaches to body surface, musculature, or gills; forms deep ulcer, abscess, or fistula at point of attachment	Bauer et al. (1973), Anonymous (1978)
L. cyprinacea	On skin	Goodwin (1999)
L. piscinae		Harding (1950), Shariff (1981)
Synergasilus lieni	Parasitizes gill filaments; compresses and ruptures gill tissue and results in embolism and necrosis	Bauer et al. (1973), Musselius (1979)
S. major		Nie and Yao (2000)
S. polycolpus		Wang et al. (2003b)

epithelial cells, and sporocysts project from the vent. Cryptobiasis is caused by *Cryptobia branchialis*, a flagellate that infects and causes an abnormal reddening of gill filaments, eventually destroying them. *Ichthyophthirius multifilis*, which parasitizes the skin and gill epithelium, is characterized by presence of small white tubercules on the body. Lesions of the cornea, blindness, and mass mortalities (in culture situations) may also occur. Trichodiniasis is a disease caused by infusoria of protozoans of the genera *Trichodina*, *Trichodinella*, and *Tripartiella*, all of which infect the skin and gills of Bighead Carp and inhibit circulation. Migala (1978) discovered several species of these genera, as well as other ciliates, infecting Bighead Carp reared in ponds in Poland. Another protozoan that parasitizes the gill epithelium of Bighead Carp is *Myxobolus pavlovskii*. In Czechoslovakia, Lucky (1978) found that the intensity of *Myxobolus* cysts increased with age whereas in Hungary, Mólnar (1979) reported the infection to be most massive among Bighead Carp fry.

Trematodes reported to parasitize Bighead Carp include *Dactylogyrus* sp., which infects gill filaments; *Diplostomum* sp., the metacercariae of which parasitize the eyes; and *Posthodiplostomum* sp., in which larvae infect the skin and subcutaneous tissue, depositing a black pigment around the cyst it forms in the skin. This infection is termed black-spot disease (Bauer et al. 1973; Musselius 1979).

The Bighead Carp also may be parasitized by cestodes, including *Ligula intestinalis* and *Diagrama interrupta*, which occur in the visceral cavity. Diagrammosis is reported in culture situations in the Russian Federation (Bauer et al. 1973). Another cestode parasite of Bighead Carp is the Asian carp tapeworm (*Bothriocephalus acheilognathi*), which causes swelling of intestines and mucus membrane discharge. This is a dangerous parasite that infects both Bighead and Silver carps and also can infect fishes of several different orders. The Asian carp tapeworm is discussed in more detail in a subsection below.

Several species of crustaceans parasitize fish in culture situations, causing disease outbreaks and mortalities. The Bighead Carp is parasitized by the copepod *Lernea* which attaches to the body surface, musculature, or gills, forming a deep ulcer, abscess, or fistula at the point of attachment. Harding (1950) first described this infection in Bighead Carp in Singapore, and Shariff (1981) reported its occurrence in the eyes and on the body surface of Bighead Carp in Malaysia. The copepod *Sinergasilus lieni* parasitized gill filaments of Bighead Carp, compressing and rupturing gill tissue and resulting in embolism and necrosis (Bauer et al. 1973).

Silver Carp

Table 5 provides an annotated list of disease-causing agents that reportedly infect Silver Carp. We cannot verify the taxonomic accuracy of the organisms cited in Table 5 or discussed in the text. We provide citations from the literature without reinterpreting what organisms to which the authors were referring.

Although several species (e.g., *Myxobolus pavlovskii*, Lucky 1978; El-Matbouli and Hoffmann 1991; and trichodiniasis, Bauer et al. 1973) occur primarily in high-density culture situations, the diseases and parasites cited in Bykhovskaya-Pavlovskaya et al. (1964) occur in

Table 5. Disease-causing agents of Silver Carp (*Hypophthalmichthys molitrix*).

Causative agent	Resulting disease; symptoms; other notes	References
BACTERIA		
Aeromonas hydrophila	Red sore disease; bacterial septicemia; hemolytic ascites disease. Raised, red lesions on the tips of fins, fin erosion, and ulcers on body	Kumar and Dey (1986), Cai and Sun (1995), Li and Lu (1997), Akhlaghi (2001)
Citrobacter freundii	Septicemia; bleeding on skin, fins, in mouth, and internal organs	Akhlaghi (2001)
Edwerdsielle tarda	Septicemia; an enteric bacterium that causes large, gas-filled, necrotic lesions in muscle tissue	Akhlaghi (2001)
Flavobacterium spp.	Septicemia; erythema at base of fins, in mouth, along folds of the lower jaw and within the opercula	Farkas (1985)
Proteus rettgeri	Affects most of body, cutaneous subfusions and ulcerations localized on the caudal trunk area	Bejerano et al. (1979), Georgescu and Caraiman (1981)
Pseudomonas dermoalba	White-skin disease; whitening of skin at base of dorsal and caudal fins; death results if not treated	Bauer et al. (1973)
P. fluorescens	Septicemia; bleeding on skin, fins, in mouth, and internal organs of fish, accompanied by anemia	Csaba et al. (1984), Akhlaghi (2001), Hoole et al. (2001)
Vibrio fluvialis biovar III	Vibriosis; hemorrhagic septicemia, erythema at base of fins, in mouth, along the grooves of the lower jaw, opercles and around the vent	Yin and Xu (1994)
Staphlococcus aureus	Eye disease	Shah and Tyagi (1986)
Yersinia ruckeri	Enteric redmouth disease; hemorrhagic septicemia	Xu et al. (1991)
VIRUSES		
Rhabdovirus carpio	Spring viraemia of carp; systemic, acute, and highly contagious; typically occurs when water temperature <18°C; most common in spring	Hoole et al. (2001), Fijan (2002)
FUNGI		
Achlya bisexualis	Saprolegniasis; aquatic fungus that infects fishes externally, fluffy, cotton-like to gray on skin, fins, gills or eyes	Jha et al. (1984)
Alternaria		Ebrahimzadeh Mousavi et al. (2000)
Aspergillus flavus	Epizootic hematoma; tumors and enlargement of the liver	Ebrahimzadeh Mousavi et al. (2000)
Aphanomyces	Ulcerations	Muruganandam and Samra (1999)
Fusarium		Ebrahimzadeh Mousavi et al. (2000)

Table 5. Continued.

Causative agent	Resulting disease; symptoms; other notes	References
Penicillium		Ebrahimzadeh Mousavi et al. (2000)
Saprolegnia parasitica	Saprolegniasis; invades epidermal tissues. Cotton-like white or gray patches of filamentous mycelium. Radiates in a circular, crescent-shaped or whorled pattern.	Jha et al. (1984)
PROTOZOANS		
Apiosoma amoebae	High numbers attach to skin and gills and cause increased mucus production and hyperplasia of the skin	Ali et al. (1989)
A. cylindriformis		Ali et al. (1989)
A. piscola		Ali et al. (1989)
Chilodonella cyprini	Chilodoniasis; feeds on epithelial cells of skin and gills, causes skin to become tattered and vulnerable to bacterial infection	Migala (1978)
C. hexasticha		Migala (1978)
C. uncinata		Migala (1978)
Chloromyxum cyprini	Attacks gall bladder	Bykhovskaya-Pavlovskaya et al. (1964)
Cryptobia agitata	On gill filaments	Bykhovskaya-Pavlovskaya et al. (1964)
C. branchialis	Ectoparasites that destroy epithelium of gill filaments in heavy infestations, causing poisoning and formation of thrombi that may lead to grave diseases and mortality of fish	Bykhovskaya-Pavlovskaya et al. (1964), Mólnar (1971)
Dexiostoma campylum		Migala (1978)
Eimeria aristichthysi	Coccidiosis; intensive infection usually affects foregut and midgut; fish becomes sluggish and emaciated; abdomen softens and swells; widespread disease in fish ponds in Russia and Hungary	Duszynski et al. (2000)
E. carpelli		Duszynski et al. (2000)
E. hypothalmichthys	Attacks kidneys	Bykhovskaya-Pavlovskaya et al. (1964)
E. sinensis (also *Goussia sinensis)*		Bauer et al. (1973), Golemanski and Grupeheva (1975), Mólnar (1976), Hoole et al. (2001)
Glaucoma scintillans		Migala (1978)
Glossatella cylindriformis	On surface of body and gills	Bykhovskaya-Pavlovskaya et al. (1964)

Table 5. Continued.

Causative agent	Resulting disease; symptoms; other notes	References
Ichthyophthius multifilis	White spot disease or ich; parasitizes skin and gill epithelium; characterized by small white tubercles on body. Lesions of cornea and blindness may also occur, often causes mass mortality in culture situations	Bauer et al. (1973), Migala (1978)
Myxidium hemiculteri	Attacks internal organs	Feng and Wang (1990)
M. sarcocheilichthysi	Attacks internal organs	
Myxobolus cerebralis	Whirling disease; damages cartilage of the head and spinal cord as parasite reproduces. Infected fishes exhibit whirling behavior when swimming	Wu et al. (1989); El-Matbouli and Hoffmann (1991)
M. dispar	On gills, skin, kidneys, muscles, and intestinal walls	Bykhovskaya-Pavlovskaya et al. (1964)
M. drjagini	Twist disease	Bykhovskaya-Pavlovskaya et al. (1964), Wu and Cai (1993)
M. ellipsoides	Infestation occurs most commonly on gills. Causes cysts on gills	Arthur and Lumanlan-Mayo (1997)
M. latus	In kidneys	Bykhovskaya-Pavlovskaya et al. (1964)
M. macrocapsularis	In gills, kidneys, wall of gas bladder, and skin	Bykhovskaya-Pavlovskaya et al. (1964)
M. pavlovskii	In gill filaments	Lucky (1978), El-Matbouli and Hoffmann (1991); Arthur and Lumanlan-Mayo (1997)
M. phylloides	In kidneys and mesentery	Bykhovskaya-Pavlovskaya et al. (1964)
M. saurogobioi		Feng and Wang (1990)
Myxosoma mai	Found in kidney of wild-caught fish	Zhang (2001)
M. sachalinensis	In kidneys and gall bladder	Bykhovskaya-Pavlovskaya et al. (1964)
M. sphaerica	In kidneys	Bykhovskaya-Pavlovskaya et al. (1964)
Sphaerosporida lieni		Feng and Wang (1990)
Sessilia sp.		Migala (1978)
Trichodina domevguei	Trichodinosis; infestation on gills and skin. Slime covers skin like fog, fins clamped, and denuded of tissue	Bauer et al. (1973), Ali et al. (1989)
T. mutabilis		Migala (1978)
T. nigra		Bauer et al. (1973), Migala (1978)
T. nobilis		Golemanski and Grupeheva (1975)

Table 5. Continued.

Causative agent	Resulting disease; symptoms; other notes	References
T. ovaliformis		Bykhovskaya-Pavlovskaya et al. (1964)
T. pediculus	On skin and gills	Bauer et al. (1973), Migala (1978)
T. reticulata		Bauer et al. (1973)
Trichodinella epizootica		Bauer et al. (1973), Migala (1978)
T. minuta	On gills	Bykhovskaya-Pavlovskaya et al. (1964)
Trichophrya piscium	Gill parasite that may block flow of oxygen	Golemanski and Grupeheva (1975)
Tripartiella bulbosa	Gill swelling often visible. Infected fishes lethargic, show weight loss	Bauer et al. (1973), Golemanski and Grupeheva (1975)
T. copiosa		Migala (1978)
T. lieni	On gills	Bykhovskaya-Pavlovskaya et al. (1964)
Trypanoplasma cyrpini	Ectoparasite; parasitic on gill	Golemanski and Grupeheva (1975)
TREMATODES		
Allocreadium hypophthalmichthydis	In intestine	Bykhovskaya-Pavlovskaya et al. (1964)
Camallanus hypophthalmichthys	In intestine	Bykhovskaya-Pavlovskaya et al. (1964)
Dactylogyrus chenshuchenae	On gill filaments	Bykhovskaya-Pavlovskaya et al. (1964)
D. hypophthalmichthys	Gill fluke disease; infects gill filaments: Swollen gills, mucus secretion, spreaded opercula, gasping for air, heavy ventilation, ceases feeding, jumps out of water, scraping	Radulescu et al. (1971), Mólnar (1984), Ali et al. (1989)
D. magnihamatus	On gill filaments	Bykhovskaya-Pavlovskaya et al. (1964)
D. vaginulatus		Li et al. (1994)
D. skrjabini	On fused gill rakers, particularly near ventral end	Bykhovskaya-Pavlovskaya et al. (1964), Mólnar (1984), Ali et al. (1989)
D. suchengtaii	On gill filaments	Bykhovskaya-Pavlovskaya et al. (1964)
D. yinwenyingae	In nares	Bykhovskaya-Pavlovskaya et al. (1964)

Table 5. Continued.

Causative agent	Resulting disease; symptoms; other notes	References
Diplostomum spathaceum (metacercariae)	Eye fluke; presented as white dots, later eye becomes opaque. Blindness occurs in severe infections, and death may result	Zhatkanbaeva (1986), Shah and Tyagi (1987), Szekely and Mólnar (1991)
Diplozoon paradoxum	On gills	Bykhovskaya-Pavlovskaya et al. (1964)
Gyrodactylus hypophthalmichthydis	On gills and fins. Increases mucus production and interferes with respiratory function.	Bykhovskaya-Pavlovskaya et al. (1964)
Posthodiplostomum cuticola	Black spot disease; larva infects the skin and subcutaneous tissue, depositing a black pigment around the cyst it forms in the skin.	Bauer et al. (1973), Fuhrmann (1979)
Larval Posthodiplostomosis		Mirle and Engelhardt (1991)
Rhabdochona denudata	In intestine	Bykhovskaya-Pavlovskaya et al. (1964)
Sanguinicola sp.	Blood flukes; in circulatory system	Bykhovskaya-Pavlovskaya et al. (1964)
Tetracotyle sp.		Bykhovskaya-Pavlovskaya et al. (1964)
CESTODES		
Bothriocephalus acheilognathi	Asian carp tapeworm; swelling of intestines, mucus membrane damage, can parasitize fishes of several different orders; dangerous parasite	Arthur and Lumanlan-Mayo (1997)
B. gowkongensis (=*B. acheilognathi)*	In intestine	Bykhovskaya-Pavlovskaya et al. (1964)
Triaenophorus nodulosus	In intestine	Bykhovskaya-Pavlovskaya et al. (1964)
COPEPODS		
Lamproglena orientalis	On gills	Bykhovskaya-Pavlovskaya et al. (1964)
Lernea bhadraensis	Anchor worm disease; head of parasite embeds into musculature with body protruding externally. Causes wound on skin	Tamuli and Shanbhogue (1996), Arthur and Lumanlan-Mayo (1997)
L. cyprinacea	On skin	Ali et al. (1989)
Sinergasilus lieni	Parasitizes gill filaments; compresses and ruptures gill tissue and results in embolism and necrosis	Bauer et al. (1973), Angelescu (1981), Molnár and Székely (2004)
S. major		Angelescu (1981)
S. polycolpus		Wang et al. (2003b)

Silver Carp collected from natural or artificial waterways. Many species of parasites and pathogens are found in wild populations. Grabda-Kazubska et al. (1987) surveyed 945 fishes of 20 species for parasites from 1979 to 1984 in lakes stocked with phytophagous fishes since 1970 and found 87 parasite species.

Silver Carp are susceptible to several bacterial diseases (Table 5). The indications of most bacterial diseases found in Silver Carp include red lesions, white spots, or bleeding from fins, mouth, or vent. Mi et al. (1993) described septicemia, a common symptom of bacterial infection, on Silver Carp, as a process of acute hemorrhagic inflammation accompanied with functional disorder in the heart, kidney, and brain. Stress due to high water temperatures (up to 32ºC) can cause Silver Carp to be vulnerable to infection with *Aeromonas hydrophila* (Akhlaghi 1999, in Coad 2005). Bacterial infections can lead to death in Silver Carp. Mass mortalities in Silver Carp related to infection of handling lesions with *Proteus rettgeri* have been reported (Bejerano et al. 1979). Bejerano et al. (1979) suggested that bacteria were introduced with poultry feces used to fertilize carp ponds. He et al. (1992) reported isolating more than 10 strains of pathogenic bacteria from Silver Carp in Shashi District, China.

The only viral disease agent of Silver Carp that we found in the literature is *Rhabdovirus carpio*, the causative agent for spring viraemia of carp, a systemic, acute, and highly contagious infection commonly occurring in the spring when water temperatures are below 18ºC.

Silver Carp are susceptible to many diseases caused by parasitic protozoans (Table 5). Host reaction to parasitic protozoans is variable and depends on host size, age, host specificity, immunity, host condition, fish density, and other environmental factors (Ribelin and Migaki 1975). Mólnar (1971) surveyed Grass, Silver, and Bighead carps in culture ponds and found 18 species of protozoa. Bauer et al. (1973) noted that although Bighead and Silver carps carried *Cryptobia branchialis*, a flagellate that attacks the gill filaments and can kill Grass Carp in several days, Bighead and Silver carps seemed resistant to developing cryptobiasis. Symptoms of disease caused by *Eimeria* sp., intracellular coccidian parasites usually settling in intestinal epithelium, include exhaustion, edema, riffling of scales, and fish infected with *Eimeria* sp. are vulnerable to secondary bacterial infection (Ribelin and Migaki 1975). *Chilodinella* sp. seems to cause problems mainly in the winter and can completely destroy gill epithelium, leaving nothing but the cartilaginous rays of the gill filaments. *Trichodina* spp. are some of the most common parasites of fish. Clinical signs of trichodinosis include excess mucus production, necrosis of the epidermis, and fins may become frayed. Heavily infected fish may be sluggish and may not feed (Ribelin and Migaki 1975).

Many trematodes have also been reported from Silver Carp. Bauer et al. (1973) noted that *Dactylogyrus hypophthalmichthys* is the most common parasite in pond-reared Silver Carp in the former U.S.S.R. from April to October. In Krasnodar Territory, age 0 and yearling Silver Carp showed 100% incidence at an average density of infection (6.3-12.5) parasites per fish (Bauer et al. 1973). *Dactylogyrus hypophthalmichthys* also infects hybrids of Silver and Bighead carps. Zhatkanbaeva (1986) found that invasion of 1 to 5 individuals of *Diplostomum spathaceum* caused 100% mortality of larval Silver Carp and Silver Carp × Common Carp hybrids (artificial cross produced in culture). Bauer et al. (1973) note that Silver Carp is especially susceptible to posthodiplostomatosis. Incidence in underyearlings and yearlings of

Silver Carp can be 100% at an intensity of infection of 1.5 to 9.3 parasites per fish. In 2-3 yr olds, values are 90-100% and 10.0-10.4 parasites. Fish parasitized by *Sanguinicola* sp. can die from damage done to be the gills by the presence of developing miracidians. A discussion of Asian carp tapeworm can be found in the following section.

Several crustaceans also parasitize Silver Carp. Tamuli and Shanbhogue (1996) found 100% infection of Silver Carp by the anchor worm (*Lernaea bhadraensis*) whereas other cultured carp species were not found to be as susceptible. Angelescu (1981) reported that synergasilosis by *Sinergasilus lieni* caused mortality of Grass and Silver carps in fish farms in the Danube Delta. Cakic et al. (2004) found *S. polycarpus* in wild fish from the Danube River. Mortality due to *S. polycarpus* has been observed in Silver Carp from a reservoir in China (Wang et al. 2003b), as well as morbidity and mortality from *S. major* in Romania (Angelescu 1981).

Krueger (1992) described disease in the medial parenchyma of the kidney, not related to parasitological, bacteriological, virological or toxicological agents, in Silver Carp from a lake outside of Berlin, Germany, with high mortality of Silver Carp. He suggested that the disease was due to unfavorable food conditions and other stresses.

Several authors have found a positive correlation between infestation level of Silver Carp and fish age or size: Lucky (1978) found that infestation with cysts from *Myxobolus pavlovskii* increased with fish age (0% in yearlings, 70% in 2-year-olds, 80% in 3-year-olds, and 100% in 4-year-olds); Wang et al. (2003b) found a positive correlation between abundance of the parasitic copepod *Sinegasilus polycarpus* and host age and length, and Tamuli and Shanbhogue (1996) found a positive correlation between length of Silver Carp and abundance of anchor worm.

Some disease-causing agents harbored by Silver Carp pose health risks to humans. The psychotropic pathogen *Listeria monocytogenes* has been found in market and fish farm samples of Silver Carp (Akhondzadeh Basti and Zahrae Salehi 2003). *Clostridium botulinum* was found in 1.1% of fresh and smoked samples of Silver Carp from the Mazandaran Province (Safari and Khandagi 1999). Ebrahimzadeh Mousavi et al. (2000) found the toxigenic fungi *Aspergillus flavus, Alternaria, Penicillium,* and *Fusarium* from Silver Carp and from pond water in which they were raised at a fish farm in northern Iran. In addition, live *Salmonella* sp. can be found in Silver Carp for at least 14 days after transfer to clean water and should, therefore be considered as a potential carrier for *Salmonella* (*S. typhimumium*; Bocek et al. 1992).

Largescale Silver Carp

We were unable to find any tabular listing of diseases or parasites of Largescale Silver Carp. Nevertheless, Lang (1981) noted the presence of a monogenetic trematode parasite, *Dactylogyrus harmandi*, known only from Largescale Silver Carp, on Hainan Island. Chan and Fan (1988) reported the same parasite on Largescale Silver Carp in northern Vietnam. This trematode differs morphologically from one that is known from Silver Carp, *D. hypophthalmichthys* (Chan and Fan 1988). However, this parasite will use Largescale Silver Carp as a host, but does so in fewer numbers than those in Silver Carp hosts. Another trematode, *D. chenthushenae*, has also been reported from Largescale Silver Carp in northern Vietnam but in few numbers. *Dactylogyrus harmandi* is not known to infect Silver Carp (Chan and Fan 1988).

Disease Transmittal to Native Fishes

Of the disease and parasite literature reviewed on Bighead and Silver carps, two parasites indicate a potential threat to native North American fishes, including cyprinids. Goodwin (1999) noted massive infestations of gill-damaging *Lernaea cyprinacea*, known as anchorworm, in Channel Catfish being cultured with Bighead Carp. This parasite is also known to affect salmonids and eels. Anchorworm occurs worldwide, is known from 40 cyprinid species, and completes its life history on a single host (Hoole et al. 2001). Although its origin in North America is unknown, it is likely that it first entered this continent with Goldfish (*Carassius auratus*) or Common Carp. Such potential for other parasites or diseases to negatively impact native North American fishes has not been examined.

Both Bighead and Silver carps are also known to be hosts of the Asian carp tapeworm (*Bothriocephalus acheilognathi*), a cestode parasite initially introduced into U.S. waters from Grass Carp (Hoole et al. 2001). Synonyms of this tapeworm are *B. opsariichthydis*, *B. gowkongensis*, and *B. phoxini*. The native range of this parasite is from the southern portion of the Amur River throughout much of China (Hoole et al. 2001). Its presence in Japan, sometimes included in its native range, is probably through early introductions of Common Carp. It is now present in many countries through transfers of both Common and Grass carps. The Asian carp tapeworm has been reported from more than 40 other cyprinid fishes and fishes of other orders (Acipenseriformes, Cyprinodontiformes, Atheriniformes, Perciformes, Osmeriformes, and Siluriformes; Hoole et al. 2001). *B. acheilognathi* from Grass Carp infected native baitfish (Golden Shiners and Fathead Minnows, *Pimephales promelas*) being cultured in midwestern states. When some infected baitfish were released into Lake Mead by anglers, the tapeworm was spread to two endangered fishes, Virgin Spinedace (*Lepidomeda mollispinis*) and Woundfin Minnow (*Plagopterus argentissimus*) in the Virgin River, Utah and Nevada (Heckmann et al. 1986, 1995). It has also been reported from Colorado Pikeminnow (*Ptychocheilus lucius*; Heckmann et al. 1986) and Humpback Chub (*Gila cypha*), both of which are endangered species. Approximately 90% of large juvenile and adult Humpback Chubs in the Little Colorado River are infected with this cestode (Humpback Chub Ad Hoc Advisory Committee 2003). The most probable pathway of introduction was by the release of infected baitfishes.

The Asian carp tapeworm is known to have infected native fishes of concern in five states: Arizona, Colorado, Nevada, New Mexico, and Utah. The two most recent reports are from the Yampa River, Colorado (infected Roundtail Chub, *Gila robusta*, a candidate for Federal listing as a threatened or endangered fish and listed as endangered by Colorado; D. Ward, Arizona Game and Fish Department, Flagstaff, Arizona, personal communication, 2004), and the San Bernardino National Wildlife Refuge (infected Yaqui Chub, *G. purpurea*; Beautiful Shiner, *Cyprinella formosa*; and Yaqui Topminnow, *Poeciliopsis occidentalis sonoriensis*, all three federally listed as endangered species; S. Bonar, Arizona Cooperative Fish and Wildlife Unit, University of Arizona, Tucson, Arizona, and B. Radke, U.S. Fish and Wildlife Service, San Bernardino National Wildlife Refuge, Douglas, Arizona, personal communication, 2004). Except for the San Bernardino Wildlife Refuge, the pathway for introduction of this cestode appears to be infected baitfishes that were released. In San Bernardino, the pathway of introduction was probably Beautiful Shiners containing the parasite that were moved to that facility from the U.S. Fish and Wildlife Service National Fish Hatchery at Dexter, New Mexico, in the mid-1990s (K. Cobble, U.S. Fish and Wildlife Service, San Andres National Wildlife Refuge, Las Cruces, New Mexico, personal communication, 2004). The Asian carp tapeworm probably came to Dexter National Fish Hatchery with infected Colorado Pikeminnow collected from the upper basin of the Colorado River, and the Green and Yampa rivers in the early 1970s. These fish were held and spawned for several years at Willow Beach National Fish Hatchery, Arizona, and moved in the early 1980s to the Dexter National Fish Hatchery. This parasite was identified in Colorado Pikeminnows at Dexter in 1984 (R. Hamman, U.S. Fish and Wildlife Service, Dexter National Fish Hatchery, Dexter, New Mexico, personal communication, 2004).

As the introduced range of Bighead and Silver carps grows in U.S. waters, a number of native fishes, particularly, but not limited to, cyprinids, percids, and centrarchids, will probably become hosts of the Asian carp tapeworm. This is a damaging parasite that erodes mucus membranes and intestinal tissues, often leading to death of the host (Hoole et al. 2001; Humpback Chub Ad Hoc Advisory Committee 2003). Although both Bighead and Silver carps are hosts of this parasite, its adverse effects on these carps are minimal (http://www.iop.krakow.pl/ias).

Human Uses of *Hypophthalmichthys*

Use as Human Food

Capture Fisheries for *Hypophthalmichthys*

Li and Xu (1995) described capture fisheries for Bighead and Silver carps in Chinese reservoirs. The Chinese use a combination of methods to catch these fishes. Blocking nets (designed to trap and funnel the fish, but not entangle them) are deployed to catch these fishes in a defined area and to funnel the fish into a harvesting basin or chamber also made of nets. The fishes are driven into the harvesting chamber using a variety of methods, including seining, the use of bubble curtains, electricity, and driving the fishes with boats. Weighted wooden boards painted white are dragged behind boats on ropes to assist in the driving of fishes. Sometimes trammel or gill nets are also used in the driving of fish, and some fishes are caught in these entanglement gears during the driving process. Fishes are targeted during their spawning migrations up tributaries or in areas where abundant food sources exist.

Most capture fisheries for *Hypophthalmichthys* in U.S. waters are done using trammel or hoop nets, essentially the same gear used by most freshwater commercial fishers. Commercial fishers for other purposes on the Illinois and Missouri rivers often use trammel nets to catch Bighead and Silver carps, driving the fishes into the net with a motorboat. On the Illinois River, the fishes are periodically emptied from the boat into “live nets” in several places in the river, to be retrieved later for transport in live-haul trucks to a distributor. Commercial fisheries for Bighead and Silver carps exist on the Mississippi, Missouri, and Illinois rivers, and probably in other locations where *Hypophthalmichthys* occur in large numbers and commercial fishing is legal. Fishes are sold live or dead. Live fish have a higher value but have more difficult handling requirements.

Culture of Carps

Culture of Common Carp has existed in China for at least 3,000 years (Chang 1987). During the Tang Dynasty (618-906 AD), people were not allowed to catch, sell, or eat Common Carp because pronunciation of Common Carp and the surname of the emperor were the same (FAO 1980). Although culture of Common Carp ceased during that period, culture of other Asian carp species (Grass, Silver, Bighead, and Black carps) began (FAO 1980). This practice continued for more than 1,000 years, but the supply of fry was irregular, often contaminated with other species, and resulted in high mortality (FAO 1980; Rottmann and Shireman 1985).

Artificial spawning of Silver Carp was first accomplished by hypophysation (injection of crude extracts of fish pituitary glands) in the mid-1950s (Eknath and Doyle 1990). Gerbilskii (1959, in Konradt 1965) found that the fractional injection method of gonadotropic hormones worked better than single doses of hormones to induce spawning. Several authors described in detail methods used to artificially propagate Silver Carp (Henderson 1979a; FAO 1980; Freeze and Crawford 1983; Kaul and Rishi 1993; Opuszynski and Shireman 1993; Ashraf and Fairgrieve 1998). A major difficulty in culturing phytophagous fishes is determining preparedness of females for maturation before injection with hormones (Makeeva et al. 1988).

Culture of Asian carps progressed from monoculture of Common Carp to polyculture (FAO 1980). Polyculture involves raising several species with different feeding habits in the same ponds using allochthonous materials such as land plants, macrophytes, snails, bran, peanut cake (Zhou et al. 1999), barley (Opuszynski 1980), manure (Mahboob and Sheri 1997), or other types of artificial feed or fertilizer to increase fish production. This practice has existed in China since the second century BC (Yang et al. 1992, in Takamura et al. 1993). Silver Carp are presently raised in polyculture systems in much of the world including Asia and Europe (Prowse 1969; Rimon and Shilo 1982), India (Eknath and Doyle 1990), and Africa (Prinsloo and Schoonbee 1987). In Israel, Common and Silver carps, tilapia hybrids, and mullets, *Mugil* spp., are grown in polyculture (Milstein 1990, in Kestemont 1995). Prinsloo and Schoonbee (1987) investigated integrated culture (the simultaneous culture of terrestrial and aquatic species) of ducks, fishes, and vegetables in South Africa. In this system, ducks were raised above the fish ponds and fishes were raised in the enriched water. Water was then drained for irrigation of vegetable plots. Other polyculture systems include carps and livestock (Kestemont 1995). Carp aquaculture in India is usually accomplished by raising six carp species in composite culture (native Catla, *Catla catla*; Rohu, *Labeo rohita*; Mrigal, *Cirrhinus mrigala*; and introduced Grass, Silver, and Common carps; Eknath and Doyle 1990). A successful system of the composite culture of Indian and Asian carps (including Silver Carp) has developed for still-water ponds in India. Under this system, besides carefully controlling stocking density and ratio of fishes, ponds are fertilized with organic and inorganic fertilizers, and fishes are fed with rice or wheat bran and oilcake (Sinha 1979).

Benefits of polyculture include increased production and economization of resources. Newton et al. (1978) reported higher production in ponds with polyculture than with monoculture (1,373 kg/ha in polyculture versus 712 kg/ha in monoculture). In a polyculture experiment using swine manure to fertilize ponds to grow Silver, Bighead, and Grass carps, the Israeli variety of Common Carp, Channel Catfish, and either Largemouth Bass or Bluegill, *Lepomis macrochirus*, Buck et al. (1978) obtained a maximum production of 4,585 kg/ha. Hepher and Schroeder (1974, in Schroeder 1979) observed that polyculture of Silver and Common carps, and tilapias resulted in 1-kg growth for each fish species in one growing season in manured ponds. Addition of Silver Carp to ponds with other species often does not result in a decrease of production of other species. For example, Opuszynski (1980) found that production of Common Carp did not decrease with addition or increase in the number of Silver Carp stocked. Moreover, in some situations, polyculture including Silver Carp has also been found to improve water quality in production ponds. Costa-Pierce et al. (1985) found that Silver Carp cultured with freshwater prawns improved water quality and early morning dissolved oxygen concentrations. Henderson (1979b) stated that polyculture of Silver and Bighead carps, and Channel Catfish resulted in no need for aerating the ponds because the phytophagous fishes kept phytoplankton from overpopulating.

Bighead Carp

In its native China and several other countries, the Bighead Carp is a popular food fish and ranks fourth in world aquaculture production (FAO 1999; Fig. 20). Before development of artificial spawning techniques, fry of Bighead Carp were caught from rivers in China using fine-meshed nets fastened to poles, similar to plankton nets, and moved to other waters for culture. The species is used in fish culture in China and is also grown in reservoirs as a type of aquaculture where market-sized fish are caught using gill nets, triangular nets from fishing vessels, or trolling with bait (Chang 1966). There and elsewhere, Bighead Carp are used in

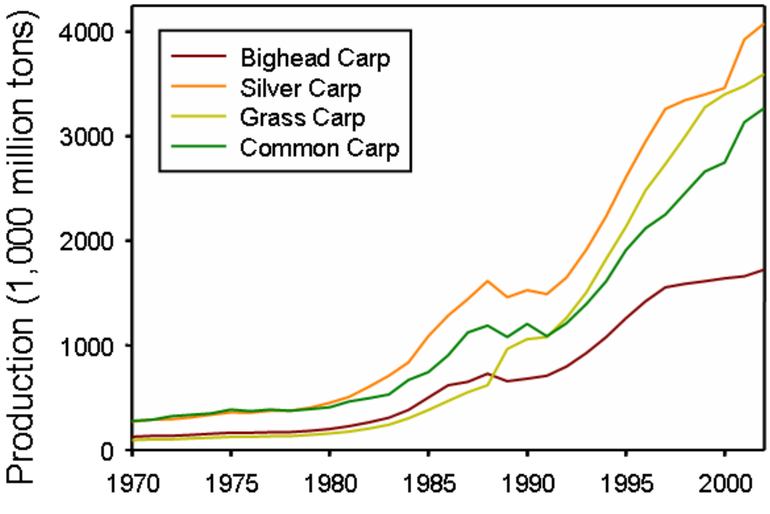

Figure 20. Global aquaculture and fishery production of Bighead (*Hypophthalmichthys nobilis*), Silver (*H. molitrix*), Grass (*Ctenopharyngodon idella*), and Common (*Cyprinus carpio*) carps ranked one through four in global production, respectively, since 1970.

polyculture with other fishes to control zooplankton and phytoplankton populations and are harvested as a food fish along with the other species. A few countries (e.g., Albania, Czech Republic, India, Italy, Mozambique, Slovakia) imported the species to augment wild fisheries.

In the United States, Bighead Carp are co-cultured in ponds with Channel Catfish, sometimes in conjunction with Grass Carp to control macrophytes. Other species involved in polyculture are Common Carp, various tilapias, Largemouth Bass, and Bigmouth Buffalo (Jennings 1988). Bighead Carp can also be raised alone in fertilized ponds (Stone et al. 2000). After Bighead Carp fry are produced by hatcheries and grown to market size by fish farmers, they are transported to live markets in Toronto, Chicago, New York, Boston, Montreal, and other cities. Wholesalers sometimes purchase these from livehaulers for resale to retail food stores that sell live fishes. Live Bighead Carp are transported by livehaulers (Engle 1998a,b) and sold primarily in Asian markets in the United States and Canada (Stone et al. 2000). Processed fish are also sold, and Arkansas has been testing marketability of canned Bighead Carp (Stone et al. 2000).

Stone et al. (2000) stated that Bighead Carp are an important source of revenue for catfish farmers during times of low catfish prices. Engle and Brown (1998) and Engle (1998b) estimated that the net benefit (after subtracting production expenses) of stocking Bighead Carp with catfish ranged from $1,628 to $2,743 annually from a 6-ha (15-acre) pond, or $108-$183/0.4 ha. Jensen (1998) estimated net profit from Bighead Carp raised in catfish ponds at $5,500 for a 6-ha pond, or $371/0.4 ha.

Silver Carp

More Silver Carp are produced than any other species of freshwater fish in the world (Fig. 20). Worldwide production of Silver Carp has increased substantially from 1988 to 1997 (from 1.6 to 3.1 million metric tons; FAO 1999). For comparison, production of Common Carp increased from 1.1 to 2.2 million metric tons during the same period (FAO 1999). In China, culture of Silver Carp continues to grow in importance. Phytophagous fishes like Silver Carp are valuable species for increasing fish production in inland waters (Krykhtin and Gorbach 1981). Opuszynski and Shireman (1993) stated that in 1989 more Silver Carp were landed commercially than any other inland freshwater fish species in the world.

Nevertheless, some aspects of the behavior and marketability of Silver Carp detract from the aquacultural production of this species. Although processed food products such as vacuum-packed sliced fillets, canned fish with oil, tomato sauce, mayonnaise, cream, mustard, or other sauces, are made from Silver Carp (e.g., Trading House Supoy, Ltd. 2004), the highest market demand for Silver Carp is for live fish. The jumping behavior of Silver Carp makes it difficult and dangerous to effectively seine fish out of aquaculture ponds (Tal and Ziv 1978b) and can result in substantial injuries, thereby reducing the economic return of harvested fish. Once harvested, Silver Carp are also very sensitive to handling stress associated with capture and live transport (Tal and Ziv 1978b). In addition to the behavior of Silver Carp, other factors such as short shelf life of the flesh (Tal and Ziv 1978b; Shetty et al. 1989; Tripathi 1989), poor taste, and abundant small bones (Tal and Ziv 1978b) reduce the appeal of the species for some consumers. Deng et al. (2001) found that freshness of Silver Carp decreased quickly by looking at variations in sensory evaluation, rigor index, and adenosine triphosphate-related compounds. They suggested that Silver Carp flesh should be stored at lower temperatures after being killed. In addition to factors associated with Silver Carp behavior and marketability, in areas without traditional markets, lack of cultural experience with Silver Carp and underdeveloped markets can limit both the utilization and economic value of this species (Pullin 1986). For example, Safriel and Bruton (1984) suggested that Asian carps had limited market potential in South Africa, and Tal and Ziv (1978b) stated that production of Silver Carp in Israel was far greater than market demand. These factors can culminate in underutilization of the species (Kals and Bartels 2004).

Laird and Page (1996) believed that Silver Carp had some potential as a food fish in the United States because of its large size, rapid growth, and acceptable flavor. Steffens et al. (1992) conducted clinical tests with patients with high blood pressure by feeding 100 g of meat paste of Silver Carp in tomato sauce and observed significant decreases in systolic and diastolic blood pressure.

Finally, Silver Carp are not being cultured for marketing in the United States at present and have been little cultured in the last 20 years (C. Engle, University of Arkansas at Pine Bluff, Arkansas, personal communication, 2005). They present a hazard to aquaculture personnel because of their jumping habits when ponds are seined. In addition, they transport poorly in live-haul trucks (P. Zajicek, National Aquaculture Association, personal communication, 2004). Silver Carp sometimes brings a lower price than Bighead Carp in Asian markets in the United States (DCC, personal observation), but some markets, for example the “scaled-fillet” market, do not distinguish between the two species. The difficulty in transport of live Silver Carp also lowers their usefulness to the live food fish market. Nevertheless, two live Silver Carp bearing what appeared to be net markings resulting from gear used for capture of wild fish, were observed in an Asian market in Toronto, Ontario, on October 7, 2004, by two of the authors of this document (Walter R. Courtenay, Jr. [WRC] and DCC).

Largescale Silver Carp

Chan and Fan (1988) noted that the Largescale Silver Carp is considered the most important species for culture in Vietnam. Chen (1998) mentioned that the rapid growth and high fat content of this fish has made it an economically important culture species in Songtao Reservoir on Hainan Island.

Control of Algae

Bighead Carp

Bighead Carp, usually in combination with Silver Carp, have been cultured in temperate waters worldwide for use in water quality management (Aliev 1976; Vinogradov 1979; Cremer and Smitherman 1980; Dong et al. 1992). These researchers, among others, suggested that filter feeding by Bighead and Silver carps may help improve the quality of pond water by continually removing plankton, thereby stabilizing plankton and lessening the probability of die-offs in fish culture. It has also been suggested that filter feeding by Bighead and Silver carps may reduce noxious blue-green algae blooms (Henderson 1978, 1983). Opuszynski and Shireman (1993) completed one of the few studies examining the effect of Bighead Carp on plankton communities without also adding Silver Carp. They stocked Bighead Carp into ponds receiving water from a hypereutrophic lake in Florida and found that ponds with Bighead Carp had a lower proportion of blue-green algae in the algal community than in ponds without fish, and tended to lower the abundance of phytoplankton.

Bighead Carp have been introduced into water treatment ponds in Arkansas, California, and Colorado in attempt to control phytoplankton and zooplankton populations. In Arkansas, for example, Bighead and Silver carps were used for improving water quality of a sewage treatment lagoon by removing plankton (Henderson 1978, 1983). In a 1-year pilot study in Arkansas where three sewage treatment lagoons were stocked with Bighead and Silver carps and three ponds were not, ponds with Bighead and Silver carps ended the growing season with a greater abundance of phytoplankton than in ponds without Asian carps (Henderson 1978). Ponds with Asian carps did have a lower biological oxygen demand, however, than ponds without these fishes. Henderson (1978) suggested wider use of both Bighead and Silver carps as biological filters for general water quality enhancement, as well as in water supply reservoirs where plankton may produce taste and odor problems. Nevertheless, because Bighead Carp are more effective at feeding on zooplankton than algae, their use in monoculture to control algae has not been encouraged.

Stone et al. (2000) stated that there is no convincing evidence that filter feeding by Bighead Carp improve water quality and made ponds less prone to die-offs. They further stated that although filter feeding by Bighead Carp undoubtedly influences the composition and size structure of the plankton community, these changes do not necessarily result in improved water quality or reduced off-flavor in water. Conflicting data have been revealed in various studies using filter-feeding fish. In some studies, Bighead Carp increased the density of algae in ponds whereas in others, there was no difference (Burke et al. 1986; Lazzaro 1987).

Silver Carp

The ability of Silver Carp to effectively filter particles as small as 7 μm and reliance on phytoplankton for much of its diet (Cremer and Smitherman 1980; Kaushal et al. 1980; Spataru et al. 1983) has lead to the use of Silver Carp as a biological control agent for phytoplankton (Sirenko et al. 1976; Costa-Pierce et al. 1985; Smith 1985). In extensive experiments in ponds, reservoirs, and lakes in Israel, Leventer (1987) found that Silver Carp reduced the amount of phytoplankton. Lieberman (1996) found that 2 years after stocking Silver Carp, nuisance algae had all but disappeared. Wu (1997) stated that Silver Carp could be used to control algal blooms, but only at low stocking densities. Smith (1985) and Laws and Weisburd (1990) noted that Silver Carp are efficient in controlling total phytoplankton biomass when relative abundance of net phytoplankton is high. Silver Carp have been used in Arkansas for removal of excessive algae from wastewater (Henderson 1977).

Some authors (Starling and Rocha 1990) suggested that Silver Carp may be used to selectively control blue-green algae (Cyanobacteria). Blue-green algae are especially noxious because they produce toxins that can affect animals or humans, and they also produce bad smells or flavors. Silver Carp do consume blue-green algae, and Xie et al. (2004) found that Silver

Carp have natural defenses to microsystins (toxins produced by some blue-green algae). Diet studies have found that *Microcystis* (a noxious blue-green alga) at times constitutes a large portion (20-98%) of the food bolus of Silver Carp (Borutskiy 1973; Tarasova et al. 1977; Gorobets 1979; Tarasova 1979, in Kirilenko and Chigrinzkaya 1983; Shapiro 1985). Phytoplankton community shifts from blue-green algae domination towards green algae have been attributed to grazing by Silver Carp (Miura 1990; Mátyás et al. 2003). On the other hand, Kucklentz (1985) found that blue-green algae, as well as total phytoplankton, increased rather than decreased after stocking Silver Carp. Some blue-green algae have mucous coverings that defend against digestion by phytoplanktivorous fishes and can survive passage through the gut (Vörös et al. 1997). Zhu and Deng (1983) found that some, but not all, *Microcystis* ingested by Silver Carp was digested. Lewin et al. (2003) found that *Microcystis* not only survived passage through the guts of phytoplanktivorous fishes, but that it was capable of taking advantage of the high nutrient concentration in the gut. In summary, the use of Silver Carp to control blue-green algae is not fully understood and has met with varied success.

Use of Silver Carp to control excessive phytoplankton growth in eutrophic ecosystems remains controversial (Costa-Pierce 1992; Starling 1993; Domaizon and Dévaux 1999; Domaizon et al. 2000) because some authors attributed an increase in phytoplankton abundance or chlorophyll *a* to grazing by Silver Carp. Opuszynski (1972) reported an increase in number and biomass of algae after stocking additional Silver Carp. Spataru et al. (1983) found an increase in phytoplankton in ponds with Silver Carp. Laws and Weisburd (1990) reported an increase in total chlorophyll *a* and phytoplankton biomass in ponds with free-roaming Silver Carp. Kucklentz (1985) noted that phytoplankton increased, rather than decreased, after stocking Silver Carp. Others reported a shift in the phytoplankton community to smaller species (Kucklentz 1985; Leventer 1987; Milstein et al. 1988; Smith 1989; Costa-Pierce 1992; Vörös et al. 1997) and speculated size-selective filtering by Silver Carp explained the community change. Results from a study from a 0.8-ha pond in Colorado into which Bighead and Silver carps were stocked led Lieberman (1996) to conclude that these fishes can be effective in controlling mat-forming algae growth in small ponds, but they may have limited use for biological control. This is because filter feeding by Bighead and Silver carps can result in increased nannoplankton concentrations, reduced zooplankton populations, and, therefore, reduced water clarity.

More often, authors attributed an increase in phytoplankton abundance or chlorophyll *a* to grazing by Silver Carp. Opuszynski (1972) reported an increase in number and biomass of algae after stocking additional Silver Carp. Spataru et al. (1983) found an increase in phytoplankton in ponds with Silver Carp. Laws and Weisburd (1990) reported an increase in total chlorophyll *a* and phytoplankton biomass in ponds with free-roaming Silver Carp. Kucklentz (1985) noted that phytoplankton increased rather than decreased after stocking Silver Carp. Others reported a shift in the phytoplankton community to smaller species (Kucklentz 1985; Leventer 1987; Milstein et al. 1988; Smith 1989; Costa-Pierce 1992; Vörös et al. 1997) and speculated size-selective filtering by Silver Carp explained the community change. By removing larger algal species, stimulating growth of smaller species, and reducing zooplankton that grazed on the smaller phytoplankton, the presence of Silver Carp is often accompanied by an increase in primary productivity (Fig. 21; Opuszynski 1980; Milstein et al. 1985a; Leventer 1987; Mátyás et al. 2003).

The ability of Silver Carp to successfully control phytoplankton communities is complicated by interactions between Silver Carp and herbivorous zooplankton (Fig. 21). In experiments in lakes, ponds, and reservoirs, Silver Carp have been found to reduce the biomass of zooplankton (Kajack et al. 1975; Opuszynski 1979a; Spataru and Gophen 1985; Leventer 1987; Milstein et al. 1988; Vybornov 1989; Lieberman 1996), either because of Silver Carp predation on smaller zooplankters or because of competition for phytoplankton. Under favorable conditions, small phytoplankton species released from predation by herbivorous zooplankton are able to flourish at noxious levels (Smith 1985). Smith (1985) demonstrated that filtering by Silver Carp in tanks without a refuge for zooplankton resulted in a zooplankton community dominated by small species whereas tanks with a refuge from fish predation were dominated by large cladocerans. He suggested that biological control of algae by filter-feeding fishes would be enhanced by designing wastewater treatment lagoons in series, alternating ponds with filter feeding fishes (Bighead and Silver carps) and ponds without fishes that would support abundant populations of herbivorous zooplankters (Smith 1993).

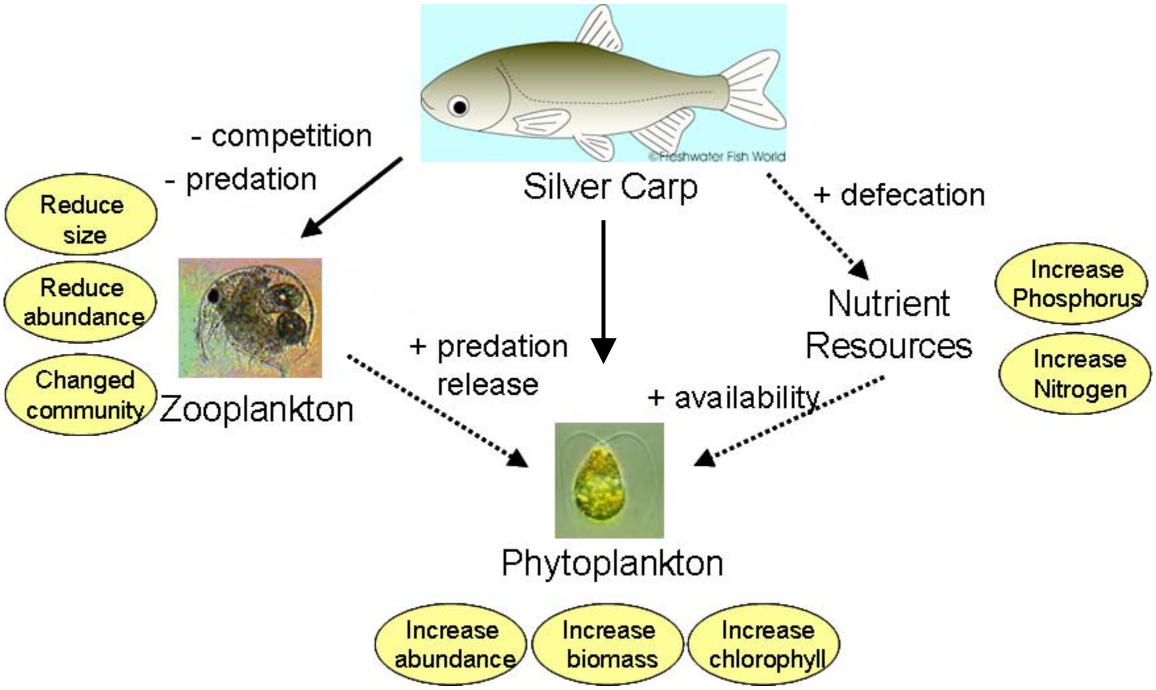

Figure 21. Using Silver Carp (*Hypophthalmichthys molitrix*) to control phytoplankton has met with mixed success because feeding and waste products oftentimes stimulate phytoplankton growth through a trophic cascade. Developed from findings of Opuszynski (1981) and Lu et al. (2002).

Largescale Silver Carp

No information was found on the use of Largescale Silver Carp to control algae. Nevertheless, because this species is most closely related to Silver Carp, its potential effectiveness in controlling algae is possibly similar to that of Silver Carp.

Removal of Excess Nutrients

Bighead Carp

Henderson (1978, 1983) suggested the use of Bighead Carp, along with Silver Carp, in plankton removal and stimulation of nutrient uptake in sewage treatment lagoons. He believed that both Bighead and Silver carps would stimulate phytoplankton blooms that would result in removal of nutrients by phytoplankton. Opuszynski (1980), however, found that while removal of phytoplankton and zooplankton by Bighead and Silver carps resulted in decreased nitrogen, phosphorous, and dissolved carbonates in ponds, at the same time organic carbon, nitrogen, and total phosphorous increased in bottom sediments. When those bottom sediments were disturbed by activities of other fishes, phytoplankton populations increased. Lieberman (1996) stocked Bighead and Silver carps into a 0.8-ha pond in Colorado and found that total phosphorus and total inorganic nitrogen increased as a result.

Silver Carp

In the 1970s, much attention was focused on Silver Carp as a potential tool for controlling eutrophication (Vörös et al. 1997). It was suggested to use Silver Carp as one part of any artificial food web devoted to recycling of dissolved nutrients in domestic wastewaters (Tarifeno-Silva et al. 1982). Tripathi (1989) explained that Silver Carp can be used in rich waters to “mop up” surplus productivity. Experiment results, however, are contradictory. Opuszynski (1980) found a decrease in nitrogen and phosphorous mineral compounds in the water, a decline in dissolved carbonates, and accumulation of organic carbon, nitrogen, and total phosphorous in the water and in bottom sediments. In Marcali Reservoir, southern Lake Balaton, Hungary, the amount of inorganic nitrogen was considerably higher than in other reservoirs in Hungary without Silver Carp, due partly to their extensive nutrient excretion (Mátyás et al. 2003). Similarly, Lieberman (1996) found that the presence of Bighead and Silver carps in a pond resulted in an increase in the total phosphorus and total inorganic nitrogen. Bioturbation caused by swimming and feeding of Silver Carp stirred up sediments and, in the process, introduced significant quantities of nutrients into the water column, stimulating plankton growth (Laws and Weisburd 1990). Excrement from Silver Carp (which can equal their body weight in 10 days; Herodek et al. 1989) has been found to enrich lake bottoms with organic matter to support benthic organisms (Leventer and Teltsch 1990). Vybornov (1989) found decreased dissolved oxygen content of water in the presence of Silver Carp. Starling (1993) reported an increase in Kjeldahl nitrogen in sediments in experimental ponds with Silver Carp. Other results from the same study, however, also indicated no effect on water transparency, turbidity, total suspended solids, dissolved oxygen, conductivity, pH, ammonia, orthophosphate, total dissolved phosphorous, or total phosphorous.

Largescale Silver Carp

No information was found on the use of Largescale Silver Carp for removal of excess nutrients. Because this species is most closely related to Silver Carp, its effect on excess nutrient levels in closed systems might be similar to that of Silver Carp.

Increase Production and Growth of Other Fishes

Bighead Carp

Because Bighead Carp are most often used with Silver Carp in polyculture situations, what is said below regarding the use of Silver Carp to improve production and growth of other fishes also applies to Bighead Carp. Bighead Carp continue to be used in polyculture with Channel Catfish and other species in the United States. Griffin (1993) reported higher yields of Channel Catfish when water was circulated through ponds with Bighead Carp. Griffin (1993) also reported that greatest efficiency was achieved when Channel Catfish and Bighead Carp were grown separately with nutrient rich water from catfish ponds as a source of feed for Bighead Carp. Bighead Carp can also be an important source of revenue for catfish farmers during times of low catfish prices (Stone et al. 2000).

Silver Carp

Silver Carp are sometimes raised in polyculture in other countries around the world with other carp species not only as a food fish but also to stimulate growth of other fishes in ponds. Silver Carp are not presently being cultured commercially in the United States (P. Zajicek, National Aquaculture Association, personal communication, 2004). Opuszynski (1981) stated that Silver Carp are used as a method of increasing fishery production by culturing with Common Carp. Yashouv (1971) reported that the presence of Silver Carp in polyculture improves growth of Common Carp and tilapias because benthic fishes cause resuspension of organic matter.

Poland, Bulgaria, Hungary, and France stocked Asian carps to increase fish production and control water quality (Kestemont 1995). The presence of Silver Carp in polyculture with Common Carp was reported to improve growth of both species (Yashouv 1971; Hepher 1988; Leventer and Teltsch 1990). Nevertheless, competition has been documented between Silver Carp and species raised in polyculture (e.g., with Catla and Rohu; Alikunhi and Sukumaran 1964, Dey et al. 1979, in Tripathi 1989; with Common Carp; Opuszynski 1981). Also, Buck et al. (1978a,b) found that production of Bighead Carp was inversely correlated to production of Silver Carp.

Largescale Silver Carp

Chan and Fan (1988) reported that native Largescale Silver Carp and introduced Silver Carp are cultured together, as well as with their hybrids, in northern Vietnam. The hybrids, however, did not grow as quickly as pure Largescale Silver Carp stock. They undertook research at a fish culture facility to compare growth rates between Largescale Silver Carp, Silver Carp, and their hybrids. Results indicated that Largescale Silver Carp obtained from the Red River and some selected from fish culture facilities that most closely resembled pure Largescale Silver Carp grew faster than Silver Carp. They then experimented with reciprocal hybrids between the two. One reciprocal hybrid between female Largescale Silver Carp and male Silver Carp grew faster than hybrids between female Silver Carp and male Largescale Silver Carp.

We did not find any additional information on polyculture of Largescale Silver Carp with other fish species.

Other Uses

Bighead Carp

We did not find any additional information on other present uses of Bighead Carp. However, there is potential for other uses of cultured Bighead Carp in the United States should interest increase in stocking the species or should new control methods be developed that would rely on cultured fish. Presently, demand for Bighead Carp from fish producers for stocking uninhabited waters is low because the species is regulated in many states and because of concern of escape and further introductions into the wild. It is possible that demand for sterile triploid Bighead Carp could grow in the future. Also, although no such methodologies presently exist, there is a possibility that reproduction interruption or gender ratio manipulation strategies may be developed in the future to control Bighead Carp in the wild that would require cultured Bighead Carp for implementation. For example, developing a genetic manipulation for the heritable inability to produce female progeny is presently being evaluated in Australia to control Common Carp (Murray Darling Basin Commission 2003). If such a method could be developed for Bighead Carp, large numbers of cultured individuals containing the genetic modification would be needed to release into the wild the control strategy but would probably prove to be prohibitively expensive.

Silver Carp

Heggelund and Pigott (1977, in Maddox et al. 1978) suggested that Silver Carp could be used as a supplemental protein source in livestock rations and as a milk replacement in the diet of weanling calves. Sumantadinata et al. (1990) found that ultraviolet-irradiated sperm of Silver Carp can be used to inseminate eggs of Common Carp to obtain gynogenesis.

There is also potential for the additional uses of cultured Silver Carp as outlined above for Bighead Carp. It is possible that demand for sterile triploid Silver Carp could grow in the future for stocking into the wild. Also, although no such methodologies presently exist, there is the possibility that reproduction interruption or gender ratio manipulation strategies may be developed in the future to control Silver Carp in the wild that would require large numbers of cultured Silver Carp to implement.

Largescale Silver Carp

We did not find any additional information on other uses of Largescale Silver Carp.

History of Introduction Including Pathways and Stage of Establishment

Bighead Carp

The Bighead Carp has been imported and introduced, or expanded its range from point of introduction, into 72 countries and Guam (Table 6). In comparison, Jennings (1988) reported the species from only 32 countries. Of the 72 countries and territories where the species is known to be present, it became established in 20 (27%), is considered probably established in 4 (5%), listed as probably not established in 10 (14%), and as not established in 32 (44%), and its status in 7 (10%) is unknown (Table 6). The introduction of Bighead Carp into countries where it was not native became more common after 1960. Only 11of the 73 introductions are known to have taken place before that time. Most introductions for which an approximate date was known occurred in the 1960s (29 introductions; Fig. 22).

Most importations were for aquaculture purposes and biological control of zooplankton and larger phytoplankton (Fig. 23). Although Bighead Carp have been introduced to improve fisheries and to improve water quality through biological control, for research purposes, and accidentally, the second most common category of introduction was by an unknown vector (Fig. 23). Within its native China, Bighead Carp have been translocated into six provinces where it is now considered invasive (Zhen-Yu and Yan 2002). Yang (1996) listed Bighead Carp, along with Silver, Black, and Grass carps as having been introduced to Yunnan Province, China, between 1958 and 1965, and that these carps are now present in most lakes and rivers of that province. He further noted that introductions of Bighead and Silver carps were causative agents of a rapid population decline in native cyprinid filter feeders (such as *Racoma taliensis, Cyprinus megalophthalmus*, *Anabarilius grahami, A. albrunops*, and *A. polylepis*) in lakes and reservoirs in Yunnan. Bighead Carp were also introduced into the Amur River by escapement from Chinese fish farms (Krykhtin 1972). In some countries such as Austria, England, Hungary, Japan, and the Syr Dar'ya Basin of Turkmenistan, Bighead Carp were accidentally included with imports of other large Asian carps. Israel no longer stocks Bighead Carp into Lake Kinneret because of effects on other fishes, especially tilapias, that are more important economically (Spataru and Gophen 1985).

Bighead Carp is considered established in open waters of Armenia, Belgium, Czech Republic, Denmark, Hungary, Italy, Japan, Kazakstan, Moldova, Philippines, Romania, Russia (Caspian Basin), Slovenia, Thailand, Ukraine, United States, Uzbekistan, and Vietnam (Table 6).

In Hungary, it is established in the Danube River and has been stocked in Lake Balaton since 1972 where it is abundant but not reproducing (Bíró 1997). Sources list the species as probably established in Albania, Bulgaria, Netherlands, Poland, and Slovakia (Table 6). It appears from Table 6 that Bighead Carp have colonized countries that have moderate to large rivers and river inflows to reservoirs that include suitable habitat for successful reproduction and larval development.

Table 6. Countries where Bighead Carp (*Hypophthalmichthys nobilis*) hasve been introduced. Adapted in part from information in the Food and Agriculture Organization Database on Introductions of Aquatic Species (http://www.fao.org) and FishBase (http://www.fishbase.org). Under Status, E = established in open waters (i.e., having naturally reproducing populations), PE = probably established, PN = probably not established, N = not established, and ? = unknown. Blanks indicate no available information. Many of the countries reporting probably established (and several reporting probably not established) continually restock Bighead Carp into open waters. Common names from Froese and Pauly (2004).

Country	Status	Year introduced	Source	Rationale for introduction	Common name	Reference
Afghanistan	PN	Unknown	Unknown	Biological control		FAO (2004)
Albania	PE	Unknown	Unknown	Aquaculture	Ballgjeri iaraman	Holčík (1991), Rakaj and Flloko (1995)
Algeria	PN	1985-1991	Hungary	Fisheries		FAO (2004)
Armenia	E	Unknown	Moldova	Unknown		Gabrielyan (2001)
Austria	?	Unknown	Unknown	Aquaculture		Holčík (1991)
Bangladesh	PN	Unknown	Unknown	Aquaculture?		Barua et al. (2001)
Belgium	E	Unknown	Unknown	Aquaculture		Elvira (2001)
Bhutan	N	1983, 1985	Nepal	Aquaculture		Petr (1999)
Bolivia	N	1990, 1991	Israel?	Aquaculture		FAO (2004)
Brazil	N	1979, 1983 1984	China Hungary	Aquaculture	Carpa cabeça grande	Welcomme (1988), Lever (1996), Garcia et al. (2004)
Brunei	N	Unknown	Unknown	Unknown		Froese and Pauly (2004)
Bulgaria	PE	Unknown	Unknown	Aquaculture	Pastar tolstolob	Krupauer (1971), Holčík (1991)
Cambodia	PN	Unknown	Unknown	Unknown		Froese and Pauly (2004)

Table 6. Continued.

Country	Status	Year introduced	Source	Rationale for introduction	Common Name	Reference
China	E	Historical transfers	China	Aquaculture	Twa tow; yung-yu	Birtwistle (1931), Roberts et al. (1973), Yang (1996), Huang et al. (2001), Zhen-Yu and Yan (2002)
Colombia	N	1988	Taiwan	Aquaculture		FAO (2004)
Costa Rica	N	1976	Taiwan	Aquaculture		Welcomme (1988), Lever (1996)
Croatia	?	Unknown	Unknown	Unknown		Holčík (1991)
Cuba	N	1968, 1976	USSR	Aquaculture		Welcomme (1988), Lever (1996)
Czech Republic	E	1965	Russia	Aquaculture, fisheries	Tolstolobee pastry; kapr	Holčík and Geczo (1973), Holčík (1991)
Denmark	E	Unknown	Unknown	Unknown	Marmor karp	Elvira (2001)
Dominican Republic	N	1981	Taiwan	Aquaculture		FAO (2004)
England	N	1975	Austria	Inadvertent	Bighead Carp	Stott and Buckley (1978)
Egypt	N	1976	China	Aquaculture		Moreau and Costa-Pierce (1997), Wassef (2000)
Fiji	N	1968	Malaysia	Research		Mastrarrigo (1971), Andrews (1985)
France	PN	1975, 1976	Hungary	Aquaculture	Carpe marbrée	Holčík (1991), Keith and Allardi (1997)
Germany	N	1964	Hungary	Aquaculture	Marmorkarpfen; gefleckter silberkarpfen	Welcomme (1988), Holčík (1991), Lever (1996)
Greece	PN	Unknown	Unknown	Unknown	Μαρμαροκνπρίνος	Economidis et al. (2000)

Table 6. Continued.

Country	Status	Year introduced	Source	Rationale for introduction	Common Name	Reference
Guam	N	Unknown	Unknown	Unknown		Froese and Pauly (2004)
Hong Kong	N	Historical?	China	Aquaculture	Boon tau ue; dai tau; fa lin; hak lin; sung ue	Chaudhuri (1968), Man and Hodgkiss (1977)
Hungary	E	1963-1968	China, USSR	Accidental, aquaculture	Perryes busa	Mólnar (1979), Pinter (1980), Holčík (1991), Bíró (1997)
India	PN	1987	Japan, Bangladesh	Aquaculture, fisheries	Belli-gende; kannada	Alikunhi et al. (1963), Tubb (1966)
Indonesia	N	1969	Taiwan	Aquaculture		Welcomme (1988), Eidman (1989)
Iran	?	1968, 1969, 1992	China	Aquaculture		Kiabi et al. (1999)
Iraq	PN	Late 1960s	Unknown	Aquaculture		Coad (1996)
Israel	N	1976	Germany	Aquaculture		Tal and Ziv (1978a), Rothbard (1981), Golani and Mires (2000)
Italy	E	1975	Eastern Europe	Sport fishing	Carpa dalla testa grande	Elvira (2001)
Japan	E	1915-1945	China	Aquaculture	Kokuren	Kuronuma (1954), Chiba et al. (1989)
Jordan	N	1973	Germany	Aquaculture		Krupp and Schneider (1989)
Kazakstan	E	Unknown	China	Aquaculture		Elvira (2001)
Korean Republic	N	1963	Taiwan	Aquaculture		Welcomme (1988), Lever (1996)
Laos	PN	1968	China	Aquaculture		Chanthepha (1969), Kottelat (2001a)

Table 6. Continued.

Country	Status	Year introduced	Source	Rationale for introduction	Common Name	Reference
Lesotho	N	1990	Unknown	Aquaculture		Moreau and Costa-Pierce (1997)
Luxembourg	?	Unknown	Unknown	Unknown	Marmorkarpfen	http://www.mev.etat.lu/adef/Publications/Chassepeche/Fische/Inhalt.htm
Malaysia	N	1800s	China	Aquaculture	Kap kepala besar; Tongsan	Welcomme (1988), Ang et al. (1989)
Mexico	N	1975	Cuba	Aquaculture	Carpa cabezona	Welcomme (1988), Lever (1996)
Moldova	E	Unknown	Unknown	Aquaculture		Elvira (2001)
Morocco	N	1981	Hungary	Aquaculture		Azeroual et al. (2000)
Mozambique	N	1991	Cuba	Aquaculture, fisheries		Moreau and Costa-Pierce (1997)
Myanmar	?	Unknown	China?	Aquaculture		Froese and Pauly (2004)
Nepal	N	1971	Hungary	Aquaculture		Shrestha (1994)
Netherlands	PE	1983	Germany	Range expansion	Grootkopkarper	de Groot (1985), Holčík (1991), Elvira (2001)
Pakistan	?	Unknown	China	Unknown		FAO (2004)
Panama	N	1978	Taiwan	Aquaculture		Welcomme (1988), Lever (1996)
Peru	N	1979	Israel, Panama	Aquaculture		Welcomme (1988), Lever (1996)
Philippines	E	1968	Taiwan	Aquaculture		Welcomme (1988), Juliano et al. (1989), Opuszynski and Shireman (1995)

Table 6. Continued.

Country	Status	Year introduced	Source	Rationale for introduction	Common Name	Reference
Poland	PE	1965	USSR	Aquaculture	Tolpyga pstra	Holčík (1991), Elvira (2001)
Romania	E	1960-1962	China	Aquaculture	Crap argintui nobil; novac; hipo	Huet (1970), Holčík (1991)
Russia	E	1949	China	Aquaculture	Pestryi tolstolob	Huet (1970), Bardach et al. (1972), Abdusamadov (1987), Reshetnikov et al. (1997), Bogutskaya and Naseka (2002)
Singapore	N	1900s	China	Aquaculture		Tubb (1966), Chou and Lam (1989), Lim and Ng (1990)
Slovakia	PE	1955	Russia	Aquaculture, fisheries	Tolstolob pastry	Holčík (1991)
Slovenia	E	Unknown	Unknown	Aquaculture?		Elvira (2001)
Sri Lanka	N	1948	China	Aquaculture, biocontrol	Bighead Carp	Pethiyagoda (1991)
Sweden	PN	Unknown	Unknown	Unknown		Froese and Pauly (2004)
Switzerland	N	1970	Unknown	Biocontrol		FAO (2004), Xie (2004)
Taiwan	?	Historical	China	Aquaculture		Tang (1960), Liao and Lia (1989)
Thailand	E	1932	China	Aquaculture	Pla song hea; pla song hue; pla tao pla teo; tongsan	Chaudhuri (1968), Welcomme (1988), de Iongh and Van Zon (1993), J.-F. Helias, Fishing Adventures Thailand, Bangkok, personal communication, 2003
Turkey	N	Unknown	Unknown	Biocontrol		FAO (2004)
Ukraine	E	Unknown	Russia?	Aquaculture?	Piestryi tolstolobik; tovstolob strokatyi	Movchan (2000), Elvira (2001)

Table 6. Continued.

Country	Status	Year introduced	Source	Rationale for introduction	Common Name	Reference
United States	E	1972	Taiwan	Aquaculture	Bighead Carp	Henderson (1979b), Cremer and Smitherman (1980)
Uzbekistan	E	1964	China	Aquaculture		FAO (2004)
Vietnam	E	1958	China	Aquaculture		Chaudhuri (1968), Welcomme (1988), Lever (1996), Kottelat (2001b)
Yugoslavia	N	1963	Romania, Hungary, USSR	Aquaculture		Welcomme (1988), Holčík (1991), Lever (1996), Jankovic (1998)

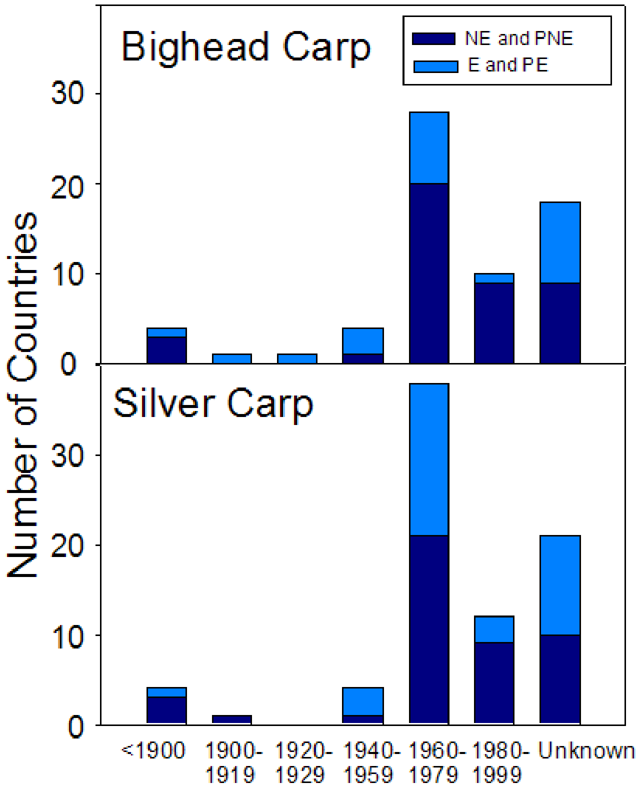

Figure 22. The number of countries into which Bighead (*Hypophthalmichthys nobilis*) and Silver (*H. molitrix*) carps have been introduced around the world since the 1900s, with the introductions that led to established (E) and probably established (PE) versus not established (NE) and probably not established (PNE) populations indicated.

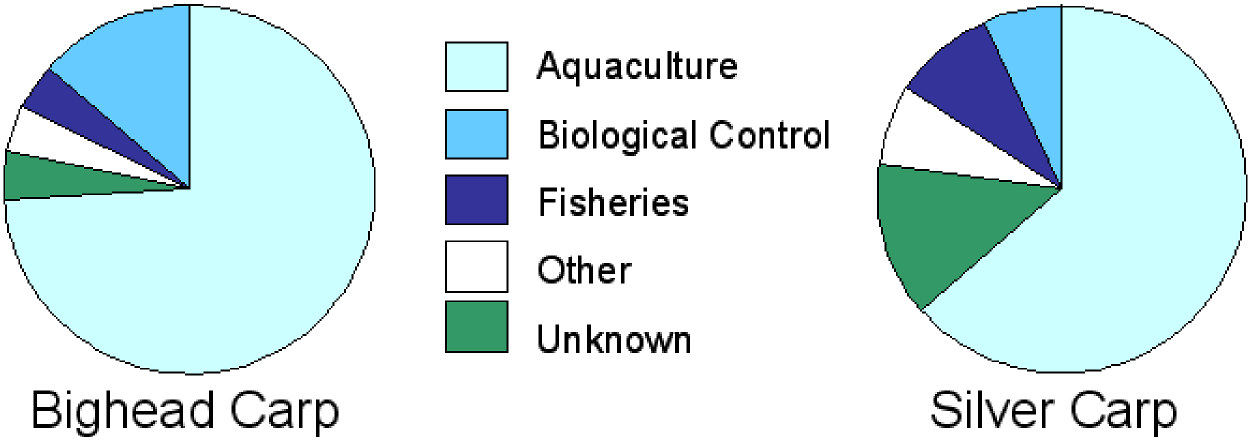

Figure 23. The proportion of countries introducing Bighead (*Hypophthalmichthys nobilis*) and Silver (*H. molitrix*) carps by various vectors. The 'other' category includes accidental introductions, diffusion from neighboring countries, and introduction for research purposes.

In Eurasia, rivers in which Bighead Carp have been reported as established include the Amu Dar'ya River, lower Ural River, lower Volga River, lower Terek River, lower Don River, lower Dniester River, and in much of the Danube River. The species has been reported in rivers of the southern Caspian Basin of Iran (Kiabi et al. 1999) and it might be established there. Its presence has been reported in the middle reaches of the Elbe River where it may become established. Mina (1992), citing Krykhtin (1972), mentioned escape of Bighead Carp into the Amur River from Chinese fish farms. The species is established there but remains rare (N. Bogutskaya, Russian Academy of Sciences, St. Petersburg, personal communication, 2004).

Data regarding countries where Bighead Carp are listed as established from the Food and Agriculture Organization Database on Introductions of Aquatic species (http://www.fao.org) and FishBase (Froese and Pauly 2004) were difficult to interpret. A few countries without large rivers claimed the species to be established, yet presence of Bighead Carp in natural waters of those countries is known to be the result of continued stocking and/or escapes from aquaculture facilities, not from natural spawning.

There are conflicting reports about the first importation of Bighead Carp into the United States. Cremer and Smitherman (1980) cited a personal communication with J. Malone (Lonoke, Arkansas, 1975) that Bighead and Silver carps were introduced in 1971 from Taiwan for biofiltration of sewage lagoons. Shelton and Smitherman (1984) cited Cremer and Smitherman (1980) and stated that Bighead Carp were introduced in 1972 into Arkansas and studied at the State Fish Hatchery at Lonoke. McCann et al. (1996) cited Cremer and Smitherman (1980) and reported that Bighead Carp were introduced in 1972 as a potential food fish. Henderson (1979b) reported that Bighead and Silver carps were introduced into Arkansas in 1973 as a potential addition to fish production ponds. Shelton and Smitherman (1984) reported that at least one shipment of Bighead Carp were imported to the United States by fish farmers from Israel and another from Yugoslavia.

Regardless of why or when Bighead Carp were imported into the country, research on various aspects of the culture and biology of the species quickly ensued in several states. In Arkansas, research began in 1975 to assess the ability of Bighead and Silver carps to improve water quality at the Benton Services Center, Benton, Arkansas (Henderson 1978, 1979a, 1983). An additional study was also conducted on the use of commonly used chemicals to control Bighead and Silver carps in culture ponds (Henderson 1976). Young from the stock in Arkansas were received by Auburn University, Alabama, in 1974 for research projects in earthen ponds (Pretto-Malca 1976; Dunseth 1977; Cremer and Smitherman 1980). Bighead Carp stock from Arkansas was also shipped to the Sam A. Parr Fisheries Research Center in Illinois for a polyculture study in earthen ponds begun in 1975 (Buck et al. 1978a,b, 1981). Additional experiments were conducted in tanks and ponds at the Illinois Natural History Survey using Grass Carp × Bighead Carp hybrids (Wiley and Wike 1986).

Soon after their initial importation into the United States, Bighead Carp, usually with Silver Carp, were stocked into wastewater treatment lagoons and impoundments in several states. The Arkansas Game and Fish Commission stocked Bighead and Silver carps into an existing wastewater treatment system to study the usefulness of the fishes in improving water quality (1975-1976, Henderson 1978, 1979a; 1977-1980, Henderson 1979b, 1983). Freeze and

Henderson (1982) referred to four sites, without providing specific locations, in Arkansas that were stocked with Bighead and Silver carps. In 1983, hybrid Grass-Bighead carps were stocked into Lewis Creek Reservoir, a power plant cooling reservoir near Willis, Texas (Bettoli et al. 1985). In 1992, Bighead and Silver carps were stocked into a pond in Arvada, Colorado, to control nuisance algae (Lieberman 1996). Pantex (1997) reported stocking Bighead Carp into the Pantex plant's wastewater treatment lagoon in Texas.

The first record of Bighead Carp in natural waters of the United States occurred in 1981 when a single individual was caught at river mile 919 in the Ohio River, below Smithland Dam, Kentucky (Freeze and Henderson 1982; Carter 1983). The specimen was believed to have escaped from a fish farm. The first open water record of this species in Arkansas is based on two specimens taken from the Arkansas River in 1988; however, as of the late 1980s, there was no evidence of natural reproduction in that state (Robison and Buchanan 1988). According to Dill and Cordone (1997), there is evidence that California ponds containing Bighead Carp have spilled since 1989, perhaps giving the species access to the Sacramento River. In the 1990s, 5,000 Bighead Carp escaped from an aquaculture facility into the Osage River, Missouri (Nico and Fuller 1999; Goodchild 1999), but Bighead Carp were already found in the Mississippi and Missouri rivers at that time. Another reported escape resulted in Bighead Carp from Kansas apparently dispersing into Oklahoma (Goodchild 1999; Nico and Fuller 1999). An earlier report of Bighead Carp from canals in Arizona was of a hybrid with Grass Carp (Marsh and Minckley 1983).

Bighead Carp have now been recorded from waters of 23 states (Fig. 24) and from the Canadian waters of Lake Erie in Ontario, Canada (U.S. Geological Survey 2004; Table 7). Pflieger (1997) documented the first evidence of natural reproduction with the capture of young Bighead Carp, in Missouri in 1989. Burr and Warren (1986) reported the collection of a

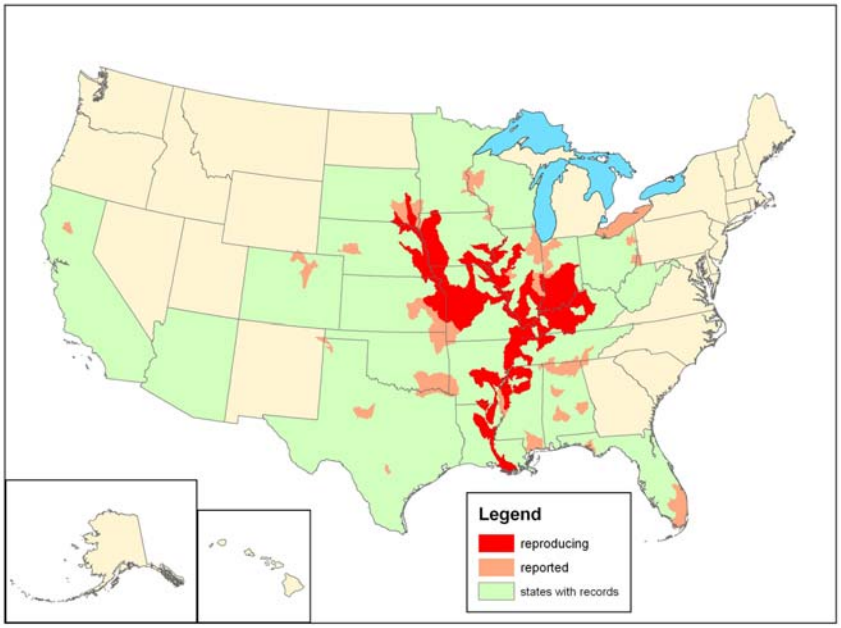

Figure 24. Introduced range of Bighead Carp, *Hypophthalmichthys nobilis,* in the United States. Map provided by the U.S. Geological Survey (2004).

Table 7. Records of Bighead Carp (*Hypophthalmichthys nobilis*) within the United States and Canada. Adapted from the U.S. Geological Survey Nonindigenous Aquatic Species Database (http://nas.er.usgs.gov) and recent records. Blanks indicate no available information.

State or province	County	Drainage	Locality	Year
Alabama	Lee	Lower Tallapoosa	Yates Reservoir	1984
Alabama	Lee	Lower Tallapoosa	Yates Reservoir	1985
Alabama		Black Warrior	Black Warrior	1996
Alabama		Gulf of Mexico	Central part of state	1998
Alabama	Lawrence	Tennessee	Wilson Lake below Wheeler Dam	2003
Alabama	Wilcox	Alabama	Millers Ferry Lock	2003
Arkansas	Saline	Upper Saline	Saline River	1988
Arkansas	Jefferson	Lower Arkansas	Arkansas River	1988
Arkansas	Prairie	Lower White	Lower White River	1988
Arkansas	Lonoke	Bayou Meto	Bayou Meto	1988
Arkansas	Craighead	Lower St. Francis	Lower St. Francis River	1988
Arkansas	Dade	Arkansas	Arkansas River	1998
Arkansas		Arkansas	Arkansas River	2002
California	Tehama	Sacramento	Three ponds in southeastern county	1992
Colorado	Larimer		East slope water treatment ponds	1996
Florida	Palm Beach	Everglades	Southeast side of Lake Okeechobee	1989
Florida	Bay	St. Andrew-St. Joseph	North Bay (part of St. Andrew Bay) below Deer Point Dam at spillway	1994
Illinois	Hancock	Mississippi	River mile 364, Mississippi River	1986
Illinois	Schuyler	Lower Illinois	Chain Lake at Illinois river mile 100	1986
Illinois	Schuyler	Lower Illinois	Long Lake	1986
Illinois	Marion	Little Wabash	Research pond	1987
Illinois	Henderson	Flint-Henderson	Mississippi River near Gadstone	1987
Illinois		Upper Mississippi	Mississippi River	1989
Illinois	Kankakee	Illinois	Kankakee River	1990
Illinois	Mason	Mississippi	Illinois River	1990
Illinois	Madison	Upper Mississippi	Mississippi River near Alton	1991
Illinois	Union	Big Muddy	Big Muddy River near Aldridge	1992

Table 7. Continued.

State or province	County	Drainage	Locality	Year
Illinois	Jackson	Upper Mississippi	Mississippi River at Rattlesnake Ferry	1992
Illinois	Alexander	Cache	Horseshoe Lake near Miller City	1993
Illinois	Fulton	Mississippi	Illinois River	1993
Illinois	Washington	Middle Kaskaskia	Kaskaskia River near Covington	1994
Illinois	Union		Lyerla Lake	1995
Illinois	Franklin	Mississippi	Big Muddy River	1997
Illinois	Moultrie	Mississippi	Lake Shelbyville, Kaskaskia River	1997
Illinois		Peruque-Piasa	Mississippi River near Alton	1998
Illinois	Peoria	Mississippi	Illinois River	1998
Illinois	Gallatin	Wabash	Fehrer Lake	1998
Illinois	Madison	Mississippi	Cahokia Canal	1998
Illinois	LaSalle	Mississippi	Illinois River	1998-1999
Illinois	Alexander	Cache	Horseshoe Lake	1999
Illinois	Crawford	Wabash	Minnow Slough	1999
Illinois		Lower Illinois	Illinois River at river mile 157.8	2000
Illinois	Mason	Illinois	Crane Lake	2000
Illinois	Cass	Illinois	Lily Lake	2000
Illinois	Tazewell	Mississippi	Illinois River	2000-2001
Illinois		Illinois	Illinois River near Chicago	2002
Illinois		Illinois	Hennepin Canal	2004
Indiana			Unspecified locality	1984
Indiana	Vermillion	Ohio	Ohio	1995
Indiana	Greene	Lower White	White River near Bloomfield	1996
Indiana	Jefferson	Silver-Little Kentucky	Ohio River near Madison	1998
Indiana	Vigo	Wabash	Bryant Creek, Oxendine Bayou	1999
Indiana	Pike	White	White River	2000
Iowa	Woodbury	Missouri	Sergent Bluff	1988
Iowa	Wapella	Lower Des Moines	Ottumwa, below dam, Des Moines River	1990
Iowa	Appanoose	Upper Chariton	Chariton River near Rathbun Lake	1991
Iowa	Monona	Missouri	Louisville Bend	1995
Iowa	Appanoose	Upper Chariton	Rathbun Lake spillway	1996
Iowa	Marion	Des Moines	Red Rock Lake Dam	1996
Iowa	Woodbury	Missouri	Sioux City	1997
Iowa	Harrison	Missouri	Remington Access	1997
Iowa	Woodbury	Big Sioux	I-29 bridge	1997
Iowa	Van Buren	Des Moines	Des Moines River at Boneporte	1998
Iowa	Wapella	Des Moines	Ottumwa Lagoon	2002

Table 7. Continued.

State or province	County	Drainage	Locality	Year
Iowa	Wapella	Des Moines	Des Moines River near Ottumwa	2002-2003
Iowa	Allamakee	Mississippi	Mississippi River Pool 9	2003
Iowa	Union	Platte	Summit Lake outlet, east of Creston	2004
Iowa	Davis	Lower Des Moines	Lake Wapello outlet (Pee Dee Creek)	2004
Kansas	Butler	Upper Walnut	Fish farm near Towanda	1987
Kansas		Missouri	Missouri River just north of Atchinson	1988
Kansas		Kansas	Kansas River at Lawrence	1993
Kansas		Missouri	Missouri River at White Cloud	1997
Kansas		Missouri-Nishnabotna	Missouri River	1998
Kansas		Middle Arkansas	Arkansas River	1998
Kansas		Arkansas	Lower Neosho River	1998
Kansas		Lower Kansas	Kansas River, Lawrence	1998
Kansas		Lower Kansas	Wakarusa River below Clinton Dam	1998
Kansas		Lower Kansas	Lower Kansas River	1998
Kansas		Middle Verdigris	River tributary, southeastern Kansas	2000
Kansas		Arkansas	Neosho River	2002
Kentucky		Ohio	Ohio River at river mile 919	1981
Kentucky			Unspecified locality	1984
Kentucky		Ohio	Green River	2001
Louisiana	Franklin	Atchafalaya	Turkey Creek Lake	1985
Louisiana	Monroe	Atchafalaya	Atchafalaya River	1989
Louisiana	Concordia	Bayou Cocodrie	Turkey Creek near Ferriday	1989
Louisiana		Caldwell	Lafourche Lake	1993
Louisiana		St. Martin	Henderson Lake	1997
Louisiana	Iberia/St. Martin	Atchafalaya	South Atchafalaya Basin	1998
Louisiana		Lower Red	Red River	1998
Louisiana	Monroe	Atchafalaya	Atchafalaya River	1998
Louisiana		Avoyelles	Spring Bayou	1999
Minnesota	Washington	St. Croix	Downstream of Bayport	1996
Minnesota	Wabasha	Mississippi	Lake Pepin (Pool 4)	2003
Missouri	Buchanan	Independence-Sugar	Missouri River at St. Joseph	1988
Missouri	Carroll	Lower Missouri	Ditch off Missouri River	1989
Missouri	Boone	Lower Missouri	Missouri River tributary	1989
Missouri			Unspecified locality	1992

Table 7. Continued.

State or province	County	Drainage	Locality	Year
Missouri	St. Charles	Mississippi	Brickhouse Slough	1993
Missouri		Lower Mississippi	Mississippi River	1994
Missouri	Miller	Lower Osage	Osage River at Osage Beach	1994
Missouri		Missouri	Missouri River at Lexington	1997
Missouri		Chariton	Chariton River	1998
Missouri		Lower Mississippi	Missouri River	1998
Missouri		Osage	Osage River	1998
Missouri			Private pond	2000
Mississippi	Jackson	Lower Mississippi	Pascagoula River near Pascagoula	1992
Mississippi	Warren	Lower Yazoo	Skillikalia Bayou	1994
Mississippi	Bolivar	Big Sunflower	Black Bayou	1994
Mississippi	Issaquena	Coldwater	Steele Bayou	1994
Mississippi	Panola	Little Tallahatchie	Lower Sardis Lake (Barrow Lake)	1999
Nebraska	Keith	Platte	North Platte River	1995
Nebraska		Missouri-Nishnabotna	Missouri River	1998
Nebraska		Missouri	Lewis and Clark Lake	1998
Nebraska		Lower Platte	Platte River	1998
Nebraska		Missouri	Unspecified, Missouri River	2000
Nebraska		Missouri	Missouri at Gavins Point Dam	2001
Nebraska		Blackbird-Soldier	Missouri River	2001
Nebraska		Big Papillion-Mosquito	Missouri River	2001
Nebraska		Keg-Weeping Water	Missouri River	2001
Nebraska		Tarkio-Wolf	Missouri River	2001
Nebraska	Cedar	Missouri	Missouri River	2003
Ohio	Erie	Lake Erie	Lake Erie at Sandusky	1995
Ohio	Erie	Lake Erie	Lake Erie at Sandusky	2000
Ohio	Jefferson	Upper Ohio-Wheeling	Ohio River at Rayland	2002
Ohio	Mahoning	Mahoning River	Lake Glacier near Youngstown	2003
Oklahoma	Ottawa	Lower Neosho	Neosho (Grand) River near Miami	1992
Oklahoma	Mayes	Lower Neosho	Neosho (Grand) River near Pensacola	1992
Oklahoma	Delaware	Lower Neosho	Grand Lake Reservoir	1996
Oklahoma		Lower Neosho	Neosho River	1996
Oklahoma		Lower Neosho	Ogeechee Bay, upper Grand Lake	1996
Oklahoma		Lower Neosho	Lake Hudson Reservoir	1996

Table 7. Continued.

State or province	County	Drainage	Locality	Year
Ontario, Canada		Lake Erie	Lake Erie near Long Point, Ontario	2000
Ontario, Canada		Lake Erie	Lake Erie off Pelee Island	2002
Ontario, Canada		Lake Erie	Crystal Bay near Amherstburg (observed)	2003
Ontario, Canada		Lake Erie	Western Lake Erie near St. Louis, Ontario	2002-2003
South Dakota		Lewis and Clark Lake	Missouri River below Gavins Point Dam	1998
South Dakota		Lewis and Clark Lake	Missouri River below Gavins Point Dam	2003
South Dakota		James River	James River	2002-2003
South Dakota		Big Sioux River	Big Sioux River	2002-2003
South Dakota		Vermillion River	Vermillion River	2002-2003
Tennessee	Dyer	Lower Mississippi	Mississippi River	1994
Tennessee	Haywood	Lower Hatchie-Mississippi	Hatchie River near Brownsville	1995
Tennessee	Marion	Middle Tennessee	Nickajack Reservoir near Chattanooga	1999
Tennessee	Marion	Middle Tennessee	Guntersville Reservoir	1999
Tennessee	Stewart	Lower Cumberland	Lake Barkley	2002
Tennessee		Tennessee	Kentucky Lake	2002
Tennessee	Lake	Mississippi	Reelfoot Lake	2003
Texas	Bexar	Upper San Antonio	Victor Braunig Reservoir	1991
Texas			Fish farms	1992
Texas		Red	Red River below Lake Texoma	1998
Texas	Jones	Brazos	Phantom Hill Reservoir	1999
Texas	Taylor	Brazos	Lake Kirby	2000
Washington			Waters of Olympic Peninsula	1991
West Virginia	Marshall	Upper Ohio	Ohio River at Moundsville	1997
Wisconsin	St. Croix	St. Croix	Downstream of Bayport, Minnesota	1996
Wisconsin	Dunn	Chippewa	Red Cedar River (observed)	2003
Wisconsin	Crawford	Mississippi	Mississippi River (Pool 9)	2003
Wisconsin	Pepin	Mississippi	Lake Pepin (Pool 4)	2003

postlarval fish in southern Illinois in 1992. Subsequently, Burr et al. (1996) noted that Bighead Carp seemed to be using the lower reaches of the Big Muddy, Cache, and Kaskaskia rivers in Illinois to spawn. Tucker et al. (1996) also found young-of-year in their 1992 and 1994 collections in the Mississippi River of Illinois and Missouri. In 1997 and 1998, Schrank et al. (2001) documented reproduction of Bighead Carp in the lower Missouri River. The species is thus well established in the Mississippi, Missouri, Ohio, and Tennessee river basins. By 1998, adult Bighead Carp ranked fourth in total commercial harvest in the Missouri section of the Missouri River (Robinson 1998). Chick and Pegg (2001) showed that Bighead Carp seemed to be increasing exponentially in Navigation Pool 26 of the Mississippi River (near St. Louis, Missouri) from 1992 to 2000. The northernmost records, as of July 2004, are from the Mississippi River in Pool 4, Minnesota/Wisconsin, and the Missouri River, Gavins Point Dam, southeastern South Dakota. In the Ohio River Basin, it has been recorded from a lake on Mill Creek (Mahoning River drainage), Youngstown, Ohio, and from the Ohio River at Moundsville, West Virginia (Table 7).

Besides large rivers, juvenile Bighead Carp are known to invade small tributaries, particularly areas below spillways. For example, in July 1998, 877 juvenile Bighead Carp were collected in one sweep of a seine (18.3 m long x 12.2 m deep with 3.175-mm mesh size) in Cedar Creek, Jackson County, Illinois. The collection site is approximately 19-24 stream km from the confluence of Cedar Creek with the Big Muddy River. Cedar Creek is about 4 m wide where these specimens were collected from a school estimated to be in the tens of thousands (J. Stewart, Southern Illinois University, Carbondale, personal communication, 2004). Populations continue to expand. A hoop net retrieved from the lower Red River, Louisiana, on April 12, 2004, contained nothing but Asian carps, mostly Bighead Carp and some Silver and Grass carps. The estimated weight of the net was 408 kg (R. Thomas, Louisiana Department of Wildlife and Fisheries, Baton Rouge, personal communication, 2004).

The major pathway for introduction of Bighead Carp in the United States has been importation for aquaculture purposes including biological control of plankton in culture ponds. The only documented introductions of Bighead Carp into the wild in the United States that we located have been escapes from aquaculture facilities. Two additional potential pathways exist for further introductions of Bighead Carp into the wild from aquaculture, in addition to escapes or releases from the facility itself. First, is the contamination of pond-grown baitfishes or Grass Carp with young Bighead Carp. The likelihood of contaminated baitfish stock leading to the release of Bighead Carp into the wild, however, is low. Few baitfish farmers have Bighead Carp onsite, and those that do raise them in separate ponds (Stone 2003). In addition, Bighead Carp are of a size that could be mistaken for baitfish for a short time. The introduction of Bighead Carp into Florida (and perhaps other states), however, is thought to have been the result of contaminated Grass Carp stock. The second potential pathway is associated with release or escapement of market-sized Bighead Carp from livehaulers transporting fish from aquaculture facilities to cities with live seafood markets. There were reports of two live Bighead Carp along a highway in Illinois in 2005 (D. Sallee, Illinois Department of Natural Resources, personal communication, 2005). The likelihood of this potential pathway resulting in viable introductions is likewise questionable. The use of Bighead Carp in sewage treatment facilities has been proposed as an alternative potential source for escapement to the wild, rather than aquaculture facilities. The relation between these sites and connections to open waters remains unclear.

There are several potential pathways for further introductions of Bighead Carp into additional water bodies that would aid in the spread of existing populations of wild Bighead Carp. One such pathway is through the release of unused baitfishes caught in the wild that are contaminated with young Bighead Carp. Anglers sometimes catch young Bighead and Silver carps in Illinois and use them as live bait in those or other waters (M. Pegg, Illinois Natural History Survey Champaign, Illinois, personal communication, 2004), not only because they look similar to native baitfishes (Fig. 25), but also because anglers collecting baitfishes are not always concerned about the species collected or used as bait. Introduction of fishes beyond their native ranges by releases of baitfishes has been a major pathway for introductions in the United States (Fuller et al. 1999).

Figure 25. Comparison of juvenile Bighead Carp, *Hypophthalmichthys nobilis* (*top*), Gizzard Shad, *Dorosoma cepedianum* (*center*), and juvenile Silver Carp, *H. molitrix* (*bottom*). Photograph taken by D. Hardesty.

Other potential pathways that involve aiding in the spread of existing populations of Bighead Carp, in addition to malicious release, include ballast water release, spread by commercial fishers, and release or escapement from livehaulers that support commercial fishers. Although the practice is kept to a minimum for economical reasons, tow operators in navigable rivers in the United States sometimes take ballast water onboard to pass under low bridges or for other purposes. It is possible, therefore, for barges to inadvertently transport fertilized eggs of Bighead Carp in ballast water beyond the presently invaded range. Given the requirement of flowing water for egg survival (Laird and Page 1996), however, the likelihood that this potential pathway would result in the release of viable eggs is low (P. Moy, University of Wisconsin Sea Grant Institute, Manitowac, Wisconsin, personal communication, 2005). Because Bighead Carp are readily available to commercial fishers and, along with Silver Carp, constitute much of their catch, several fishers are now specializing in Asian carps—particularly live fish, since they demand the highest market price. Release and escapement from livehaulers is a potential pathway, albeit remote, for additional releases.

The final potential pathways for further introductions of Bighead Carp into the wild in the United States involve those associated with the live sale of the species in live seafood markets, regardless as to whether the fish were cultured in fish farms or were caught live in the wild. Live Bighead Carp are available in live food fish markets in several major U.S. and Canadian cities, the same pathway that probably led to introduction of the Northern Snakehead, *Channa argus* (family Channidae), into a pond in Crofton, Maryland (Courtenay and Williams 2004), and more than likely in the Potomac River of Maryland and Virginia; Massapoag Pond, Massachusetts; Meadow Lake, South Philadelphia, Pennsylvania; and Burnham Harbor, Chicago, Illinois. The introduction pathway that resulted in several specimens of Bighead Carp being caught or observed in Lake Erie remains a mystery. It is possible that the cultural practice of prayer animal release, a pathway long considered anecdotal or conjectural but known to exist (Severinghaus and Chi 1999), may have been involved in the Lake Erie introductions. A last potential pathway, although not known from the literature, is the release of Bighead Carp through animal rights activism.

Silver Carp

The Silver Carp has been widely introduced throughout the world. The species has been imported into or has spread by way of connected waterways to at least 88 countries and territories (Table 8). Of these introductions, there are reproducing populations of Silver Carp in 24 countries (or 27% of all countries where introduced). The database of introductions of aquatic species maintained by the FAO (2004) lists another 23 countries not thought to have reproducing populations that stock Silver Carp annually. There are an additional 33 countries in which Silver Carp are either believed to be “probably established” (*n*=11) or are “probably not” established (*n*=22; Table 8). There are an additional 23 countries in which the Silver Carp fails to have reproducing populations (Table 8). It remains unknown whether Silver Carp have become established in eight countries in which they have been introduced (Table 8). In comparison to other reviews, Li et al. (1990) reported that Silver Carp have been introduced into 34 countries.

The first introduction of Silver Carp for aquaculture where we found documentation was from China into Taiwan before the 18th century (Froese and Pauly 2004). Large-scale introduction of Silver Carp is a relatively new phenomenon. Only 9 of the 88 known introductions took place before 1960 (Fig. 22). The vast majority of introductions for which an approximate date of introduction was known occurred in the 1960s and 1970s (41 introductions). Thirteen introductions into additional countries or territories were made during the 1980s and 1990s (Fig. 22).

The most common reason for introducing Silver Carp outside its native range has been for aquaculture (61 introductions; Fig. 23); however, other vectors have been responsible for some introductions. Escapes or releases from aquaculture facilities have resulted in naturally reproducing populations in open waters. For example, the escape of approximately 47 Silver

Table 8. Countries and territories where Silver Carp (*Hypophthalmichthys molitrix*) have been introduced. Adapted in part from information in the Food and Agriculture Organization Database on Introductions of Aquatic Species (http://www.fao.org) and FishBase (http://www.fishbase.org). Under Status, E = established in open waters (i.e., having naturally reproducing populations), PE = probably established, PN = probably not established, and ? = unknown. Blanks indicate no available information. Many of the countries reporting probably established (and several reporting probably established) continually restock Silver Carp into open waters. Common names from Froese and Pauly (2004).

Country of introduction	Status	Year introduced	Source	Rationale for introduction	Common name	References
Afghanistan	E	Unknown	Unknown	Aquaculture, weed control		Coad (1981), Krykhtin and Gorbach (1981)
Albania	PN	Unknown	Unknown	Aquaculture	Ballgjeri i bardhe	FAO (1997), Froese and Pauly (2004)
Algeria	PN	1985, 1986, 1991	Hungary	Fisheries		FAO (1997)
Armenia	PE	Unknown	Far East	Aquaculture		Gabrielyan (2001)
Austria	N	Unknown	Unknown	Aquaculture		Welcomme (1988), Froese and Pauly (2004)
Bangladesh	PN	1969	Hong Kong, Japan	Aquaculture		Barua et al. (2001)
Belgium	N	1975	Yugoslavia	Phyto- and zooplankton control		FAO (1997), Froese and Pauly (2004)
Bhutan	N	1984	Unknown	Aquaculture		Welcomme (1988), FAO (2004)
Brazil	PN	1968, 1979, 1982, 1983	Japan, China, Hungary	Aquaculture		FAO (1997)
Bulgaria	N	Unknown	Unknown	Aquaculture	Byal tolstolob	Welcomme (1988), FAO (2004)
Colombia	?	1988	Taiwan Island	Aquaculture		Welcomme (1988), Yang (1996), Cen and Zhang (1998), Xie and Chen (2001)

Table 8. Continued

Country of introduction	Status	Year introduced	Source	Rationale for introduction	Common name	References
Costa Rica	PN	1976	Taiwan Island	Aquaculture		Welcomme (1988), FAO (2004)
Cuba	PE	1967, 1978	Former USSR	Aquaculture		Welcomme (1988)
Cyprus	E	1976	Israel	Phyto- and zooplankton control, angling/sport		FAO (2004)
Czech Republic	E	1953	Unknown	Diffusion from neighboring country	Tolstolobik bílý	Welcomme (1988), FAO (2004)
Denmark	PN	Unknown	Unknown	Aquaculture		Welcomme (1988), FAO (2004)
Dominican Republic	PE	1971, 1981	Taiwan Island	Fisheries, aquaculture		Welcomme (1988), FAO (2004)
Egypt	N	1962	Japan	Research		Moreau and Costa-Pierce (1997), FAO (2004)
Estonia	N	1980-1989	Hungary, Russia	Weed control		Welcomme (1988)
Ethiopia	PN	1975	Japan	Stocking, aquaculture		Welcomme (1988), Froese and Pauly (2004)
Fiji	PN	1968	Malaysia	Research		Froese and Pauly (2004)
France	PE	1975	Asia, Hungary	Phyto- and zooplankton control	Carpe argentée	Keith and Allardi (1997), FAO (2004)
Germany	PE	1964, 1970,1972	Hungary, China	Aquaculture, water quality (control plankton)	Silberkarpfen; Tolstolob	Kucklentz (1985), Welcomme (1988), FAO (2004)
Greece	PE	1980	Poland	Fisheries	Asinokyprinos	Welcomme (1988), Froese and Pauly (2004)
Guam	?	1974	Taiwan Island	Aquaculture		FAO (1997)

Table 8. Continued

Country of introduction	Status	Year introduced	Source	Rationale for introduction	Common name	References
Honduras	PN	1976	Taiwan Island	Aquaculture		Froese and Pauly (2004)
Hungary	E	1963, 1964, 1968	China, Russia	Aquaculture	Fehér busa	Mólnar (1971), FAO (1997), Jankovic (1998)
India	E	1959, 1963, 1971, 1972	Japan, Hong Kong, China, Southeast Asia	Accidental escape during flooding, aquaculture, fisheries	Belli-gende	Dobriyal (1988), Welcomme (1988), Sehgal (1989), Shetty et al. (1989), Tripathi (1989), Kaul and Rishi (1993)
Indonesia	N	1964, 1969	Japan, Taiwan Island	Aquaculture		Welcomme (1988), Froese and Pauly (2004)
Iran	N	1968, 1969, 1992	China, Romania	Aquaculture, fisheries, phyto- and zooplankton control	Kopur-e noqrehi	Coad (1996, 2005), FAO (2004)
Iraq	E	1966-1969	Unknown	Aquaculture, research		FAO (1997, 2004)
Israel	E	Early 1960s, 1966, 1969, 1979-1981	Japan, unknown	Aquaculture, polyculture, control of plankton, research, fisheries	Kasaf	Spataru and Gophen (1985), Leventer and Teltsch (1990), Gelman et al. (1992)
Italy	E	Unknown	Unknown	Aquaculture	Carpa argentata	Froese and Pauly (2004)
Jamaica	?	1978	Unknown	Aquaculture		Chakalall (1993), Aiken et al. (2002), FAO (2004)
Japan	E	1878-1940, 1969	China	Aquaculture, accidental	Hakuren	Chiba et al. (1989), Froese and Pauly (2004)
Jordan	?	Unknown	Unknown	Weed control		FAO (2004)
Kazakstan	E	1958-1961	China	Accidental		Verigin et al. (1978), Krykhtin and Gorbach (1981), Froese and Pauly (2004)
Korean Republic	PN	1963	Japan	Aquaculture, research		Welcomme (1988), FAO (2004)

Table 8. Continued

Country of introduction	Status	Year introduced	Source	Rationale for introduction	Common name	References
Kyrgyzstan	E	Unknown	China	Accidental		Verigin et al. (1978), Krykhtin and Gorbach (1981)
Laos	PE	1960s	Thailand, Vietnam, and China	Aquaculture		Gupta et al. (2000), Kottelat (2001a)
Latvia	E	Unknown	Unknown	Unknown		Winkler et al. (2000)
Lebanon	PN	Unknown	Unknown	Aquaculture, weed control		FAO (2004)
Lesotho	N	1988	South Africa	Aquaculture		FAO (2004)
Luxembourg	N	?	Unknown	Unknown		Troschel and Bartel (1998)
Madagascar	N	1982	North Korea	Research		FAO (2004), Froese and Pauly (2004)
Malawi	N	1970	Israel	Aquaculture		FAO (2004), Froese and Pauly (2004)
Malaysia	N	1800s	China	Aquaculture	Kap perak; tongsan putih; Pey lin	FAO (2004), Froese and Pauly (2004)
Mauritius	?	1976	India	Unknown		Moreau and Costa-Pierce (1997), Froese and Pauly (2004)
Mexico	PN	1965	China	Aquaculture, fisheries, control of aquatic blooms	Carpa plateada	Welcomme (1988), FAO (1997)
Morocco	PE	1980, 1981	Bulgaria, Hungary	Phyto- and zooplankton control		Welcomme (1988), FAO (2004)
Mozambique	N	1991	Cuba	Aquaculture, fisheries		FAO (1997), Froese and Pauly (2004)
Muldova Republic	PN	Unknown	China	Stock a cooling reservoir		Fulga and Statova (1992)

Table 8. Continued

Country of introduction	Status	Year introduced	Source	Rationale for introduction	Common name	References
Nepal	N	1965, 1967	India, Japan	Aquaculture		FAO (1999, 2004)
Netherlands	PN	1966	Hungary	Unknown	Zilverkarper	Welcomme (1988), FAO (2004)
New Zealand	N	1969	Hong Kong	Phyto- and zooplankton control, research		Champion et al. (2002)
Nigeria	N	1984	Unknown	Aquaculture		FAO (2004)
Pakistan	E	1982-1983	Nepal, China	Increase production, angling, sport, aquaculture		FAO (1997), Mahboob and Sheri (1997)
Panama	PN	1978	Taiwan Island	Aquaculture		Eldredge (1994)
Papua New Guinea	?	Unknown	Unknown	Unknown		Welcomme (1988), FAO (2004)
Peru	PN	1979	Panama	Aquaculture		Froese and Pauly (2004)
Philippines	N	1964, 1968	China, Taiwan Island	Aquaculture	Babangan	Welcomme (1988), FAO (2004)
Poland	E	1965	Former USSR	Aquaculture	Tolpyga biala	Opuszynski (1979a), FAO (1997)
Puerto Rico	PE	1972	United States	Accidental		Erdman (1984)
Romania	E	Unknown	China	Phyto- and zooplankton control, aquaculture	Crap argintiu; Crap-chinezesc-argintiu; Sânger	FAO (1997), Froese and Pauly (2004)
Russian Federation	E	1959, 1961, 1966, 1968, 1970	China	Biological control, accidental	Belyi tolstolob; Tolpyga; Maksun	Mukhamedova (1977), Karasev (1978), Krykhtin and Gorbach (1981), Abdusamadov (1987), Fulga and Statova (1992)

Table 8. Continued

Country of introduction	Status	Year introduced	Source	Rationale for introduction	Common name	References
Rwanda	PN	1979	Korea	Aquaculture		Moreau and Costa-Pierce (1997)
Saudi Arabia	PN	Unknown	Unknown	Aquaculture, weed control		FAO (2004)
Singapore	N	1900s	China	Aquaculture		Welcomme (1988), FAO (2004)
Slovakia	E	Unknown	Unknown	Diffusion from neighboring countries	Tolstolob biely	Yang (1996), Froese and Pauly (2004)
South Africa	PE	1975	Israel	Increase production, aquaculture	Silwerkarp	Schoonbee et al. (1978), Pieterse et al. (1981), Moreau and Costa-Pierce (1997)
Sri Lanka	N	1948	China	Aquaculture, weed control		FAO (1997), Froese and Pauly (2004)
Sweden	PN	Unknown	Unknown	Aquaculture	Silverkarp	Hölcík (1991), Froese and Pauly (2004)
Switzerland	N	1970	Unknown	Phyto- and zooplankton control		FAO (2004), Froese and Pauly (2004)
Tajikistan	E	Unknown	Unknown	Unknown		Krykhtin and Gorbach (1981)
Taiwan Island	N	Pre-18th century	China	Aquaculture		FAO (2004)
Tanzania	N	1981	India	Aquaculture, research		Moreau and Costa-Pierce (1997), FAO (2004)
Thailand	N	1913	China, Hong Kong	Aquaculture	Pla leng hea; Pl leng heu; Pla lin, Pla pae long; Pla pea long; Pla pin hea; Pla pin heu	Froese and Pauly (2004)
Tunisia	PN	1981	Hungary	Phyto- and zooplankton control		FAO (1997)

Table 8. Continued

Country of introduction	Status	Year introduced	Source	Rationale for introduction	Common name	References
Turkey	PE	Unknown	Unknown	Aquaculture, weed control		FAO (2004)
Turkmenistan	E	1958-1961	Yangtze Basin, China	Aquaculture		Krykhtin and Gorbach (1981), Pavlovskaya (1995)
Ukraine	E	Unknown	Unknown	Aquaculture	Belyi tolstolobik; Tolstolobik; Tovstolob zyvchajnyi	International Task Force for Assessing the Baia Mare Accident (2001)
United Kingdom	PN	Unknown	Unknown	Aquaculture		Hölcík (1991)
United States	E	1971, 1973, 1980	Taiwan Island	Biofiltration of sewage lagoons, aquaculture, fisheries		Cremer and Smitherman (1980), Freeze and Henderson (1982), Robison and Buchanan (1988), Welcomme (1988), Schrank et al. (2001)
Uzbekistan	E	1961, 1964-1975	China	Aquaculture, escaped from ponds, planned introductions		Verigin et al. (1978), Salikhov and Kamilov (1995), Kamilov and Salikhov (1996), Kamilov and Komrakova (1999)
Vietnam	E	Unknown	China	Aquaculture		FAO (1997), Froese and Pauly (2004)
Yugoslavia	E	1963, early 1970s	Romania, Hungary, former USSR	Aquaculture		Jankovic (1992, 1998), Froese and Pauly (2004)
Zambia	?	Unknown	Unknown	Aquaculture		FAO (2004)
Zimbabwe	?	Unknown	Unknown	Aquaculture		Moreau and Costa-Pierce (1997), FAO (2004)

Carp in 1971 into the Himalayan region of India, after flooding inundated the Deoli Fish Farm near the tail end of Gobindsagar Reservoir resulted in the establishment of the species in the reservoir (Sehgal 1989; Tripathi 1989). Silver Carp first entered the commercial catch in 1976 and by 1987 comprised 65% of the total catch (Sehgal 1999). Escape from rearing ponds in the Terek region of the Caspian Basin also resulted in establishment of Silver Carp (Abdusamadov 1987). Silver Carp also escaped from ponds of the Experimental Industrial Venture for Fisheries in Uzbekistan (in the Syr Dar'ya River Basin; Kamilov and Salikhov 1996). From there, they spread throughout the basin (Kamilov and Salikhov 1996) and have been reproducing naturally in the Syr Dar'ya since 1977 (Verigin et al. 1978, in Shubnikova 1978). Similar to the Bighead Carp, Silver Carp have been able to colonize countries with moderate to large rivers and river inflows to reservoirs that included suitable habitat for successful reproduction. Other potential, although not documented, pathways for introductions include activities of animal rights activists and escapes or releases from live-haul trucks.

Silver Carp have also been introduced throughout regions of the world for various other reasons. They have been stocked in open waters to increase fish production by filling the planktivorous "vacant niche" (11 introductions, Fig. 10; Wilamovski 1972; Mukhamedova 1977; Spataru 1977; Opuszynski 1979b; Shetty et al. 1989; Salikhov and Kamilov 1995; Mahboob and Sheri 1997; Moreau and Costa-Pierce 1997). They have also been stocked into lakes, reservoirs, and ponds to control phytoplankton or macrophytes and to improve water quality (19 introductions, Fig. 24; Leventer and Teltsch 1990). In addition, Silver Carp have been introduced by way of contamination of fishes of other species imported for stocking. For example, in 1975 a consignment of Grass Carp arrived from Austria to England for experiments on water and weed control. This consignment was contaminated with Silver and Bighead carps (Stott and Buckley 1978).

Yang (1996) listed Silver Carp, along with Bighead, Black, and Grass carps as having been introduced to Yunnan Province, China, between 1958 and 1965, and that these carps are now present in most lakes and rivers of that province. He further noted that introductions of Bighead and Silver carps were causative agents of a rapid population decline in native cyprinid filter feeders (such as *Racoma taliensis, Cyprinus megalophthalmus*, *Anabarilius grahami*, *A. albrunops*, and *A. polylepis*) in lakes and reservoirs in Yunnan.

There are conflicting reports about the first importation of Silver Carp into the United States. Cremer and Smitherman (1980) cited a personal communication with J. Malone (Lonoke, Arkansas, 1975) that Bighead and Silver carps were introduced in 1971 from Taiwan for biofiltration of sewage lagoons. Shelton and Smitherman (1984) stated that Silver Carp were introduced in 1972 under an agreement of maintenance with the Arkansas Game and Fish Commission and cited a personal communication with J. M. Malone. Henderson (1979b) reported that Bighead and Silver carps were introduced into Arkansas in 1973 as a potential addition to fish production ponds. Shelton and Smitherman (1984) reported that Silver Carp were imported to the United States in at least one other shipment from Yugoslavia by a private fish farmer.

The use of Silver Carp in sewage treatment facilities has been proposed as an alternative potential source for escapement to the wild, rather than aquaculture facilities. The relation between these sites and connections to open waters remains unclear, as does the degree of involvement by the U.S. Environmental Protection Agency with these stocking events.

Silver Carp were also used in research projects soon after importation, in many of the same studies as Bighead Carp. In 1974, the Arkansas Game and Fish Commission began researching the benefits and threats of Bighead and Silver carps (Henderson 1978, 1979a; Freeze and Henderson 1982). A study was conducted on the utility of commonly used chemicals to control Bighead and Silver carps in culture ponds (Henderson 1976). Young from the stock in Arkansas were received by the Auburn University, Alabama, in 1974 for research projects in earthen ponds with Bighead Carp (Pretto-Malca 1976; Dunseth 1977; Cremer and Smitherman 1980). Bighead and Silver carps stock from Arkansas was also shipped to the Sam A. Parr Fisheries Research Center in Illinois for a polyculture study in earthen ponds for experiments begun in 1975 (Buck et al. 1978a,b, 1981). Additional experiments were conducted in tanks at the Illinois Natural History Survey on polyculture (Henebry et al. 1988).

Soon after their initial importation into the country, Silver Carp, usually with Bighead Carp, were stocked into wastewater treatment lagoons and impoundments in several states. The Arkansas Game and Fish Commission stocked Bighead and Silver carps into an existing wastewater treatment system to study the usefulness of the fishes in improving water quality (1975-1976, Henderson 1978, 1979a; 1977-1980, Henderson 1979b, 1983). Freeze and Henderson (1982) referred to four sites, without providing specific locations, in Arkansas that were stocked with Bighead and Silver carps. In 1992, Bighead and Silver carps were stocked into a pond in Arvada, Colorado, to control nuisance algae (Lieberman 1996). Pantex (1997) reported stocking Silver Carp into the Pantex plant's wastewater treatment lagoon in Texas.

In 1974 or 1975, specimens of Silver Carp were collected from Bayou Meto and the White River, Arkansas County, Arkansas (U.S. Geological Survey 2004). The report of these captures was filed in a memorandum from the Director, Fish Farming Experimental Station, Stuttgart, Arkansas, to the Director, U.S. Fish and Wildlife Service Region 4, Atlanta, Georgia. In that memorandum, it was stated that the Silver Carp is a "potential threat to native fish." Silver Carp were propagated and distributed by private hatcheries and by the Arkansas Game and Fish Commission (Freeze and Henderson 1982). In January 1980, several Silver Carp were collected from Crooked Creek, northeastern Arkansas County, which flowed through two private fish hatcheries possessing Silver Carp (Freeze and Henderson 1982). By 1981, Silver Carp had been collected from the White, Arkansas, and Mississippi rivers in Arkansas (Robison and Buchanan 1988). From there, they continued to spread through the Mississippi River Basin. Silver Carp have now been collected from the natural waters of 16 states and Puerto Rico (Table 9). Introduction of this species into Puerto Rico resulted from release of fingerlings mixed with a shipment of Grass Carp from Lonoke, Arkansas (Erdman 1984). Rinne (1995) listed Silver Carp as introduced to Arizona in 1972 and denoted it as established. Apparently in reference to the same record, William Silvey of the Arizona Game and Fish Department recently informed us that the only Silver Carp documented in Arizona open waters was a population inhabiting an urban lake in Chandler during the early 1970s.

In the early 1980s commercial fishers in Arkansas caught 166 Silver Carp from seven sites; but an intensive 1980-1981 survey to determine the distribution and status of Bighead and

Table 9. Records of Silver Carp (*Hypophthalmichthys molitrix*) within the United States. Adapted from the U.S. Geological Survey Nonindigenous Aquatic Species Database (http://nas.er.usgs.gov) and recent records. Blanks indicate no information available.

State	County	Drainage	Locality	Year
Alabama	Tallapoosa-Elmore	Lower Tallapoosa	Yates Reservoir (Sougahatchee Creek)	1984, 1986
Alabama		Black Warrior-Tombigbe	Black Warrior drainage	1996
Alabama		Gulf of Mexico	Central part of state	1998
Arkansas	Arkansas	Arkansas	White River	1975
Arkansas	Arkansas	Bayou Meto	Bayou Meto	1975
Arkansas	Jefferson	Arkansas	Arkansas River, Pine Bluff, Lock and Dam 4	1981
Arkansas	Arkansas	Bayou Meto	Bayou Meto just below the confluence with Crooked Creek, near Abeles, Arkansas	1981
Arkansas	Lonoke	Bayou Meto	Crooked Creek above confluence with Bayou Meto in southeastern county	1981
Arkansas	Lonoke	Bayou Meto	Bayou Meto, near bridge, Arkansas	1981
Arkansas		Lower Arkansas	Arkansas River (lower section, possibly near Lock and Dam 2)	1981
Arkansas		Lower Red-Ouachita	Oachita River	1981
Arkansas	Prairie	Lower White-Bayou Des Arc	White River near Des Arcs, Arkansas	1981
Arkansas		Mississippi	Mississippi River at river mile 804	1982
Arkansas	Dade	Arkansas	Arkansas River	1988
Arkansas		Arkansas-White-Red	White River, Akansas River	1988
Arkansas	Lonoke	Bayou Meto	Bayou Meto	1988
Arkansas	Craighead	Cache	Lost Creek	1988
Arkansas	Faulkner	Lake Conway-Point Remove	Lake Conway	1988
Arkansas	Pope	Lake Conway-Point Remove	Lake Conway	1988
Arkansas	Mississippi	Little River Ditches	Little River Ditches	1988
Arkansas	Poinsett	Little River Ditches	Little River Ditches	1988
Arkansas	Jefferson	Lower Arkansas-Maumell	Lower Arkansas	1988
Arkansas	Pulaski	Lower Arkansas-Maumelle	Arkansas River	1988
Arkansas	Lawrence	Lower Black	Black River	1988
Arkansas	Mississippi	Lower Mississippi-Memphis	Mississippi River	1988
Arkansas	Phillips	Lower White	Lower White	1988
Arkansas	Prairie	Lower White	Lower White	1988
Arkansas	Prairie	Lower White-Bayou Des Arc	White River	1988

Table 9. Continued.

State	County	Drainage	Locality	Year
Arkansas	Saline	Upper Saline	Saline River	1988
Arkansas	Monroe	Cache	Cache River near confluence with White River (near Clarendon, Arkansas)	2003
Arizona	Maricopa	Middle Gila	Urban lake in Chandler (suburb of Phoenix)	1972
Arizona			Arizona waters-extirpated	1990
Colorado	Larimer	Cache La Poudre	Power plant reservoir on Rawhide Creek	1980
Colorado		More than one	East slope of water treatment ponds	1996
Hawaii		Hawaii	Not specific	1992
Illinois	Jackson	Upper Mississippi-Cape Girardeau	Mississippi River	1983
Illinois	Hancock	Flint-Henderson	Mississippi River, below Lock and Dam 19 (river mile 364), 1 mile south of Hamilton	1986
Illinois	Coles	Embarras	Below Lake Charleston spillway	1987
Illinois	Marion	Little Wabash	Research pond	1987
Illinois	Monroe	Cocokia-Joachim	Mississippi river mile 160 at Merrimac	1990
Illinois	Jackson	Big Muddy	Big Muddy River at Rattlesnake Ferry	1994
Illinois	Alexander	Cache	Horseshoe Lake	1994
Illinois	Alexander	Cache	Ditch at Horseshoe Lake	1995
Illinois	Alexander	Cache	Lake Creek, Horseshoe Lake spillway in floodwaters	1996
Illinois	Jackson	Big Muddy	Kinkaid Creek below spillway of Kinkaid Reservoir	1998
Illinois	Alexander	Cache	Horeshoe Lake, below spillway	1998
Illinois	Massac	Lower Ohio	Ohio River at Fort Massac State Park	1998
Illinois	Massac	Lower Ohio	Ohio River at Cottonwood Bar	1998
Illinois	Pope	Lower Ohio-Bay	Lusk Creek at confluence with Ohio River	1998
Illinois	Madison	Peruque-Piasa	Mississippi River, Pool 26	1998
Illinois	Randolph	Upper Mississippi-Cape Girardeau	Kaskaskia River at lock and dam, about 6.5 miles NNW of Chester	1998
Illinois	Randolph	Upper Mississippi-Cape Girardeau	Mississippi River at mouth of Kaskaskia River, just upstream of Fort Kaskaskia state historical site	1998

Table 9. Continued.

State	County	Drainage	Locality	Year
Illinois	Randolph	Upper Mississippi-Cape Girardeau	Mississippi River, about 2 miles downstream of Cora, Illinois	1998
Illinois	Alexander	Cache	Horseshoe Lake	1999
Illinois	Alexander	Cache	Lake Creek, Horseshoe Lake spillway	1999-2003
Illinois	Johnson	Lower Ohio	Cache River, Post Creek, 2 miles south of West Vienna, Illinois	1999
Illinois	Crawford	Middle-Wabash-Busseron	Minnow Slough	1999
Illinois	Jackson	Big Muddy	Big Muddy River, River Ferry, 4 miles southeast of Grand Tower, Illinois	2000
Illinois	Brown	Lower Illinois	Illinois River, La Grange Reach	2000
Illinois	Cass	Lower Illinois	Illinois River	2000
Illinois		Lower Illinois-Lake Chautauqua	Illinois River, river mile 157.8	2000-2001
Illinois	Cass	Lower Illinois-Lake Chautauqua	Muscooten Bay near Beardestown, Illinois	2000
Illinois	Mason	Lower Illinois-Lake Chautauqua	Illinois River, La Grane Reach	2000
Illinois	Mason	Lower Illinois-Lake Chautauqua	Meyers Ditch, an Illinois River side channel at river mile 129.3	2000
Illinois	Tazwell	Lower Illinois-Lake Chautauqua	Illinois River	2000
Illinois	Madison	Peruque-Piasa	Mississippi River, Pool 26	2000
Illinois	Gallatin	Saline	Saline River at Route 1, bridge 4 miles southeast of Equality, Illinois	2000
Illinois	Lawrence	Embarras	Embarras River at Lawrenceville, Illinois	2001
Illinois	Calhoun	Lower Illinois	Illinois River, river mile 13.6 near Grafton, Illinois	2001
Illinois	Perry	Upper Mississippi-Cape Girardeau	Mississippi River at first island downstream of Grand Towers, Illinois	2001
Illinois	Jackson	Big Muddy	Big Muddy River south of Murphysboro	2002
Illinois	Calhoun	The Sny	Mississippi River, Pool 25, near Batchtown, Illinois	2002
Illinois	Fulton	Lower Illinois-Lake Chautauqua	Spoon River	2003
Illinois	Pulaski	Lower Ohio	Post Creek cutoff about 4 miles of Grand Chain, Illinois	2003
Illinois	Clark	Middle Wabash-Busseron	Wabash River at Darwin, Illinois	2003
Illinois	Adams	Bear-Wyaconda	Mississippi River vicinity of Lock and Dam 20	2004
Illinois		Cahokia-Joachim	Mississippi River, Lock and Dam 27 downstream to Kaskaskia River	2004

Table 9. Continued.

State	County	Drainage	Locality	Year
Illinois	Will	Des Plaines	Chicago Sanitary and Ship Canal, around river mile 294, about two miles south of the electric barrier in Romeoville	2004
Illinois	Hancock	Flint-Henderson	Mississippi River at Lock and Dam 19	2004
Illinois	Brown	Lower Illinois	Illinois River, La Grange Reach	2004
Illinois	Mason	Lower Illinois-Lake Chautauqua	Illinois River, La Grange Reach	2004
Illinois	La Salle	Lower Illinois-Senachwine Lake	Illinois River up to Starved Rock Lock and Dam, river mile 231.0	2004
Illinois		Lower Ohio	Ohio River	2004
Illinois		Lower Ohio-Bay	Ohio River	2004
Illinois		Lower Wabash	Wabash River	2004
Illinois		Middle Wabash-Busseron	Wabash River	2004
Illinois		The Sny	Mississippi River, Lock and Dams 25-21	2004
Illinois	Madison	Peruque-Piasa	Mississippi River, near Lock and Dam 26	2004
Illinois		Upper Mississippi-Cape Girardeau	Mississippi River from Kaskaskia River downstream to the Ohio River	2004
Indiana		Ohio	Southeast part of state	1992
Indiana	Greene	Lower Wabash	West fork of White River	2003
Indiana	Gibson	Lower White	White River at Hazelton	2004
Indiana		Lower Wabash	Wabash River	2004
Indiana		Middle Wabash-Busseron	Wabash River	2004
Iowa	Lee	Flint-Henderson	Mississippi River (river mile 364) just below dam at Keokuk	2003
Iowa	Marion	Lower Des Moines	Des Moines River below Lake Red Rock	2003
Iowa	Van Buren	Lower Des Moines	Des Moines River (river mile 51) at Keosauqua	2003
Iowa	Wapello	Lower Des Moines	Des Moines River (river mile 90) at Ottumwa	2003
Iowa		Upper Chariton	Chariton River below Lake Rathbun	2003
Iowa	Des Moines	Flint-Henderson	Mississippi River, Pool 18	2004
Kansas	Marin	Verdigris	Eastern rivers in Kansas	1998
Kansas		Middle Verdigris	Fixed research site	2001
Kentucky	Union	Highland-Pigeon	Ohio River at Uniontown	1986
Kentucky	Union	Highland-Pigeon	Below Uniontown lock and dam	1991
Kentucky	Marshall	Lower Tennessee	Tennessee River, below Kentucky Dam	1995

Table 9. Continued.

State	County	Drainage	Locality	Year
Kentucky	Livingston	Lower Ohio-Bay	Ohio River (river mile 918.5) at Smithland Lock and Dam near Smithland	1999
Kentucky	Jefferson	Silver-Little Kentucky	Ohio River at Louisville (at falls)	1999
Kentucky	Livingston	Kentucky Lake	Kentucky Lake	2004
Kentucky	Lyon	Lower Cumberland	Lake Barkley	2004
Kentucky	Ballard	Lower Mississippi-Memphis	Fish Lake	2004
Kentucky	Ballard	Lower Mississippi-Memphis	Ballard Wildlife Management Area, all lakes	2004
Kentucky	Ballard	Lower Mississippi-Memphis	Peal Wildlife Management Area, all lakes	2004
Kentucky	Ballard	Lower Mississippi-Memphis	Swan Lake Wildlife Management Area, all lakes	2004
Kentucky	Ballard	Lower Mississippi-Memphis	Boatwright Wildlife Management Area, all lakes	2004
Kentucky		Lower Ohio	Ohio River	2004
Kentucky	Bullitt	Salt	Salt River, just south of Louisville	2004
Louisiana		Lower Mississippi	Mississippi River	1983
Louisiana	Franklin	Boeuf	Turkey Creek Lake	1985
Louisiana	Monroe	Atchafalaya	Atchafalaya River	1988
Louisiana	Franklin	Boeuf	Bouef River near Turkey Creek	1988
Louisiana	Franklin	Boeuf	Confluence of Turkey Creek and Caldwell parishes	1988
Louisiana	Maui	Boeuf	Boeuf River, Richland and Caldwell parishes	1988
Louisiana	Richland	Boeuf	LaFourche Canal	1988
Louisiana	Lincoln	Dugdemona	Farm pond; Miller Lake	1988
Louisiana	East Carroll	Lower Mississippi-Greenville	Mississippi River and backwater lake	1988
Louisiana	Concordia	Lower Mississippi-Nachez	Mississippi River and backwater lake	1988
Louisiana	Ouachita	Lower Ouachita	Ouachita Wildlife Management Area, water pumped from LaFourche Canal	1988
Louisiana	Ouachita	Lower Ouachita	Ouachita River	1988
Louisiana	Natchitoches	Lower Red-Lake Iatt	Red River	1988
Louisiana	Catahoula	Tensas	Black River	1988
Louisiana		Little	Little River	1989
Louisiana		Loggy Bayou	Loggy Bayou	1989
Louisiana	East Carroll	Lower Mississippi-Greenville	Mississippi River and backwater lake	1989
Louisiana	Monroe	Atchafalaya	Atchafalaya drainage	1998
Louisiana	Point Coupee	Atchafalaya	Atchafalaya River, Mud Hole, old river control structure	1998
Louisiana		Lower Mississippi-Baton Rouge	Mississippi River drainage	1998

Table 9. Continued.

State	County	Drainage	Locality	Year
Louisiana		Lower Mississippi-Greenville	Mississippi River drainage	1998
Louisiana		Lower Mississippi-Nachez	Mississippi River drainage	1998
Louisiana		Lower Red	Red River drainage	1998
Mississippi	Tunica	Lower Mississippi-Helena	Mississippi River, St. Francis Lake sandbar, river mile 672	2000
Mississippi	Bolivar	Big Sunflower	Mississippi River, gravel bar west of Rosedale, MS	2001
Mississippi	Issaquena	Lower Mississippi-Greenville	Chotard Lake	2002
Mississippi	Yazoo	Yazoo	Yazoo River at Highway 49W	2004
Missouri	New Madrid	Little River Ditches	Dry Run Lake, 1 mile northeast of New Madrid	1997
Missouri		Lower Missouri	Missouri River	1998
Missouri		Lower Missouri-Blackwater	Missouri River	1998
Missouri	St. Charles	Peruque-Piasa	Mississippi River Pool 26	1998
Missouri	Cape Girardeau	Whitewater	Castor River, headwater diversion channel	1998
Missouri	St. Charles	Peruque-Piasa	Mississippi River Pool 26	2000
Missouri	Perry	Upper Mississippi-Cape Girardeau	Mississippi River at Wilkinson Island	2000
Missouri	Scott	Upper Mississippi-Cape Girardeau	Mississippi River, 16 river miles south of Cape Girardeau	2001
Missouri	Cooper	Lamine	Lamine River	2002
Missouri	Lincoln	The Sny	Mississippi River Pool 25, 3.5 miles northeast of Foley, Missouri	2002
Missouri		Lamine	Lamine River	2003
Missouri	Cooper	Lamine	Blackwater River	2003
Missouri		Lower Grand	Grand River	2003
Missouri	Boone	Lower Missouri-Moreau	Missouri River near Hartsburg	2003
Missouri	Callaway	Lower Missouri-Moreau	Cedar Creek near Jefferson City	2003
Missouri	Cole	Lower Missouri-Moreau	Moniteau Creek about 1 mile northwest of Marion, Missouri	2003
Missouri	Howard	Lower Missouri-Moreau	Moreau River	2003
Missouri		Lower Osage	Osage River	2003
Missouri		Cahokia-Joachim	Mississippi River, Lock and Dam 27 downstream to Kaskaskia River	2004
Missouri		Flint-Henderson	Mississippi River at Lock and Dam 19	2004
Missouri	Chariton	Lower Missouri-Crooked	Palmer Creek	2004

Table 9. Continued.

State	County	Drainage	Locality	Year
Missouri		Lower Missouri-Moreau	Little Chariton River	2004
Missouri	Boone	Lower Missouri-Moreau	Hart Creek	2004
Missouri	Boone	Lower Missouri-Moreau	Unnamed creek 1.5 miles southeast of Hartsburg, Missouri	2004
Missouri	Callaway	Lower Missouri-Moreau	Auxvasse River	2004
Missouri	Cooper	Lower Missouri-Moreau	Petite Saline Creek	2004
Missouri	Howard	Lower Missouri-Moreau	Moniteau Creek near Rocheport, Missouri	2004
Missouri	Howard	Lower Missouri-Moreau	Bonne Femme Creek	2004
Missouri	Osage	Lower Missouri-Moreau	Loose Creek	2004
Missouri		Peruque-Piasa	Mississippi River, near Lock and Dam 26	2004
Missouri		The Sny	Mississippi River, Lock and Dams 25-21	2004
Missouri		Upper Mississippi-Cape Girardeau	Mississippi River from Kaskaskia River downstream to Ohio River	2004
Nebraska		Missouri	Nonspecific (probably Missouri River)	2000
Nebraska	Dodge	Lower Platte	Elkhorn River 3 miles northwest of Scribner, Nebraska	2003
Nebraska	Dodge	Lower Elkhorn	Elkhorn River, near Crowell, Nebraska	2003
Puerto Rico		Eastern Puerto Rico	At Dorado Beach Hotel golf course pond	1972
South Dakota		Lewis and Clark	Missouri River below Gavins Point Dam	2003
South Dakota		Missouri	Missouri River up to Gavins Point Dam	2003
South Dakota	Yankton	Lower James	Mouth of the James River	2003
South Dakota	Lincoln	Lower Big Sioux	Big Sioux River near Canton, South Dakota	2004
Tennessee		Lower Mississippi-Memphis	Mississippi River overflow	1989
Tennessee	Shelby	Lower Mississippi-Memphis	Mississippi River, river mile 743 near Memphis, Tennessee	2000

Silver carps in the state, Arkansas Game and Fish Commission personnel could not locate additional specimens (Freeze and Henderson 1982). Although Arkansas state personnel did not find young-of-year fish, several specimens taken by the commercial fishers were sexually mature and exhibited secondary sexual characteristics (Freeze and Henderson 1982). Burr et al. (1996) found young-of-year in a ditch near Horseshoe Lake and reported this as the first evidence of successful spawning of Silver Carp in Illinois waters and the United States. Douglas et al. (1996) collected more than 1,600 larval *Hypophthalmichthys* from a backwater outlet of the Black River in Louisiana in 1994. Like Bighead Carp, Silver Carp is established throughout much of the Mississippi River Basin, and its range is still expanding (Fig. 26).

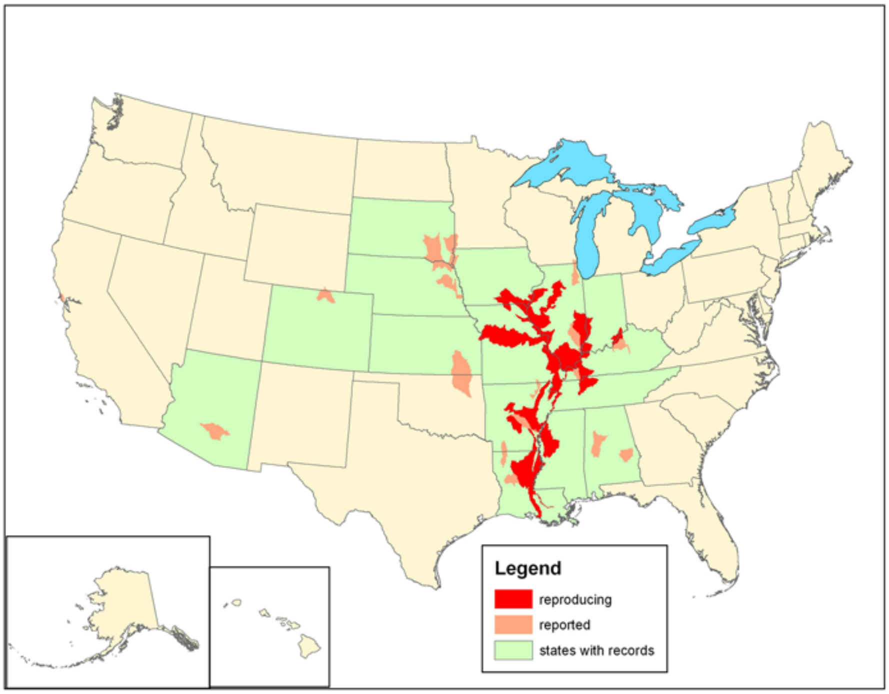

Figure 26. Introduced range of Silver Carp, *Hypophthalmichthys molitrix*, in the United States. Map provided by the U.S. Geological Survey (2004).

The major pathway for introduction of Silver Carp in the United States has been importation for aquaculture purposes including biological control of plankton in culture ponds. The pathway that led to presence of this species in open waters probably was escape from these facilities because of flooding. Silver Carp are difficult to handle and transport because of their propensity to jump and avoid being taken by seines (Green and Smitherman 1984). These negative attributes have resulted in Silver Carp being little cultured in the United States since around 1985 (C. Engle, University of Arkansas at Pine Bluff, Pine Bluff, Arkansas, personal communication, 2005). Silver Carp are not being cultured commercially at this time; therefore there is little risk of further introductions of this species into the wild from aquaculture facilities unless commercial demand for the species increases. Should culture of Silver Carp resume, potential pathways for introduction would be escapement or release from the facility, the unlikely contamination of pond-grown baitfishes (Stone 2003), contamination of pond-grown Grass Carp, and escapement from livehaulers transporting fish from aquaculture facilites to cities with live seafood markets.

As in Bighead Carp, there are several potential pathways for further introductions of Silver Carp into additional water bodies that involve aiding in the spread of existing populations of wild Silver Carp. One such pathway is through the release of contaminated baitfishes caught in the wild. Anglers sometimes catch young Bighead and Silver carps in Illinois and use them as live bait in those or other waters (M. Pegg, Illinois Natural History Survey Champaign, Illinois, personal communication, 2004), not only because they look similar to native baitfishes (Fig. 25), but also because anglers collecting baitfishes are not always concerned about the species collected or used as bait. In 2003, fisheries biologists collected a "5-gallon bucket" of what was thought to be young-of-year Gizzard Shad. Only when the bucket was dumped into an aquarium was it realized that the fish were actually all young-of-year Silver Carp (D. Sallee, Illinois Department of Natural Resources, Sterling, Illinois, personal communication, 2003). Release of live bait has been responsible for more than 100 introductions of fishes beyond their ranges in the United States (Litvak and Mandrak 1999). Although adult and market-sized Silver Carp are fragile and do not survive collection and transport well (Green and Smitherman 1984), fingerling Silver Carp are less susceptible to mortality due to handling stress (DCC, personal observation). Other potential pathways that involve aiding in the spread of existing populations of Silver Carp, in addition to malicious release, include ballast water release, spread by commercial fishers, and release or escapement from livehaulers that support commercial fishers (see Bighead Carp section for discussion of these potential pathways).

The final potential pathways for further introductions of Silver Carp into the wild in the United States involve those associated with the live sale of the species in live seafood markets, regardless as to whether the fish were cultured in fish farms or were caught live in the wild. Live Silver Carp are sometimes available in live food fish markets in several major U.S. and Canadian cities. Goodchild (1999) placed Silver Carp on a watch list of freshwater food fish species in Ontario that had not yet been reported by importers or wholesalers, or been observed in retail markets, but that might become popular as a live food fish in the future. DCC and WRC, however, observed two live Silver Carp for sale at a Toronto fish market in 2004. A last potential pathway, although not known from the literature, is the release of Bighead Carp through animal rights activism.

Largescale Silver Carp

Hybrids of Largescale Silver and Silver carps were introduced to the mid- Syr Dar'ya Basin in Kazakstan (about 40-42º N) from northern Vietnam in the early to mid-1980s (Payusova and Shubnikova 1986; Salikhov and Kamilov 1995) where they are assumed to be established. There is no indication that the Largescale Silver Carp has been introduced into the United States or other countries of the Western Hemisphere.

Environmental Effects of *Hypophthalmichthys*

Even though most species that are introduced outside their native range cause no appreciable change in the invaded ecosystem (Williamson 1996), the introduction of some nonnative species results in costly economic damages and negative ecological changes (Kolar and Lodge 2002). Documenting and quantifying ecological changes, however, can be challenging. Many authors have commented on the difficulty of documenting the specific role of introduced fishes, even in obvious cases of depletion of native species (Crossman 1991). This may be especially true in large river ecosystems, required habitat for *Hypophthalmichthys*, where relatively little is known about ecology of fishes (Dettmers et al. 2001) or plankton communities (Berner 1951). Covarying factors such as changing hydrology, water temperatures and flow rates, the abundances of other biota, and human activities, confound efforts to document the effects of introduced *Hypophthalmichthys*. This is also true of the introduction of Bighead and Silver carps into the Mississippi River Basin. Here we present documented negative effects of introduced *Hypophthalmichthys* around the world (and in the United States, although less is known about this new introduction) and speculate about the potential effects of the genus on freshwater ecosystems in the United States.

Kohler and Courtenay (1986) characterized the negative effects of nonnative species in invaded ecosystems into five broad categories: habitat alteration, trophic alteration, spatial alteration, gene pool deterioration, and disease transmission. The primary category of negative effects that Bighead and Silver carps have on ecosystems into which they are introduced is through trophic alteration; most of our discussion focuses on the consequences of predation by and competition with *Hypophthalmichthys*. Below we delineate documented and potential effects of *Hypophthalmichthys* on each of the categories of negative effects identified in Kohler and Courtenay (1986).

Habitat Alteration

Changes in water quality are the most probable direct habitat effects on the habitat because of the introduction of *Hypophthalmichthys*. The effect of these fishes on water quality, however, appears to vary. Water nutrient concentrations have been documented to decrease (Opuszynski 1980), increase (Mátyás et al. 2003), and remain unchanged (Starling 1993) in the presence of Silver Carp. Laws and Weisburd (1990) found that sediment resuspension by Silver Carp introduced nutrients into the water column, stimulating plankton growth. Vybornov (1989) found decreased dissolved oxygen content of water in the presence of Silver Carp.

Hypophthalmichthys also may change benthic chemistry and communities. Starling (1993) reported an increase in Kjeldahl nitrogen in sediments in experimental ponds with Silver Carp. Excrement from Silver Carp (which can equal their body weight in 10 days; Herodek et al. 1989) has been found to organically enrich lake bottoms and alter the structure of the benthic macroinvertebrate community (Leventer and Teltsch 1990).

Many studies have shown that *Hypophthalmichthys* can increase turbidity, primarily by causing increased production of small algae (Wu et al. 1997; Yang et al. 1998; Radke and Kahl 2002). Increased turbidity can have direct affects on site-feeding predators (Gregory and Northcote 1993; Vogel and Beauchamp 1999) and can also result in reduced growth of aquatic macrophytes. No information was available on these indirect effects of *Hypophthalmichthys* on altering habitats.

Trophic Alteration

Foraging and Predation: Effect of Hypophthalmichthys on the Plankton Community

A substantial amount of research has been conducted on the effects of *Hypophthalmichthys* on water quality and eutrophication. These studies have resulted in conflicting conclusions and recommendations (see Control of Algae section). Sometimes, *Hypophthalmichthys* were successfully used to control noxious algal blooms, but more often they aggravated or caused algal blooms, apparently through a trophic cascade (Fig. 21). By removing larger algal species, thereby stimulating growth of smaller species and reducing the abundance of zooplankton grazing on smaller phytoplankton, the presence of Silver Carp is often accompanied by an increase in primary productivity and chlorophyll α concentrations (Fig. 21; Opuszynski 1980; Milstein et al. 1985b; Leventer 1987; Mátyás et al. 2003). The effect of Bighead Carp on phytoplankton communities is less well studied (except in combination with Silver Carp), but Bighead Carp also eat zooplankton and larger phytoplankton (Dong and Li 1994).

Many studies have found a shift to smaller zooplankton in the presence of *Hypophthalmichthys* (Spataru and Gophen 1985; Wu et al. 1997; Fukushima et al. 1999; Yang et al. 1999; Xie et al. 2000; Shao et al. 2001). Most studies have assessed the effect of Silver Carp alone or with Bighead Carp; there is little information on the effect of Bighead Carp alone. Xie and Yang (2000) and Lu and Xie (2001) suggested that predation by Silver Carp was a driving force shaping the copepod community structure of Lake Donghu during the past several decades. Wu (1997) found that at a low density (<190 g/m^2) of Silver Carp the zooplankton community shifted to being dominated by larger species whereas at a high density, the zooplankton community shifted to being dominated by smaller species.

Once established, these planktivorous carps could cause shifts in the food web and compete with other zooplanktivorous fishes and fish larvae for food. Changes in the community towards smaller size plankton may have negative effects on fishes native to the United States that subsist on larger zooplankton (see below).

Competition: Effect of *Hypophthalmichthys* on Benthic Macroinvertebrates

Any potential effects of *Hypophthalmichthys* on benthic macroinvertebrates are little studied and poorly understood. Laird and Page (1996) speculated that filter-feeding freshwater mussels could be negatively affected by competition with *Hypophthalmichthys* for food. Although the United States has the greatest diversity of freshwater mussels in the world (Turgeon et al. 1988), more than 40% of these species are in danger of extinction because of a variety of stressors (Master 1990). We did not find information on potential competition between freshwater mussels and *Hypophthalmichthys*. If such an interaction occurs, however, there could be substantial negative effects to freshwater mussel species. *Hypophthalmichthys* have been shown to alter the structure of benthic macroinvertebrate communities. Excrement from Silver Carp (which can equal their body weight in 10 days; Herodek et al. 1989) has been found to organically enrich lake bottoms and alter the structure of the benthic macroinvertebrate community (Leventer and Teltsch 1990).

Competition: Documented Effects of *Hypophthalmichthys* on Other Fishes

Competition for food resources between *Hypophthalmichthys* and other planktivorous fishes raised in polyculture has been documented (e.g., with Catla and Rohu; Alikunhi and Sukumaran 1964; Dey et al. 1979, in Tripathi 1989; with Common Carp; Opuszynski 1981). Also, Buck et al. (1978a,b) found that production of Bighead Carp was inversely correlated to production of Silver Carp. Competition is difficult to document in large and dynamic systems such as large rivers. There is growing evidence of declines in native species, particularly fishes that are planktivorous as adults, after the introduction of *Hypophthalmichthys* into the wild (in natural and human-altered systems). Below is a discussion of changes in the fish communities of India, the Middle East, China, and elsewhere, after the introduction of *Hypophthalmichthys*. Experiments to confirm competition for a limiting resource were not conducted in these instances. These authors speculated, however, that competition with Bighead and Silver carps for plankton resources explained the decline in native fish species.

In India, the introduction of Silver Carp into several reservoirs has resulted in the decline of native planktivores. The accidental establishment of Silver Carp in the Gobindsagar Reservoir in 1971 has generated animated debate from ecologists and fishery managers because of the propensity of the species to negatively affect native planktivorous species, particularly Catla and Rohu (Shetty et al. 1989; Sugunan 1997; Esmaeili and Johal 2003). After the introduction of Silver Carp, commercial fish catches from the reservoir changed dramatically (Petr 2002). Silver and Common carps dominated catch within 10 years of establishment (Petr 2002). At first, as the catch of Silver Carp increased, catches of Catla and Rohu declined, as did total catch (Shetty et al. 1989). Dey et al. (1979) and Natarajan (1988) documented similar declines in Kulgarhi Reservoir, India. Then, from 1987 to 1993, total catch from Gobindsagar Reservoir increased each year (Petr 2002). Between 1974 and 1975 (before introduction of Silver Carp) and 1992-93 (15 years after Silver Carp were introduced), catch of the indigenous Golden Mahseer (*Tor putitora*) in Gobindsagar Reservoir declined from 16.8% to 0.5% of the catch (although total catches increased over the same period from 28.7 tons of Golden Mahseer in 1974-75 to 46 tons in 1992-93; Sugunan 1995).

Other examples of reductions in native fishes after introducing Bighead and Silver carps and other Asian carps are from the Middle East. After their introduction into the Aral Sea Basin in the 1960s, Silver Carp fry quickly became 85-90% of total larval fish present in the basin (Pavlovskaya 1995). During the same period, larvae of the Aral Barbel (*Barbus brachycephalus*) declined from 80% to 0.04% of larval fishes in the basin (Pavlovskaya 1995). Although the Amu Dar'ya and other catchment rivers of the Aral Sea Basin historically harbored 43 species of fishes in the 1960s, only 22 species were collected in the early 1980s (though some of the extirpated species required riverine habitat lost by water removal for irrigation). Pavlovskaya (1995) credited the introduction of Asian carps and water manipulation for irrigation of aquaculture as the primary causes of the loss of fish biodiversity (Pavlovskaya 1995). Silver Carp were stocked into Lake Kinneret, Israel, in 1969 to increase production of harvestable fishes (Spataru and Gophen 1985). Spataru and Gophen (1985) speculated that Silver Carp competition with tilapias led to declines of the economically more important native tilapias in the lake.

Within their native China, Bighead and Silver carps have been translocated to three autonomous regions and three provinces where they are now considered invasive and associated with declines in native planktivorous fishes (Li and Xie 2002). In Changshouhu Reservoir at Longxi River, a branch of the Yangtze River in Shichuan Province, a population of Sharpbelly, *Hemiculter leucisculus*, decreased remarkably soon after the stocking densities of Silver and Bighead carps increased (Li 2001). Also, although stocking Lake Dong with Grass, Bighead, and Silver carps increased fish production fourfold in 7 years, the diversity of the fish fauna in the lake before the introduction of the carps seems to have been reduced (International Lake Environment Committee 2001). Xie and Chen (2001) stated that stocking of Bighead and Silver carps into the plateau lakes of China had disastrous effects on endemic fishes, especially filter-feeding, endemic Barbless Carp (*Cyprinus pellegrini*). The catch of Barbless Carp, that once represented 50% of yield of total fishes caught, declined to 20% in the 1960s, to 10% in the early 1970s, and plummeted to <1% in the 1980s. Xie and Chen (2001) presented four reasons that these carps posed a threat to the local fish community: (1) they are powerful filter feeders, (2) they grow fast and reproduce quickly, (3) they may compete for food with every fish species at early-life stages and with some as adults, and (4) they have a wide food spectrum and can cause declines in zooplankton abundance. Yang (1996) listed Bighead and Silver carps, along with Black and Grass carps, as having been introduced to Yunnan Province, China, between 1958 and 1965 and that these carps are now present in most lakes and rivers of that province. He further noted that these introductions were causative agents of a rapid population decline in native cyprinid filter feeders (such as *Racoma taliensis, Cyprinus megalophthalmus*, *Anabarilius grahami, A. albrunops*, and *A. polylepis*) in lakes and reservoirs in Yunnan. Although this region of China has substantial freshwater fish diversity (with 432 documented species), 30% of these species have not been collected since 1991 (Yang 1996). Yang (1996) identified nonnative fishes as one of the major threats to native fishes (along with land conversion, irrigation, and overfishing).

Other examples of declines in native fishes after the introduction of *Hypophthalmichthys* include the following. Costa-Pierce (1992) reported that economically important planktivores such as Able de Heckel (*Leucaspius delineatus*) and Bleak (*Alburnus alburnus*), as well as piscivorous (as adult) Zander (*Sander lucioperca*) were “nearly wiped out” by dense stocking of Silver Carp into a lake in Germany in 1977. Zander populations rebounded dramatically after the removal of Silver Carp. In that study, fish species most negatively affected by the presence of Silver Carp were those that spawn in the sublittoral zone and have pelagic, plankton-eating fry. Introductions of Bighead Carp into reservoirs in Thailand were associated with declines in commercially important native zooplanktivorous clupeids (de Iongh and Van Zon 1993). Although these studies did not quantify diet overlap and competition for limited food resources, a large body of circumstantial evidence is building regarding the negative effect of *Hypophthalmichthys* on native fishes, particularly those relying on plankton as a food resource.

Competition: Documented and Potential Effects in the Mississippi River Basin

Several authors have noted that since nearly all fishes typically feed on zooplankton as larvae and juveniles, thus there is potential for *Hypophthalmichthys* to adversely affect all fishes in the Mississippi River and Great Lakes basins (Laird and Page 1996; Chick and Pegg 2001; Chick 2002). Costa-Pierce (1992) indicated that fishes with early-life stages that were pelagic and zooplanktivorous declined after introduction of Silver Carp to a lake in Germany. Walleye (*Sander vitreum*) and crappies (*Pomoxis* spp.) are important fishes of the Mississippi River Basin that similarly have pelagic, zooplanktivorous early-life history stages. If the presence of *Hypophthalmichthys* reduces the abundance of zooplankton, particularly in backwater habitats used heavily by native fishes as nursery areas, native fishes may be negatively affected (Williamson and Garvey, *in press*).

Fishes that are planktivorous throughout their lives are of special concern for negative interactions with *Hypophthalmichthys*. Tucker et al. (1996) and (Pflieger 1997) noted that *Hypophthalmichthys* could affect adult native filter feeders in the Mississippi River Basin, such as Paddlefish, Bigmouth Buffalo, and Gizzard Shad. There are many smaller fishes in the large rivers of the basin that are also planktivorous throughout their life cycle, including regionally abundant Emerald Shiner (*Notropis atherinoides*) and Threadfin Shad (*Dorosoma petenense*) (Pflieger1997). Recently, the diets of Bighead and Silver carps in the Illinois River System have been found to have significant overlap with those of Gizzard Shad and Bigmough Buffalo (Schuyler et al. 2004). Gizzard Shad are a primary forage base for predacious fishes and important to the ecology of midwestern rivers; thus, this should be cause for concern.

Much concern has been voiced about the potential effects of *Hypophthalmichthys* on Paddlefish, a large filter feeder native to the Mississippi River Basin. Although the status of Paddlefish in the United States is unclear, many have stated that Paddlefish populations have been declining in major U.S. rivers since the 1900s because of overexploitation and habitat degradation (Carlson and Bonislawski 1981; Russell 1986; Sparrowe 1986; Graham 1997). The U.S. Fish and Wildlife Service was petitioned to list the Paddlefish as threatened under the Endangered Species Act in 1989 (Allardyce 1991). The petition was denied because of insufficient data (Allardyce 1991); however, competition with *Hypophthalmichthys* for food and habitat could negatively affect Paddlefish in waters where they are declining. Using experimental mesocosms, Schrank et al. (2003) demonstrated that when zooplankton were limited, age 0 Bighead Carp had a competitive advantage over age 0 Paddlefish.

Schuyler et al. (2004) found less diet overlap between *Hypophthalmichthys* and Paddlefish than with either Gizzard Shad or Bigmouth Buffalo. Adult Paddlefish feed primarily on large crustacean zooplankton, to a lesser extent consume smaller crustaceans and rotifers, and also at times consume slightly larger items such as *Chaoborous* and the larval stages of insects (Rosen and Hales 1981; Hoxmeier and DeVries 1997). Schuyler et al. (2004) found that Bighead Carp were less selective of the zooplankton they consumed than were Paddlefish and a higher proportion of their diet consisted of rotifers and smaller zooplankton than that of Paddlefish. However, weak diet overlap does not necessarily mean that *Hypophthalmichthys* will not affect Paddlefish. Predation by *Hypophthalmichthys* can significantly reduce larger zooplankton (e.g., Spataru and Gophen 1985; Wu et al. 1997; Fukushima et al. 1999; Yang et al. 1999; Xie et al. 2000; Shao et al. 2001), sizes preferred by Paddlefish. Although no cause-effect relation can be confirmed, backwaters and pools of the Mississippi and Illinois rivers with high catch rates for *Hypophthalmichthys* also had lower abundances of large crustacean zooplankton (J. Chick, personal communication, Illinois Natural History Survey, Brighton, Illinois, 2005). A decrease in the size of zooplankton due to predation by Bighead and Silver carps, whose diets are not dominated by larger zooplankton, may not be intuitive, but there are several potential and possibly additive factors resulting in this effect. First, if all zooplankton species are consumed heavily at a similar rate, there will be a selective pressure towards those portions of the plankton community with shorter generation times, which tend to be rotifers and smaller zooplankton. Second, predation on the small juveniles of crustacean zooplankton can limit or eliminate their survival to the adult stages. This was the result for large evasive copepods in Lu et al. (2002). Third, Silver Carp compete with larger zooplankton for food resources (Milstein et al. 1985b; Burke et al. 1986). Lastly, *Hypophthalmichthys* predation decreases the size of zooplankton within a species (Radke and Kahl 2002; Kim et al. 2003), possibly removing a species from the size category that will be consumed effectively by Paddlefish. Thus, although none of these mechanisms of zooplankton community alteration by *Hypophthalmichthys* have been demonstrated in the United States, it seems likely that *Hypophthalmichthys* have the potential to alter the food web in ways that could negatively affect fishes such as Paddlefish that feed on large crustacean zooplankton.

For competition to occur there must first be a limiting resource. At this time it is not known whether plankton resources are limiting for fishes in the large rivers of the United States or whether the introduction of *Hypophthalmichthys* could cause resources to become limited. Further research in this area is needed. Also, *Hypophthalmichthys* may affect trophic dynamics in unpredictable ways—some of which may favor some native species while negatively affecting others. Despite these uncertainties, there is a strong possibility of negative effects to native fishes from *Hypophthalmichthys* through diet competition and food web interactions.

If zooplankton resources are or become limiting, then the ability of Bighead Carp to switch from zooplankton to other diet items afford them a competitive advantage over Paddlefish (Schrank et al. 2003). The limited information available on Paddlefish diets seems to indicate that they are not as flexible in diet as Bighead and Silver carp (Rosen and Hall 1981; Hoxmeier and DeVries 1997).

Predator-prey Interactions: Potential Effects on Mississippi River Basin Piscivores

If *Hypophthalmichthys* negatively affect important planktivorous forage fishes such as Gizzard Shad, Threadfin Shad, and Emerald Shiner, fishes and birds that prey on these species could be negatively affected. Adult *Hypophthalmichthys* are too large to be preyed on by almost any native predator. Young Bighead and Silver carps have undoubtedly been incorporated into the diets of piscivorous birds and fishes to some degree, but the extent of this predation remains unknown. Little information is available regarding predators of *Hypophthalmichthys*. Negonovskaya (1980) reported that Zander, Northern Pike (*Esox lucius*), Eurasian perch (*Perca fluviatilis*), and Ide (*Leuciscus idus*) fed on Bighead Carp in reservoirs in the former USSR and that predation on young-of-year resulted in economic losses. Young-of-year *Hypophthalmichthys* grow larger, more quickly than native prey fishes and outgrow piscivorous fishes. Schrank and Guy (2002) found that Bighead Carp in Missouri were almost 200 mm at 1 age. Gizzard Shad, which also tend to outgrow predators in some situations (Kolar et al. 2003), average around 130 mm in length at the end of their first year in Missouri (Pflieger 1997). Most other zooplanktivorous prey fishes, such as Threadfin Shad or Emerald Shiners, rarely or never achieve that length. It also remains unknown if the quality of forage provided by *Hypophthalmichthys* is comparable to native species for piscivorous birds and fishes. Not enough is known to adequately assess the potential effects of *Hypophthalmichthys* on native prey fishes or the predators that prey on them.

Spatial Alteration

Although altering trophic interactions is perhaps the primary means by which *Hypophthalmichthys* could affect native fishes in the United States, spatial alterations such as aggressive behavior and interference competition for limited habitat may also play a role. Schrank et al. (2003) speculated that Bighead Carp might have prevented Paddlefish from consuming zooplankton in their study because of aggressive behavior or interference competition. Russell (1986) noted that Paddlefish preferred standing or low velocity waters deeper than 1.2 m and used water more than 3 m deep in the winter. *Hypophthalmichthys* use similar habitats (see the Habitats, Migrations, and Local Movements section). In the lower Missouri River, which is channelized for navigation, such habitats are limited and consist primarily of deep holes behind wing dikes and the portions of tributaries that cross the Missouri River floodplain. It is unknown whether the presence of large numbers of *Hypophthalmichthys* in these environments affects Paddlefish negatively. New technologies such as acoustic videography would prove useful in assessing the behavioral interactions of *Hypophthalmichthys* with native fishes.

Gene Pool Deterioration

Deterioration of the gene pools of native fishes through hybridization with Bighead and Silver carps would not be expected because there are no close relatives of *Hypophthalmichthys* in North America.

Disease Transmission

Hypophthalmichthys are known to carry a variety of diseases (see the Associated Diseases and Parasites section), including the Asian carp tapeworm. Asian carp tapeworm has caused special concern because it has infected endangered southwestern cyprinids, sometimes causing death (Hoole et al. 2001; Humpback Chub Ad Hoc Advisory Committee 2003). Bighead Carp were also implicated in massive infestations of anchorworm in co-cultured Channel Catfish (Goodwin 1999). The effects of *Hypophthalmichthys* on diseases and parasites in organisms native to the United States cannot be fully predicted.

Potential Range

Bighead Carp

Bighead Carp tolerate a wide range of environmental factors in their natural habitat, including extremes in turbidity and water temperature (from cold temperate to tropical). Potential range of the Bighead Carp in North America is limited by climatic conditions, primarily temperature and spawning habitat. The native range in eastern Asia extends from 43.5° N (47º N in its introduced area of the Amur River) southward to approximately 21º N, roughly the equivalent of the distance between southern Quebec and Ontario to southern Florida on the East Coast and southern Washington south to Baja California Sud on the West Coast. The average annual temperature in the native range ranges from -4 to 24°C (Hseih 1973). Air temperature extremes in this region range from -30 to 16°C during the coldest month (January) and between 20 and 30°C during the warmest month (July).

It is difficult to delineate the present range of established (reproducing) populations of Bighead Carp in the United States because of their rapid spread and the difficulty associated with monitoring rare species. At present, they have been found and reported in the open waters of at least 23 states and are established in the Mississippi River Basin. In the Mississippi River, Bighead Carp have been caught from Louisiana upstream to southeastern Minnesota. In the Ohio River, they have been caught upstream to western West Virginia and southern Ohio. Bighead Carp have been found in the Missouri River from St. Louis upstream to Iowa and southern South Dakota. A few Bighead Carp have also been taken and observed in Lake Erie in Ohio and Ontario, Canada; however, they are not thought to be established in the Great Lakes.

In addition to the states with established populations of Bighead Carp, there are at least seven states where they have been caught from open waters, usually by anglers. These states include Alabama, California, Colorado, Florida, Tennessee, Texas, and Washington. On the basis of the present distribution of established and introduced populations around the world, it appears that Bighead Carp could become established in much of the continental United States. The limiting factor in most regions of the United States would be access to a river with moderate to swift current of a length of at least 100 km to fulfill the spawning requirement. Another factor that may limit the distribution of Bighead Carp in the United States is the requirement for the incubation of eggs in waters with fairly high ionic concentrations (Gonzal et al. 1987). In the laboratory, when eggs of *Hypophthalmichthys* were incubated in water with a hardness of less than around 200 mg/L calcium carbonate, eggs continued to absorb water and burst prematurely. Areas in the United States presently inhabited by *Hypophthalmichthys* suggest that more research is needed on this requirement for successful reproduction (Fig. 27). *Hypophthalmichthys* are presently found in waters with water hardness <200 mg/L calcium carbonate, although it is possible that successful reproduction cannot occur in these areas. In addition, Fig. 27 indicates mean water hardness across the country, and does not account for seasonal variation. Understanding seasonal variation in water hardness may be critical to predicting the potential distribution of Bighead Carp in the United States. Successful reproduction is only one

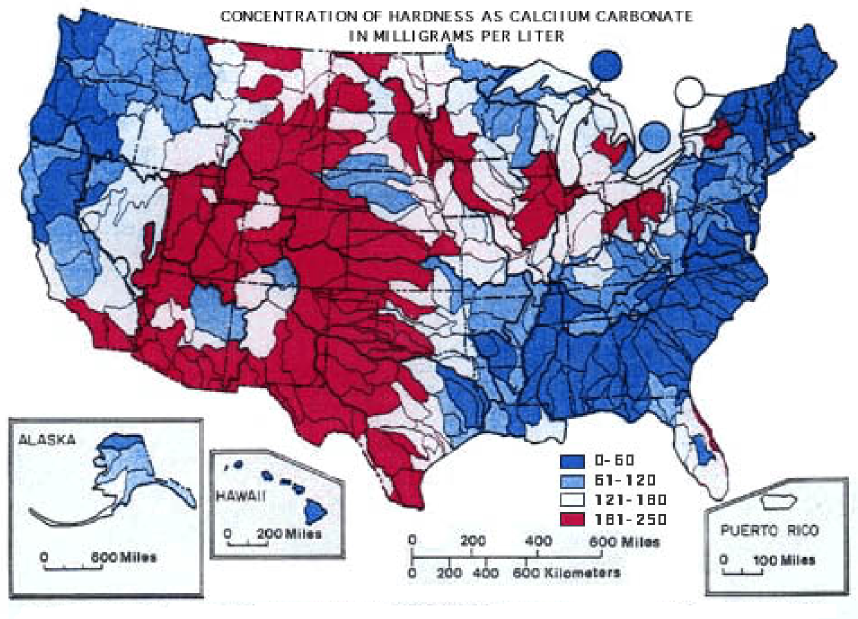

Figure 27. Mean hardness as calcium carbonate at National Stream Quality Accounting Network stations in 1975 water year. Taken from Briggs and Ficke (1977).

requirement to continued survival and spread of Bighead Carp. For successful establishment, in addition to having reproduction requirements met, larvae and juveniles must be able to recruit successfully into the population for *Hypophthalmichthys* to become established in additional areas in the United States.

Silver Carp

Like Bighead Carp, Silver Carp have wide environmental tolerances. They can tolerate long winters under ice cover as well as temperatures higher than 40°C (Opuszynski et al. 1989).Fry and fingerlings can survive in waters with a pH of 5.0 to 9.0, dissolved oxygen 1-28 mg/L, total alkalinity 88-620 mg/L, and salinity 7.5-12.0 mg/L (Singh et al. 1967 in Tripathi 1989).

In Asia, Silver Carp are native from about 54°N southward to 21°N (Xie and Chen 2001; Froese and Pauly 2004). Most of North America falls within these latitudes. Fifty-four degrees north latitude bisects British Columbia, Alberta, Saskatchewan, Manitoba, Quebec, and cuts across the southern basin of Hudson Bay; 21°N includes approximately three-quarters of Mexico (to Guadalajara in the west to the northern part of the Yucatan Peninsula in the east). This fact, along with establishment of this species in countries with climates as tropical as most of Vietnam, as arid as Afghanistan and Pakistan, and as temperate as Kyrgyzstan and Latvia, lead to the conclusion that climate alone in the United States should not limit distribution of Silver Carp.

Because food availability, predation, and competition are not known to limit populations of this species elsewhere, access to habitats required for successful reproduction (i.e., substantial lengths of flowing water) will play a large role in determining potential range of Silver Carp in

American waters. Another factor that may limit the distribution of Silver Carp in the United States is the requirement of incubation of eggs in waters with fairly high ionic concentrations (Gonzal et al. 1987). In the laboratory, when eggs of *Hypophthalmichthys* were incubated in water with a hardness of less than around 200 mg/L calcium carbonate, eggs continued to absorb water and burst prematurely. The location of areas in the United States presently inhabited by *Hypophthalmichthys* suggests that more research is needed on this requirement for successful reproduction (Fig. 27). *Hypophthalmichthys* are presently found in waters with water hardness <200 mg/L calcium carbonate, although it is possible that successful reproduction cannot occur in these areas. In addition, Fig. 27 indicates mean water hardness across the country, and does not account for seasonal variation. Understanding seasonal variation in water hardness may be critical to predicting the potential distribution of Silver Carp in the United States.

Successful reproduction is only one requirement to continued survival and spread of Bighead Carp. For successful establishment, in addition to having reproduction requirements met, larvae and juveniles must be able to recruit successfully into the population for *Hypophthalmichthys* to become established in additional areas in the United States.

Largescale Silver Carp

There is no evidence that the Largescale Silver Carp has been introduced to the United States. Within its native range, the species occurs in a subtropical to tropical climate. Therefore, should pure stock be introduced to U.S. waters, its potential range could be limited to subtropical waters such as those present in southern Florida and Hawaii. Hybrids of Largescale Silver and Silver carps, however, would be expected to tolerate temperate waters as they do in Kazakstan at 42-44º N (Salikhov and Kamilov 1995).

Potential Range in the Great Lakes Region

Angling groups, commercial fishers who depend on catching native species, and government agencies of states within the Great Lakes Basin, have expressed concern that Bighead and Silver carps could expand their U.S. range to include the Great Lakes. The most probable pathway for gaining access to the Great Lakes is through the Chicago Sanitary and Shipping Canal (Fig. 28), an artificial connection at the southern basin of Lake Michigan and the Illinois River System. Fear that these and other Asian carps may enter the Great Lakes provided support for the construction of a permanent electrical barrier to replace a demonstration barrier in the Chicago Sanitary and Ship Canal, near Romeoville, Illinois (Fig 28). Costs for construction of this second barrier are substantial ($9.1 million) and were supplied by the U.S. Army Corps of Engineers, and the states of Illinois, Wisconsin, Minnesota, Michigan, Pennsylvania, Ohio, New York, and Indiana (Moy 2005). Using statistical modeling, Kolar and Lodge (2002) predicted that Silver Carp could become established in the Great Lakes. Results of the 2004 Asian Carp Corral, an annual survey of the Illinois Waterway System designed to monitor the upstream movement of Bighead and Silver carps, indicated that these fishes had not moved closer than about 21 miles below the barrier site, which is 50 miles from Lake Michigan (Steingraeber 2004).

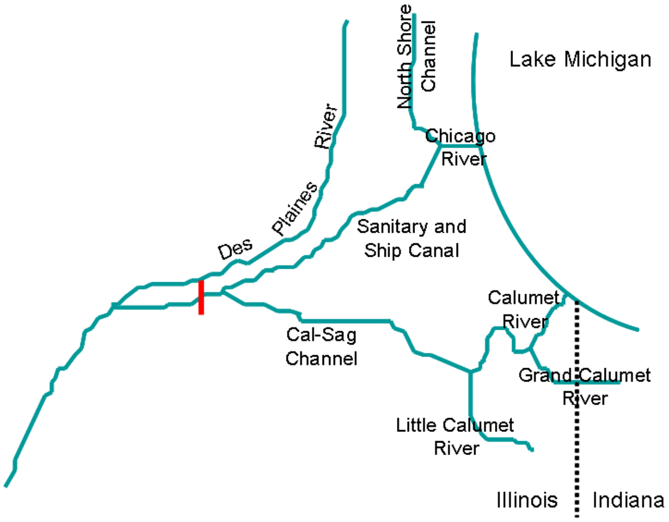

Figure 28. Schematic of the Chicago Sanitary and Shipping Canal, Chicago, Illinois. The site of the temporary and permanent electrical barrier for aquatic invasive species now under construction in Romeo, Illinois, is indicated with the red bar. Modified from figure provided by P. Moy, Wisconsin Sea Grant Program, Manitowoc, Wisconsin.

Because these carps appear to be incapable of reproducing in lakes, instead requiring rivers with 100 km or more of undammed flowing water for successful reproduction, we examined availability of such habitat on the U.S. side of the Great Lakes. We did not include an analysis of Lake Ontario tributaries because of the multitude of connected wetlands that are difficult to map. Figure 29 includes 22 rivers flowing into Lakes Erie, Huron, Michigan, and Superior that could potentially serve as spawning sites for these carps.

Population and Distribution Control Measures

Control programs that successfully reduce the abundance or control the distribution of nonindigenous fishes typically integrate a variety of control strategies targeting the species of concern (Dawson and Kolar 2003). Little research has been conducted on Bighead and Silver carps regarding control of undesired populations. The most thoroughly researched avenue of population control for these species is the use of piscicides. The toxicity of 13 chemicals to Bighead Carp has been determined in 34 studies and the toxicity to Silver Carp has been determined for 21 chemicals in 83 studies (Pesticide Action Network 2004). Only three studies examined the toxicity of chemicals presently or recently registered by the U.S. Environmental Protection Agency for use as piscicides in the United States (Henderson 1976; Marking and Bills 1981; Chapman et al. 2003). *Hypophthalmichthys* constituted more than 90% of the mortality because of a cyanide spill in Hungary, but it is unknown if these fishes are especially susceptible to cyanide, of if that percentage reflects the species assemblage of the Danube River System where it occurred (International Task Force for Assessing the Baia Mare Accident 2001). Although toxicological studies have been conducted on Bighead and Silver carps, no field testing has been conducted to specifically target these species. Chemical treatment of the Mississippi

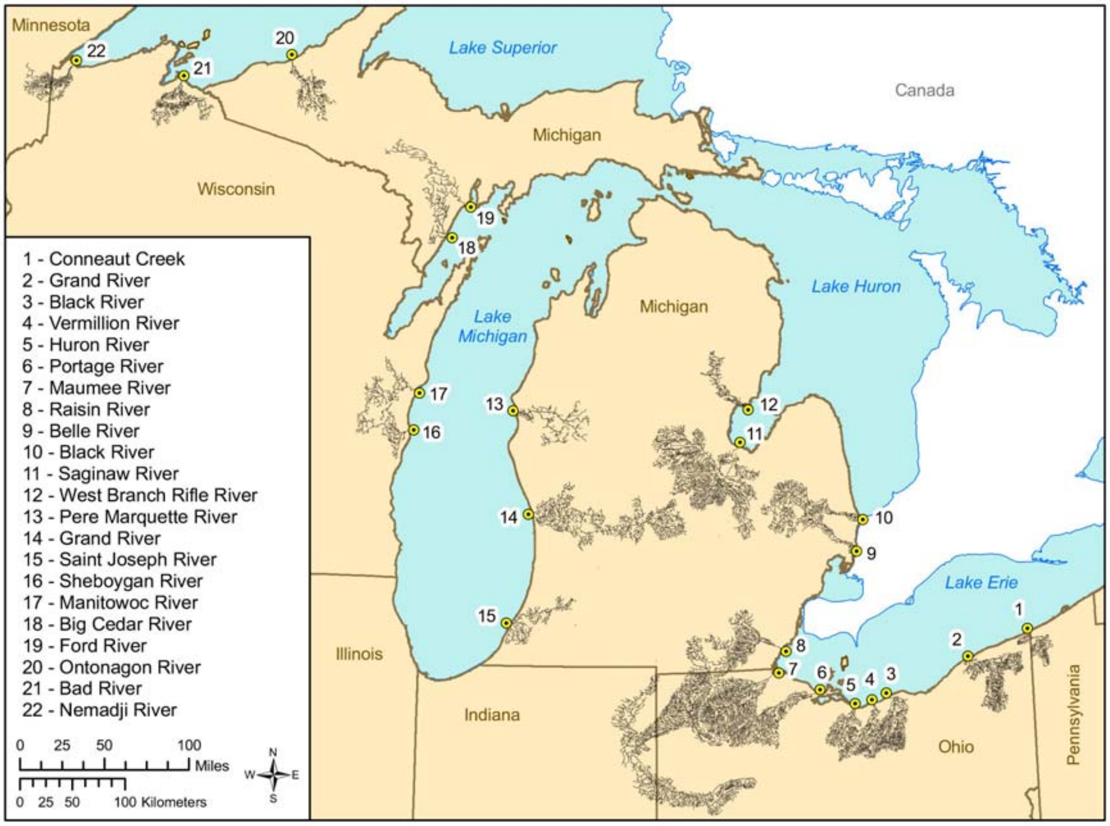

Figure 29. Map of Lakes Erie, Huron, St Clair, Michigan, and Superior indicating rivers lacking dams and having a minimum length of 100 kmthat may be suitable for spawning by Bighead (*Hypophthalmichthys nobilis*) and Silver (*H. molitrix*) carps. Map developed by C. Lowenburg, U.S. Geological Survey.

River and other large rivers in the United States to control Bighead and Silver carps is not logistically and economically feasible. In addition, chemical treatments would need to be conducted regularly and would probably not be supported by the public or regulatory agencies.

Other management strategies presently available to control the abundance and distribution of Bighead and Silver carps are relatively new, experimental, or have not been used on systems as large as the Mississippi River. In an analysis of potential measures to control the expansion of Bighead and Silver carps into Minnesota, FishPro Consulting Engineers and Scientists (2004) suggested that (1) public education, (2) research and monitoring (especially in new control techniques), (3) regulation of Bighead and Silver carps and enforcement of rules and regulations pertaining to the species, (4) fisheries management, (5) barriers and deterrents to prevent Bighead and Silver carps from spreading into areas not yet infested, (6) ecological risk assessments to predict present and future distribution, and (7) targeted harvest, not managed to be sustainable, are the best measures to control the future spread of these fishes. Potential behavioral barriers and deterrents to spread include strobe lights, air bubble curtains, acoustic deterrents, electrical deterrents, and hydrodynamic louver screens (FishPro Consulting Engineers and Scientists 2004). Potential physical barriers for Bighead and Silver carps include vertical drops, rotating drums and traveling screens, floating curtains, and areas with high water velocity (FishPro Consulting Engineers and Scientists 2004). Commercial harvest of Bighead and Silver carps requires specialized and expensive gear that combines blocking, driving, gill netting, and seining based on an understanding of the behavior of these fishes (Li and Senlin 1995).

Pegg et al. (2004) are presently evaluating the effectiveness of bioacoustic, electrical, and integrated bioacoustic electrical cross channel barriers in restricting the movement of *Hypophthalmichthys*. Early results indicate that electrical barriers can be quite effective in deterring movement of adult Bighead Carp. Pegg et al. (2004) also found that bioacoustic barriers that combine sound and bubbles can also be effective, if proper sound frequencies are employed.

Predator enhancement, the stocking or increased stocking of predators, is sometimes used to control pest fishes (Cowx 1994). Little information is available on the predators of *Hypophthalmichthys*. Negonovskaya (1980) reported that Zander, Northern Pike, Eurasian perch, and Ide fed on Bighead Carp in reservoirs in the former USSR and that predation on young-of-year resulted in economic losses. Piscivorous fishes in the United States undoubtedly include larval and juvenile Bighead and Silver carps in their diets, but the extent to which this is occurring is unknown. Bighead and Silver carps grow quickly and would probably quickly outgrow stocked predators. More research would be necessary before implementing a predator enhancement program to control *Hypophthalmichthys*.

The use of pheromones as “bait” in fisheries of Bighead and Silver carps is under investigation (E. Little, U.S. Geological Survey, Columbia, Missouri, personal communication, 2004), but has not yet been thoroughly tested. If pheromones play a part in the observed long-distance spawning migrations of *Hypophthalmichthys* or in the aggregation of the large schools of juveniles, then pheromones may eventually become useful management tools. For example, attractant pheromones, once identified and developed for field use, could be used to improve efficiency of removing fish with nets. Another possible use of Bighead and Silver carp pheromones would be to use alarm substances to keep these fishes from moving into additional uninhabited areas. Alarm pheromones, also known as "Schreckstoff" (or scary stuff) substances (von Frisch 1941), are released by a damaged or frightened individual and elicit a fright reaction in conspecifics. Bighead and Silver carp alarm pheromones could be dripped in areas such as locks or other potential barriers to movement to keep the fishes from moving into uninhabited waters.

Another avenue for research to control Bighead and Silver carps (as well as other nonnative fishes) is to develop stocks of fishes where the ability to produce only monosex offspring is heritable. The development of ‘daughterless’ Common Carp is ongoing (Nowak 2002). Using this control strategy, ‘daughterless carp’ would be cultured in large numbers and released into the wild. These fertile fishes would mate with feral stock and all resulting progeny would be sterile. In this way, reproduction would be limited in the future by a scarcity of females. Although research and development of this control method is not complete, it may hold future promise for control of Common Carp and other invasive fishes.

The development and use of sterile Bighead Carp (and Silver Carp, also should commercial culture of this species reoccur) for the purpose of aquaculture would reduce the risk of additional harmful introductions from this pathway. Triploidy induction techniques seldom produce triploidy in all individuals of any species. Therefore, if triploids are used to prevent reproduction in Bighead and Silver carps, then each fish must be individually tested for ploidy and diploid fishes discarded (Rottmann et al. 1991). There is a legislated procedure (Public Law 104- 40 1995) whereby the ploidy of Grass Carp is individually tested and results certified by the U.S. Fish and Wildlife Service at the expense of the aquaculturist. Installation of such a procedure for Bighead Carp would be possible and could reduce the risk of establishment in additional waterbodies, but such a program would result in increased expense to the culturist. It should be noted that while the functional sterility of triploid Grass Carp has been demonstrated (Van Eenenham et al. 1990), similar studies have yet not been performed on *Hypophthalmichthys*. Triploid fish are generally assumed to be sterile because of problems with reduction division during gametogenesis (Thorgaard 1983). It seems likely that triploid *Hypophthalmichthys* would be sterile, but in some fish species, including some carps, triploids have been shown to be sometimes fertile (Zhang and Takashima 1992; Pandian and Koteeswaran 1998; Abramenko et al. 2004).

Another option to reduce the risk of harmful introductions from aquaculture, most relevant if the species were not already established in the wild, would be the use of monosex or gynogenetic stocks. Gynogenetic stocks are developed using sperm-activated eggs without contribution of the male genome (Mizra and Shelton 1988). Gynogenetic stocks of Silver Carp have successfully been developed by inactivating sperm or eggs of fishes using ultraviolet radiation, subjecting eggs to cold/heat shock, inducing tetraploidy by exposing zygotes to heat/cold after the first meiotic division, and crossing tetraploid with diploid fish. Kowtal (1991) stated that the resultant progeny are triploid and sterile. Zou et al. (2004) examined the incorporation of heterologous genetic materials in first and second generation gynogenetic Silver Carp originally produced from stock from the Yangtze River in 1987. By examining the genetic similarity of individuals in the successive generations, they determined that heterologous genetic materials had obviously entered the gynogenetic stock of Silver Carp, an indication of natural reproduction. Tave (1993) compared the growth rates of triploid and diploid Bighead Carps in ponds. After the ponds were drained, ploidy of all individuals was determined, and 7.9% of all triploid stocks were actually diploids. These findings suggest that although sterility can be induced in Bighead and Silver carps, that further research is needed before the high percentages of triploidy that are now achieved with Grass Carp (Van Eendenham et al. 1990).

In summary, no “off-the-shelf” control measure, other than a public education campaign, used to control and spread or abundance of other nuisance fishes, are ready for immediate use on Bighead and Silver carps. Regulation of these species varies greatly from state to state. Moreover, the efficacy of presently used behavioral and physical barriers needs to be determined for these fishes and for the scale of water bodies requiring management. Commercial markets for these fishes are only now beginning to develop.

State Regulations as of January 2005

State laws regarding the regulation and prohibition of invasive species are continually in flux; this is also true for the regulation of Bighead and Silver carps. Within a given state, however, regulations for Bighead Carp parallel those for Silver Carp in all instances except one (and that was only for 1 year; see discussion on approved commercial species below). That is, a review of state codes revealed that if a state regulates Bighead Carp, it generally regulates Silver Carp in the same manner. Since 2002, a variety of state regulations have been passed regarding Bighead and Silver carps (Table 10). Most of these regulatory changes have been in response to growing concern over the spread of these species to the Great Lakes drainage.

Before mid-2002, 17 states specifically prohibited or regulated (required a permit) for possession of Bighead and Silver carps (Fig. 30). Since mid-2002, eight additional states (five from the Great Lakes drainage) have enacted legislation prohibiting or regulating the possession of these species (Fig. 30). All but three of the same states that regulated possession (Arizona, Arkansas, and Washington) also regulated the importation of Bighead and Silver carps before mid-2002. Additionally, all states but Louisiana and Michigan of the states adding legislation to regulate possession of these species since mid-2002 enacted legislation to regulate their importation. The new Louisiana statute does not specifically list Bighead and Silver carps in its language; rather it lists “carp” excepting Common Carp and Goldfish (Table 10).

The sale of Bighead and Silver carps was regulated in Colorado, Georgia, Iowa, Minnesota, Mississippi, Ohio, Texas, and Virginia before mid-2002. Since that time, because of concerns over the sale of Bighead Carp, especially in live fish markets, statutes have been enacted in Illinois, Indiana, New York, and Pennsylvania prohibiting the sale of Bighead and Silver carps. In Illinois, it is presently illegal to sell live Bighead or Silver carps within the City of Chicago. In New York, it is illegal to sell live Bighead or Silver Carp in the state, with an exception for the sale of these fishes in live markets in New York City, provided they are killed before leaving the retail establishment.

The culture of Bighead and Silver carps is specifically prohibited in Minnesota, Ohio, and Oklahoma. In addition, culture of all finfish in Alaska is prohibited. Other states generally maintain approved species lists for aquaculture, some of which include these species, have a prohibited species list, or have a permit system for which aquaculturalists include a list of species they wish to culture as part of the application process. Decisions as to whether to allow the culturing are then made, in part, based on the species requested to culture. Transportation of Bighead and Silver carps is presently regulated in California, Colorado, Florida, Georgia, Illinois, Louisiana, Minnesota, Nevada, New York, Pennsylvania, South Carolina, and Texas. South Carolina requires a transportation permit only if the species is being transported with the intent to release. Also, legislation in New York allows transportation of Bighead and Silver carps to New York City (Table 10). In addition to legislation that specifically targets Bighead and Silver carps, some states have blanket legislation prohibiting the importation, culture, possession, or transportation of any fish or nonnative fishes. This type of legislation may or may not be used to regulate Bighead and Silver carps within any given state.

Several states encourage the commercial take of Bighead and Silver carps by including them in approved or permissible commercial species lists (Illinois, Missouri, and Nebraska before mid-2002; Tennessee since that time). Iowa first added Bighead Carp to the permissible

Table 10. State regulations approved since mid-2002 placing restrictions on Bighead (*Hypophthalmichthys nobilis*) and Silver (*H. molitrix*) carps.

State	**New legislation**	**Date effective**
Arkansas	Raising restricted species now requires a Restricted Species Permit (Silver and Bighead carps on restricted list; GFC Code 42.09)	Oct. 1, 2002
Iowa	Added Silver Carp to the list of permissive commercial catch (Iowa Administrative Code 82.2)	Jan. 14, 2004
Illinois	(1) It is illegal to import, sell, transport, carry, own, keep or otherwise possess any live Bighead or Silver carps within the City of Chicago (Section 7-12-385, Chicago City Ordinances) and (2) added Bighead and Silver carps to the list of injurious species, making it illegal for the species to be possessed, propagated, bought, sold, or transported without a permit (17 Ill. Adm. Code Part 805)	Apr. 9, 2003; May 1, 2005
Indiana	Added Bighead and Silver carps to the list of fish that a person must not import, possess, propagate, buy, sell, barter, trade, transfer, loan, or release into public or private waters (312 IAC 9-6-7)	Dec. 1, 2002
Louisiana	Cannot possess, sell, or transport without obtaining the written permission of the Secretary of the Department of Wildlife and Fisheries, any of the following species of fish: carp (except those taken in state waters, provided such fish shall be dead when in a person's possession, Common Carp and Goldfish, among others listed; RS 56:319)	May 28, 2003
Michigan	Added Bighead and Silver carps and hybrids of those species to the list of prohibited species. A person shall not possess or release a live prohibited species (Section 41301 of Act 451 of 1994)	Mar. 30, 2004
New York	Added Bighead and Silver carps to the list of species that cannot buy, sell or offer for sale, possess, transport, import or export, or cause to be transported, imported or exported live individuals or viable eggs without a permit. There are exceptions for several areas, including New York City (Title 6 NYCRR, Section 180.9)	Feb. 4, 2004
Pennsylvania	Added Bighead and Silver carps to list of live species for which transportation in or through this Commonwealth is prohibited (Title 58 PA Code, Sec. 73.1). Added Bighead and Silver carps to list unlawful to possess and introduce or import; unlawful to sell, purchase, offer for sale or barter live (Sec. 63.46)	Sept. 6, 2003
South Dakota	Below Gavins Point Dam, can now only collect bait for use at that location, cannot transport from site (listed in 2004 Fishing Regulations)	2004
Tennessee	(1) Added to list of Class V wildlife (need importation permit and no one but zoos can possess; Ch. 1660-1-18-.03) and (2) added to the approved commercial species list, but because Class V, cannot be possessed alive or by commercial fishers but may be taken (Proclamation 02-13)	Mar. 3, 2003; Oct. 16, 2002
Utah	Carp, including hybrids, of Family Cyprinidae (all species except Koi), prohibited for collection, importation, and possession (R657-3-23)	June 3, 2003
Washington	Listed as a 'prohibited species' under the first use of the authority to list species (WAC 220-12-090)	Jan. 16, 2004

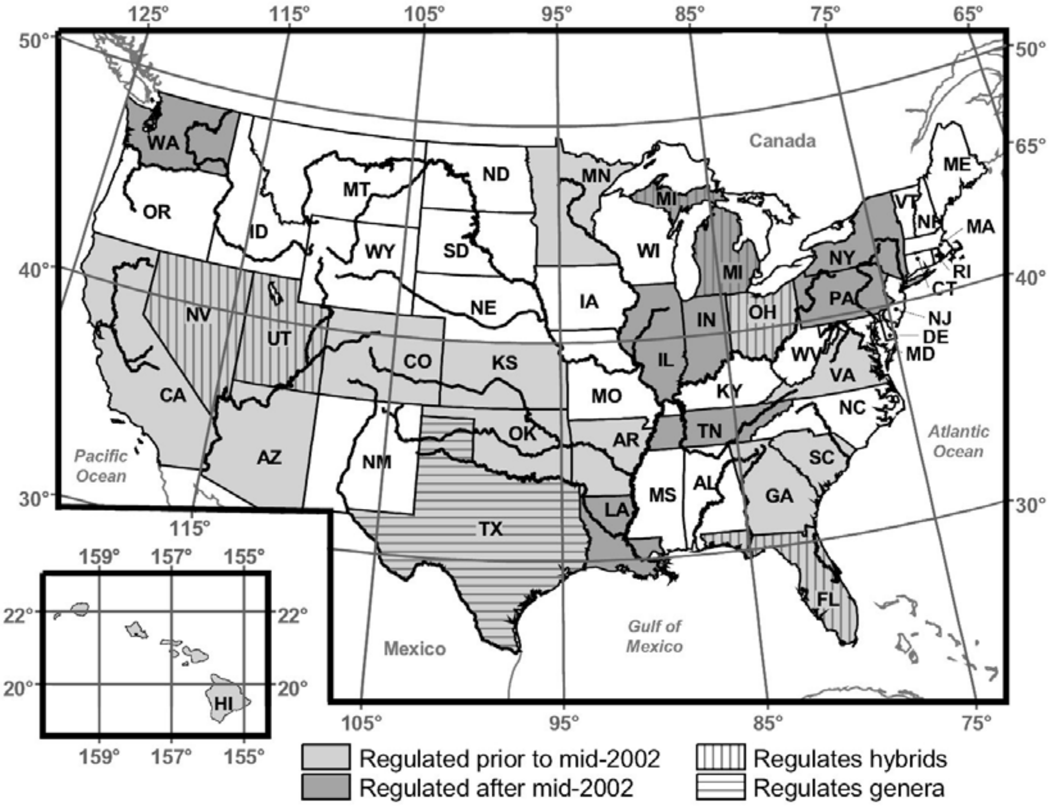

Figure 30. States that regulated the possession of Bighead (*Hypophthalmichthys nobilis*) and Silver (*H. molitrix*) carps before and after mid-2002 (states regulating the species are shaded). Also shown are states that prohibit possession of Largescale Silver Carp (*H. harmandi*) and hybrids of Bighead or Silver Carp with Largescale Silver Carp.

commercial species list in 2003 and then added Silver Carp to the list in 2004. Commercial fishers in Tennessee may take Bighead and Silver carps, but they may not possess them live (Table 10). The use of Bighead and Silver carps as live bait is only specifically regulated in Arkansas and only since mid-2002. Connecticut restricts the use of “carp” as bait and, although no scientific name is given in the legislation, it was no doubt written with Common Carp in mind. South Dakota recently restricted the removal of live baitfish collected below Gavins Point Dam because of concern over moving juvenile Bighead and Silver carps collected for bait, but the use of these species as bait is not specifically prohibited.

In January 2005, the state of Illinois amended Section 17, Illinois Administrative Code 805 to list Bighead and Silver carps (and several other species) to the state injurious species list. This designation prohibits possession or sale of live Bighead and Silver carps in the state. The amendment makes an exception for the live hauling of Bighead or Silver carps that were caught or cultured in other states through Illinois. Although Bighead and Silver carps remain on the permissible commercial species in the state, transportation of live fishes require a special permit. This new legislation will become effective May 2005.

There have been illegal activities involving Bighead Carp. In fall 2002, a fish farmer in Amana, Iowa, was sentenced by a Federal Court in Des Moines for illegally possessing and transporting Bighead Carp from a Missouri fish farm to his Iowa fish farm with the intention of raising the species in 1 of 63 ponds on the complex. Attempts by the fish farmer to obtain permits to bring Bighead Carp legally into Iowa in 1992 and 1993 were denied by the Iowa Department of Natural Resources, citing potential dangers to native fishes should the Bighead Carp escape. Also, in February 2004, Department of Interior investigators arrested an Arkansas fish dealer and farmer in Chinatown in downtown Chicago. The Arkansas dealer had illegally transported live Bighead Carp into Illinois and was retailing and wholesaling the fish, along with other fish species, out of their semitruck. Additionally, they did not have a Non-Resident Fish Dealer's License. They were cited for those violations along with failure to have required labeling on aquatic life being shipped.

Even though half of the states specifically regulate Bighead and Silver carps, our review shows that only Texas outlaws the possession of Largescale Silver Carp. In Texas, the genera *Hypophthalmichthys* and *Aristichthys* are prohibited. Additionally, in Florida, Michigan, Nevada, Ohio, and Utah (Fig. 25), hybrids of Bighead and Silver carps are regulated and would thus include hybrids of these species with Largescale Silver Carp. Utah regulates hybrids of the entire cyprinid family (except for Koi Carp).

Environmental Risk Assessment Process

Bighead and Silver carps were brought into the United States in the early 1970s, primarily to control phytoplankton in culture ponds and in wastewater treatment lagoons. In addition, because Bighead Carp is a popular food fish in China, a market developed for sale of the species in Asian live seafood markets in the United States and Canada. Silver Carp is not presently being cultured commercially in the United States, but two live, wild-caught Silver Carp were observed in an Asian live seafood market in Toronto, Ontario, on October 7, 2004 by two of the authors (WRC and DCC). Bighead Carp is cultured in the United States and appears to be accepted in the market by Asian immigrants. To our knowledge, the Largescale Silver Carp has not been imported into the United States.

This assessment of the organism risk potential of each of the three species of *Hypophthalmichthys* to the United States uses the Generic Nonindigenous Aquatic Organisms Risk Analysis Review Process (Risk Assessment Management Committee 1996) and draws on information presented earlier. Citations for all statements in this section that are presented as fact are provided in the biological synopsis portion of this document. Those statements that are conjecture based on the best available information are clearly indicated. The Generic Nonindigenous Aquatic Organisms Risk Analysis Review Process involves the rating of seven elements of risk (four assessing the probability of establishment and three the consequences of establishment) to determine the overall organism risk potential. Each element is assigned an estimated level of risk, rated as high, medium, or low. The degree of certainty associated with risk-level assignment is also expressed for each of the seven risk elements. Categories for uncertainty include Very Certain, as certain as we are going to get; Reasonably Certain, certain within reason; Moderately Certain, more certain than not; Reasonably Uncertain, uncertain within reason; and Very Uncertain, a guess. Below, risk assignments and the associated degree of certainty are provided for each of the seven elements of risk required to assess the organism risk potential for each species of *Hypophthalmichthys*. See Risk Assessment Management Committee (1996) for detailed methods on using this risk-analysis process.

In many respects, the biology and natural history of the species of *Hypophthalmichthys* are so similar that we considered them together in text. We considered the species separately for the characteristics and circumstances in which they differ. Species-specific organism risk potential models for Bighead, Silver, and Largescale Silver carps follow the discussion of the rating elements of the risk.

Rating Elements of Risk Model

(1) Estimate probability of the exotic organism being on, with, or in the pathway

Bighead Carp: High—Very Certain
Silver Carp: High—Very Certain
Largescale Silver Carp: Low—Reasonably Certain

Bighead and Silver carps have been reproducing in natural waters of the United States since at least 1989 and 1995, respectively. Recent and ongoing field sampling confirms that both species continue to expand their range and increase in abundance in the United States. Bighead Carp have been introduced to waters of 73 countries and territories, including the United States. This species has been collected from waters of 23 U.S. states and one Canadian province (Ontario). Silver Carp have been introduced to 88 countries and territories, including the United States, and specimens have been collected from 16 U.S. states and Puerto Rico. Hybrid Bighead × Silver carps were introduced to an urban lake in Arizona, and hybrids of Bighead and Silver carps have been collected from the Missouri River. There are no records of Largescale Silver Carp having been introduced into the United States.

Although Silver Carp have seldom been cultured in the past 25 years, Bighead and Silver carps have been, and remain in, the United States pathway (as evidenced by growing, self-sustaining populations). Therefore, the risk of establishment of Bighead and Silver carps being in the pathway is high and proven, with complete certainty. Largescale Silver Carp are not in the pathway, with reasonable certainty.

(2) Estimate probability of the organism surviving in transit

Bighead Carp: High—Very Certain
Silver Carp: High—Very Certain
Largescale Silver Carp: Medium—Reasonably Certain

Both Bighead and Silver carps have survived transit from countries of origin into the United States. Both species have also survived transit in live-haul trucks within the United States and Canada and there is a high probability of individuals of each species surviving transport for use as baitfishes. The Silver Carp is not presently being cultured for marketing purposes in the United States. Mortality because of handling stress resulting from harvesting and subsequent poor ability to survive transport in live-haul trucks limit the use of Silver Carp for marketing purposes. Nevertheless, two wild-caught, live Silver Carp were observed in a market in Toronto in 2004, indicating that live transport of subadult market-sized individuals is possible. Smaller individuals of both species may be transported purposefully or accidentally by anglers or baitfish dealers and released into uninfested waters. Even though market-sized Silver Carp experience high mortality while in transport, young Silver Carp do not appear as fragile. The existence of transport of live Bighead and Silver carps within and beyond the United States demonstrates that the likelihood of these fishes surviving transport is high, with complete certainty.

Less is known about the ability of Largescale Silver Carp to survive transport than for Bighead and Silver carps. Hybrid Largescale Silver Carp are known to have survived transport from China to Kazakstan, where they were stocked, but they have probably been transported minimally otherwise. The similarity of Largescale Silver Carp to Silver Carp suggests that it could survive transit to the United States. Survival of Largescale Silver Carp in live-haul trucks is unknown. We have assigned a risk of medium with reasonable certainty to the Largescale Silver Carp.

(3) Estimate probability of the organism successfully colonizing and maintaining a population where introduced

Bighead Carp: High—Very Certain
Silver Carp: High—Very Certain
Largescale Silver Carp: Medium—Reasonably Certain

Appropriate habitats (lakes, ponds, reservoirs, canals, rivers, streams, and associated backwaters), a hospitable climate, and abundant food resources to support all three species of *Hypophthalmichthys* are found in much of the United States. Preferred food of Bighead Carp is zooplankton whereas Silver and Largescale Silver carps prefer phytoplankton. All three species can consume other foods as well. Both zooplankton and phytoplankton are locally abundant in U.S. waters, especially in large rivers and reservoirs.

Both Bighead and Silver carps have demonstrated abilities to colonize and maintain populations in the United States and other countries. Furthermore, both species continue to expand their distribution within the United States. Given the successful establishment and spread of Bighead and Silver carps in the United States and elsewhere, we can say with complete certainty that the probability of successful colonization of those species is high.

On the basis of its native distribution, it would appear that pure stock of the subtropical and tropical Largescale Silver Carp has potential to survive and perhaps become established if introduced in southern Florida and Hawaii, and perhaps in southern Texas. Lack of access to suitable rivers for spawning, however, may preclude spawning. We are reasonably certain that the probability of establishment of Largescale Silver Carp is medium within the geographic range in the United States dictated by climate tolerance of this species. Hybrids between Silver and Largescale Silver carps were introduced to and became established in Kazakstan, indicating that these hybrids, if introduced in the United States, could become established in U.S. waters capable of supporting Silver Carp.

(4) Estimate probability of the organism to spread beyond the colonized area

Bighead Carp: High—Very Certain
Silver Carp: High—Very Certain
Largescale Silver Carp: Medium-High—Moderately Certain

Habitats (rivers, streams, lakes, reservoirs, ponds, and canals), climate, and food resources in the United States have proven acceptable to both Bighead and Silver carps, resulting in substantial spread beyond areas from which these fishes escaped or were released. Range expansion of both species continues and populations appear to be increasing exponentially in some areas. The continuing spread of Bighead and Silver carps in the United States demonstrates with complete certainty that the risk of spread is high.

Because the Largescale Silver Carp is closely related to the Silver Carp, it is reasonable to expect that it has a similar ability to spread from the point of introduction. The subtropical and tropical distribution of Largescale Silver Carp, however, suggests that if it does become established, relatively little of the United States would provide suitable habitat for pure stock (perhaps only Hawaii, southern Florida, and southern Texas). Lack of access to suitable rivers for spawning in these areas may preclude successful spawning. Hybrid Largescale Silver × Silver carps are established in Kazakstan. The likelihood of hybrids to spread beyond points of release within the United States is probably higher than that of the pure stock. Because less of the United States is suitable for colonization by pure Largescale Silver Carp, we assigned a risk of medium-high to the probability of spreading beyond the point of introduction. We are only moderately certain of this designation since this species has only been introduced once and only as a hybrid with Silver Carp.

(5) Estimate economic impact if established

Bighead Carp: Medium to high—Reasonably Certain
Silver Carp: Medium to high—Reasonably Certain
Largescale Silver Carp: Low to Medium—Moderately Certain

Both Bighead and Silver carps are established throughout much of the Mississippi River Basin and continue to expand their range. Population sizes of both species are also increasing. This fact, taken with the presence of similar climate and habitat in the United States as in their native range, indicates that these species may eventually dominate fish communities in suitable waters. It appears that native predators are unable to significantly reduce expanding populations of these carps. Because these fishes feed on plankton, their diets overlap to some extent with the young of virtually all native fishes, and all life-history stages of planktivorous species, including fishes and invertebrates. If food resources become limiting, Bighead and Silver carps may compete directly with these native species. Because many native fishes are important as sport and food species, their decline would result in a negative economic impact on recreational angling and other industries that benefit from sport fishing, such as tourism.

Bighead and Silver carps now outnumber the catch of native species sought after commercially in several waters of the Midwest. Recent (2004) deployment of a hoop net in the

Red River, Louisiana, caught approximately 408 kg of Bighead, Silver, and Grass carps, and no native fishes. Between 2002 and 2004 in the lower Missouri River, using methods similar to those most often used by local commercial fishers, more than twice as many *Hypophthalmichthys* were caught than all other commercial species combined. Commercial species were not weighed, but the average weight of individual *Hypophthalmichthys* was estimated to be at least double that of the individual commercial species caught. This indicates that in some areas there exists a negative economic impact to persons who depend upon commercial fishing targeting native species for their livelihoods. There is the possibility that some of these negative economic impacts could be reduced if the market for Bighead and Silver carps from commercial fishers improves. This, however, would present competition with aquaculturists raising the Bighead Carp in particular for sale in ethnic markets. Presently, only a limited, low value market exists.

The jumping behavior that Silver Carp exhibit in response to boat engine noises has potential for negative economic effects to areas they invade. Reports of large jumping Silver Carp seriously injuring boaters, their equipment, and water-skiers are becoming more frequent. Recreational anglers and personal watercrafters report a growing number of injuries including cuts from fins, black eyes, broken bones, back injuries, and concussions. Silver Carp also cause property damage such as damages to boats that range from minor to severe, including broken radios, depth finders, fishing equipment, and antennae. In addition, when a Silver Carp lands in a boat, it often leaves slime, scales, feces, and blood for boaters to contend with. Threat of personal injury, perhaps even human deaths, and damage to personal property is likely to reduce the amount of recreation occurring in invaded waters and may reduce the money brought into the region for such activities.

Because of the negative effects of potential declines in native fish stocks available for commercial and recreational fishing and because of lost recreational opportunities due to the jumping behavior of Silver Carp, we are reasonably certain that established populations of Bighead and Silver carps present a medium to high risk of causing negative economic consequences on the environment. On the basis of the subtropical and tropical native distribution of the species, Largescale Silver Carp, would survive in only a small portion of the United States. Hybrids between Largescale Silver Carp and Silver Carp may have similar economic effects on the environment as Silver Carp. We therefore rated Largescale Silver Carp as having a Low-Medium probability of causing economic impacts with moderate certainty.

(6) Estimate environmental impact if established

Bighead Carp: Medium to High—Reasonably Certain
Silver Carp: Medium to High—Reasonably Certain
Largescale Silver Carp: Medium—Reasonably Certain

Declines in native fishes, particularly of planktivorous species, are well documented from several other countries in which these fishes have been introduced. Given examples of declines in native fishes after the introduction of Bighead and Silver carps, it is reasonable to expect similar declines in native fishes in the United States, particularly those that rely heavily on plankton as a food resource. Extirpations and extinctions of native and endemic fishes have been linked to the introduction of Bighead and Silver carps elsewhere, although in these events, these fishes were not the only nonnative species indicated, and other factors, such as water removal and habitat degradation played roles in those events. Virtually all native fishes rely on plankton during larval and early juvenile stages and because *Hypophthalmichthys* frequently occur in high densities, the potential for competition with early-life stages of native fishes could be quite high. *Hypophthalmichthys* are known to occupy the same habitats as some native species in the United States. Competition for habitat between *Hypophthalmichthys* and native species is probably high, especially in large rivers, lakes, and reservoirs. Because species of the genus *Hypophthalmichthys* are not native to waters of the United States, there is little possibility of hybridization or interbreeding with native fishes, although *Hypophthalmichthys* can hybridize with each other and the resulting offspring are fertile. Potential for *Hypophthalmichthys* to cause habitat degradation is probably low, since they are planktivorous, but this is incompletely understood. Changes in water quality and sediment chemistry are possible.

Adverse effects of *Hypophthalmichthys* on native wildlife and wildlife resources, exclusive of fishes, would probably be minimal. One possible exception is freshwater mussels that rely on plankton for filter feeding and many are already imperiled because of habitat degradation and invasion by zebra mussel (*Dreissena polymorpha*). There is no indication, based on published literature, that this interaction has been examined. The effects of filter feeding and nutrient cycling by introduced *Hypophthalmichthys* in the United States could significantly alter trophic interactions in areas where these fishes come to dominate the fish community.

Potential to transfer pathogens (parasites, diseases) remains largely unknown. Nevertheless, both Bighead and Silver carps are hosts for the Asian carp tapeworm, a cestode capable of being transferred to other fishes of several different orders. Although this tapeworm has minimal effects on the host carps, it is capable of causing severe damage to the intestines of novel hosts that can lead to death. This parasite has been found in several species of native North American fishes including several endangered species. Bighead, Silver, Grass, and Black carps are known to host the Asian carp tapeworm, but it is unknown whether Largescale Silver Carp hosts this species.

Adverse effects on Threatened and Endangered Species would probably be high, particularly through possible transfer of the Asian carp tapeworm to those fishes. Candidate Threatened and Endangered fish taxa, such as Paddlefish, would likewise be at risk because of the potential direct competition for food and habitat.

The likelihood and magnitude of effects on designated critical habitats of Threatened and Endangered Species could be significant. Where low water velocity habitat may be limiting for native fishes, for example, in the channelized Missouri River, presence of large numbers of large and active Bighead and Silver carps could force native fishes from preferred habitats. Should these Asian carps become abundant, the most likely result would be an alteration of habitat use by native fishes. The most likely habitats affected would be rivers, larger tributaries, lakes, ponds, reservoirs, and perhaps canals. Habitats that would be most at risk would be low velocity, deep water areas and backwaters where Bighead and Silver carps are most abundant.

The possibility that carps of the genus *Hypophthalmichthys* could bring about the risk of extinction of native fishes is presently unknown, but losses of endemic fish biodiversity are documented associated with the introduction of Bighead and Silver carps. Fish species that would be most at risk are those that are planktivorous throughout their life-history stages but larval and juvenile stages of many species could be adversely affected.

There is likelihood that damage to ancillary fisheries resources through control measures will be substantial. Netting and electrofishing could be effective in reducing populations of Bighead and Silver carps, but they would also affect native fishes present in the area where such control measures are used. Similarly, use of piscicides, such as rotenone, would be expensive (perhaps prohibitively so), only locally effective, and would negatively affect all fishes and invertebrates, not just the target carps. Even most nonlethal methods to prevent the spread of Bighead and Silver carps, such as electrical barriers or bubble curtains, would negatively affect migratory native fishes. This effect could be minimized, however, if somewhat species-specific sonic barriers could be developed. Treatment of ballast water in vessels moving from waters containing reproductive populations of Bighead and Silver carps to waters devoid of these fishes may become necessary. At present, there is no method known to substantially reduce populations of Bighead and Silver carps. On the basis of presently available technology, eradication is not possible.

Because of the factors described above, we are reasonably certain that the environmental impacts from introduced, established populations of Bighead and Silver carps will range from medium to high with reasonable certainty. Only future monitoring of native fishes and invertebrate populations where these fishes are present will determine a more precise evaluation of these risks.

We are reasonably certain that the risk of environmental impacts of Largescale Silver Carp would be medium. This is because the potential range of pure stocks of the tropical and subtropical Largescale Silver Carp would be substantially smaller than for the other members of the genus.

(7) Estimate impact from social and /or political influences

Bighead Carp: Medium—Reasonably Certain
Silver Carp: Medium—Reasonably Certain
Largescale Silver Carp: Medium—Reasonably Certain

Angling groups, commercial fishers who depend on catching native species, and government agencies of states within the Great Lakes Basin, have expressed concern regarding the continuing range expansion and growing populations of Bighead and Silver carps. Apprehension that these and other Asian carps may enter the Great Lakes provided substantial support for the construction of a permanent electrical barrier to replace a temporary barrier in the Chicago Sanitary and Ship Canal, near Romeoville, Illinois. Costs for construction of this second barrier are substantial ($9.1 million) and came from the U.S. Army Corps of Engineers, and the states of Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania, and Wisconsin. The cost of operating this new barrier is estimated to be $20,000 per month. The

Department of Fisheries and Oceans Canada is conducting a risk assessment on Asian carps of the genera *Ctenopharyngodon*, *Hypophthalmichthys*, and *Mylopharyngodon* in Canada. Canadian scientists have expressed a strong desire to work with Federal agencies in the United States to protect the Great Lakes from these invasive fishes.

As the geographic distribution expands and populations of *Hypophthalmichthys* increase in waters of the United States, there may be negative effects to boaters and other groups that use inland waters for recreational purposes. The degree of negative effects to these segments of society cannot be estimated at this time. If, however, these negative impacts become significant over time, it is reasonable to expect that pressures to control these fishes in the United States may grow and eventually involve political influences.

Organism Risk Potential

The risk associated with all components of the probability of establishment (organism within pathway, entry potential, colonization potential, and spread potential) was rated high for Bighead Carp. Therefore, the probability of establishment earned a high rating. Two components of the consequences of establishment were rated medium to high (economic and environmental impacts), and one was rated medium (perceived or social impacts), requiring that the consequence of establishment be rated as medium to high. The organism risk potential of Bighead Carp in the United States, therefore, which combines the probability of establishment and the consequences of establishment, was determined to be a high, or an unacceptable risk. This classification justifies mitigation to control negative effects and means that Bighead Carp are organisms of major concern for the United States.

The risk associated with all components of the probability of establishment (organism within pathway, entry potential, colonization potential, and spread potential) was rated high for Silver Carp, requiring a high rating. Two components of the consequences of establishment were rated medium to high (economic and environmental impacts), and one was rated medium (perceived or social impacts), requiring that the consequence of establishment be rated as medium to high. The organism risk potential of Silver Carp in the United States, therefore, was determined to be a high, or an unacceptable risk. This classification justifies mitigation to control negative effects and means that Silver Carp are organisms of major concern for the United States.

The risk associated with being in the pathway was rated low, the entry potential was rated medium, the colonization potential was rated high, and the spread potential was rated medium to high for Largescale Silver Carp. These ratings for the components of the probability of establishment require a low rating for Largescale Silver Carp. Two components of the consequences of establishment were rated medium (environmental and perceived or social impacts), and one was rated low (economic impacts), requiring that the consequence of establishment be rated as medium for Largescale Silver Carp. The organism risk potential of Largescale Silver Carp in the United States, therefore, was determined to be medium, or an unacceptable risk. This classification justifies mitigation to control negative effects and means that Largescale Silver Carp are organisms of moderate concern for the United States.

Bighead Carp, *Hypophthalmichthys nobilis*

Probability of establishment	=	Organism within pathway (High)	Entry potential (High)	Colonization potential (High)	Spread potential (High)	=	**High**

Consequence of establishment	=	Economic (Medium to High)	Environmental (Medium to High)	Perceived (Medium)	=	**Medium to High**

Organism risk potential	=	Probability of establishment (High)	Consequences of establishment (Medium to High)	=	**High**

Definition of organism risk potential rating:

Low = acceptable risk = organisms of little concern (does not justify mitigation)
Medium = unacceptable risk = organisms of moderate concern (mitigation justified)
High = unacceptable risk = organisms of major concern (mitigation justified)

Silver Carp, *Hypophthalmichthys molitrix*

Probability of establishment	=	Organism within pathway (High)	Entry potential (High)	Colonization potential (High)	Spread potential (High)	=	**High**

Consequence of establishment	=	Economic (Medium to High)	Environmental (Medium to High)	Perceived (Medium)	=	**Medium to High**

Organism risk potential	=	Probability of establishment (High)	Consequences of establishment (Medium to High)	=	**High**

Definition of organism risk potential rating:

Low = acceptable risk = organisms of little concern (does not justify mitigation)
Medium = unacceptable risk = organisms of moderate concern (mitigation justified)
High = unacceptable risk = organisms of major concern (mitigation justified)

Largescale Silver Carp, *Hypophthalmichthys harmandi*

Probability of establishment	=	Organism within pathway (Low)	Entry potential (Medium)	Colonization potential (Medium)	Spread potential (Medium to High)	=	**Low**

Consequence of establishment	=	Economic (Low to Medium)	Environmental (Medium)	Perceived (Medium)	=	**Medium**

Organism risk potential	=	Probability of establishment (Low)	Consequences of establishment (Medium)	=	**Medium**

Definition of organism risk potential rating:
Low = acceptable risk = organisms of little concern (does not justify mitigation)
Medium = unacceptable risk = organisms of moderate concern (mitigation justified)
High = unacceptable risk = organisms of major concern (mitigation justified)

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