Biological Synopsis of Grass Carp (*Ctenopharyngodon idella*)

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ABSTRACT

Grass carp (*Ctenopharyngodon idella*) has the potential to cause great ecological harm in Canadian waters. Fisheries and Oceans Canada is conducting a qualitative and quantitative risk analysis to determine the ecological risk that this species poses in Canada. To undertake the risk analysis, it was necessary to develop a biological synopsis for the species. This synopsis summarized information on the species' description, distribution, biology and natural history, use by humans and impacts. Grass carp is a large member of the carp and minnow family (Cyprinidae) and is native to southeastern Russia and northwestern China. This herbivorous species has been deliberately introduced into many countries for vegetation control purposes. In the United States, escapes from aquaculture facilities have led to the establishment of grass carp in the wild. In Canada, grass carp escaped from an aquaculture facility in Alberta and were intentionally released for vegetation control in Saskatchewan. Only a few individuals have been found in the Great Lakes, presumably bought from the live fish food markets and released. As a result of altering habitat and competing with other herbivorous species, grass carp can impact water quality, aquatic flora and fauna, and wildlife species.

RÉSUMÉ

La carpe de roseau (*Ctenopharyngodon idella*) peut être une très grande nuisance écologique dans les eaux canadiennes. Pêches et Océans Canada mène actuellement une analyse qualitative et quantitative des risques en vue de déterminer les risques écologiques que présente cette espèce au Canada. Pour entreprendre cette analyse des risques, il était nécessaire d'établir la situation biologique de l'espèce en résumant les données touchant sa description, sa répartition, sa biologie, son histoire naturelle, son utilisation par les humains et ses impacts. La carpe de roseau, membre de grande taille de la famille des carpes et des ménés (Cyprinidés), est indigène dans le sud-est de la Russie et le nord-ouest de la Chine. Cette espèce herbivore a été volontairement introduite dans de nombreux pays à des fins de lutte contre la végétation. Aux États-Unis, des carpes de roseau ont pu s'établir en milieu sauvage après s'être échappées de stations aquacoles. Au Canada, des individus se sont échappés d'une station aquacole de l'Alberta, alors que d'autres ont été intentionnellement lâchés à des fins de lutte contre la végétation en Saskatchewan. Seuls quelques individus ont été trouvés dans les Grands Lacs; ils avaient

probablement été achetés dans des marchés de poissons vivants, puis relâchés. En altérant les habitats et en entrant en compétition avec d’autres espèces herbivores, la carpe de roseau peut affecter la qualité de l’eau, perturber la flore et la faune aquatiques et nuire à certaines les espèces sauvages.

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1.0. INTRODUCTION

The deliberate or unintentional release of non-native species has negatively impacted Canadian freshwater biodiversity (Metcalfe-Smith and Cudmore-Vokey 2003). Grass carp (*Ctenopharyngodon idella*), along with four other species collectively known as the Asian carps, has been recognized as a species with great potential to cause ecological harm in Canadian waters. In 2004, the Province of Ontario banned the sale of live Asian carps in the live food fish industry in an attempt to decrease the likelihood of these species being released into natural waters. Subsequently, Fisheries and Oceans Canada began a qualitative and quantitative risk analysis to determine the ecological risk these species pose in Canada. The United States Geological Survey (USGS) has completed biological synopses and risk analyses on four Asian carp species: bighead carp (*Hypophthalmichthys nobilis*), silver carp (*H. molitrix*) and largescale silver carp (*H. harmandi*) (Kolar *et al.* 2004), and black carp (*Mylopharyngodon piceus*) (Nico *et al.* 2001). To undertake a risk analysis of grass carp in Canada, a synopsis of the species life history and known impacts of the species was required and is presented here.

1.1. NAME AND CLASSIFICATION

From FishBase (2004) and ITIS (2004):

Kingdom: Animalia
Phylum: Chordata
Class: Actinoptergii
Order: Cyprinoformes
Family: Cyprinidae
Genus and Species: *Ctenopharyngodon idella* (Valenciennes 1844)
Original Scientific Name: *Leuciscus idella* – no longer valid

Common English Name: grass carp. Other English Names: white amur, silver orfe
Common French Name: *carpe de roseau*

1.2. DESCRIPTION

The grass carp (Figure 1) is one of the largest members of the family Cyprinidae, and is the only member of the genus *Ctenopharyngodon* (Shireman and Smith 1983, Chilton and Muoneke 1992). No subspecies are known (Shireman and Smith 1983, N. Bogutskaya, Zoological Institute, Russian Academy of Sciences, St. Petersburg, pers.

comm.). This species is characterized by: a wide, scaleless head; subterminal or terminal mouth with simple lips; no barbels; slightly protracted upper jaw and, very short snout, its length is less than, or equal to, its eye diameter and its postorbital length is more than half its head length (Page and Burr 1991, Eccles 1992, Opuszynski and Shireman 1995). The body is slender and fairly compressed with a rounded belly and a complete, slightly decurved lateral line, extending along the middle of the depth of the tail (Shireman and Smith 1983, Page and Burr 1991, Opuszynski and Shireman 1995). Dorsal fin origin is above, or just in front of, the pelvic fin origin and the number of fin rays for the dorsal, anal and caudal fins are 7, 8 and 18, respectively (Page and Burr 1991, Keith and Allardi 2001). The dorsal and anal fins do not have spines (Shireman and Smith 1983). The moderate to large cycloid scales (35-45 lateral count) are dark-edged with a black spot at the base (Shireman and Smith 1983, Page and Burr 1991, Opuszynski and Shireman 1995). Gill rakers (about 12) are unfused, short, lanceolate and widely set (Shireman and Smith 1983, Opuszynski and Shireman 1995). Pharyngeal teeth are biserial and 2.5-4.2, 2.4-4.2, 2.4-5.2 or 1.4-5.2 (Shireman and Smith 1983). Diploid chromosome number is n=48 and biochemical analysis of five tissues revealed an estimated 49 loci (Opuszynski and Shireman 1995).

The colour of adult grass carp is dark gray on the dorsal surface with lighter sides (white to yellow) that have a slightly golden shine. Fins are clear to gray-brown (Page and Burr 1991, Opuszynski and Shireman 1995).

This species generally attain weights of 30-50 kg (Chilton and Muoneke 1992) and can reach lengths greater than 1 m (Fraser 1978, Pauley 1978, Page and Burr 1991, Nico and Fuller 2001).

A detailed review of larval morphology is given by Shireman and Smith (1983). Grass carp protolarvae and early mesolarvae have 42-43 myomeres and an average of 31 preanal myomeres (Conner *et al.* 1980, Shireman and Smith 1983).

Triploid hybrids have fewer scales in the lateral line, relatively longer guts and fewer deformities than diploids (Cassani *et al.* 1984). Morphological characteristics of artificially bred grass carp X bighead carp hybrids have proven to be 100% accurate in distinguishing them from pure grass carp (Allen and Stanley 1983).

Similar species established in North America are common carp (*Cyprinus carpio*) and goldfish (*Carassius auratus*), both native to Asia and introduced to Canada (Page and Burr 1991). The common carp has barbels where grass carp do not, and goldfish lack the dark-edged scales characteristic of grass carps (Page and Burr 1991).

2.0. DISTRIBUTION

2.1. NATIVE DISTRIBUTION AND ABUNDANCE

Grass carp is a sub-tropical to temperate species, native to large rivers and lakes in eastern Asia. Its native range extends from southern Russia southward to northern Vietnam and from coastal waters inland (Figure 2). In large rivers, like the Amur (border of China and Russia), Yang Tze (northern China), Yellow River (central China) and the Min River (crosses the border from Vietnam into China), the grass carp is found only in the lower and middle reaches of the river (Opuszynski and Shireman 1995).

Grass carp are considered uncommon in their Amur basin native range, relative to other species of Asian carps (Shireman and Smith 1983). The only data available on the abundance of wild grass carp are commercial fishery statistics. Average annual catches of 30 metric tonnes were reported in the Amur River during the late 1940s to early 1950s, and reached 110 metric tonnes per year from 1957-1966; however, overfishing led to population declines in the 1970s (Shireman and Smith 1983).

There is a broad range of climatic conditions within the native range of the grass carp. Mean annual air temperatures range from 25^{o}C in the southernmost part of its range to -6^{o}C in the northernmost part (Figures 3 and 4). The distribution of mean annual air temperatures within its range is bimodal, with one mode centred on 0^{o}C, the other on 16^{o}C (Figure 4).

2.2. NON-NATIVE DISTRIBUTION (EXCLUDING CANADA)

Grass carp have been extensively introduced (mainly for macrophyte control) to many parts of the world. Grass carp have been widely introduced in North, Central and South America, the South Pacific Islands, Asia, the Indian subcontinent, a number of states of the former USSR, Europe, Scandinavia and Africa (FishBase 2004) (Figure 5). Of the 115 countries in which grass carp have been introduced, 58 (50%) appear to have self-sustaining populations, 38 (33%) have failed populations, and the fate of introductions in the remaining countries is not known (FishBase 2004). Grass carp have been introduced into 49 countries in Europe, 17 of which have known established populations (Figures 6 and 7).

This species was first imported to the United States in 1963 to aquaculture facilities in Alabama and Arkansas and, soon after, escaped into the open waters of Arkansas (Courtenay *et al.* 1984). By the early 1970s, there were many reports of grass carp captured in the Missouri and Mississippi rivers (Pflieger 1978). Since then, grass carp have spread rapidly as a result of widely scattered research projects, stockings by government agencies, unauthorized releases, interstate transport, escapes from farm ponds and aquaculture facilities and natural dispersal from introduction sites (USGS 2004). Widespread stocking of grass carp as a biological control against nuisance aquatic plants in ponds and lakes continues (USGS 2004).

Currently, grass carp have been recorded from 45 states; there are no reports of introductions in Alaska, Maine, Montana, Rhode Island, and Vermont (USGS 2004) (Figure 8). Grass carp is established in Arkansas, Kentucky, Illinois, Louisiana, Minnesota, Missouri, Mississippi, Tennessee and Texas (Courtenay 1993, USGS 2004).

2.3. DISTRIBUTION IN CANADA

Grass carp have been found in three provinces in Canada: Alberta, Saskatchewan and Ontario (Figure 9). Grass carp was first captured in Canada in the Ontario waters of Lake Erie, west of Point Pelee in 1985. Other single-specimen captures subsequently occurred at three locations in Lake Huron, and a pond and a tributary of Lake Ontario, both in Toronto. In 2000, several thousand triploids were released into Loch Leven in Cypress Hills Provincial Park in Saskatchewan for weed control. There are no signs of reproduction (J. Keith, Conservation Data Centre, pers. comm.). In 2000 or 2001, 50-100 individual triploid grass carp escaped from an irrigation canal into Lake Newell, a large, off-stream irrigation storage reservoir located near Brooks, Alberta. There are no signs of reproduction and it is unknown if any survivors remain (B. MacKay, University of Lethbridge, Aquaculture Centre, pers. comm.).

3.0 BIOLOGY AND NATURAL HISTORY

3.1. AGE AND GROWTH

Wild grass carp from the Amur basin usually live from 5 to 11 years, although based on scale samples, some individuals can reach up to 15 years of age and one specimen from North Dakota was found to be greater than 33 years old (Shireman and Smith 1983, W. Courtenay, USGS, pers. comm.).

As with most species, growth in grass carp is a function of age, size and abiotic factors such as density, nutrition, temperature and oxygen (Chilton and Muoneke 1992). The most rapid length increases seem to take place in age 0-4 fishes, while weight increases are especially pronounced for age 4-6 fishes (Chilton and Muoneke 1992). Shireman and Smith (1983) presented mean length for each year class for grass carp found in the Amur River basin (Figure 10).

Cultured grass carp may reach up to 1 kg in the first year and grow approximately 2-3 kg/yr in temperate areas and 4.5 kg/yr in tropical areas (Shireman and Smith 1983). A study by Shelton *et al.* (1981) of grass carp growth at different stocking densities indicate that the growth of age 0 fishes was strongly affected by density. After one year, average size decreased with increasing density, with maximum weights attained in ponds with the lowest density (Shelton *et al.* 1981). Grass carp require cellulose and protein in their diet, with protein being especially important for optimal growth in young fishes (40-120 g) (Chilton and Muoneke 1992).

3.2. PHYSIOLOGICAL TOLERANCES

Grass carp tolerate a range of water temperatures from 0 to 33°C, with temperatures greater than 38°C being lethal for adults (Fedorenko and Fraser 1978). Upper lethal temperature for grass carp fry ranges from 33-41°C, and for yearlings the range is 35-36°C, depending on season (Chilton and Muoneke 1992). The mean critical thermal maximum is 39.3°C (Chilton and Muoneke 1992). Lower temperature tolerance (as indicated by permanent loss of balance) occurs at 0-0.1°C (at 12-15 hour exposures) for fry (Chilton and Muoneke 1992). There is low survival of eggs below 18°C (Stott and Cross 1973).

Grass carp also appear to tolerate moderately rapid changes in temperature. Fingerlings 5 to 7 cm could tolerate an increase from 4-22°C in 2 to 3 hours (Shireman and Smith 1983).

Huisman and Valentign (1981) hypothesized that grass carp are adapted to conserve energy at high temperatures. Although fry do not feed at temperatures below 8°C, they are capable of surviving for long periods of time under such circumstances (Chilton and Muoneke 1992).

Dissolved oxygen levels below 3 mg/l can cause stress in grass carp, but they are able to tolerate oxygen concentrations as low as 0.2 mg/l, (Shireman and Smith 1983). Fingerlings can survive oxygen levels in the range of 0.41 to 28 mg/l, pH of 5.0 to 9.0, alkalinity of 620mg/l, salinity of 0 to 3.8 ppm and free suphides as high as 5 ppm (Shireman and Smith 1983). Young grass carp are more susceptible to low oxygen concentrations than older fishes and vulnerability varies with season (Chilton and Muoneke 1992). Tolerance of lower dissolved oxygen concentrations during the winter is higher than during the summer (Versar, Inc. 1999).

Juveniles and adults may withstand salinities of 11 to 12 parts per thousand (ppt) and up to 19 ppt for brief periods (Meyer *et al.* 1975). Cross (1970) found that age 2 and older grass carp were highly tolerant of salinities up to 17.5 ppt. Liepolt and Weber (1969) (cited in Versar, Inc. 1999) found that they could withstand salinities up to 100 ppt for several days. Although this is not a condition that would frequently be encountered in the wild, it demonstrates the high tolerance level of grass carp to salinity.

3.3. REPRODUCTION

Age of maturity is a function of temperature and available high quality nutrition (Stanley *et al.* 1978). In tropical climates, maturity occurs at earlier ages and smaller sizes (Shireman and Smith 1983). Mature grass carp require approximately 1,500 to 2,000 degree days within a year for gonadal development and maturation (Shireman and Smith 1983, Beck 1996).

Grass carp at maturity are approximately 50-86 cm in length. Males generally mature one year earlier than females. In their native range, Pearl River populations mature at 2 to 3 years, Yangtze River populations mature at 3 to 4 years and Amur River populations mature at 6 to 10 (Shireman and Smith 1983). Maturity occurs between the ages of 1 to 8 years in the introduced and cultured grass carp populations of tropical climates. A population of grass carp in Germany attained maturity between 4 and 8 years of age (Fedorenko and Fraser 1978, Shireman and Smith 1983, FishBase 2004). Grass carp in temperate areas of the United States are sexually mature at 4-5 years (NatureServe 2003).

When introduced to some temperate areas, grass carp may approach spawning condition at approximately the same time as in their native distribution, but their gonads do not mature. This is possibly related to a lack of combined nutritional, photoperiod and water temperature requirements (Goodchild 1999).

External sexual dimorphism appears in adults at the onset of maturity with the appearance of tubercles on the dorsal and medial surfaces of the pectoral fins in males (Shireman and Smith 1983). Females may also develop deciduous tubercles, but they are not as highly developed as in the males. Females exhibit soft, bulging abdomens and swollen, pinkish vents at onset of maturity (Shireman and Smith 1983).

Water temperature required for stimulation of sexual maturation and spawning ranges between 20°C and 30°C. Optimum spawning temperature is generally thought to be between 20°C and 22°C, which Shireman and Smith (1983) felt may account for its restrictive native range and failure to reproduce in many areas after introduction. Crossman *et al.* (1987) reported spawning required water temperatures exceeding 27°C. However, grass carp have been shown to spawn at water temperatures as low as 15°C (Shireman and Smith 1983).

In their native areas, grass carp begin migration to spawning areas when water temperatures reach 15-17°C (Chilton and Muoneke 1992). Water temperature and level play key roles in inducing spawning and vary with latitude. Spawning occurs above 18°C, peaking at 20-22°C in the former Soviet Union and 26-30°C in China (Chilton and Muoneke 1992). Increases in water level exceeding 122 cm within a 12 hour period are required for spawning (Chilton and Muoneke 1992). If water levels do not rise during the spawning season, females with small reserves of body fat will either release no eggs or release only a portion; non-released eggs are subsequently absorbed (Gorbach 1970). A well-marked and limited spawning season occurs in temperate latitudes but the breeding season expands and becomes less distinct in tropical areas. Multiple spawning in a year has been reported, but probably rarely occurs (Shireman and Smith 1983).

Grass carp spawn in the primary channels of rivers and canals during high water (Shireman and Smith 1983). Spawning usually takes place in spring and summer in the upper part of the water column over rapids or sand bars (Shireman and Smith 1983). Preferred spawning habitat is found in turbid, turbulent water at the confluence of rivers or below dams (Fedorenko and Fraser 1978, Stanley *et al.* 1978). Grass carp prefer to spawn in water currents ranging from 0.6 and 1.5 m/sec, but will spawn in currents as low as 0.2 m/sec, or even in ponds where current is absent (Stanley *et al.* 1978).

Lin (1935) in Chilton and Muoneke (1992) the spawning behaviour of grass carp. In spawning areas, females are usually outnumbered by males by about two to one. During the spawning process, each female is usually followed by two or more males. The fish swim into the strongest current found at mid-stream. The fish begin swimming and chasing as the males push their heads against the female's body and lean to one side. This may be the moment when the eggs and milt are released and fertilization occurs.

Fecundity is directly proportional to length, weight and age and ranges from 0.001 to 2 million eggs, but generally averages 0.5 million for a 5 kg brood stock (Shireman and Smith 1983, Chilton and Muoneke 1992). In the Amur basin, fecundity ranged from 0.2 to 1.7 million eggs with an average of 0.8 million (Fedorenko and Fraser 1968). Geographic location does not appear to affect fecundity (Shireman and Smith 1983).

Grass carp eggs are 2.0-2.5 mm in diameter when released, but quickly swell to a diameter of 5-6 mm as water is absorbed (Lin 1935 from Chilton and Muoneke 1992). The eggs are semi-buoyant and non-adhesive, requiring well-oxygenated water and a current to keep them suspended until hatching (Stanley *et al.* 1978, Chilton and Muoneke 1992, NatureServe 2003). Eggs may travel downstream 50 to 180 km (Fedorenko and Fraser 1978).

Successful development reportedly occurs only in large rivers where water velocity exceeds 0.8 m/sec and volume is approximately 400 m^3sec^{-1} (Shireman and Smith 1983). However, it has been demonstrated that eggs are adequately supported at currents as low as 0.23 m/sec (Leslie *et al.* 1982) and juvenile grass carp have been collected from backwater lakes with currents less than 0.05 m/sec (Raibley *et al.* 1995). Optimal temperature for incubation is 21°C to 26°C, with mortality increasing at temperatures below 20°C (Fedorenko and Fraser 1978, Shireman and Smith 1983). In fact, large-scale deaths and deformities leading to death occurred when newly fertilized eggs were exposed to temperatures below 20°C; however, this vulnerability was less apparent on eggs over 20 hours old (Chilton and Muoneke 1992). Chilton and Muoneke (1992) stated that the incubation period was about 20-40 hours. In the United States, eggs hatched in 26-60 hours at 17-30°C (NatureServe 2003).

Newly hatched larvae are vulnerable to predators as they depend on sufficient water currents to keep them suspended. Within a few days of hatching, larvae must enter quiet waters of the rearing habitat (Fedorenko and Fraser 1978). Juveniles, between one and ten years, may move out of these nursery areas and migrate upstream or downstream as much as 1000 km from the original spawning grounds (Shireman and Smith 1983, Goodchild 1999).

Survival is probably low for the early stages from egg to fingerling, particularly in the first week after hatching. Survival of fingerlings in ponds ranged from 22.9 to 60.2%. Yearlings had a survival rate of 91% and 1+ to 2+ year fishes had a survival rate of 76% (Shireman and Smith 1983).

Grass carp used for biological control of aquatic vegetation are generally triploid fishes - those with a 72 chromosomal count (Opuszynski *et al.* 1985) due to concerns regarding unmitigated natural reproduction (Cassani 1995). The first attempt to develop triploid fishes was the production of an intergeneric triploid hybrid. However, the hybrid was not nearly as effective in controlling aquatic weeds because of the gut length (Osborne 1982). Later, non-hybrid triploid grass carps were produced by shocking eggs with heat, cold or pressure (Chilton and Muoneke 1992, Courtenay 1993, Versar, Inc. 1999). There are two characteristics which render male triploid grass carp functionally sterile. First, only 60 sperm cells in every one billion are viable and second, the number of cells per volume of milt is very low (Chilton and Muoneke 1992). In triploid females, some individuals are capable of incidental ovulation and forming the yolk of eggs (Van Eenennaam *et al.* 1990). Little is known about the propensity for reversion (Versar, Inc.1999).

3.4. FEEDING AND DIET

Factors such as age, size (and therefore gut length), temperature, availability of plant species, size of waterbody and stocking density (in pond cultures) may influence grass carp feeding strategies (Opuszynski and Shireman 1995). While active feeding begins at 7-8°C, intensive feeding occurs only when water temperature is at least 20°C (NatureServe 2003). Chilton and Muoneke (1992) stated that grass carp rarely fed at temperatures below 3°C and, while in their over-winter habitat, they do not feed at all (Fischer and Lyakhoich 1973).

Three or four days after hatching, larval grass carp begin feeding on rotifers and protozoans, moving up to larger cladocerans at 11-15 days post-hatch (Fedorenko and Fraser 1978, Opuszynski and Shireman 1995). By two weeks after hatching, and at sizes of 12-17 mm long, grass carp feed on larger prey, such as *Daphnia* and insect larvae (Fedorenko and Fraser 1978, Opuszynski and Shireman 1995). After three weeks, the occurrence of plants in the diet increases, with the appearance of filamentous algae and macrophytes. Nearly exclusive macrophyte feeding begins at 1 to 1.5 months after hatching (Opuszynski and Shireman 1995). However, juveniles will consume other items including chironomids, cladocerans, copepods, insects and their aquatic larvae, crustaceans and small fishes (Chilton and Muoneke 1992).

Adult grass carp are selective in their choice of certain plant species (Table 1), preferring submerged plants with soft leaves (Bain *et al.* 1990, Pine and Anderson 1991) and consuming the most preferred species first until they become scarce (Bain 1993). Other plant species, such as filamentous algae and firmer-leaved macrophytes (e.g. Eurasian water milfoil (*Myriophyllum spicatum*)), are consumed when they are the only species available (Opuszynski and Shireman 1995). When the supply of macrophytes is low, adult grass carp are able to utilize other food sources including benthos, zooplankton, water beetles and crayfishes (NatureServe 2003). However, studies indicate that grass carp lose weight when kept in unvegetated ponds with sufficient animal food sources (van Zon *et al.* 1977). Tree leaves and twigs from banks have been found in the stomachs of grass carp deprived of aquatic plants (Bailey and Boyd 1971), indicating that they did not shift to animal sources in the absence of plants. In contrast, Lopinot (1972) indicated that grass carp will feed on almost anything when vegetated food is scarce including small fishes, worms and insects, but in pond culture, they seem to prefer pelleted food to vegetation.

3.5. HABITAT

Freshwater radio-telemetry studies indicate that adult grass carp have a strong preference for densely vegetated inshore areas of backwaters of large rivers, pools, ponds and lakes 1-3 m in depth, usually remaining less than 10 m from shore (Shireman and Smith 1983, Page and Burr 1991). During periods of low water temperature, flooded creek channels and deep mid-stream areas are also utilized (Shireman and Smith 1983). Bain *et al.* (1990) found that grass carp prefer submergent vegetated areas, particularly those dominated by hydrilla (*Hydrilla verticillata*). The depth distribution of grass carp may mirror the seasonal depth distribution of aquatic macrophytes, especially during the warmer months when both plants and fishes are growing most rapidly (Nixon and Miller 1978, Bain *et al.* 1990, Versar, Inc. 1999).

Spawning habitat is generally quite turbid (Stanley *et al.* 1978) and rearing habitat consists of the quiet waters of vegetated lagoons, impoundments or lakes (Fedorenko and Fraser 1978).

During the winter, grass carp stay in deep holes in the river beds (Fischer and Lyakhoich 1973, Shireman and Smith 1983).

3.6. INTERSPECIFIC INTERACTIONS

Grass carp, like most other cyprinids, have few defenses and are susceptible to predation by a variety of animals at all stages of life (Shireman and Smith 1983). In a study by Hatton (1977), adult grass carp did not show any mechanisms or behaviour for successfully avoiding or escaping predation by largemouth bass (*Micropterus salmoides*).

Early life stages can be attacked by invertebrates such as copepods, hemipterans, coleopterans and odonatan nymphs (Shireman and Smith 1983). Larger grass carp are attacked by a number of piscivorous fishes, such as largemouth bass, northern pike (*Esox lucius*), pike perch (*Sander lucioperca*) and snakeheads (*Parachanna* and *Channa* spp.) (Shireman and Smith 1983). Other predators of various life stages include frogs, water snakes, herons, hawks and otters (Shireman and Smith 1983). Shireman *et al.* (1978) found that grass carp greater than 450 mm were not preyed upon by largemouth bass. As grass carp can grow to over a meter in length, they are assumed to be able to avoid predation by all species when these sizes are attained (Pfeiffer and Lovell 1990).

In one study, the biomass of largemouth bass increased in direct proportion to biomass of grass carp – perhaps because removal of vegetation by carp increased vulnerability of forage fishes to bass predations (NatureServe 2003).

Although silver carp (*Hypopthalmichthys molitrix*) and bighead carp (*H. nobilis*) have overlapping spawning seasons with grass carp, natural hybridization has not been documented (Shireman and Smith 1983). However, grass carp have been artificially hybridized with these species as well as with the black carp (*Mylopharyngodon piceus*), goldfish (*Carrassius auratus*), common carp (*Cyprinus carpio*), black bream (*Megalobrama terminalis*), eastern bream (*Abramis brama orientalis*), white bream (*Parabramis pekinensis*), rohu carp (*Labeo rohita*), *Labeo ariza*, catla (*Catla catla*), mrigal (*Cirrhina mrigala*), and puntius carp (*Puntius gonionotus*) (Shireman and Smith 1983). In an early attempt to create sterile forms to prevent unchecked reproduction of released grass carp, they were hybridized with the common carp; however, these hybrids were found to be fertile (Chilton and Muoneke 1992).

3.7. BEHAVIOUR AND MOVEMENTS

Grass carp exhibit migrations related to spawning, feeding and overwintering. Grass carp migrations of up to 1700 km in the United States were reported by Guillory and Gasaway (1978). However, within ten years after stocking in the Mississippi drainage system, individuals were captured nearly 2700 km from the point of release indicating that grass carp have strong dispersal potential (Moyle 1986). Size seems to be a factor in determining movement patterns, with larger individuals moving greater distances than smaller ones (Gorbach and Krykhtin 1988, Bain *et al.* 1990).

Information on diurnal movements has been equivocal. Some studies have shown distinct movements throughout the 24 hour day, with movements greatest around dawn, elevated activity levels persisting until midday, and less active during the night (Nixon and Miller 1978, Hockin *et al.* 1989). Nixon and Miller (1978) found that the only abiotic environmental factor having any effect on movement was water temperature (movement increasing with increased water temperature). However, Cassani and Maloney (1991) found that water temperature did not significantly affect grass carp movement, and their radio-tracking studies did not show any evidence of diel movement in grass carp.

Based on temperature and current velocity, grass carp eggs may drift from 50 to 180 km downstream before hatching (Stanley *et al.* 1978). The pelagic larvae then have a behavior of alternately sinking and swimming giving them the potential for very extensive downstream migration (Stanley *et al*. 1978). They eventually leave the main waterways to enter flood plains, reservoirs and lakes that act as their nursery areas where the young shelter in vegetated areas.

Juveniles feed and grow in the lower reaches of their native Amur River for up to five years prior to the slow migration northward to their main spawning grounds in the upper river (Gorbach and Krykhtin 1988). This journey takes place over several years and they have been known to travel as far as 500 km in the first two years; one individual (61 cm) traveled 155 km in nine months (Chilton and Muoneke 1992).

After spawning, the fish leave the river for backwaters, floodplains or lakes until autumn when they return back to the river to over-winter (Fischer and Lyakhoich 1973). The young do not associate with adults over the winter months (Shireman and Smith 1983).

Chappelear (1990) suggested that grass carp will move to more favourable conditions when faced with low dissolved oxygen concentrations (less than or equal to 1 mg/l).

In stocked populations, average daily movements decreased over time after the stocking, suggesting that grass carp may require an acclimation period before becoming associated with vegetated areas (Chappelear 1990, Chilton and Muoneke 1992, Kartalia

1992). The location of, and association with, macrophyte beds generally occurs within days (Chilton and Muoneke 1992). Once this association was established, the average distance moved per day decreased dramatically, until the vegetation within the area was nearly consumed (Chappelear 1990). During the first year after release, grass carp establish home ranges which can last from three months to one year (Cassani and Maloney 1991, Chilton and Muoneke 1992).

In closed systems, Buckley and Stott (1977) described grass carp as a shoaling species, often seen near the surface and Ellis (1974) observed loose aggregations of individuals, several of which would simultaneously break the surface. Grass carp are able to cross barriers by jumping up to 1m high (Beck 1996).

3.8. DISEASES AND PARASITES

A comprehensive list of the diseases and parasites of grass carp is found in Table 2. There have been many instances of transfer of disease or parastic organisms from wild grass carps to other countries and species (Shireman and Smith 1983). The most well known is an Asian tapeworm (Bothriocephalus opsarichthydis), native to China and the Amur River basin, first found in several species of native North American fishes in the 1970's following its introduction via infected grass carp (*Ctenopharyngodon idella*) (Bjergo et al. 1995). This tapeworm is known to parasitize several fishes found in Canada including common carp (*Cyprinus carpio*), golden shiner (*Notemigonus crysoleucas*) and fathead minnow (*Pimephales promelas*) channel catfish (*Ictalurus punctatus*) (Hoffman and Schubert 1984, GSMFC 1998). Infestations of 80 helminths in a 30 cm host individual have been reported (Hoffman and Schubert 1984). This tapeworm is now widespread in North America, primarily through release of grass carp, infestation in the common carp and transplantation with baitfishes and *Gambusia* species (GSMFC 1998). After infection, the tapeworm either kills the individual or creates diseased and weakened individuals. In the case of the Endangered woundfin (*Plagopterus argentissimus*) in the Virgin River, Utah, the tapeworm lead to a rapid population decline from which it has barely recovered (Bock 2004). Food and game fishes infected also become undesirable for consumption, causing economic harm (GSMFC 1998).

4.0. USE BY HUMANS

4.1. USE AS HUMAN FOOD

Although the flesh of grass carp is bony, there are many regions in the world where they are consumed as food (Opuszynski and Shireman 1995). Grass carp are commercially fished in some areas in the native range; however, they rarely comprise a large proportion of the catch (Shireman and Smith 1983). They are taken incidentally in common or silver carp fisheries in the Amur basin (Shireman and Smith 1983). Commercial fisheries for grass carp did exist in Japan; however, annual production declined from 7-47 metric tonnes during 1956-1959 to 0-9 metric tonnes during 1960-1975 (Tsuchiya 1979). Commercial harvest of this species from the Mississippi River in Missouri existed throughout the 1990s (Pflieger 1997), and harvest from the Mississippi and Missouri rivers is increasing (USGS 2004). In 1996, grass carp accounted for 8% of the total commercial fish harvest from this area (USGS 2004).

Grass carp are available in live fish for food markets in Canada. In 1996, over 90,000 kg of grass carp were reported imported by major wholesalers in the Greater Toronto Area (GTA), and over 85,000 kg were reported imported in 1997 (Goodchild 1999). During 2003, close to 50,000 kg were reported by the Canadian Food Inspection Agency (CFIA) as entering Ontario; however, only close to 9,000 kg of grass carp were voluntarily reported sold, primarily live, to retail fish markets in Toronto during the period of April 2003-March 2004 (OMNR, unpubl. data).

4.2. VEGETATION CONTROL

Because of its strong preference for aquatic vegetation, the grass carp is being widely introduced throughout the United States to control aquatic vegetation in lakes and ponds (Page and Burr 1991). Chilton and Muoneke (1992) suggested that popularity of grass carp stems from their ability to be cultured easily, hardiness, effective biological controls on wide variety of aquatic vegetation, and “delicious” source of high quality protein.

A stocking model developed for coldwater lakes by Swanson and Bergersen (1988) included eight key factors that influenced stocking densities and probability of success of aquatic vegetation control: water temperature, density, distribution, aquatic plant species, human disturbance, lake management objective, size and ploidy of stocked fishes.

Stocking rates need to be increased as temperature decreases (as indicated by daily temperature units (DTU) decrease, or increasing elevation) because grass carp plant consumption and growth decrease (see Table 3). Along with DTU, vegetation biomass value greatly influences stocking rates. Stocking densities need to be based on the standing crop (biomass) of aquatic vegetation. This is estimated by multiplying plant distribution by average plant density; therefore, the higher the vegetation biomass the higher the required stocking rate.

Based on these factors, baseline stocking rates range from 8-10 fish/acre for low-elevation lakes with low plant biomass to 36-40 fish/acre for high-elevation lakes with high vegetation biomass.

4.3. RECREATIONAL ANGLING

Grass carp can be caught by recreational fisherman and state angling fish records range from 4 to 32 kg (Table 4).

4.4. PRAYER RELEASE

Asian carps, including grass carp, may be used as a prayer release animal. East Asian peoples believe that by freeing captive animals into the wild as a form of prayer, merits are accrued (Crossman and Cudmore 1999, Severinghaus and Chi 1999). The frequency of occurrence of this happening in Canada is unknown.

5.0. IMPACTS ASSOCIATED WITH INTRODUCTIONS

Various authors (e.g., Shireman and Smith 1983, Chilton and Muoneke 1992, Bain 1993, Goodchild 1999) have reviewed the literature on grass carp and discussed the potential impacts caused by the introduction of this species. Shireman and Smith (1983) indicated that there are numerous contradictory results reported in the literature concerning grass carp interactions with other species. They concluded that the effects of grass carp introduction on a waterbody are complex and apparently depend on the stocking density, macrophyte abundance and community structure of the ecosystem. The introduction of grass carp into an aquatic system has been shown to directly, or indirectly, impact aquatic macrophytes, water quality and aquatic fauna including plankton, benthic macroinvertebrates, fishes and wildlife.

5.1. IMPACTS ON AQUATIC MACROPHYTES

Adult grass carp generally make up most (95%) of their diet from macrophytes, utilizing a wide variety of aquatic macrophytes (Fedorenko and Fraser 1978). One year after 270,000 grass carp were stocked in Lake Conroe, Texas, over 3,600 hectares of submerged aquatic vegetation were eliminated (Bettoli *et al.* 1993). They are selective in the vegetation they consume and not all plants are consumed (Bain 1993). This feeding on, and decrease in, density and composition of macrophytes leads to the loss of the unique absorbing capability of plants in the system for allochthonous sources of nutrients (Lembi *et al.* 1978). Further impacts to water quality and other tropic levels can also occur as a result of the elimination of macrophytes and are further outlined below.

5.2. IMPACTS ON WATER QUALITY

As Chilton and Muoneke (1992) noted, results of studies on the impacts of grass carp introduction on water quality are inconsistent. However, in general, turbidity, alkalinity, chlorophyll *a*, ammonia-nitrogen and phosphorus concentrations can increase after the removal of vegetation by grass carp, while dissolved oxygen levels can decrease (Rose 1972, Lembi *et al.* 1978, NatureServe 2003).

Due to their short guts, grass carp can digest only about half of the plant material it consumes each day (Fedorenko and Fraser 1978). The remaining material is expelled into the water, enriching it and promoting algal blooms with an associated increase (at least 10-fold) in chlorophyll *a* concentrations (Rose 1972, Fedorenko and Fraser 1978, Lembi *et al.* 1978). The blooms, and the associated decay of plant matter, can reduce water clarity and decrease dissolved oxygen concentrations, especially in the water column directly above the sediments (Boyd 1971, Lembi *et al.* 1978).

Grass carp have been associated with increased turbidity and alkalinity as a result of their feeding behaviour and removal of macrophytes (Lembi *et al.* 1978, NatureServe 2003). Grass carp will also dig into the banks to consume the roots of terrestrial plans (D. Chapman, USGS, pers. comm.). Increased bacterial counts have also occurred (Van Zon *et al.* 1977).

Phosphorus, manganese and iron concentrations increased in some waterbodies after the removal of macrophytes by grass carp (Rose 1972, Van Zon *et al.* 1977). Significantly higher turbidity, potassium and ammonium-nitrogen concentrations were found in Indiana ponds after the introduction of grass carp (Lembi *et al.* 1978).

However, increased nutrients do not occur in all cases after grass carp introductions (see Opuszynski and Shireman 1995). In some studies of phosphorus and nitrogen levels, either no increase or a minimal short-term increase was found after grass carp were stocked (Van Zon *et al.* 1977). A study of the effects of grass carp on water quality and phytoplankton in a reservoir in Alabama indicated that there were only moderate increases in phytoplankton, total organic carbon and total phosphorus (Webb *et al.* 1987). Other studies investigating water quality changes after introductions of grass carp have determined that temperature and oxygen values are not seriously affected (see Opuszynski and Shireman 1995).

5.3. IMPACTS ON FAUNA

With the removal of aquatic macrophytes, there are indirect impacts on the invertebrate and vertebrate animal communities that rely on these plants (Chilton and Muoneke 1992). Plankton growth and benthic organisms can increase due to fewer limits on resources. In turn, this can increase food sources for both planktivores and benthivores. However, macrophyte removal can negatively impact other benthic macroinvertebrates, fishes and wildlife through loss of food sources, refugia or spawning habitat.

5.3.1. Plankton

In some waterbodies where grass carp were introduced, a decrease in abundance and diversity of plankton communities occurred (Chilton and Muoneke 1992), and zooplankton density declined in the limnetic and littoral zones (Bettoli *et al.* 1993). In contrast, other studies have shown an increase in zooplankton numbers and biomass, likely as a result of increased bacterial counts (Van Zon *et al.* 1977).

5.3.2. Benthic Macroinvertebrates

Direct competition for plant material has been shown to decrease the abundance of snails and cause the displacement or decrease the size of crayfishes (Fedorenko and Fraser 1978, Chilton and Muoneke 1992). Grass carp have been shown to feed on benthic macroinvertebrates, such as crayfishes and fingernail clams, after depleteting vegetation (Lewis 1978). In some cases, crayfish abundance can increase due to the high levels of grass carp excrement (W. Shelton, University of Oklahoma, pers. comm.).

Not only can grass carp impact benthic macroinvertebrates through competition and predation, their removal of macrophytes leads to loss of shelter or refuge habitat for these organisms. Grass carp, through moderate weed consumption, produced better conditions for the exploitation of phytophilic, benthic organisms (Petrids 1990). For example, gastropods and the isopod, *Asellus aquaticus*, greatly decreased in abundance from increased predation by fishes (Petrids 1990).

5.3.3. Fishes

As outlined in Bailey (1978), impacts to fish communities from grass carp introductions vary greatly and are often contradictory. Some waterbodies exhibited changes in diversity and biomass of their fish populations, while others did not. As the study of Arkansas lakes by Bailey (1978) indicated, there seems to be no consistent changes in the quality of fish populations. However, removal of vegetation can have negative effects on native fishes, such as elimination of food sources, shelter and spawning substrates (Taylor *et al.* 1984).

Direct competition occurs for plant material between grass carp and other herbivorous fishes, such as forages fishes. According to Coker *et al.* (2001), there are 63 freshwater fish species in Canada that have some preference for macrophytes in their diet; nearly half of which exhibit a high preference. Grass carp may compete with planktonic and benthic species, including catfishes and hybrid sunfishes for aquatic plants (Shireman and Smith 1983), especially during grass carp juvenile stages and at lower water temperatures (Fedorenko and Fraser 1978). Grass carp have been reported to occasionally feed on salmonid fry and may occasionally utilize early stages of other small fishes (Goodchild 1999). As macrophyte-associated animals lose their shelter habitat, they can be more vulnerable to consumption by fishes, including sport fishes; notably largemouth bass (*Micropterus salmoides*) which has been shown to increase in growth following the introduction of grass carp (Chilton and Muoneke 1992). Hubert (1994) cited a study that found vegetation removal by grass carp led to better growth of rainbow trout (*Oncorhynchus mykiss*) due to increases in phytoplankton and zooplankton production, but it also led to higher predation on rainbow trout by cormorants (*Phalacrocorax auritus*) due to lack of cover. With changes in diet, densities and growth of native fishes, the introduction of grass carp can, therefore, result in changes in resident fish communities.

The removal of macrophytes can directly degrade habitat for those fishes which depend upon aquatic vegetation for all, or part, of their life cycle, such as northern pike (*Esox lucius*) and largemouth bass (Taylor *et al.* 1984, Chilton and Mueoneke 1992). Standing crop of forage fishes in the littoral zone has been shown to decrease due to lower recruitment rates as a result of loss of nursery habitat following vegetation removal (Chilton and Mueoneke 1992). Grass carp removed *Hydrilla* spp. from a pond in Florida and, in doing so, destroyed spawning grounds of native centrarchids (Shireman and Smith 1986). Similarly, grass carp stocked in a reservoir caused the elimination of vegetation and changed spawning substrate which resulted in a 50% reduction of centrarchids (Opuszynski and Shireman 1995). Forester and Lawrence (1978) found that the standing crop of bluegill (*Lepomis macrochirus*) was significantly lower in ponds where grass carp were introduced. Competition for food organisms, predation and water quality parameters were ruled out as the reasons for this decrease. Forester and Lawrence (1978) suggested that the grass carp interfered with bluegill spawning by constantly invading spawning areas. Therefore, grass carp introductions can decrease the reproductive success of vegetation-dependant spawners.

Conversely, other species responded to the introduction of grass carp by increasing in abundance. Increases in abundance and standing crop of catfishes have been observed (Chilton and Mueoneke 1992). The standing crop of open-water fish species can increase because of an increase in their preferred non-vegetated habitat (Opuszynski and Shireman 1995). Studies in Arkansas, found that standing crops of bass (*Micropterus* spp.), bluegill, redear sunfish (*L. microlophus*) and crappie (*Pomoxis* spp.) fluctuated after grass carp introductions, but there was no discernible trend (Opuszynski and Shireman 1995). In some cases, other fish species have increased, possibly as a result of the increase in nutrients resulting from incomplete digestion of food by grass carp (Goodchild 1999). In polyculture, filter feeding omnivorous fishes directly utilized the detritus of the feces of grass carp, thereby increasing their total net production (Huazhu *et al.* 1990).

Grass carp may also carry parasites and diseases known to be, or potentially, transmittable to native fishes. As discussed previously, the Asian tapeworm, *Bothriocephalus opsarichthydis,* has been introduced to North American via introduced grass carp and has infected North American cyprinids (Bjergo *et al.* 1995, GSMFC 1998).

5.3.4. Wildlife

Other taxa can also be affected by the removal of introduced grass carp. Waterfowl, such as ducks, utilize aquatic plants such as *Potamogeton* spp., as habitat and food, directly competing with carp (Chilton and Muoneke 1992, Opuszynski and Shireman 1995). Fedorenko and Fraser (1978) suggest that competition with grass carp for aquatic vegetation may cause the numbers of many waterfowl species, and even some mammals to decline.

5.4. IMPACT SUMMARY

Bain (1993) stated that grass carp have significantly altered the food web and trophic structure of aquatic systems by inducing changes in plant, invertebrate, and fish communities. He indicated that effects are largely secondary consequences of decreases in the density and composition of aquatic plant communities. Organisms requiring limnetic habitats and food webs based on phytoplankton tend to benefit from the presence of grass carp. Conversely, Bain (1993) reported that declines have occurred in the diversity and density of organisms that require structured littoral habitats and food chains based on plant detritus, macrophytes and attached algae.

Stocked grass carp have been associated with a decline in the abundance and diversity of fish species, declines in game fish size, reductions in macroinvertebrate number and diversity, reductions in submerged macrophytes and changes in population structure in some areas. Indiscriminate exploitation of aquatic vegetation by grass carp may lead to destruction of important habitat and food sources of other organisms. Aquatic vegetation is an important component of the habitat of many fishes including recreational species like largemouth bass and major reductions in plant coverage have been associated with declines in fish populations.

6.0. CONSERVATION STATUS

In its native range in the Amur basin, depauperate stocks of grass carp led to suggestions that regulations such as size limits, season and catch quotas should be implemented (Shireman and Smith 1983); even a 10-year fishing ban (beginning in 1971) was recommended (Gorbach 1972). In China, historical regulations included setting size limits and restricting fishery activities with respect to spawning fishes and their spawning season and areas (Shireman and Smith 1983).

According to NatureServe (2003), grass carp was given a global conservation status of G5 (globally secure) in 1996. National ranks for both the United States and Canada are NE (exotic), which were assigned in 1996. Sub-national ranks of SE (exotic) were assigned to grass carp by all American states (states not reported to have introductions are Alaska, Maine, Montana, Rhode Island and Vermont) and Canadian provinces (Alberta, Saskatchewan and Ontario) where they are found. The exception was Arizona, which gave grass carp a rank of SE2 (exotic, but very rare and susceptible to extirpation) (NatureServe 2003).

7.0. SUMMARY

Information concerning the description, distribution, life history and biology of the grass carp, along with its uses by humans and impacts to aquatic ecosystems, was compiled. These species are long-lived, grow to very large sizes, and can impact, directly or indirectly, aquatic macrophytes, water quality and aquatic fauna.

This information was used to develop an ecological risk assessment for grass carp in Canada based upon the *Canadian National Code on Introductions and Transfers of Aquatic Organisms* (Task Group on Introductions and Transfers 2002). The risk assessment for grass carp, and the other four species of Asian carps, is found in Mandrak and Cudmore (2004).

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Table 1. Aquatic plants eaten by grass carp in North America in approximate order of preference. Refer to Opuszynski and Shireman (1995) for a more complete list of plant preferences.

Common waterweed	*Elodea canadensis*
Hornwort	*Ceratophyllum demersum*
Stonewort	*Chara* spp.
Lesser duckweed	*Lemna minor*
Floating pondweed	*Potamogeton natans*
Ivy-leaved duckweed	*Lemna trisulca*
Water milfoil	*Myriophyllum* spp.
Fennel-leaved pondweed	*Potamogeton pectinatus*
Broadleaf cattail	*Typha latifolia*
Common reed	*Phragmites communis*
Common rush	*Juncus effusus*
Black sedge	*Carex nigra*
European frog’s bit	*Hydrocharis morsus-ranae*
Watercress	*Nasturtium officinale*
Shiny pondweed	*Potamogeton lucens*
Sedge	*Carex pseudo-cyperus*

Table 2. Infectious disease agents and parasites of Chinese carps (from Opuszynski and Shireman 1995).

Viruses	*Rhabdovirus* sp.; *R. carpio*; *R.* GRV
Bacteria	*Achromobacter* sp.; *A. curydice; A. pestifer; Aeromonas* sp.; *A. punctata; A. salmonicida* var. *achromogenes; Bacillus cereus; B. megaterium;* Carp erythrodennatitis bacteria; *Citrobacter* sp.; *Flavobacterium aquatile; Flexibacter columnaris; Micrococcus luteus; M. flavus; Myxococcus piscicola; Paracolobactrum aerogenoides; Pseudomonas* sp.; *P. dermoalba; P. fluorescens; P. fragi; P. putida; Staphylococcus aureus*
Fungi	*Branchiomyces sanguinis; Saprolegnia* sp.; *Ichthyophonus hoferi*
Protozoa	*Apiosoma* sp.; *A. cylindriformis; A. magna; A. minimicro nucleate; A. piscicola; Balantidium ctenopharyngodontis; Chilodonella* sp.; *C. cucullulus; C. cyprini; C. hexasticha; Chloromyxum* sp.; *C. cyprini; C. nanum; Costia necatrix* (= *Ichthyobodo necator);* *Cryptobia* sp.; *C. branchialis; C. cyprini; Dexiostoma campylum; Eimeria carpelli; E. cheni; E. mylopharyngodonis; E. sinensis; Enamoeba ctenopharyngodontis; Epistylis* sp.; *E. lwoffi; Euglenosoma caudate; Frontonia acuminate; F. leucas; Glaucoma pyriformis;* G. *scintillans; Glugea* sp.; *Hemiophrys macrostoma; Hexamita* sp.; *Icthyophthyrius* sp.; *I. multifiliis; Myxidium* sp.; *M. ctenopharyngodonis; Myxobolus dispar; M. ellipsoids; M. drjagini; M. pavlovskii; Sessilia* sp.; *Sphaerospora carassii; Sphaerosporidae lieni; Spiromtcleus* sp.; *Tetrahymena pyriformis; Thelohanellus oculi-leucisci; Trichodina* sp.; *T. bulbosa; T. carasii; T. domerguei; T. meridionalis; T. nigra; T. ovaliformis; T. pediculus; T. reticulate; Trichodinella* sp.; *T. subtilis; Trichophrya* sp.; *T. piscium; T. sinensis; T. variformis; Tripartiella* sp.; *T. bulbosa, T. lata; Trypanoplasma* sp.; *Zschokkella nova*
Trematoda	*Amurotrema dombrowskajae; Ancryocephalus subaequalis; Apharyngostrigea curnu; Aspidogaster amurensis; Cotylurus communis; C. pileatus; Dactylogyrys* sp.; *D. aristichthys; D. ctenopharyngodontis; D. hypophthalmichthys; D. inexpectatus; D. lamellatus; D. magnihamatus, D. nobilis; D. scrjabini; Diplostomum* sp.; *D. indistinctum; D. macrostomum; D. mergi; D. paraspathaceum; D. spathaceum; Siplozoon* sp.; *D. paradoxum; Fasciolata* sp.; *Gyrodactylus* sp.; *G. ctneopharyngodontis; G. elegans;* G. *kathariner*; G. *medius*; G. *wageneri*; *Metagonimus yokogawai*; *Opisthorchis* (= *Chlonorchis)*; *sinensis; Posthodiplostomum* sp.; *P. cuticola*; *Sphaerostoma bramae*; *Tetracotyle* sp.; *T. percae fluviatilis*; *T. variegata*
Cestoda	*Biacetabulum appendiculatum; Bothriocephalus gowkongensis;* (= *acheilognathi); B. opsarichthydis; Diagramma interrupta; Khawia sinensis; Ligula intestinalis; Triaenophorus lucii; T. nodulosus*
Nematoda	*Capillaria amurensis;* C. *pretrushewskii; Capillaria* sp.; *Philometra* sp.; *P. lusiana; Philometroides lusii; Rhabdochona denudata; Skrjabilianus amuri; Spiroxys* sp.
Hirudinea	*Hemiclepsis marginata; Piscicola geometra*
Athropoda	*Argulus* sp.; *A.foliaceus; Ergasilus* sp.; *Lernaea* sp.; *L. ctenopharyngodontis; L. cyprinacea; L. elegans; L. piscinae; L. quadrinucifera; Neoergasilus longispinosus; Paraergasilus medius; Sebekia oxycephala; Sinergasilus lieni; S. major*

Table 3. Vegetation biomass and stocking rates for six Colorado lakes (from Swanson and Bergersen 1988).

Vegetation biomass (tonnes/acre)	Stocking rate (fish/acre) by lake elevation (ft) and associated DTUs [a]				
	9500-8500 ft 400-750 DTUs	8500-7500 ft 750-1100 DTUs	7500-6500 ft 1100-1450 DTUs	6500-5500 ft 1450-1800 DTUs	5500-3500 ft 1800-2450 DTUs
0.2-1.1	16-20	8-12	8-12	8-12	8-12
1.1-2.2	26-30	16-20	16-20	8-12	8-12
2.2-4.5	36-40	26-30	26-30	16-20	16-20
>4.5	36-40	36-40	36-40	26-30	26-30

[a] DTUs = annual sum of mean daily water temperature degrees above 55°

Table 4. Grass carp angling records from the Hot Spot Fishing website.

Fish	Weight	Length (inches)	Girth (inches)	Date	Location	State	Country
Grass Carp	70 lb. 0 oz.			4/12/99	Martin Lake	Alabama	United States
Grass Carp	47 lb. 1.6 oz.	46.5		7/12/02	Encanto Lagoon	Arizona	United States
Grass Carp	65 lb. 14 oz.			4/28/95	Horseshoe Lake	Arkansas	United States
Grass Carp	42 lb. 0 oz.	38		1999	Bear Creek Pond	Colorado	United States
Grass Carp	13 lb. 4.5 oz.			1/16/96	Waita Reservoir	Hawaii	United States
Grass Carp	69 lb. 8 oz.			7/13/00	Lake Petersburg	Illinois	United States
Grass Carp	65 lb. 3.2 oz.			2002	private pond	Indiana	United States
Grass Carp	61 lb. 8 oz.	49.5		5/1/98	Greenfield Lake	Iowa	United States
Grass Carp	60 lb. 0 oz.	48		7/6/00	Sugar Valley Lakes	Kansas	United States
Grass Carp	55 lb. 8 oz.			3/14/01	private pond	Kentucky	United States
Grass Carp	34 lb. 12.16 oz.			6/3/92	Guntown Sportsman Lake	Mississippi	United States
Grass Carp	62 lb. 15 oz.			7/18/97	, Western Farm	Missouri	United States
Grass Carp	40 lb. 8 oz.			5/4/97	Rock Creek Lake	Nebraska	United States
Grass Carp	50 lb. 0 oz.			2001	Garrison Lake	New Jersey	United States
Grass Carp	68 lb. 12 oz.			6/8/98	Summerlins Pond, Leland	North Carolina	United States
Grass Carp	64 lb. 46 oz.	46	32.75	2/5/98	Arbuckle Lake	Oklahoma	United States
Grass Carp	67 lb. 0 oz.			4/13/99	Norris Reservoir	Tennessee	United States
Grass Carp	44 lb. 0 oz.	46		2/10/98	Bastrop Bayou	Texas	United States
Grass Carp	8 lb. 2.56 oz.	26.42		11/14/92	Gulf of Mexico, Sims Bayou Canal	Texas	United States
Grass Carp	52 lb. 8 oz.	47.1		2002	unknown pond	West Virginia	United States

From: http://www.hotspotfishing.com/records/fish-records-Carp.asp, accessed April 14. 2004

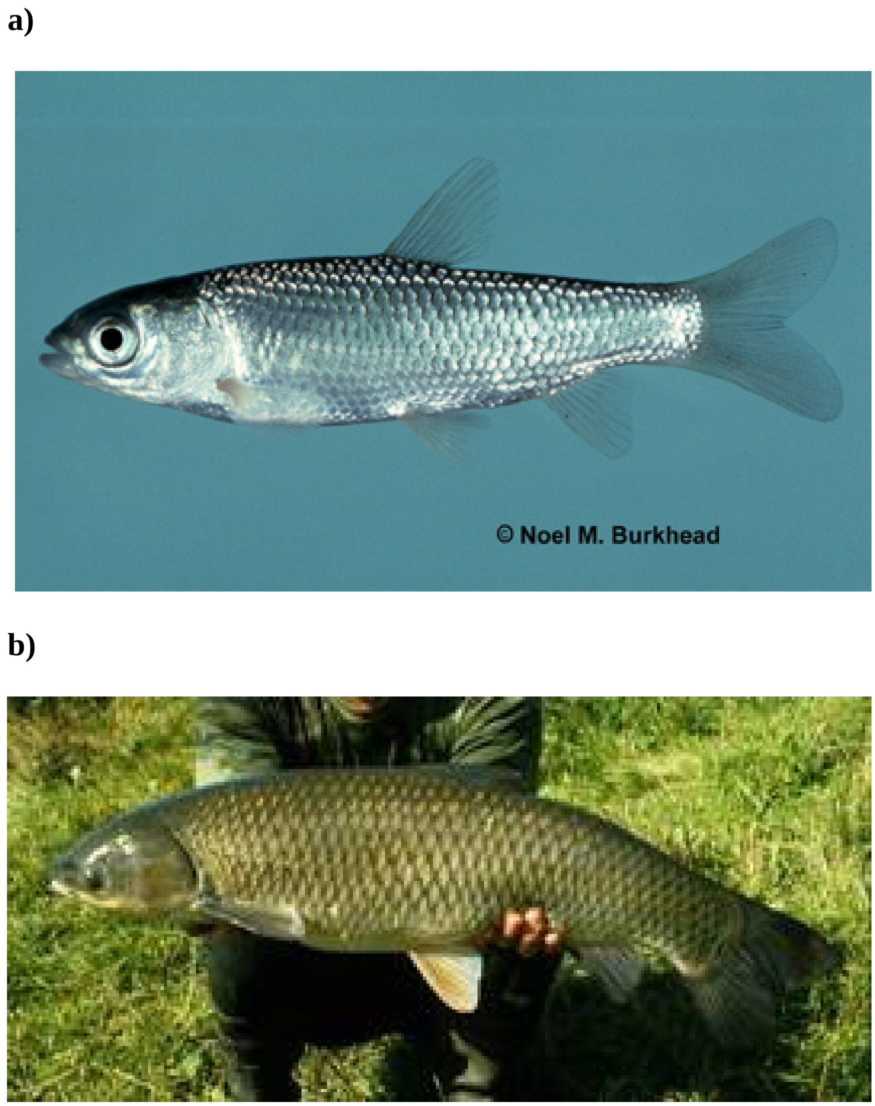

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Figure 1. Grass carp (*Ctenopharyngodon idella*). a) juvenile (http://nas.er.usgs.gov/queries/SpFactSheet.asp?speciesID=514); and, b) adult grass carp (http://www.fishbase.org/Summary/SpeciesSummary.cfm?genusname=Ctenopharyngodon&speciesname=idella).

Figure 2. Native distribution of grass carp (modified from Opuszynski and Shireman 1995).

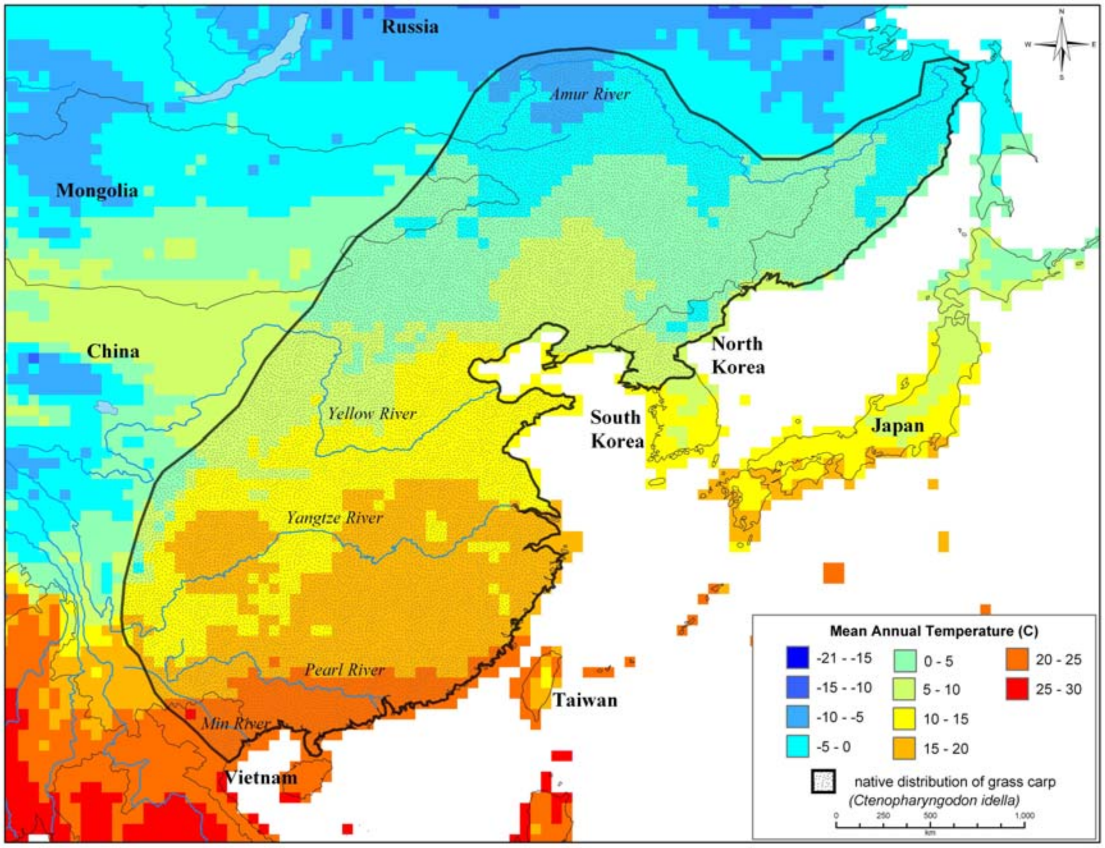

Figure 3. Native distribution of grass carp overlaid onto mean annual air temperature (based on 0.5^o latitude x 0.5^o longitude grids; data from Intergovernmental Panel on Climate Change (IPCC) data distribution center (http://ipcc.ddc.cru.uea.ac.uk)).

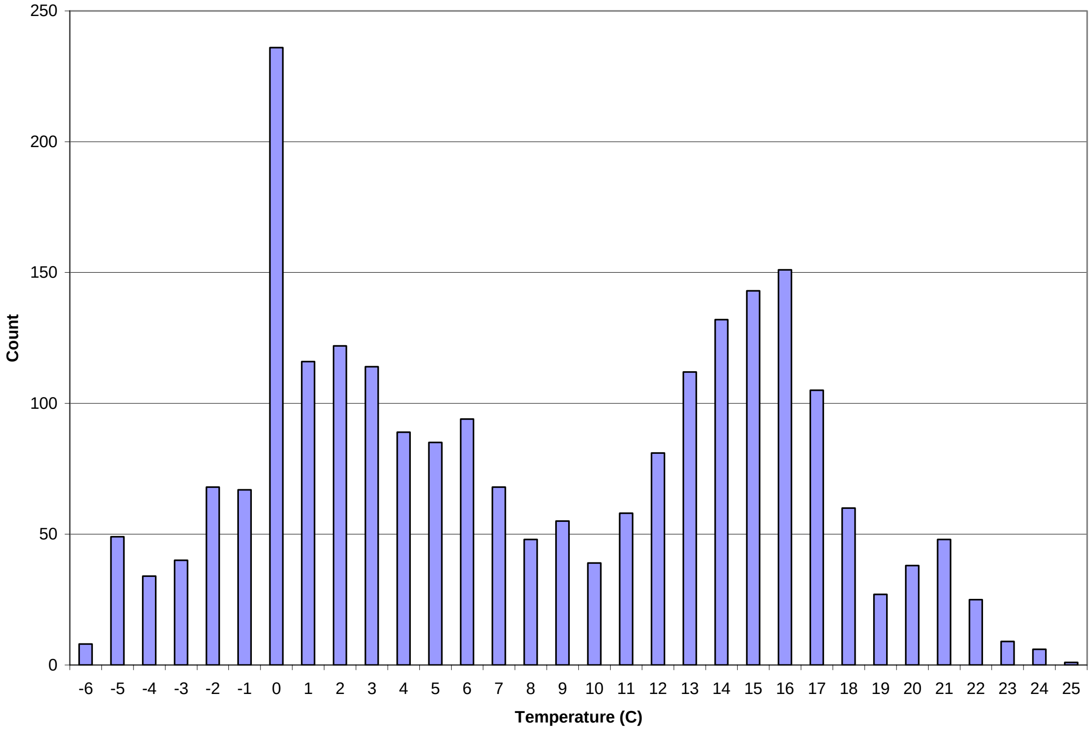

Figure 4. Frequency distribution of mean annual air temperature within the native distribution of grass carp as represented in Figure 3.

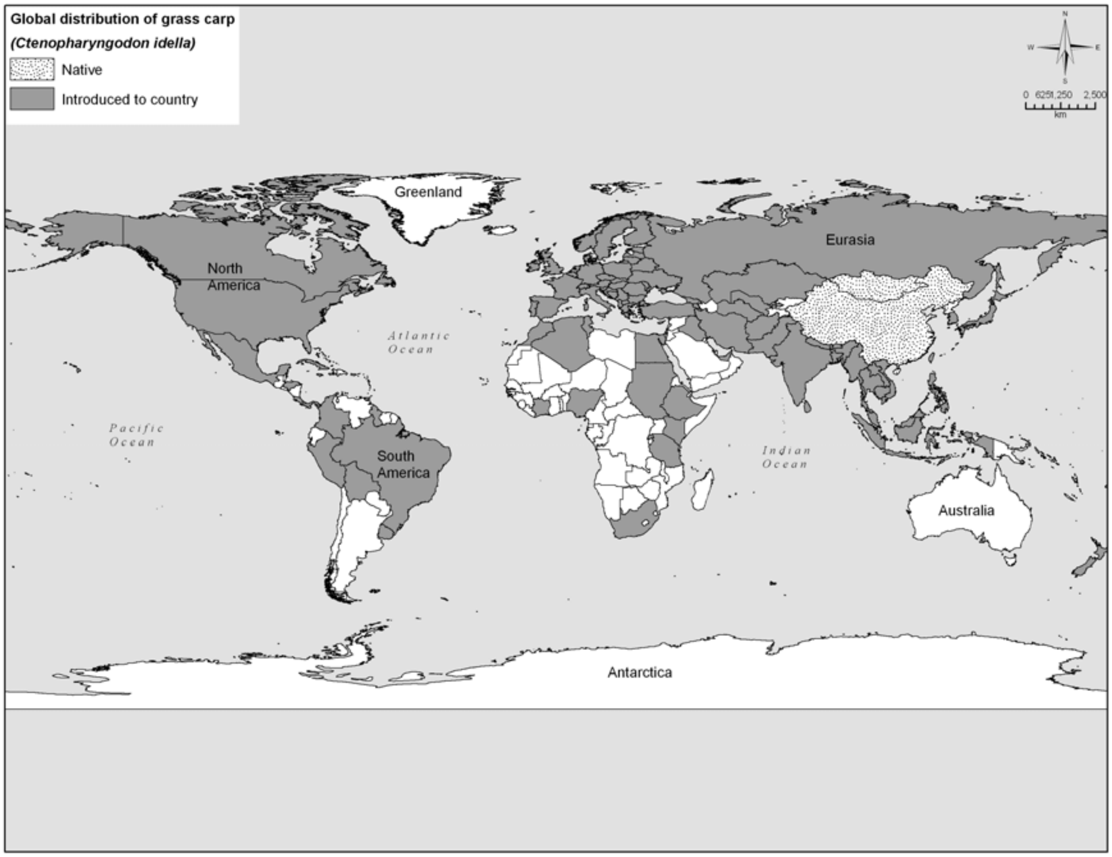

Figure 5. Global distribution of grass carp.

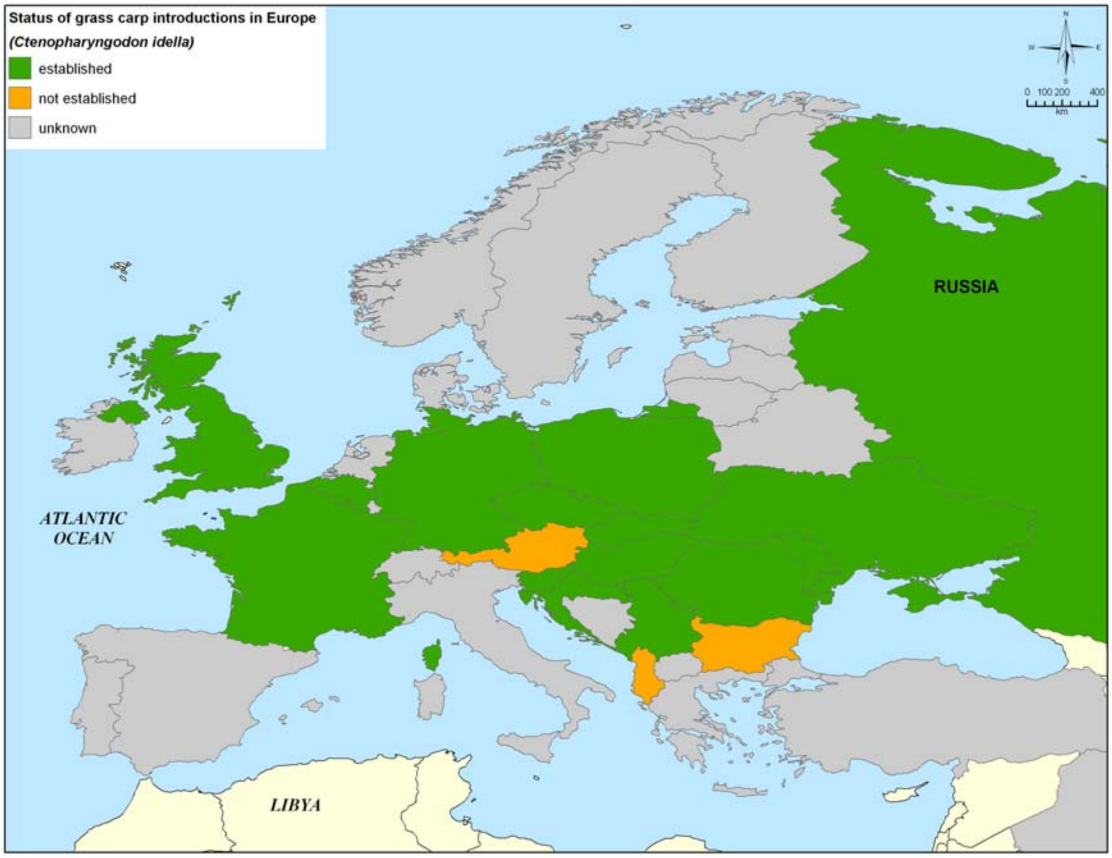

Figure 6. Grass carp distribution and status in Europe.

Figure 7. Grass carp distribution Europe with extent of known reproducing populations delineated (Opuszynski and Shireman 1995).

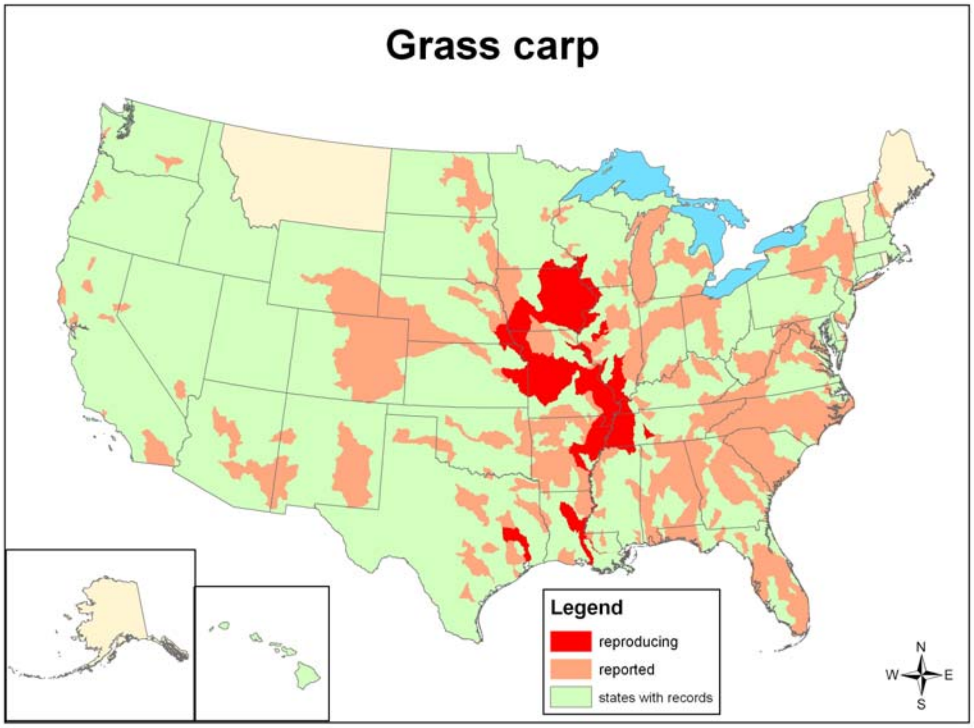

Figure 8. Grass carp occurrence in the United States (USGS 2004).

● Canadian records of grass carp

(Ctenopharyngodon idella)

ID	Water Body	Date of Capture
1	Lake Newell	2000 or 2001
2	Loch Leven in Cypress Hills Provincial Park	2000
3	Lake Huron	unknown
4	Lake Huron,off Point Edward	1989
5	Lake Huron,northeast of Bluewater Bridge	1989
6	Lake Erie,west of Point Pelee	1985
7	Don River	2003
8	High Park Pond	1999

Figure 9. Canadian records of grass carp.

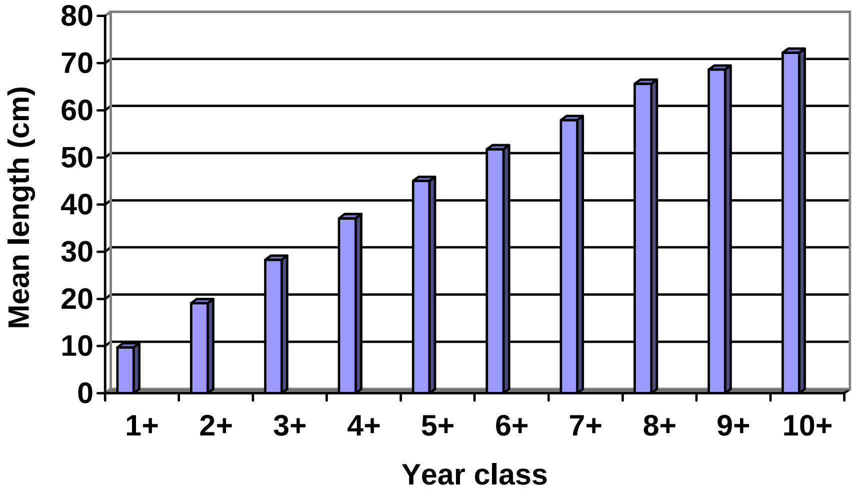

Figure 10. Mean length for each year class of grass carp in the Amur basin (data from Shireman and Smith 1983).