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History of Introductions and Governmental Involvement in Promoting the Use of Grass, Silver, and Bighead Carps

Anita M. Kelly*
Aquaculture/Fisheries Center, University of Arkansas at Pine Bluff
2001 Highway 70 East, Lonoke Agricultural Center, Lonoke, Arkansas 72086, USA

Carole R. Engle
Aquaculture/Fisheries Center, University of Arkansas at Pine Bluff
1200 North University Drive, Mail Slot 4912, Pine Bluff, Arkansas 71601, USA

Michael L. Armstrong
Arkansas Game and Fish Commission
2 Natural Resources Drive, Little Rock, Arkansas 72205, USA

Mike Freeze
Keo Fish Farm
Post Office Box 123, Keo, Arkansas 72083, USA

Andrew J. Mitchell
Harry K. Dupree Stuttgart National Aquaculture Research Center
Stuttgart, Arkansas 72160, USA

Abstract.—Numerous natural resource agency and media reports have alleged that Asian carps were introduced into the wild through escapes from commercial fish farms. This chapter traces the chronology associated with importations of Asian carps to North America and discusses the likeliest pathways of their introduction to the wild. The U.S. Fish and Wildlife Service first imported an Asian carp species, grass carp *Ctenopharyngodon idella*, in 1963. Since then, state and federal agencies, universities, and private fish farmers have interacted to import Asian carps, to develop production technologies, and to promote their use in both public and private sectors in a number of different states. These importations and stocking, whether in confinement or, in the case of the grass carp, sometimes in open waters, were purposeful and legal. Asian carps were introduced to take advantage of their unique food preferences (planktivory by silver carp *Hypophthalmichthys molitrix* and bighead carp *H. nobilis*, herbivory by grass carp, and molluscivory by black carp *Mylopharyngodon piceus*). The first known accidental release of diploid grass carp was in 1966 by the U.S. Fish and Wildlife Service in Stuttgart, Arkansas. Other early reports of grass carp in the wild were from waters in Alabama, Georgia, and Florida. Grass carp were reported from the wild in 1970, 2 years before the first private hatchery received grass carp. By 1972, grass carp had been stocked in open water

* Corresponding author: akelly@uaex.edu

systems in 16 different states. Silver carp and bighead carp were first imported purposely by a commercial fish producer in Arkansas in 1973. All silver and bighead carps were transferred to the Arkansas Game and Fish Commission by March 1974 where they first successfully spawned silver carp and bighead carp later that year. The first report of silver carp in the wild was in Arizona in 1972, although strong evidence suggests that this may have been a misidentification, followed by reports in Arkansas in the wild in 1975. The Arkansas report occurred 2 years before bighead carp and silver carp were returned to private hatcheries for commercial production. By 1977, silver carp and bighead carp had been introduced to Alabama, Arizona, Arkansas, Illinois, and Tennessee. Research and stockings of silver carp and bighead carp were conducted by at least six state and federal agencies and three universities in seven states in the 1970s and 1980s. Public-sector agencies, which were successful in encouraging development and use of Asian carps that today are in commercial trade, are the likeliest pathways for the earliest escapes of grass carp, silver carp, and bighead carp.

Introduction

The group of fishes that have been referred to as "Asian carps" constitute some of the most widely consumed finfishes worldwide. The Food and Agriculture Organization of the United Nations maintains an online database (FISHSTAT PLUS, www.fao.org/fi/statist/FISOFT/FISHPLUS.asp) on global landings of both capture and aquaculture species. Silver carp *Hypophthalmichthys molitrix*, grass carp *Ctenopharyngodon idella*, and common carp *Cyprinus carpio* top the list, with the majority of production of these supplied from aquaculture. Bighead carp *H. nobilis*, with most of the biomass supplied from aquaculture, is the sixth most consumed finfish worldwide (FAO 2004). Culture techniques for these species of carp were developed centuries ago to ensure a supply of this important food source (Bardach et al. 1972; Avault 2000). In the U.S. farm-gate sales of farm-raised carps (bighead, black, common, and silver) on private farms were valued at $5.3 million in 2005, up from $3.25 million in 1998 (USDA 2006).

Many natural resource agency and media reports have alleged that in the United States, Asian carps were introduced to the wild when they escaped from commercial fish farms. Many of these media reports specifically mention flooding of fish farms in the early and mid-1990s as the source of introductions to the wild (Sea Grant Pennsylvania 2003; Higbee and Glassner-Shwayder 2004; Belkin 2005; Faroutliers 2006; Great Lakes Fisheries Commission 2008; USEPA 2008; USFWS 2008). While escapes may have occurred during the floods of the 1990s, sufficient evidence exists to contradict these events as initial introductions of these species into the wild. The purpose of this chapter is to trace the associated chronology of importations and introductions of Asian carps, with the exception of black carp, which is discussed by Nico et al. (2005), and to discuss the likeliest pathways into the wild. Given that these species were established in the wild prior to the 1990s, alternative possibilities of escape other than from commercial fish farms during flooding in the 1990s should be explored.

Context of Asian Carp Importation and Early Use

Agriculture in the United States and in most other countries is based on exotic plant and animal species introduced as sources of food

and fiber for humans that colonized the United States (Diamond 1997). Wheat, oats, rice, corn, flax, cotton, cattle, chickens, swine, and most other species that are the foundation of our food and fiber supply in the United States are exotic species. Asian carps similarly were introduced into the United States to take advantage of their unique characteristics.

It is important to understand the context within which decisions related to importations and uses of Asian carps were made. The 1960s and 1970s were decades during which environmental concerns over the broad use of chemicals emerged. The emerging concerns over environmental contamination from widespread chemical use (Carson 1962; Odum 1971) led to political mandates to find safer alternatives to chemicals. For example, the Federal Water Pollution Act requires that agricultural, aquacultural, and silvicultural alternatives for water reuse be evaluated and encouraged as treatment mechanisms (Federal Water Pollution Control Act 2008). At that time, Asian carps were viewed by many as an attractive and environmentally friendly biological control alternative to chemical control. For example, Henderson and Wert (1976) indicated, "aquaculture wastewater alternatives appear to be economically attractive regardless of the market for products if water quality goals are met." Asian carp polyculture was promoted as a way to clean waters of excessive plankton and, at the same time, produce food from wastes. The U.S. Environmental Protection Agency (USEPA) released several publications in the 1970s and 1980s related to the use of aquaculture for wastewater treatment (USEPA 1976, 1980a, 1980b, 1982, 1983).

Release and Escape of Grass Carp into the Wild

Crossman and Cudmore (1999) reported that grass carp were released or escaped into the waters of North America through the commercial aquaculture vector, which may be an incomplete and misleading view. Grass carp had been stocked into several water bodies and specimens were found in the Mississippi River prior to 1972, the first year commercial fish farmers possessed grass carp for production. Mitchell and Kelly (2006) provide a comprehensive chronology of the importation and introductions of grass carp to the United States. Mitchell and Kelly (2006) note that the first importation of grass carp into the United States was from Malaysia by the U.S. Fish and Wildlife Service (USFWS) in 1963. Auburn University received their first grass carp in 1964 and 1965 from Taiwan while the Arizona Game and Fish Department (Page Springs Hatchery) imported grass carp from Hong Kong in 1965 (Marsh and Minckley 1983).

The first grass carp spawns occurred on May 19, 1966 at USFWS in Stuttgart, Arkansas (Mugmon and Taylor 1967; Sills 1970). The first accidental release of grass carp to the environment occurred at this time (M. Martin, former U.S. Fish and Wildlife Service employee, personal communication). In 1970, wild grass carp from a 1966 spawn were first reported from Bayou Lagrue and the White River just below the USFWS laboratory at Stuttgart (Bailey 1972). Wastewater from the Stuttgart laboratory empties into Bayou Lagrue (3 mi from the lab), which flows into the White River, which then flows southeast about 15 to 20 mi into the Mississippi River. Fry were observed swimming through screens on rearing troughs at Stuttgart during a joint spawning effort between the Stuttgart laboratory and the Arkansas Game and Fish Commission (AGFC) in 1970 (Bailey 1972); this was the most likely means of the original escape (1966) of grass carp into the wild. By 1971, grass carp from the 1966 year-class were found in the Mississippi River as far north as Illinois (Guil-

lory and Gasaway 1978). By 1974, grass carp from the 1971 year-class were seen frequently throughout the Mississippi River (Guillory and Gasaway 1978). Because the 1971 year-class corresponds to the year grass carp were stocked into open waters in Arkansas (Bailey 1972), Mitchell and Kelly (2006) suggested that these fish were likely from fish stocked by AGFC in open systems, although they could have been offspring from the original 1966 escapees. Other early escapees appeared in waters in Alabama, Georgia, Mississippi, and Florida (Guillory and Gasaway 1978). The source of the Florida fish originated from Deer Point Lake, a research site, but the sources of the fish in Alabama, Georgia, and Mississippi are unknown (Guillory and Gasaway 1978).

The first recorded public stocking of grass carp occurred in 1969 in Lake Greenlee, a topographically isolated lake near Brinkley, Arkansas (Bailey and Boyd 1971). In 1970, the U.S. Forest Service stocked grass carp obtained from Auburn University into Lake Davis, south of Tupelo, Mississippi (record made of telephone call from K. Sneed, former director of the U.S. Fish and Wildlife Service Fish Farming Experimental Station in Stuttgart, Arkansas, to R. M. Buress, Warm Springs Hatchery). By October 1970, grass carp were known to be in seven states: Alabama, Arizona, Arkansas, Florida, Georgia, Louisiana, and Mississippi (Guscio and Gangstad 1970). In December 1971, AGFC stocked the first grass carp in an open system, Lake Conway, Arkansas (Guillory and Gasaway 1978). By December 1972, the AGFC had stocked 290,992 fish in 54 Arkansas ponds and lakes (AGFC summary of fish stockings in authors' collection). By 1972, five state lakes in Alabama and a few in Florida had been stocked apparently with fish from Auburn University spawns (Sneed 1972). By 1972, grass carp were documented to have been stocked in 16 states (Guillory and Gasaway 1978).

Because grass carp are a nonnative species, many states were concerned that the fish would reproduce and possibly reach harmful population levels (Theriot and Sanders 1975; Stanley 1978) and thus banned the stocking of fertile (diploid) grass carp. The use of sterile (triploid) fish would prevent grass carp from reproducing in the wild. Triploid fish have three sets of chromosomes and are incapable of producing normal viable offspring (Allen and Wattendorf 1987). Stocking triploid grass carp would limit the negative impacts while still providing long-term, low-cost plant control and the production of harvestable fish (Sutton 1985; Sutton and Vandiver 1986).

Public agencies (1972–1985) were actively involved in research to produce sterile grass carp to stock federal, state, and private waters (Stanley and Sneed 1974; Stanley 1976; Beck et al. 1980, 1984; Allen and Stanley 1983). Originally, research to produce sterile carp evolved around the production of hybrid carp, an interspecific cross between male grass carp and female bighead carp (Stanley and Sneed 1974; Stanley 1976; Beck et al. 1980). These fish contained an odd number of chromosomes (i.e., triploids) and were incapable of reproduction, but were hybrids of the two species and not true grass carp, which limited successful plant control. In 1983, triploid grass carp (not hybrids) were produced through efforts of commercial producer Jim Malone (Lonoke, Arkansas) and personnel at the Universities of Maine and Washington (Malone 1983). Triploid grass carp produced using the methods developed by Malone result in fish that are functionally sterile (van Eenennaam et al. 1990). In 1984, Robert Wattendorf of the Florida Department of Natural Resources developed a method for rapid detection of triploidy in grass carp using a Coulter counter (Wattendorf 1986). In 1985, the official USFWS biological opinion on grass carp was

rendered by Bob Stevens, then chief of fisheries for USFWS: "The stocking of triploid grass carp in either closed or open water situations will result in no adverse impact on the environment" (letter of opinion in the authors' collection). In 1985, USFWS established a Triploid Grass Carp Ploidy Inspection Program to minimize the risk that fertile grass carp would be inadvertently shipped around the country.

Production of triploid fish became the standard, and previous methods to produce reproductively limited grass carp (i.e., hybrids) were largely abandoned. There was pressure, mostly by state agencies, to import these fish from states producing them for stocking in both public and private waters. Starting with three states (California, Florida, and North Carolina) in 1984, the certification program grew steadily as game and fish and state conservation departments requested USFWS assistance to bring sterile grass carp into their states (A. J. Mitchell, unpublished data). From 1985 to 2006, more than 7.5 million triploid grass carp were shipped throughout the United States to about 30 states (summary information for triploid grass carp inspections in authors' collections). From 2002 to 2006, about 2.2 million triploid grass carp were sold to more than 20 states with USFWS certification (summary information for triploid grass carp inspections in authors' collections). The efforts of the USFWS and several state agencies continue to support grass carp as a biological control for aquatic weeds. It should be noted that some states allow the use of diploid grass carp, particularly in states that have established wild populations.

Primary public sector institutions involved with early use of grass carp were the USFWS, Fish Farming Experimental Station, Stuttgart, Arkansas; Auburn University, Auburn, Alabama; and AGFC. Federal agencies translated several Chinese articles on spawning and rearing Asian carps with the obvious use for promotion of and research on the culture of these fish (Lee 1979; Chang 1980). Other early public sector players included USFWS facilities in Marion, Alabama, and Warm Springs, Georgia; U.S. Department of Agriculture/Agricultural Research Service Laboratory, Fort Lauderdale, Florida; Chief Engineers, Army Corps of Engineers, state conservation or game and fish departments at Eastaboga, Alabama, Page Springs, Arizona, and Eustis, Florida; and University of Florida and Oregon State University. Efforts of these groups were likely responsible for establishment of this fish in the United States by the early 1970s.

Possible Vectors for Escape of Silver and Bighead Carps

While Arkansas fish growers have been credited widely for original introductions of silver carp and bighead carp into U.S. waters, the first report of silver carp in the United States was in an urban lake in Arizona in 1972 (Kolar et al. 2007), although strong evidence suggests that this may have been a misidentification. How silver carp might have arrived in Arizona and been introduced there remains unknown. As discussed in depth below, the first confirmed record of a silver carp capture was in 1974 or 1975, prior to substantial use of silver carp in the private sector.

Although a commercial fish producer first imported silver carp and bighead carp in 1973 (J. Malone, Jr., J. M. Malone and Son, Inc., personal communication; research notes by S. Y. Lin, Food and Agriculture Organization of the United Nations, in authors' collections), by March 1974 all these fish had been transferred to AGFC and were to remain there for 3 years (formal agreement between the producer and AGFC on January 15, 1974) to initiate research into production and water quality

control. AGFC was the first to spawn these silver carp and bighead carp in the United States (research notes of Lin in authors' collection; Henderson 1977).

Once AGFC had received all the silver carp and bighead carp that had been imported into the United States, they studied the use of silver carp and bighead carp for about 10 years (Henderson 1976, 1978, 1979a, 1979b, 1983; Henderson and Wert 1976; Freeze and Henderson 1982; Freeze and Crawford 1983). Some research evaluated silver carp and bighead carp use in aquaculture (Henderson 1976, 1979a). Additionally, a mandate from the Federal Water Pollution Act of 1972 required that aquacultural alternatives for water reuse be evaluated and encouraged as treatment mechanisms. This resulted in interest in use of silver carp and bighead carp to treat sewage waste. Governmental agencies provided funding for research such as that reported in Henderson (1978) on use of silver and bighead carps in a lagoon treatment system in 1975–1976. That study evaluated the effect of the fish on water quality and the potential for using this nutrient source for fish production. Henderson (1979b) reported results from another project funded by the USEPA that involved stocking six sewage treatment lagoons of the Benton Services Center treatment plant in Benton, Arkansas. The National Marine Fisheries Service also funded AGFC to study the effects of silver carp on water quality in a sewage treatment system (1976 Arkansas Game and Fish Commission annual report summary by S. Henderson in authors' collection). The USEPA provided additional funding for research (1982) on use of carps to remove excessive nutrients and algae from wastewater (Henderson 1983).

AGFC was known to have stocked silver carp or bighead carp in four sites by 1982 (Freeze and Henderson 1982). These included a sewage plant at a correctional facility (Benton Correction Facility sewage plant), a lake stocked for recreational and commercial fisheries (Hill's Lake in eastern Pulaski County/western Lonoke County), and a manmade lake owned by AGFC (Mallard Lake in northeast Arkansas; M. Freeze, unpublished data). The fourth location was possibly another city sewage facility, perhaps the City of Lonoke. Fish could have escaped from any or all these stocking sites. Mallard Lake was drained into the St. Francis River, a tributary of the Mississippi River, after the silver carp failed to control the algae for which they had been stocked (Freeze, unpublished data).

The Illinois Natural History Survey, which received bigheaded carps in 1974 from AGFC (Buck et al. 1978a), conducted pond studies from 1974 through 1988 at the Sam A. Parr Fisheries Research Center, a joint facility of the Illinois Natural History Survey and the Illinois Department of Natural Resources located near Kinmundy, Illinois (Buck et al. 1978a, 1978b, 1981). The Illinois Natural History Survey evaluated silver carp as filter-feeders in polyculture and in manure treatment systems (Henebry et al. 1988). The Illinois Natural History Survey also experimented with female grass carp × male bighead carp hybrids in ponds and laboratory settings (Wiley and Wike 1986).

Auburn University, which also received fish in 1974 from AGFC (summary of research in 1974 by B. Bailey, Arkansas Game and Fish Commission, in authors' collection; Pretto-Malca 1976), studied bighead carp and silver carp polyculture in earthen ponds (Pretto-Malca 1976; Dunseth 1977; Burke and Bayne 1990). Cremer and Smitherman (1980) stocked silver carp and bighead carp in cages and ponds at Auburn University to compare growth, food habits, and filtering capability. Thus, the major public sector players in the promotion of the use of bighead and silver

carp were AGFC, Auburn University, Illinois Natural History Survey, and USFWS.

Numerous other state and federal agencies and universities also engaged actively in the research, testing, and use of silver carp and bighead carp. In USFWS's *Third Report to the Fish Farmers*, Dupree and Huner (1984) state, "The bighead carp is an excellent food animal, and highly prized by Asians in the United States. It is well suited for culture in combinations with other fishes such as the grass carp, silver carp, and common carp. Its acceptance by consumers in the United States is rapidly increasing." The USFWS did research on grass carp x bighead carp hybrids from 1979 to 1984 (Mitchell, unpublished data) and polyculture studies with bighead carp and catfish (late 1980s) (Mitchell, unpublished data). Texas Parks & Wildlife Department allowed triploid hybrids (grass carp x bighead) to be imported (early to mid-1980s; Mitchell, unpublished data). The Tennessee Valley Authority performed silver carp sewage studies in 1976 and 1977 (Maddox et al. 1979), and the University of Arkansas at Pine Bluff conducted polyculture studies with silver and bighead carp in 1976. Wilson et al. (1984) reported stocking silver carp in eutrophic dairy farm impoundments in South Carolina to control phytoplankton. Bettoli et al. (1985) refer to stocking more than 7,000 each of grass carp and the hybrid grass–bighead carp into Lewis Creek Reservoir, a power plant cooling reservoir near Willis, Texas, in 1983. In Hawaii, Laws and Weisburd (1990) stocked silver carp into 24 commercial freshwater aquaculture ponds in 1984 to study the effects on algal biomass. Rottmann et al. (1991) reported results of fry-rearing studies following spawning of both grass and bighead carps, implying that gravid broodstock were maintained at the University of Florida facility in Gainesville, Florida. Ponds adjacent to Lake Apopka, Florida were used to study food habits, feeding behavior, and effects of triploid bighead carp (Opuszynski and Shireman 1993).

Hybrid carp were stocked into two California irrigation canals in 1980, and silver carp and bighead carp were stocked into a small shallow pond in Arvada, Colorado in 1992 for control of nuisance algal problems with funding by the U.S. Bureau of Reclamation and the National Biological Service (Nibling and Thullen 1980; Lieberman 1996). Memphis State University worked with grass carp and bighead hybrids from 1979 to 1985 (Beck et al. 1980; Beck and Biggers 1982, 1983a, 1983b). The Arkansas State Pollution Control and Ecology Commission developed a program to stock silver carp in sewage systems of small towns that could not comply with USEPA regulations (Malone, personal communication). In 1989, 12 municipalities received silver carp, including one (Clarendon) that had to be restocked because the silver carp escaped from the lagoons with the outflow waters through an inadequate barrier (Malone, personal communication and sales records).

Commercial production of silver and bighead carp began only in 1977 after AGFC returned fish to private growers. However, wild silver carp were found in Arkansas County (Bayou Meto and the White River) in 1975 (Kolar et al. 2007). Thus, the earliest escapes of silver carp occurred before private growers began to raise them. The likeliest pathway of first introduction was through the state hatcheries that first spawned them.

It is important to note that silver carp are not presently cultured in the United States and have been little cultured in the past 25 years, largely because of their jumping habits and poor handling qualities during production, harvest, and transport (Kolar et al. 2007). Large quantities of silver carp were never raised in the United States for sale as food

(FAO 2004). With this in mind, it is not likely that silver carp escaped from ponds during the floods of the 1990s as they were not in use in commercial aquaculture facilities at that time.

Summary

Grass carp, silver carp, and bighead carp were introduced into the United States primarily to develop nonchemical and environmentally friendly biological control mechanisms. The involvement of federal and state agencies in promoting the use of Asian carps resulted in substantial and positive economic effects. The research and outreach initiatives resulted in a farm-raised carp industry on private farms in the United States, and bighead carp became an important revenue source. Federal, state, and municipal agencies and institutions used these fishes for research purposes and for biological control of macrophytes and algae, and some unintentional escapes from these public sector facilities were documented. In the case of grass carp, the public sector also at times intentionally stocked grass carp into open systems. Federal and state agencies later actively enabled and collaborated with private sector fish farmers in the use of these species. A careful chronology of possession, spawning events, and appearances in the wild demonstrate that the likeliest scenario of the first escapes of grass, silver, and bighead carps were from the public sector and not from fish farms during the floods of the 1990s. Grass, silver, and bighead carps were established in the Mississippi River basin prior to the 1990 floods. There are no documented cases of escape from aquaculture due to flooding of ponds until 1994, when bighead carp escaped to the Osage River (Kolar et al. 2007). As commercial trade developed for grass carp and bighead carp, the potential for subsequent escapes from private fish farms also developed. The active involvement of state and federal agencies in promoting commercial production of these species resulted in economic benefits, commercial trade of Asian carps, and pathways of introduction to the wild.

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