Review of Grass Carp Biology

A.Y. Fedorenko and F. J. Fraser

Interagency Committee on Transplants and Introductions of Fish and Aquatic Invertebrates in British Columbia

Fisheries and Marine Service
Department of Fisheries and Environment
Vancouver, B.C.

Fish and Wildlife Branch
Ministry of Recreation and Conservation
Victoria, B.C.

September 1978

Fisheries and Marine Service Technical Report No. 786

Fisheries and Environment Canada — Pêches et Environnement Canada
Fisheries and Marine Service — Service des pêches et de la mer

Fisheries and Marine Service
Technical Report No. 786

September 1978

A REVIEW OF THE BIOLOGY OF GRASS CARP (*CTENOPHARYNGODON IDELLA*, VAL.) AND ITS EVALUATION AS A POTENTIAL WEED CONTROL AGENT IN BRITISH COLUMBIA

by

A.Y. FEDORENKO and F.J. FRASER

Interagency Committee on Transplants and Introductions
of Fish and Aquatic Invertebrates in B.C.

Fisheries and Marine Service
Department of Fisheries and Environment
1090 West Pender Street
Vancouver, B.C. V6E 2P1

Fish and Wildlife Branch
Ministry of Recreation and Conservation
Parliament Buildings
Victoria, B.C. V8W 1C8

ABSTRACT

The biology of grass garp (*Ctenopharyngodon idella* Val.) is reviewed, particularly feeding habits, reproduction, behavioral activity, predators and parasites. The grass carp is tolerant of temperatures and oxygen extremes, feeds on both animal and plant material, is known to host over 80 species of parasites and can probably reproduce successfully in North America. This fish species is a potential threat to native fish populations through competition for food and space, interference with spawning, alteration of fish habitat and spread of disease. The grass carp can also be a threat to water quality through poor assimilation of plant material. Aquatic weed species are consumed selectively and high water temperatures of 20 - 33°C are required for intensive feeding on plants to occur.

A potential serious impact of the proposed grass carp introduction into British Columbia is expected because of substantial differences existing between the biological and physical parameters of the B.C. Okanagan Basin Lakes and those of the grass carp's natural habitat. Consequently, the authors and the Interagency Transplant Committee conclude that the proposed introduction is highly undesirable and should not be considered.

KEY WORDS: grass carp review, aquatic weeds, biological control, Eurasian water milfoil, Okanagan Basin Lakes.

RÉSUMÉ

La carpe herbivore (*Ctenopharyngodon idella* Val.) fait l'objet d'une étude qui porte notamment sur ses habitudes alimentaires, sa reproduction, son comportement, ses prédateurs et ses parasites. Capable de supporter des écarts extrêmes de température et de concentration d'oxygène, de se nourrir de matière tant végétale qu'animale, la carpe herbivore, hôte de plus de 80 espèces de parasites, pourrait probablement se reproduire avec succès en Amérique du Nord. L'espèce est cependant susceptible de nuire aux populations de poissons indigènes du fait qu'elle peut entrer en compétition avec eux pour la nourriture et l'espace, entraver leur fraie, dégrader leur habitat et propager des maladies. La carpe herbivore peut aussi contribuer à polluer l'eau étant donné la faible assimilation des matières végétales qu'elle ingère. Sa consommation de plantes aquatiques se fait de façon sélective et nécessite des températures de 20 à 33°C pour devenir intensive.

Les lacs de l'Okanagane forment un réseau considérable et complexe d'un attrait appréciable pour la pêche sportive. Ils s'intègrent aussi au réseau du fleuve Columbia du côté de la frontière américaine. Comme les paramètres physiques et biologiques de ce réseau sont sensiblement différents de ceux de l'habitat naturel de la carpe herbivore, il est impossible de déterminer dans quelle mesure elle pourrait s'y adapter. La gravité des effets possibles de son introduction a toutefois conduit les auteurs et le comité mixte sur le déplacement à conclure que ce projet ne saurait être retenue.

MOTS CLÉS: étude de la carpe herbivore; plantes aquatiques; lutte biologique; myriophylle verticillé; lacs de l'Okanagane.

INTRODUCTION

Grass carp (*Ctenopharyngodon idella Val.*) also known as the white amur, are native to those rivers of China and Siberia that flow into the Pacific Ocean. Recently this species has been introduced into many regions for culture as a food fish (Europe, USSR, Mexico), or for aquatic weed control (India, United States). These fish are currently under investigation for weed control in Canada, China, Czechoslovakia, England, Hungary, India, Japan, Malaysia, New Zealand, Poland, USSR, Taiwan, and the United States.

Grass carp were first imported into the U.S. in 1963 (Guillory and Gasaway, 1978). They were acquired from Malaya by the U.S. Bureau of Sport Fisheries and Wildlife for the purpose of weed control. Since that time some 40 states have acquired this species. Arkansas in particular has been stocking grass carp heavily in its public fishing waters to control various aquatic weeds. Arkansas hatcheries serve as a supplier of grass carp to other parts of North America.

Canada appears to be free of grass carp at the present time. Exceptions are the University of Victoria, B.C. where several hundred grass carp were imported from Arkansas in 1977 for microbiological and feeding studies (Dr. T. Buckley, Univ. of Victoria, pers. comm.).

In view of the interest in grass carp as a control of Eurasian milfoil (*Myriophyllum spicatum*) in the Okanagan Basin Lakes, the Interagency Transplant Committee for Fish and Aquatic Invertebrates is submitting the following evaluation of and recommendations on grass carp as a biological weed control agent.

BIOLOGY OF THE GRASS CARP

Grass carp (Fig. 1) are one of the largest members of the carp or minnow family (Cyprinidae) reaching a weight of over 45 kg and a length of over one meter (Opuszynski, 1972). They can tolerate water temperatures from 0 to 33°C (Anon. 1976c) with 38 - 39°C being the lethal level (Opuszynski, 1972). Oxygen levels tolerated are as low as 0.4 ppm (Negonovskaya and Rudenko, 1974). Juveniles and adults can withstand salinities of 11 to 12 parts per thousand and of up to 19 parts per thousand for brief periods (Meyer et al. 1975).

FEEDING HABITS

The feeding habits of grass carp are variable and dependent on a number of factors such as age and size of fish, temperature, species of plants available, size of pond, stocking density, amount of disturbance, and previous feeding history (Buck et al. 1975). In addition, the rate of feeding may be interrupted or diminished by windy weather and by sudden changes of temperature (Hickling, 1966). There is also some evidence that the fish do not feed during the spawning season (Prowse, 1971).

Grass carp are predominantly surface and mid-water feeders (Terrell and Fox, 1975). They have a toothless mouth and rely on pharyngeal teeth to tear and masticate vegetation (Hickling, 1966). Juvenile grass carp select animal type food such as benthos and zooplankton in preference to vegetation (Edwards, 1974). The older grass carp in their native waters are generally omnivorous with aquatic plants forming the bulk of their diet (Stevenson, 1965; Kilgen and Smitherman, 1971). Meyer et al. (1975) summarized the diet of grass carp in their natural habitat by life stages as follows:

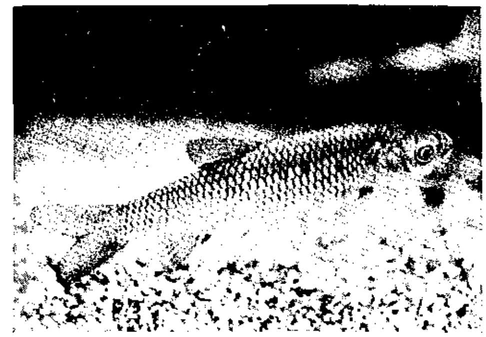

Figure 1. The grass carp, <u>Ctenopharyngodon</u> <u>idella</u>, Val.

> **Fry**-rotifers, infusoria, zooplankton, and some phytoplankton;
> **Small fingerlings**-zooplankton, small crustaceans and amphipods, chironomids, and tubifex;
> **Large fingerlings**-crustaceans and amphipods, chironomids, duckweed, and tender plants;
> **Sub-adults**-tender plants, shoots of macrophytes, and some animal matter;
> **Adults**-95% or more macrophytes.

The exact size at which grass carp become herbivorous depends on temperature, with the fish starting to feed on plants sooner in warm water than cool water (Stanley, Miley II, and Sutton, 1978). Sobolev (1970) reported that in ponds in Belorussia, juvenile grass carp, up to the age of about 35 days or a length of 3.5 to 4.0 cm, fed primarily on zooplankton. These juvenile carp were very selective at this time and preferred cladocerans *Daphnia longispina, Polyphemus pediculus, Bosmina longirostris* and *Scapholeberis mucronata* to cladocerans *Chydorus* and *Ceriodaphnia,* and to copepods *Cyclops* and *Diaptomus.* Grass carp fingerlings held in a laboratory readily consumed cladocerans (*Daphnia* sp.),oligochaetes (*Tubifex* sp.) and isopods *(Asellus sp.)* (Cross, 1969), and effectively captured nymphs of mayflies and stoneflies, amphipods, chironomid larvae, and snails (Edwards, 1973). Fingerling grass carp also ate carp eggs (Singh et al. 1976, cited in Stanley et al. 1978).

Among the grass carp transplanted into the U.S., vegetation was the dominant food of juveniles 6 - 7 cm in length (Mitzner, 1978) and of those fish 0.5 – 6.1 kg in weight (Lewis, 1978). In the Amur Basin, grass carp as small as 3.0 cm were already found to feed primarily on vegetation (Hickling, 1966) and in another study, grass carp only 2.5 cm long consumed small aquatic plants such as *Lemna* spp. (Stevenson, 1965).

Adult grass carp may switch to alternate foods when the supply of macrophytes is low (Tang, 1970). These may be benthos (Lewis, 1978), zooplankton, water beetles (gyrinids) or crayfish (Forester and Avault, Jr. 1978). Grass carp have been angled successfully with dead and live minnows, liver, worms, algae, and a variety of artificial lures (Martin, 1970, cited in Forester and

Avault, Jr. 1978). Grass carp held in aquaria fed on newly emergent rainbow trout fry, though not on trout eggs buried in redds (Edwards, 1973).These carp, while searching for food, did not disturb the stones covering possible food organisms. Lewis (1978) found no evidence of predation by grass carp, 1.5 to 7.6 kg in weight, stocked in the presence of dense populations of fingerling catfish and hybrid sunfish.

Some evidence exists that adult grass carp prefer aquatic invertebrates to macrophytes and algae. In experiments where grass carp were presented with both weeds and amphipods (*Gammarus* sp.), no weeds were taken until animal food became scarce (Anon. 1972b). Grass carp may prefer macrophytes to algae as was shown in an experiment where grass carp, held in ponds infested with massive blooms of filamentous algae, consumed mainly macroflora (72% of total food ingested) with only 9% of the total grass carp food intake being of algal origin (Anon. 1972b). However, under other conditions, filamentous algae may be readily consumed (Avault, 1965).

Temperature affects greatly the amount and type of food consumed by adult grass carp (Edwards, 1974). The adults take relatively little food at temperatures below 10°C and their growth is slow (Hickling, 1966; Colle, Shireman, and Rottmann, 1978). Intensive feeding on plants by adults does not occur until temperatures of 20–33°C are reached (Anon. 1972b). At 20°C, daily plant consumption by grass carp was 50% of body weight, at 22°C daily consumption was 100–200% of fish weight (Opuszynski, 1972). The carp held at water temperatures below 12°C selected aquatic invertebrates rather than plant food (Anon. 1972b). Temperature, however, had no effect on grass carp preference for types of weed (Edwards, 1974).

The degree of plant assimilation by the grass carp is generally less than 50% (Cross, 1969) and is affected directly by temperature (Hickling, 1966). Assimilation values as low as 20% were reported under aquarium conditions (Anon. 1972b). Cross (1969) attributed this inefficiency largely to the unusually short gut length of the grass carp, only a fifth of the length expected for a herbivore. As a result, much of the partly digested and highly disintegrated plant food returns to the environment as a potential source of eutrophication.

REPRODUCTION

Sexual Maturation

Grass carp reach maturity between the ages of four and ten years, depending on food supply and length of growing season; at that time they measure approximately 60 cm (Cross, 1969; Opuszynski, 1972; Martino, 1974). Fecundity of grass carp in the Amur Basin ranged from 0.2 to 1.7 million eggs with an average of 0.8 million (Gorbach, 1972). The number of eggs depends mainly on fish weight and less on length and age (Gorbach, 1972). An adequate supply of high quality plant food is required for high fecundity of grass carp (Stanley et al. 1978).

In their native rivers, grass carp spawn from April to mid-August (Anon. 1976c). Maturation, however, may occur in any month of the year (Hickling, 1967, cited in Stanley et al. 1978). As a result of seasonal gonadal development, those grass carp transplanted into temperate countries approach a spawning condition at about the same time as they would in their native habitat, but the gonads do not mature and natural spawning does not occur (Prowse, 1971). Whether this is an effect of day-length or change in temperature is not clear. Prowse (1971) adds that in a non-seasonal climate, such as in Malaya, grass carp have more than one spawning season.

Temperature required for stimulation of sexual maturation and spawning ranges from 15°C to 30°C, with an optimum of 20°C to 22°C (Kuronuma, 1958; Martino, 1974; Stanley et al. 1978). A current of 0.6 to 1.5 m / sec and a freshet-like rise in the water level are required as well (Anon. 1976c; Stanley et al. 1978). Grass carp, however, can also reproduce at water velocities as low as 0.2 to 0.5 m/sec and in ponds where current is absent (Martino, 1974).

Major grass carp spawning areas are found in turbulent waters at the confluence of rivers or below dams (Stanley et al. 1978). Because of water turbidity, natural spawning of grass carp is yet to be observed.

Egg Incubation

The eggs of grass carp are semi-buoyant and non-adhesive, and require a current to keep them suspended until hatching; consequently, successful reproduction occurs only in large rivers or canals where water velocity exceeds 0.8 m/sec and volume is about 400 m^3sec (Stanley, 1976a; Stanley et al. 1978). The eggs also require well-oxygenated water for incubation, a condition usually met in rivers with fast current (Stanley et al. 1978). The latter authors suggest that high turbidity in natural waters may protect eggs and larvae from predation.

The optimal temperature for egg incubation is 22°C to 26°C (Jahnichen, 1973, cited in Stanley et al. 1978). At temperatures below 20°C egg mortality is high and deformities increase (Stott and Cross, 1973). The incubation time decreases with increase in temperature from about 60 hr at 17°C, to 39 hr at 20°C, to 21 hr at 25°C (Anon. 1970, cited in Stanley et al. 1978). The effect of temperature is critical; the longer the incubation time the longer the eggs must stay suspended in the current.

The length of waterway needed to carry the eggs before hatching depends on water temperature and velocity and is highly important to the survival of spawn because the larvae must remain afloat until they reach the nursery area. Based on water temperature and velocity, the distance of travel may range from 50 to 180 km of river (Stanley et al. 1978).

Larvae and Juveniles

The newly hatched larvae are extremely vulnerable to predation and silt and must have some current until they become positive swimmers (Stanley, 1976a; Stanley et al. 1978). The grass carp larvae are more tolerant of temperature extremes than are the embryos (Stott and Cross, 1973) and require temperatures of 19°C to 30°C for survival (Stanley et al, 1978). Large fry mortalities may occur at temperatures below 15 - 16°C; at 10 - 16°C larger juveniles become less mobile and more vulnerable to predators (Stanley et al. 1978). The 4 to 6 week old juveniles tolerate dissolved oxygen concentrations as low as 0.33 to 0.57 ppm and pH values of 9 to 10 (Negonovskaya et al. 1975, cited in Stanley et al.1978).

Within the first six days after hatching the grass carp larvae must enter the quiet rearing waters such as vegetated lagoons, impoundments or lakes and commence active feeing (Stanley et al. 1978). Initial prey consist of microplankton such as rotifers, followed by larger zooplankton such as *Daphnia, Polyphemus, Scaphholeberis* (Sobolev, 1970), and insect larvae (Stanley et al. 1978).

BEHAVIORAL ACTIVITY

Grass carp juveniles 48 mm long were observed to swim in compact schools near the water surface above submerged vegetation (Shireman, Colle, and Rottmann, 1978). These fish showed no avoidance reaction to attacks from predatory largemouth bass and became ready prey to them. Forester and Lawrence (1978) reported that the schooling habit of grass carp probably disturbed the spawning bluegills in ponds in Alabama.

Using ultrasonic telemetry, Mitzner (1978) showed that grass carp, 0.48 - 0.69 kg in weight, inhabited all areas of a lake (maximum depth of 12m) but preferred the shallow areas less than 3 m deep. Much of the time the grass carp remained sedentary near weed beds with more rapid and extended movements in midwater. Normal swimming speed in midwater was 0.12 - 0.35 m/sec with maximum speed of 1.46 m/sec. Nixon and Miller (1978) also found that grass carp, 3.7 - 12.7 kg in weight, preferred shallow water areas and took long rest periods of up to 8 hrs long between moves. Fish activity increased during the day. Low water temperature limited activity of grass carp more than did varying weather or oxygen conditions.

PREDATORS

Predation is perhaps the major factor limiting the abundance of introduced grass carp. Birds, snakes and especially fish such as pike perch (*Lucioperca lucioperca*), northern pike (*Esox lucius*), and largemouth bass (*Micropterus salmoides*) prey effectively on grass carp juveniles (Lembi et al. 1978; Stanley et al, 1978). Colle et al. (1978) attributed the 95% mortality of juvenile grass carp (4.8 - 18.6 cm long), stocked in a pond in Florida, largely to predation by piscivorous birds. Hatton (1977, cited in Shireman et al. 1978) found that the Florida largemouth bass consumed grass carp which were 60% of the bass total length. Shireman et al. (1978) calculated the maximum lengths of grass carp that can be ingested by largemouth bass of various sizes and concluded that stocked grass carp should be longer than 45 cm in order to eliminate all bass predation.

PARASITES AND DISEASES

A worldwide list of the grass carp parasites compiled by Riley (1978) shows a rich parasitic fauna consisting of 45 species of protozoans, 20 species of trematodes, 5 species of cestodes, 4 species of nematodes and 6 species of crustaceans. Of these, *Gyrodactylus ctenopharyngodontis* and *Dactylogyrus ctenopharyngodontis* are host-specific parasites that threaten only the grass carp; the harmful parasites, *Bothriocephalus gowkongensis*, known to infect other cyprinids (Courtenay and Robins, 1975) and *Sinergasilus major* and *Thelohanellus oculi - leucisci*, known to infect species other than cyprinids, are potential threats to fishes of North America (Riley, 1978). The author also found that bluegill, largemouth bass, brown bullhead, lake chubsucker and golden shiner from a pond in Florida served as native hosts of certain parasites found in grass carp.

Stevenson (1965) reported that grass carp from Arkansas are vulnerable to infections by the endemic parasitic copeped *Lernaea cyprinacea.* Some mortality in grass carp stocked in Iowa was caused by parasites *Gyrodactylus* spp. and *Lernaea* spp. (Mitzner, 1978). Recently, an exotic ciliate protozoan *Hemiophrys* sp. known to be carried by grass carp, was collected in Missouri (Courtenay and Robins, 1975). The host source of this protozoan is thought to be the grass carp now resident in the Mississippi River. Riley (1978) cited other examples, among them a recent discovery of potentially harmful exotic parasites in grass carp in the U.S.

Knowledge of grass carp parasitology is much more extensive for regions outside of North America. Parasites carried by grass carp fry brought to New Zealand from Hong Kong in 1971 included species of *Dactylogyrus, Gyrodactylus, Tripartiella, Ichthyophthirius* and cestode *Bothriocephalus* (Edwards and Hine, 1974). A complete parasitological autopsy on 234 grass carp of all ages introduced into the fish farms of the Volga delta, USSR, revealed 26 species of parasites: 12 protozoans, 4 gill flukes, 6 internal flukes, 2 cestodes, 1 nematode and 1 parasitic crustacean (Stepanova, 1971). The number of parasite species was found to increase with host age, and the local species of parasites predominated over the imported ones. Another parasitological autopsy on 167 young grass carp caught in the central and lower reaches of the Amur, USSR, revealed 20 species of parasites, two of which were the pathogenic *Trichodina nobilis* and *Thelshanellus oculi-leucisci* (Yukhimenko, 1972). No parasites, however, were found among the eggs or free swimming carp fry 7.0 - 7.3 mm in length. The fungal and bacterial diseases of grass carp, as reported by other workers, include *Saprolegnia, Achromobacter, Pseudomonas* and *Aeromonas* (Shireman et al. 1976).

At least some of the above pathogens are known to occur in salmonids in Canada, for example, the protozoans *Ichthyophthirius* and *Trichodina*, and the fluke *Gyrodactylus* (Canadian Committee on Fish Diseases, 1972). Recent microbiological studies in British Columbia have shown that the juvenile grass carp imported from Arkansas in 1977 carried no bacterial pathogens exotic to B.C. (Dr. T. Buckley, Univ. of Victoria, pers. comm.). However, the presence of viruses, fungi, nematodes and other parasites, possibly carried by the imported Arkansas grass carp, remains unknown.

EFFECT OF GRASS CARP ON AQUATIC WEEDS

There is abundant evidence that grass carp can utilize and effectively control a wide variety of aquatic weeds under various climatic conditions. Unfortunately, most surveys are limited in scope and present an incomplete picture of grass carp feeding biology. This is true particularly with regard to the feeding response by different sized grass carp to a variety of macrophyte communities with and without animal prey, and a wide range of water temperatures.

Experiments carried out in India in 1966 showed that the grass carp controlled thick infestations of *Hydrilla, Najas,* and also *Ceratophyllum* among submerged weeds, and *Wolffia, Lemna* and *Spirodela* among the floating ones (Singh et al. 1966). Infestations of *Ottelia, Vallisneria, Nechamandra, Utricularia, Trapa, Myriophyllum, Limnophila, Azolla* and *Salvinia* were also cleared by grass carp. The fish were observed to utilize *Potamogeton* *pectinatus, Halophila ovata, Nitella, Spirogyra* and *Pithophora*. However, the grass carp did not appear to feed actively on *Eichhornia, Pistia, Nymphoides* or *Nymphaea*.

In Malaysia, grass carp were found to eat freely the floating plants *Lemna* and *Spirodela* but only nibbled at the roots of *Eichhornia, Pistia,* and *Salomia* with little effect on their growth (Prowse, 1969). In New Zealand, two year old grass carp stocked at 350 to 650 kg/ha in a farm drainage ditch greatly reduced the standing crop of *Callitriche stagnalis* and *Nasturtium officinale* during the period from December to April (Edwards and Moore, 1975). However, the carp had no effect on *Polygonum decipiens*. Studies in Bulgaria showed that the grass carp effectively controlled a wide variety of weeds such as *Typha, Sparganium,* and *Potamogeton* (Anon. 1969). Control was greatest during late May and June when water temperatures were above 20^oC. In Great Britain, Pentelow and Stott (1965) found that experimental grass carp measuring 19 cm and weighing 140 g, fed readily and grew well on *Elodea canadensis* (Canadian waterweed) at the prevailing summer temperatures. In Japan, *Myriophyllum spicatum* (Eurasian water milfoil) was brought under control by the grass carp in experimental farm ponds (Kuronuma and Nakamura, 1957). In Illinois, USA, grass carp were found to reduce filamentous algae in experimental pools by 99% (Buck et al. 1975). Carp in neighbouring pools totally eliminated common macrophytes *Potamogeton foliosus, P. pusillus, Najas flexilis* and *N. gracillima*, but fed little on *Ceratophyllum demorsum*. Other examples of effective weed control by grass carp were reported by Kilgen (1978) and Mitzner (1978). Lembi et al. (1978) and Lewis (1978) reported effective removal by grass carp of filamentous algae *Pithophora* and *Cladophora*.

Experiments on food selectivity by grass carp are inconclusive. Results as to the preferred plant diet do not always coincide e.g. Colle et al. (1978) vs. Mitzner (1978), even when testing is done in a single climatic zone (Sobolev, 1970). The author attributes this inconsistency to the varied diet of the grass carp and the capacity of the fish to adapt to different ecological conditions. In general, plants selected by grass carp are succulent with little fibre content eg. *Hydrilla, Anacharis, Elodea* and *Lagarosiphon* spp. (Prowse, 1971). Plants that are fibrous and woody such as emergent reeds, sedges, and rushes have low selectability. In a feeding study on grass carp carried out in Alabama USA, all of the 12 weed species present were eliminated but with obvious selectivity (Avault, 1965). The preferred species were the filamentous algae and the softer, more succulent plants such as *Eleocharis* (needlerush), *Potamogeton* (pondweed), *Najas* (naiad), and *Elodea* spp. (waterweed). The least preferred weeds were *Myriophyllum brasiliense* (parrot feather), *M. spicatum* (Eurasian milfoil), *Alternanthera* spp. (alligatorweed), and *Eichhornia* spp. (water hyacinth). These latter weeds were eaten only after all the other had been eliminated. Other reports confirm this general trend in weed selectability by grass carp (Hickling, 1966). Cross (1969) listed several plant species in order of preference by the grass carp (Table 1).

Fish age and size are important variables affecting grass carp feeding intensity. For example, fingerling grass carp, 8 to 10 cm long and stocked at rates of 40 to 100 fish per hectare of experimental ponds, fed on but were unable to control the established growths of rooted aquatics such as *Najas* and *Potamogeton* spp. (Sills, 1970).

Table 1. Plants eaten by grass carp, in approximate order of preference.*

Canadian pondweed	*Elodea canadensis* Michx.
Hornwort	*Ceratophyllum demersum* L.
Stonewort	*Chara* spp.
Lesser duckweed	*Lemna minor* L.
Broad-leaved pondweed	*Potamogeton natans* L.
Ivy-leaved duckweed	*Lemna trisulca* L.
Eurasian water milfoil	*Myriophyllum* spp.
Fennel-leaved pondweed	*Potamogeton pectinatus* L.
Great reedmace	*Typha latifolia* L.
Common reed	*Phragmites communis* Trin.
Common rush	*Juncus effusus* L.
Black sedge	*Carex nigra* (L)
Frogbit	*Hydrocharis morsus-ranae* L.
Watercress	*Nasturtium officinale* R. Br.
Shiny pondweed	*Potamogeton lucens* L.
Sedge	*Carex pseudocyperus* L.

* Compiled by Cross (1969) from sources: Stroganov (1963); Verigin et al. (1963); Penzes and Tolg (1966); Krupauer (1967).

An important factor in the use of grass carp for weed eradication is the density of fish required for effective control. In experimental ponds in England, different densities of 2 year old grass carp (mean weight 168 g) were fed a heterogenous weed diet from July to September of 1969 (Stott and Robson, 1970). The mean temperature was 15.8^oC with a range of 8.5 to 21.5^oC. Figure 2 shows the resulting relationship between the grass carp stocking rate and the relative frequency of submerged plants as a percentage of initial frequency. Weed growth was reduced to about 50% of its potential when the mid-season biomass of the carp was approximately 375 kg/ha. These rates, however, are specific to the type of system involved. In the above situation, the weeds were known to be readily eaten by grass carp, no other fish species were present, and the temperature was typical of a temperate climate.

One year old grass carp (mean size 18 cm) were stocked alone in 0.04 ha earthen ponds in July at rates of 99 or more fish per hectare (Kilgen and Smitherman, 1971). The carp effectively removed a macrophytic mixture of *Chara* spp., *Potamogeton di-*

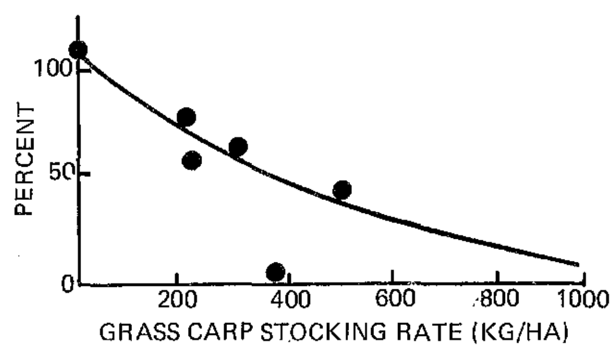

Figure 2. Relation between the final relative frequency of submerged weeds, expressed as a percentage of initial frequency, and the grass carp stocking rate, expressed as mid-season (May to September) biomass.

versifolius and *Myriophyllum spicatum*, having respective initial biomass of 112, 448 and 1,008 kg/ha, in less than 99 days, and caused a decrease in the amount of *Eichhornia crassipes.* Under these conditions, the carp diet consisted of mainly macrophytes and algae (75 - 95% by volume), and only a small amount of mature insects (0 - 18%). In Arkansas, where more than 100 lakes were stocked with the grass carp for aquatic vegetation control, the stocking rate varied from 5 to 49 fish per hectare (Anon., 1976). Table 2 and 3 give information on effective rates and sizes of grass carp stocking in weed infested waters in India and on daily consumption of some weeds by the grass carp (Singh et al. 1966).

EFFECT OF GRASS CARP ON NATIVE FISH

Grass carp, as stated previously, are omnivorous with a preference for aquatic invertebrates, particularly during the juvenile stages of fish development and at low water temperatures. It is inevitable then that under certain conditions grass carp will compete directly with other plankton-and-benthos-feeding fish species. Studies relating to Lake Taneycomo in Missouri, a high quality trout lake where periodic heavy weed growths occur, have shown that at water temperature of 13°C, grass carp, if introduced, would be in direct competition with the trout for the amphipod food resource (Anon. 1972b). As a result, proposals to introduce grass carp into Lake Taneycomo have been rejected. Lewis (1978) reported potential competition for benthic food between grass carp and resident catfish and hybrid sunfish. However, Kilgen and Smitherman (1971) found little food competition between grass carp and insectivorous channel catfish, Israeli carp, and three basses (largemouth, redeye, and spotted). The diet of grass carp was found to consist of 84% macrophytes and only 9% insect larvae by volume. In comparison, the other fish fed predominantly on insects. This behavioural shift in food preference by grass carp when in competition with certain other fish species is exploited in Asian fish ponds, where grass carp are a primary harvester of macrophytes (Stevenson, 1965; Tang 1970).

Our knowledge of grass carp food selectivity is largely incomplete. Consequent indiscriminate exploitation of non-target aquatic vegetation may lead to destruction of important habitat and food sources of other fishes. For example, in a pond at Tamarac, Florida, the grass carp, by removing *Hydrilla* spp., destroyed the spawning grounds of native centrarchid fishes (Courtenay and Robins, 1975). Decline in the numbers of northern pike which require vegetated habitat was also attributed to the removal of weeds by grass carp (Aliev, 1976, cited in Stanley et al. 1978).

Vegetation control may require the density of adult grass carp in ponds to exceed some 56 kg/ha (Burrows, 1977). At such

Table 2. Information on effective rate of stocking of grass carp to control various aquatic weeds.*

Weed Species	Initial av. wt. of fish in g	Stocking rate in No/ha	Weed quantity in tons/ha	Duration of clearance in days	Remarks
Hydrilla verticillata	995	1,210	11.0	10	Weed introduced
*Hydrilla +*** *Najas indica*	62	5,200	7.4	18	Natural infestation
Hydrilla + Najas indica	113	654	68.3	42	Natural infestation
Najas indica	94	1,250	10.8	41	Natural infestation
Najas indica	94	1,250	13.8	41	Natural infestation
Najas indica	789	1,667	19.0	14	Natural infestation
Ceratophyllum demersum	2,640	400	5.7	5	Weed introduced
Ceratophyllum demersum	616	1,250	8.5	10	Weed introduced
Ceratophyllum demersum	830	1,250	5.7	6	Weed introduced
Ceratophyllum demersum	623	1;250	5.7	6	Weed introduced
Ceratophyllum demersum	974	250	37.2	49	Natural infestation
Nechamandra alternifolia	1,830	250	6.8	43	Natural infestation
Nechamandra alternifolia	2,000	400	3.8	18	Natural infestation
Utricularia stellaris	948	725	3.1	9	Weed introduced
Spirodela polyrhiza	474	1,250	6.5	20	Weed introduced
Lemna trisulca	124	1,000	1.7	11	Natural infestation
Lemna trisulca	100	2,000	3.6	9	Weed introduced
Lemna + Wolffia arrhiza	87	2,500	5.6	12	Weed introduced
Lemna + Wolffia arrhiza	150	2,500	4.5	11	Weed introduced
Salvinia cucullata	958	1,190	3.1	17	Weed introduced

* Source: Singh et al. (1966).

** '+' indicates a mixture of weed species.

Table 3. Daily consumption of some aquatic weeds by grass carp.*

Weed Species	Consumption in g/day/fish	Initial av. fish size in g	Final av. fish size in g	Period of observation
Hydrilla verticillata	903	955	1,070	Apr. 22—May 4, 1966
Najas indica	210	94	470	July 7—Aug. 17,1965
Najas indica	269	94	474	July 7—Aug. 17,1965
Najas indica	813	789	989	Oct. 28—Nov.11,1965
Hydrilla verticillata +** *Najas indica*	80	62	113	Apr. 23—May 11,1965
Ceratophyllum demersum	680	616	623	Sept. 17—27, 1965
Ceratophyllum demersum	757	830	892	Oct. 12—19, 1965
Ceratophyllum demersum	757	623	748	Oct. 12—19, 1965
Spirodela polyrhina	260	474	616	Aug. 17—Sept.7,1965
Lemna trisulca	155	124	145	Apr. 6—17, 1965
Lemna trisulca	200	100	169	Sept. 15—24, 1965
Lemna trisulca + *Wolffia arrhiza*	187	87	150	Sept. 10—22, 1965
Wolffia arrhiza	164	150	200	Oct. 8—16, 1965
Utricularia stellaris	479	943	975	May 3—June 1, 1966
Salvinia cucullata	155	958	1,000	May 30—June 16,1966

* Source: Singh et al. (1966).
** '+' indicates a mixture of weed species.

densities, this species may well displace some resident species through competition for food and space. Introduced grass carp are already the dominant fish, at least locally, in some water systems in Mexico (Anon. 1976a). In the USSR, several cases have been reported where perch and northern pike have completely disappeared from lakes after grass carp introduction (Vinogradov and Zolotova, 1974). In some shallow prairie lakes in the U.S., where grass carp densities of 560 to 1120 kg/ha have been reported, grass carp completely destroyed the habitat of certain of the gamefishes and promoted turbid waters with heavy algal blooms (Burrows, 1977). In four small lakes (2 - 12 ha) in Florida, a three-year study showed that after the introduction of grass carp (67 kg/ha), the game fishes (warmouth (*Lepomis gulosus*) and largemouth bass (*Micropterus salmoides*)), other than bluegills, had a significantly lower production and, in one pond, coarse species increased substantially (Anon., 1976a). In experimental ponds in Alabama, stocking of grass carp at densities of 74 to 124 fish per hectare was found to interfere with bass and bluegill production (Anon. 1976e). Forester and Lawrence (1978) attributed the significant reduction in bluegill standing crop in ponds in Alabama to schooling habit of the resident grass carp which probably disturbed the bluegill spawners. However, in densely vegetated experimental pools in Illinois, bluegills and golden shiners coexisted with grass carp and were not found to be measureably affected in their growth or reproduction (Buck et al, 1975). Also, growth and production of channel catfish and striped bass in ponds in Louisiana did not seem to be adversely affected by the grass carp but rather by the presence of water hyacinths (Kilgen, 1978).

EFFECT OF GRASS CARP ON WATER QUALITY

There have been various reports and speculations relating water turbidity and algal blooms to resident grass carp (Hickling, 1966; Prowse, 1969; Vinogradov and Zolotova, 1974; Courtenay and Robins, 1975; Anon. 1977b). In some cases this species may be confused with the common carp (*Cyprinus carpio*) which do have a rooting behaviour that results in muddying of waters. In contrast, the grass carp with their terminal mouths are adapted to open water feeding (Anon. 1972a). However, because the macrophytic food consumed by the grass carp is only partially digested even at high temperatures, grass carp excrete large quantities of nutrients that may contribute to abnormal algal blooms (Hickling, 1966; Kogan, 1974, cited in Stanley et al. 1978). In the USSR, routine introductions of silver carp (*Hypophthalmichthys molitrix* Val.) together with the grass carp apparently prevents algal bloom formation (Stanley et al. 1978).

A study in Arkansas showed that grass carp, fed *Egeria densa* (winter elodea), retained in their bodies about a third of the phosphorus contained in the plant food (Stanley, 1974). This may indicate that the species can be an effective biological agent for removal of some phosphorus from the water. But, the principal impact of grass carp feeding in this case was to increase the rate of recycling of nitrogen and phosphorus by excretion of ammonium and the orthophosphate with consequent enrichment of the water. Lembi et al. (1978) reported significant increases in water turbidity and potassium and ammonium-nitrogen concentrations but not in phytoplankton abundance as a result of grass carp introduction. In experimental ponds in Georgia USA, nutrient release from grass carp feeding was found to have no effect on the pond plankton community, either in numbers or composition, or on the water chemistry (Terrell, 1975). The nutrients released in that study were apparently not available to the plankton community; instead, the sediments accumulated great concentrations of orthophosphate, iron, and magnesium. Stanley et al. (1978) cited examples where oxygen and water quality were improved by the presence of grass carp. This may indicate that in certain situations grass carp introductions are not related to the development of algal blooms.

OTHER EFFECTS OF GRASS CARP INTRODUCTION

Grass carp can affect biota other than native fish. Stanley et al. (1978) cited examples where the zoobenthos either increased or decreased and changed in composition as a result of grass carp introduction. In certain U.S. states, grass carp are considered to be a special threat to rice crops and to aquatic vegetation needed by waterfowl and by certain furbearers. The Everglades kite, for example, is an endangered bird species of Florida that feeds exclusively on the aquatic snail, *Pomacea paludosa* (Courtenay and Robins, 1975). The snail lays its eggs on the emergent vegetation which in turn is vulnerable to grass carp grazing. In this case, the grass carp poses an indirect threat to the survival of this bird. Kuronuma and Nakamura (1957, cited in Forester and Avault, Jr. 1978) reported diminished production of freshwater shrimp (*Leander paucidens*) after grass carp introduction. The decline in yield of crawfish (*Procambarus clarkii*) in ponds in Louisiana,where this species is a valuable resource, was attributed largely to competition for plant food and predation on juvenile crawfish by the grass carp (Forester and Avault, Jr. 1978). Kuronuma (1958) reported that grass carp may feed on terrestrial grass at the water's edge when the supply of submerged plants runs out, thereby precipitating bank erosion. Other indirect hazards of importing exotic fishes such as grass carp include the introduction of small plants, seeds and other viable plant parts with water accompanying the fish.

REPRODUCTION POTENTIAL, DISTRIBUTION AND POSSIBILITY OF CONTROL

Stanley et al. (1978) stated that successful grass carp reproduction may occur in only a few areas because proper combination of physical and biological factors must occur in juxtaposition. Thus a river or a large canal is needed with the proper flow rate, temperature, and oxygen, as well as a turbulent area for spawning, located a correct distance upstream from a rearing area that has adequate food resources and a limited predator abundance.

Successful spawning of grass carp has occurred in rivers of Japan, Formosa, Philippines, USSR, and recently in Mexico (Kuronuma, 1958; Stanley, 1976a). In Mexico, a quarter of a million grass carp fry were stocked into the Rio Balsas from 1972 to 1974 (Anon. 1976a). By 1975, the grass carp were a dominant and successfully reproducing species there. Even in Britain, which is climatically temperate, there is a concern that sites receiving heated effluents from power generating stations may serve as spawning grounds for this species (Stott and Cross, 1973).

Courtenay and Robins (1975) stated that for successful establishment of most exotic fishes in North America, a massive single release or a sustained stocking is required. This appears to hold true for grass carp since in rivers where introduced grass carp have become naturalized, they first reproduced 5 to 10 years after the first introduction of large numbers (Stanley, 1976a). This interval is probably governed by the length of growing season and the time required to reach sexual maturity. Although sustained stocking of grass carp in North America has been occurring since 1963, to date no record has been made of their successful natural reproduction (Pflieger, 1978). Stanley (1976a) speculates that this may occur by 1978 when the large numbers of grass carp released into the Mississippi River system during 1973 - 1975 reach sexual maturity. Already the possibility exists that the small grass carp caught regularly by commercial fishermen in the Missouri River may have been reproduced there (Anon. 1976e).

The chances of grass carp acclimatizing to North American waters are considerable since certain regions between Central America and Winnipeg have a climate similar to that of the central Amur Valley where carp originated (Stanley, 1976a). Also, the six rivers in the USSR where introduced grass carp have become successfully established, closely resemble certain U.S. rivers such as the Mississippi, Colorado, Yellowstone and Willamette in latitude, length and climate. These rivers often carry sufficiently high flows over a distance of some 200 km required to accommodate the spawning carp and the semi-bouyant eggs. Good potential spawning sites of grass carp are provided by the numerous dams along the Mississippi and Arkansas rivers; canals, especially those in the Imperial Valley of California, might also serve as good sites (Stanley et al. 1978). However, the survival of grass carp fry in North America may be reduced because of scarcity of good nursery areas and the presence of the abundant predators such as largemouth bass (Stanley et al. 1978).

As stated earlier, grass carp can reproduce in the absence of current. Such successful spawning has been reported in ponds of USSR, Japan and Formosa (Burrows, 1977). Spawning in ponds may also be induced by injection of a fish pituitary hormone as is done in India for the production of experimental stocks of grass carp (Singh et al. 1966). The species can also be spawned successfully by hand-stripping (Sills, 1970).

Numerous examples attest to the dispersal of grass carp away from their points of introduction. In the U.S. the grass carp have spread throughout at least 35 states since 1963 by way of stocking and natural dispersal (Guillory and Gasaway, 1978). This species has entered two major rivers, the Missouri and Mississippi, presumably from the abundantly stocked Arkansas waters (Anon. 1975). Large specimens of grass carp caught on at least two occasions in Illinois waters are believed to have moved up the Ohio River from the Mississippi River (Anon. 1977b). In the USSR, the species following their release into the Volga River in 1964, have been found to reproduce in the Volga delta in 1971 (Stanley, 1976a). They have now spread throughout the Volga system, penetrated into the Ural River by crossing the Caspian Sea, have spread throughout the Soviet Central Asian rivers, and are presently common in the catches in the brackish bays of the Aral Sea and the inshore zones of the Sea of Azov (Anon. 1976b).

Once established, the eradication of grass carp may prove extremely difficult. During periods of high flow, grass carp migration within a watershed would be greatly facilitated. Barriers to the movement of common carp (*Cyprinus caprio*) are not sufficient to restrain grass carp movement (Burrows, 1977). The latter species are good swimmers and jumpers (Ellis, 1974), and are highly evasive of seines and trapnets. The one point of encouragement about the control of these fish is their high sensitivity to low concentrations of rotenone and Antimycin B. For example, 0.006 ppm of rotenone was found sufficient to kill a 10 cm grass carp held at 27°C (Anon. 1972a). A sedative (Thanite) and electrofishing were found to have a limited effect on the control of grass carp (Cumming et al. 1975).

An excellent solution to the population control of the grass carp would be the production of a sterile population. However, no proven sterile variety exists at present. The University of California has terminated unsuccessfully a nine year study on this topic (Anon. 1976b). Other hybridization attempts were also largely unsuccessful (Stanley, 1976b). A recently developed sterile hybrid between grass carp and Israeli mirror carp (Merkowsky and Avault Jr. 1976) is yet to be tested for its efficiency in weed control. Furthermore, should a monosex population be produced, at least two years of additional study would be required to establish whether or not spontaneous sex reversal is likely to occur.

REGULATIONS AGAINST THE GRASS CARP IN NORTH AMERICA

The incomplete state of knowledge of grass carp management and biology, and the potential serious impact of this species on different aquatic systems have led to banning of further grass carp introduction, transportation and possession by more than 35 states in the U.S. since 1976 (Anon. 1977a). Three of the states, Idaho, Washington and Oregon are Canada's downstream neighbours. Their stringent rules prohibit possession, sale, introduction, importation, propagation, or release of grass carp within the state boundaries. Most of the states involved allow this fish to be used in research, zoos, and public aquaria but only after first obtaining permission from the appropriate agency. Some states, such as Pennsylvania, prohibit all importation, even for experimental purposes.

In western Canada, the B.C. Provincial Fish and Wildlife Branch issued a ban against the grass carp in August of 1977. Under the B.C. Fishery regulations it is prohibited to introduce live fish or eggs of grass carp into any waters of B.C. without official approval. The Branch has confirmed that they are unwilling to grant such an approval at this time until there is assurance of no adverse consequences and of guaranteed advantages of such an introduction. To date, these two criteria have not been met.

THE OKANAGAN BASIN LAKES

BIOLOGY

The Okanagan Basin Lakes, located in south-central British Columbia, include lakes Kalamalka, Wood, Okanagan, Skaha, Vaseux, and Osoyoos (Fig. 3). They form part of the Columbia River system which extends through the northwestern United States.

Seasonal temperature regime of the lakes is typical of a temperate region. During the winter, surface temperatures are near freezing; summer surface waters measure some 20°C (Table 4), (Clemens et al. 1939; Canada - B.C. Okanagan Basin Agreement, 1974).

Table 4. Mean Temperatures (°C) in Okanagan Lake, April-Oct., 1971.*

Depth	April 26	May 3	June 4	June 23	July 23	September 1	October 4
1m	5.2	6.0	9.5	15.	20.	20.	14.
5m	5.1	5.5	8.5	13.	15.	19.	13.

* Source: Canada-B.C. Okanagan Basin Agreement, 1974.

Some 14 aquatic macrophyte species, among them the prolific Eurasian milfoil, occur presently in the Okanagan River system (Table 5). Productivity of the Basin lakes ranges from eutrophic (Wood, Osoyoos and Vaseux), to mesotrophic (Okanagan and Skaha), to oligotrophic (Kalamalka), (Canada - B.C. Okanagan Basin Agreement, 1974).

Among the numerous fish species inhabiting the Okanagan Lakes are the whitefishes (*Coregonidae*), trout and salmon (*Salmonidae*), suckers (*Catostomidae*), minnows (*Cyprinidae*), catfishes (*Ictaluridae*), codfishes (*Gadidae*), perches (*Percidae*), basses and sunfishes (*Centrarchidae*), and sculpins (*Cottidae*) (Canada - B.C. Okanagan Basin Agreement, 1974). Fish species valuable to man include kokanee (*Oncorhynchus nerka*), lake trout (*Salvelinus namaycush*), rainbow trout (*Salmo gairdneri*), Mountain whitefish (*Prosopium williamsoni*), and largemouth bass (*Micropterus dolomieui*).

WEED PROBLEM

The Eurasian water milfoil (*Myriophyllum spicatum*), thought to have been introduced into British Columbia as an aquarium plant, is at present the major nuisance aquatic weed in the Okanagan Basin Lakes. This macrophyte is a rooted, submerged, aquatic perennial that grows to a depth of over 6 m and self-propagates readily from weed fragments as small as 5 mm in length (Newroth, 1974).

The largest body of water in the Basin affected by the Eurasian milfoil is the Okanagan Lake with an area of 34,800 ha and a mean depth of 76 m; the smallest is the Vaseux Lake with an area of 280 ha and a mean depth of 27 m (Canada - B.C. Okanagan Basin Agreement, 1974). Since 1970, the Eurasian milfoil has spread throughout the six Okanagan Basin Lakes. In 1976, over

Table V. Macrophyte species observed in the Okanagan Basin Lakes in 1975.*

Chara spp.	*Potamogeton foliosus*
Ceratophyllum demersum	*P. gramineus*
Elodea canadensis	*P. natans*
Myriophyllum exalbescens	*P. pectinatus*
M. spicatum	*P. richardsonii*
Nitella spp.	*P. zosteriformis*
Potamogeton crispus	*Ranunculus aquatilis*

* Source: Environmental Studies Division, Water Investigations Branch, survey maps, 1975.

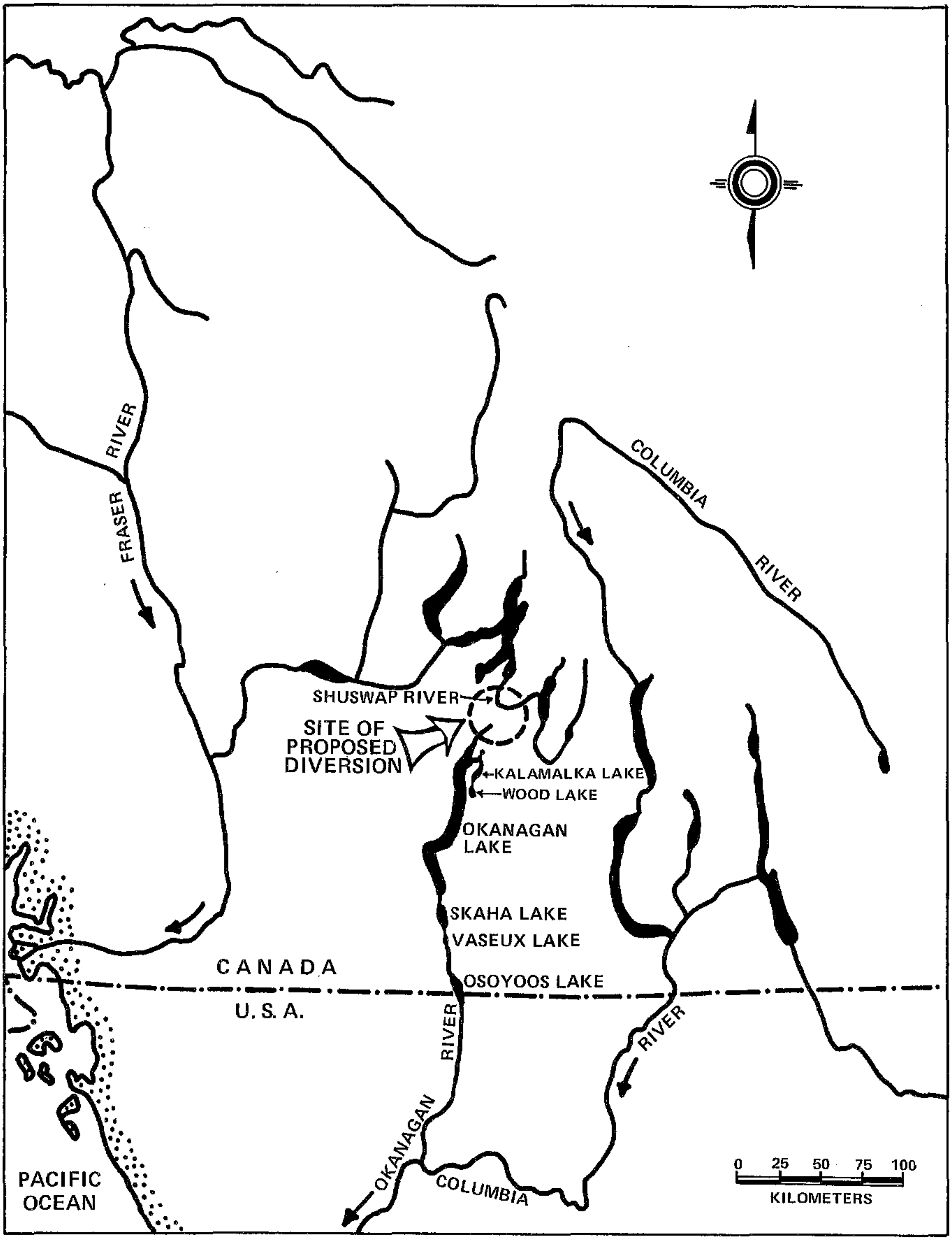

Figure 3. Okanagan Basin Lakes and adjoining river systems.

364 ha and 185 km of lake shoreline were infested (Water Investigations Branch, 1977). In certain areas, other macrophyte species also have become a 'nuisance' weed e.g. *Potamogeton crispus* (Newroth, 1974).

DISCUSSION

Generally speaking, nearly all introductions of exotic fish species into new areas have created serious disruptions in ecological balance, often in irreversible ways. Examples of introduced fish which have become serious nuisance problems are numerous. They include the common or European carp (*Cyprinus carpio*) introduced to North America over a century ago, and the Asian walking catfish (*Clarias batrachus*) introduced in 1965. In Florida, the four introduced fish species that have caused serious ecological disruption are the walking catfish, black acara (*Cichlasoma bimaculatum*), blue tilapia (*Tilapia aurea*), and pike killifish (*Belonesox belizanus*) (Courtenay and Robins, 1975). Other examples of nuisance fish are alewife, sea lamprey, rainbow smelt and gizzard shad (Buck et al. 1975).

The grass carp may be an ideal weed control agent given a closed water system, relatively high temperatures, target weeds that are attractive to the carp, limited 'other preferred' foods, and no important native species with which to compete.

The effectiveness of grass carp as a weed control agent in the Okanagan Basin Lakes is in serious doubt. First, it must be stressed that the grass carp feeding behaviour in northern North American lakes is an unknown factor. In particular, the potential effects of grass carp on the Okanagan Basin aquatic plants, invertebrates, fish and fowl are yet to be investigated.

Since the Eurasian milfoil ranks only midway among the weeds given on the grass carp 'preference' list (Table 1), the more 'preferred' non-target species such as the *Elodea* and *Potamogeton* spp. also found in the Okanagan lakes, may well be the first ones to be removed.

The effective stocking rate of grass carp into the Okanagan waters can only be speculated upon at the present time, but the vast area involved suggests that very large numbers of fish would be required. Such an introduced population of exotics would undoubtedly disrupt the local fish fauna, among them several valuable food and game species.

The importance of temperature on the type and quantity of food ingested by the grass carp and the requirement of high temperatures (20^{o} - 33^{o}C) for intensive plant feeding, render the relatively cool B.C. waters less than suitable for grass carp introduction for plant control. High temperatures are available for only two to three months of the year and then only at the surface. There also exists the questionable effect of nutrients released by grass carp on water quality and phytoplankton growth. In addition, further spread of the Eurasian milfoil may actually be effected by the grass carp itself through the production of weed fragments during ingestion by fish, and of weed fragments possibly excreted in carp faeces in semi-digested form.

Sterile grass carp are not available and the threat of natural spawning and proliferation of this species is very real. Once introduced, the numbers and movement of grass carp will be impossible to control and their spread throughout the Columbia River system would be inevitable. There is also the possibility of grass carp invading adjacent coastal rivers via brackish interconnections.

A further complication to such an introduction is the currently dormant proposal by the B.C. Water Resources Service to divert waters from the lower Shuswap River into the north end of Okanagan Lake (Figure 3) (Dept. of Fisheries and Forestry of Canada et al. 1969). Should this proposal become activated at some future time, the intermixing of Okanagan and Fraser System waters and their fauna would be the undesirable result. In addition, should grass carp become abundant, their use in Canada would be limited as they are not a preferred sport or food fish. Other negative aspects of grass carp transplants include the inadvertent introduction of disease organisms and of other living organisms.

There are four basic criteria which must be met before an introduced biological control agent can be judged successful:

1) that it be effective on the target species,
2) that its numbers be controllable,
3) that it be readily contained within the affected area,
4) that it coexist with native species without detriment to them.

In view of the known grass carp information concerning their feeding, reproduction, migratory patterns and behavioural interaction with other species, it is clearly evident that grass carp cannot meet even one of the above criteria let alone all four. As a result, the authors are led to no other conclusion but that the introduction of grass carp into the Okanagan Basin Lakes would in all probability not solve the Eurasian milfoil problem and most certainly would create a very serious ecological disruption which would be essentially irreversible. Simply stated, grass carp introduction proposals for the Okanagan Basin Lakes, or other areas in B.C. should not be given serious consideration.

SUMMARY

1. Grass carp are successfully used for vegetation control in many parts of the world.
2. Juveniles select animal food such as benthos and zooplankton in preference to vegetation.
3. Adult grass carp are omnivorous, preying on animal food when macrophyte supply is low.
4. Intensive feeding on plants does not occur until temperatures of 20^{o}C to 33^{o}C are reached.
5. Digestive assimilation of plant material is less than 50% and the high nutrient levels of the excrement may alter water quality and cause algal blooms.
6. Grass carp may reduce or displace native fish populations through competition for food and space, interference with spawning, and alteration of fish habitat.
7. Grass carp are known to feed on salmonid fry.
8. Parasitic fauna of grass carp include over 80 species, some which are known to infest cyprinids, salmonids and other fishes.

9. Grass carp feed on weeds selectively; *Myriophyllum spicatum* (the 'nuisance' weed in Okanagan Lakes) ranks only mid-way on the grass carp preference list of macrophytes.

10. Safe and effective control of *M. spicatum* in the Okanagan Basin Lakes using the grass carp is questionable due to the system's low seasonal temperatures, multispecies macrophyte community and valuable fishery resource.

11. Since the Okanagan Basin Lakes connect with the U.S. portion of the Columbia River system, the introduction of grass carp into the Okanagan Lakes would require consultation with the American authorities.

12. Since successful reproduction of grass carp in North America is highly probable and since the effect of this species on the Okanagan Lakes cannot be predicted without further study, the Interagency Committee on Transplants and Introductions in B.C. recommends against the introduction of the grass carp into the waters of B.C.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the editorial comments of Gordon Bell, Roly Brett, Richard Morley, Brian Pearce, Hugh Sparrow, Leif Sunde and Ron Thomas. Thanks are also extended to Chris Côté, Thelma Morris and Jennifer Ross for typing and preparation of the manuscript.

Edwards, D.J., and P.M. Hine. 1974. Introduction, preliminary handling, and diseases of grass carp in New Zealand. N.Z. J. Mar. Freshwater Res. 8 (3): 441 - 454.

Edwards, D.J., and E. Moore. 1975. Control of water weeds by grass carp in a drainage ditch in New Zealand. N.Z. J. Marine Freshwater Res. 9 (3): 283 - 292.

Ellis, J.E. 1974. Observations on the jumping and escapement of white amur. Prog. Fish. Cult. 36 (1) : 15.

Forester, J.S., and J.W. Avault, Jr. 1978. Effects of grass carp on freshwater red swamp crawfish in ponds. Trans. Am. Fish. Soc. 107 (1): 156 - 160.

Forester, T.S., and J.M. Lawrence. 1978. Effects of grass carp and carp on populations of bluegill and largemouth bass in ponds. Trans. Am. Fish. Soc. 107 (1): 172 - 175.

Gorbach, E.I. 1972. Fecundity of the grass carp (*Ctenopharyngodon idella* (Val.)) in the Amur Basin. J. Ichthyol 12 (4): 616 - 625.

Guillory, V., and R.D. Gasaway. 1978. Zoogeography of the grass carp in the United States. Trans. Am. Fish. Soc. 107 (1): 105 - 112.

Hatton, D.C. 1977. Predatory behaviour of largemouth bass on soft and spiny-rayed forage species. Ph.D. Thesis, Univ. of Fla., Gainesville. 73p.

Hickling, C.F. 1966. On the feeding process in the White Amur, *Ctenopharyngodon idella* (Val.) J. Zool. 148: 408 - 419.

Hickling, C.F. 1967. On the biology of a herbivorous fish the white amur or grass carp, *Ctenopharyngodon idella* Val. Proc. R. Soc. Edinburgh Sect. B. 70 (1): 62 - 81.

Jahnichen, H. 1973. 6 million individuals of amur carp! *In* Experience with the artificial reproduction of the amur carp (*Ctenopharyngodon idella*) in the DDR. Z. Binnenfisch. DDR 20 (7): 213 - 223. (In German).

Kilgen, R.H. 1978. Growth of channel catfish and stripped bass in small ponds stocked with grass carp and water hyacinths. Trans. Am. Soc. 107 (1): 176 - 180.

Kilgen, R.H., and R.O. Smitherman. 1971. Food habits of the White Amur stocked in ponds alone and in combination with other species. Prog. Fish. Cult. 33 (3). 123 - 127.

Kogan, Sh. I. 1974. Overgrowing of the Kara Kum Canal and some after effects of introducing the white amur into water bodies. Gidrobiol. Zh. 10 (2): 110 - 115. (In Russian).

Krupauer, V. 1967. Food selection of two year old grass carp. Bull. V.U.R. Vodnany 3: 7 - 17. (in Czech., English summary).

Kuronuma, K. 1958. Spawn taking of Chinese carp in the Tone River, Japan. Indo-Pacific Fish. Counc. Curr. Affairs Bull. 22, 3p.

Kuronuma, K. and K. Nakamura. 1957. Weed control in farm pond and experiment by stocking grass carp. Indo-Pac. Fish. Counc. Proc. 7 (II): 35 - 42.

Lembi, C.A., B.G. Ritenour, E.M. Iverson, and E.C. Forss. 1978. Trans. Am. Fish. Soc. 107 (1): 161 - 171.

Lewis, W.M. 1978. Observations on the grass carp in ponds containing fingerling channel catfish and hybrid sunfish. Trans. Am. Fish. Soc. 107 (1): 153 - 155.

Martin, M. 1970. Grass carp - undesirable or desirable. Bureau of Sport Fisheries and Wildlife. Fish Farming Experimental Station, Stuttgart, Arkansas. 6p. (unpublished).

Martino, K.V. 1974. Natural reproduction of the grass carp in the Lower Volga area. Hydrobiol. Review 10 (1): 76 - 78.

Merkowsky, A., and J.W. Avault Jr. 1976. Polyculture of channel catfish and hybrid grass carp. Prog. Fish. Cult. 38 (2): 76 - 77.

Meyer, F.P., H.K. Dupree, R.J. Muncy, G.B. Pardue, and J.G. Stanley. 1975. Report on the status of the grass carp in North America. 10p. (unpublished).

Mitzner, L. 1978. Evaluation of biological control of nuisance aquatic vegetation by grass carp. Trans. Am. Fish. Soc. 107 (1): 135 - 145.

Stott, B., and T.O. Robson. 1970. Efficiency of grass carp (*Ctenopharyngodon idella*, Val.) in controlling submerged water weeds. Nature 266: 870.

Stott, B., and D.G. Cross. 1973. A note on the effect of lowered temperatures on the survival of eggs and fry of the grass carp *Ctenopharyngodon idella* (Val.). J. Fish Biol. 5 (6): 649 - 658.

Stroganov, N.S. 1963. The food selectivity of the Amur fishes. *In* Symp. Probl. Fish. Exploit. of Plant Eating Fishes in the Water Bodies of the U.S.S.R. Ashkhabad Acad. Sci. Turkmen U.S.S.R.

Tang, Y.A. 1970. Evaluation of balance between fishes and available fish foods in multispecies fish culture ponds in Taiwan. Trans. Am. Fish. Soc. 4: 708 - 718.

Terrell, J.W. and A.C. Fox. 1975. Food habits, growth, and catchability of grass carp in the absence of aquatic vegetation. Proc. Southeastern Assoc. Game and Fish. Comm. 18 (1974): 251 - 259.

Terrell, T.T. 1975. The impact of macrophyte control by the white amur (*Ctenopharyngodon idella*). Verh. Internat. Verein. Limnol. 19: 2510 - 2514.

Verigin, B.V., N. Viet, and N. Dong. 1963. Data on the food selectivity and daily ration of the white amur. *In* Symp. Probl. Fish. Exploit. of Plant Eating Fishes in the Water Bodies of the U.S.S.R. Ashkhabad Acad. Sci. Turkmen U.S.S.R.

Vinogradov, V.K., and Z.K. Zolotova. 1974. The influence of the grass carp on aquatic ecosystems. Hydrobiol. J. 10 (2): 72 - 78.

Water Investigations Branch. 1977. Aquatic plant management programme: Okanagan lakes. News Bulletin, Ministry of Env. Province of B.C. 7p.

Yukhimenko, S.S. 1972. Parasites of young silver carp *Hypophthalmichthys molitrix* (Val.) and grass carp *Ctenopharyngodon idella* (Val.) in the Amur River. Izv. Tikhookean Nauchno-Issled. Inst. Rybn. Khoz. Okeanogr. 77: 151 - 159. Tr. from Ref. Zh. Biol. 1972. No. 12K7.