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WHITE AMUR BIBLIOGRAPHY

by

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The findings of an extensive literature search on the white amur are presented followed by a bibliography of all documents, both scientific and popular, that were considered. This document will serve as a general reference publication for anyone interested in the area of herbivorous fish.

PREFACE

The work described in this report was performed under Contract No. DACW39-80-C-0035 between the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., and the University of Florida, Gainesville. The work was sponsored by the U. S. Army Engineer District, Jacksonville, and the Office, Chief of Engineers, U. S. Army, Washington, D. C.

This report represents a portion of the progress achieved toward completion of the contract and was written by Mr. Charles R. Smith and Dr. Jerome V. Shireman, University of Florida. The report documents the work done on an extensive literature search on the subject of the white amur. The report is comprised of the findings of that search and a complete bibliography of documents considered.

The work was monitored at WES in the Environmental Laboratory (EL) by Dr. Andrew C. Miller under the general supervision of Mr. B. O. Benn, Chief, Environmental Systems Division. Mr. J. L. Decell was Manager of the Aquatic Plant Control Research Program; Dr. John Harrison was Chief of EL.

Commanders and Directors of WES during the conduct of the work and publication of the report were COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

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1. IDENTITY

1.1 Taxonomic nomenclature

Cuvier and Valenciennes (1844) originally named the species *Leuciscus idella* which was retained also by Richardson (1846). Steindachner (1866) redescribed the species as the orthotype *Ctenopharyngodon laticeps* (Jordon 1963). Gunther (1868) synonymized *laticeps* while retaining the genus, but changed the specific epithet to *idellus*. *Ctenopharyngodon idella* is the accepted name today (Pflieger 1975a). Nichols (1943), Berg (1949), and Fischer and Lyakhnovich (1973) discuss other synonyms which have appeared in the literature. Nelson (1976) provides the most up-to-date and accurate suprageneric classification.

1.2 Common names

Grass carp and white amur are the two most frequently used English common names today. Common names used in other languages and authors are presented in Table 1.

2. DESCRIPTION

2.1 Gross morphology and anatomy

Gross taxonomic characters and descriptions are given in Cuvier and Valenciennes (1844), Richardson (1846), Gunther (1868), Nichols (1943), Berg (1949), Berry and Low (1970), Fischer and Lyakhnovich (1973), and Pflieger (1975a). Ontogenetic changes occur in the relative length of some body dimensions and in the relative weight of certain body parts (Fischer and Lyakhnovich 1973). Stroganov and Buzinova (1971) observed both seasonal and age-related variation in the liver

Table 1. Standard Common and Vernacular Names (Shireman and Smith 1981)

COUNTRY	STANDARD COMMON NAME	VERNACULAR NAME	AUTHORITY
China	Hwan yu	Hwan yu	Richardson (1846)
		Hwan u	Richardson (1846)
	Chow hu	Chow hu	Birtwistle (1931a)
	Waan ue	Waan ue	Herre (1932), Lin (1935a)
	Huan	Huan	Chow (1958)
		Wan (Cantonese)	Chow (1958)
	Huan-yü	Huan-yü	Gidumal (1958)
		Waan yue (Cantonese)	Gidumal (1958)
	Whan yu	Wuan yu	Naik (1972)
		Ts'ou	Naik (1972)
		Ts'oyu	Naik (1972)
		Waan yu	Naik (1972)
	Ts'ao-yu	Ts'ao-yu	I-kui et al. (1966, 1973), Roberts et al. (1973)
Czechoslovakia	Amur bily	Amur bily	Blanc et al. (1971)
		Amur biely (Slovakian)	Blanc et al. (1971)
Denmark	Graseskårpe	Graseskarpe	Blanc et al. (1971)
Germany	Graskarpfen	Graskarpfen	Molnar (1969)
Hong Kong	Waan yu	Waan yu	Naik (1972)
Hungary	Amur	Amur	Blanc et al. (1971)
India	Grass carp	Grass carp	Alikunhi et al. (1962, 1963a)
Israel	Karpion haesef	Karpion haesef	Blanc et al. (1971)
Japan	Sogyo	Sogyo	Ojima et al. (1972)
Malaysia	Chow hu	Chow hu	Naik (1972)
		Wan yu	Naik (1972)
Mexico	Carp herbivora	Carpa hervivora	Rosas (1976)
Poland	Bialy amur	Bialy amur	Blanc et al. (1971)
Romania	Crap-de-iarba	Crap-de-iarba	Blanc et al. (1971)
Soviet Union	Amur	Amur	Berg (1949)
		Belyi amur (Lake Khanka)	Berg (1949)
United States	Grass carp	Grass carp	
	White amur	White amur	
Vietnam	Ca cham	Ca cham	Naik (1972)

and intestines. Kafuku (1977) reports on the ontogenesis of intestinal coiling. Inaba and Nomura (1956), Hickling (1966), Verigin (1969), Berry and Low (1970), and Harka (1974) report in detail dentition, buccal cavity, and internal anatomy. Slack (1962) examines changes in ovarian appearance during maturation, while Babrova (1969) and Shelton and Jensen (1979) report on anatomical differentiation of the gonads. Lin (1935b) describes the appearance of milt. Russian workers provide the best description of mature and overripe spawn (Anon. 1970i); others may be found in Lin (1935b), Inaba et al. (1957), Alikunhi et al. (1962, 1963b, 1973), and Chen et al. (1969). A diffuse adrenal gland is found in the kidney pronephros (Mezhnin 1975). From commercial and nutritional standpoints, the percent compositions by weight of fillet, head, and other body parts in grass carp compare favorably with data on silver carp (Hypopthalmichthys molitrix) and common carp (Cyprinus carpio) (Okoniewska and Okoniewski 1968, Ioshev and Boiadzhier 1970, Jahnichen 1971).

Numerous investigators have induced hybridization of grass carp and bighead carp [Hypopthalmichthys (Aristichthys) nobilis]. Aliev (1967) obtained matroclinous offspring resulting from grass carp roe fertilized with bighead milt, while Andriasheva (1968), Kraxnai and Marian (1977), and Sutton et al. (unpubl. ms.) describe intermediate hybrids from the same cross. The reciprocal cross yields intermediate young with morphology as reported by Berry and Low (1970) and Verigin et al. (1975); the first authorities pay particular attention to anatomy. Sutton et al. (unpubl. ms.) review the literature and history of grass carp hybridization with bighead carp. Fertilizing grass carp roe with common carp milt has been largely unsuccessful and apparently only gynogenetic individuals survive (Aliev 1967). The reciprocal cross results in intermediate hybrids, tending toward the common carp, with possible gynogenetic specimens occurring infrequently (Makeyeva and Verigin 1974, Makeeva 1976). Stanley (1975) and Stanley and Jones (1976) present a comparative morphological study of intermediate hybrids from this cross with normal parentals and with androgenetic and gynogenetic grass carp. Aliev (1967) provides descriptions of patroclinous intermediate yearlings from crosses of the grass carp with female silver carp and with male black bream (*Megalobrama terminalis*). Other intergeneric hybridizations involving grass carp have yielded inviable larvae, and/or morphological descriptions are not available. Sections 2.2, 2.3, 11.1 and 11.2 review in more detail the literature on manipulated reproduction.

2.2 Cytology and histology

Bobrova (1969) and Shelton and Jensen (1979) discuss the cellular and histological changes occurring during gonad differentiation in grass carp. Berry and Low (1970) describe the gonad cytology and histology of young grass-bighead carp hybrids. Reports on ovarian maturation include those from Slack (1962), Makeeva (1963), Gorbach (1966), Chen et al. (1969), and Nicolau and Steopoe (1970). Bobrova (1969) investigated the cytology of ovum development from fertilization to first cleavage, and Mantelman (1973) compared this process in the grass carp with those taking place in the silver carp and in crosses of grass carp with silver and bighead carps. Makeeva and Mikodina (1977) report the structure and chemical nature of the two-layered egg membrane. Chinese researchers have described the cellular changes brought about by injection of luteinizing releasing hormone in the pituitary (Anon. 1978a, 1978b). Statuva (1974) examines the effects of hypophyseal injections on pituitary cytomorphology.

Among other cytological and histological studies, Berry and Low (1970) give thorough comparative descriptions of the alimentary tracts in grass carp, bighead, and their hybrid. Mezhnin (1975) describes the adrenal gland. Yamamoto and Ueda (1978) examine the structure of the olfactory epithelium. Andriysheva (1969) compares thermostability and alcohol resistance of muscle tissue between grass carp and their interpopulation hybrids. Discussions of cellular blood characteristics may be found in Molnar (1969), Molnar and Tammassy (1970), Lyakhnovich and Leonenko (1971), and Kelenyi (1972). Makeeva (1976), Stanley (1976b), and Stanley et al. (1976) report erythrocyte sizes of grass and common carps in comparison to their hybrid.

Much effort has been directed toward the karyomorphology of grass carp and its hybrids. The diploid chromosome number equals 48 (Nogusa 1960, Ojima et al. 1972, Manna and Khuda-Bukhsh 1977). Bozhko et al. (1976) also describe karyomorphology. Hybridization with male bighead carp results in triploid offspring (Kraznai and Marian 1977; Marian 1978; Marian and Kraznai 1978, 1979; Beck et al. 1980). Mantelman (1973) found that fertilizing silver carp roe with grass carp milt yielded mostly diploid along with a few apparently polyploid larvae. Vasilev et al. (1975, 1978) obtained inviable diploid and viable gynogenetic progeny by using female grass carp with male common carp. In the opposite cross, triploid specimens resulted and survived while diploids died.

2.3 <u>Proteins and other constitutents</u>

Jahnichen (1971) reviewed the literature concerning water, protein, fat, and ash contents of grass carp. Okoniewska and Okoniewski (1968) determined the percent composition of these constituents as well as various amino acids in the flesh and compared them to a reference protein (egg albumen). Ioshev and Boiadzhiev (1970) also researched the nutritional quality of grass carp. Tan (1971) found different plant diets to have little effect on protein content, but to change significantly the fat and ash content. In work with grass carp fingerlings, Dabrowski (1979) reported that increases in dietary protein caused increases in both the protein and fat constituents relative to ash. Shimma and Shimma (1969) investigated the distribution and fatty acid components of lipids in grass carp captured from the wild or cultured with different diets.

Molnar (1969) determined the relative amounts of various chemicals in grass carp blood. Mean hemoglobin content was 8.9 g% (Molnar and Tamassy 1970). The blood characteristics of grass carp and other species have been shown to correlate with the proportions of animal and plant food in the diet (Molnar 1969, Gyula 1970, Molnar and Tamassy 1970). Sukhomlinov and Matvienko (1974, 1977a, 1977b) found hemoglobin to have a typical absorption spectrum and was composed of two heterogeneous heme proteins differing in their relative amounts of various amino acids. Hensel and Paulov (1978) report on similarities and differences of grass carp serum protein spectra relative to those of other cyprinids. Adamova and Novikov (1973) investigated serum proteins by gel electrophoresis. Pokhil (1969) demonstrated species specific antigens in grass carp blood by comparative agglutination experiments with other cyprinid species.

Hickling (1966) reported the distribution of amylase, proteases, and lipase in the alimentary tracts of grass carp which were starving, had empty guts, or were actively feeding on different diets. Workers with the Alabama Department of Conservation (1972) investigated the proteolytic enzyme responses of the gut to fasting and to seasonal changes. Little cellulase activity occurs in grass carp digestion

(Lindsay and Harris 1980). Fish (1960) measured gut pH to vary from 7.4 to 8.0.

Using Sephadex G-100 filtration, Malaysian and Indian researchers demonstrated the presence of three gonadotropic hormones in grass carp pituitaries (Prowse 1969a, 1970i Sundararaj et al. 1972). Research at the Yangtze Institute of Fisheries revealed ovarian enzyme responses to injections of luteinizing releasing hormone (Anon. 1978a). Giurca (1970) and Rabega et al. (1973) examined quantitating changes in RNA of the pituitary and gonads during gonad maturation and after hypophyseal injections.

Utter and Folmar (1978) performed an electrophoretic survey of eighteen enzyme systems and general protein in five tissues (blood serum, eye, liver, heart, muscle) of grass carp. Stanley et al. (1976) electrophoresed hemoglobin, serum protein, and various isozymes from gynogenetic and adrogenetic grass carp, common carp, and their hybrid. Burlakov et al. (1973) also compared electropherograms of isozymes from this hybrid cross with those of the parentals. Kirilenko and Ermolaev (1976) investigated the absolute and relative amounts of adenosine compounds in grass carp muscle. Junca and Matei (1975) compared skeletal muscle proteins of grass carp with several other cyprinids.

3. Distribution

3.1 Original range

The grass carp is indigenous to the Amur basin and flatland rivers of eastern China (Berg 1949, Nikolsky 1954, Fischer and Lyakhnovich 1973). The southern distribution includes records from the Yangtze, Yellow, and Pearl River basins (Dah-Shu 1957, Herre 1934, Lin 1935a, Mori 1936). Herre (1932), Shaw (1934), and Nichols (1943) provide other Chinese localities. A complete description of climate and topography of the area may be found in Hsieh (1973). Zhadin and Gerd (1961) give hydrological data on the Amur River.

3.2 Present distribution

The grass carp has been introduced into over fifty countries worldwide (Table 2) and is established outside its native range, in Japan, the Soviet Union, and Mexico. Kuronuma (1954, 1955, 1958) and Inaba et al. (1957) documented natural reproduction in the Tone River of Japan and Tsuchiya (1979) discusses the present status of this population. The Soviet Union has naturally spawning grass carp in the Amudarya, Syrdarya, Ili, Terek, Volga, and Kuban Rivers and in the Kara Kum Canal (Nikolsky and Aliev 1974). Reproduction has been investigated in Amudarya by Bykov (1970), the Volga by Martino (1974), the Ili River by Nezdoliy and Mitrofanov (1975) and Dukravets (1972), the Syrdarya by Zaki Mokhamed (1977) and by Verigin et al. (1978), the Kuban by Motenkov (1966, 1969), and the Kara Kum Canal by Aliev and Sukhanova (1974) and Aliev (1976). Verigin (1964) and Vinogradov and Zolotova (1974) review the introduction and establishment of grass carp in the Soviet Union. Zhadin and Gerd (1961) provide detailed climatic and hydrological data for Soviet rivers. Most recently, grass carp have spawned naturally in the Rio Balsas system of Michoacan, Mexico (Anon. 1975f, 1976c, Rosas 1976, Arredondo-Figueroa unpubl. ms. 1976).

Reproduction in open water bodies has occurred in the Philippines, Taiwan, Yugoslavia, and the United States, but establishment is problematical. Spawning in the Pampanga and Agno Rivers on Luzon, Philippines, is unverified and the grass carp is rare relative to other species (Datingaling 1976, Bailey and Haller unpublished ms.). Reproduction was reported in two Taiwan reservoirs (Tang 1960a, 1960b; Lin 1965), but Bailey and Haller (unpublished ms.) believe that one of

Table 2. Introductions of Grass Carp (Modified from Shireman and Smith 1981)

COUNTRY	DATE	SOURCE	PURPOSE	AUTHORITY
Afghanistan	1966-67	China	Culture	El-Zarka (1974)
Argentina	1970	Japan	Experimental weed control	Mastrarrigo (1971)
Austria	1970	Romania	Experimental	Liepolt andWeber (1969), Busnita (1970b)
Bangladesh	1976	?	Culture	Bari (1976)
Bulgaria	1964	Soviet Union	Polyculture	Boev (1970) Krupauer (1971)
Burma	1969	India	Culture	Anon. (1969o)
Cambodia	?	?	Culture	Ling (1977)
Canada	?	?	Experimental	Sutton (1977a)
Cuba	1966	Soviet Union	Experimental	Anon. (1970b)
Czechoslovakia	1961-65	Soviet Union	Polyculture	Krupauer (1968a, 1971) Holcik (1976a, 1976)
Denmark	?	?	Experimental	Blanc et al. (1971)
East Germany	1965	Soviet Union	Experimental weed control	Jahnichen (1973)
Egypt (UAR)	1976	United States	Experimental Culture and weed control	Bailey (1977)
England	1964	Hungary	Experimental weed control	Cross (1969)
Ethiopia	1975	Japan	Weed control	Anon. (1975a)
Fiji	1968	Malaysia	Experimental weed control and culture	Adams and Titeko (1970) Marsters (1971)
France	1967	Hungary	Experimental weed control	Wurtz-Arlet (1969, 1971)
France	1968	Soviet Union	Culture	Anon. (1969a)
Hong Kong	?	China	Culture and weed control	Chow (1958)
Hungary	1963-66	China and Soviet Union	Polyculture	Krupauer (1971)
India	1959	Hong Kong and Japan	Culture and weed control	Chaudhuri et al. (1976)
Indonesia	1964	Japan	Culture	Anon. (1970h)
Iran	1966	Soviet Union	Experimental	Anon. (1970g), Ivanov (1970)
Iraq	1968	Japan	Culture	Anon. (1969n)

Table 2. Introductions of Grass Carp (continued)

COUNTRY	DATE	SOURCE	PURPOSE	AUTHORITY
Israel	1952	?	Polyculture	Yashouv (1958)
	1965	Japan	Polyculture	Tal and Zid (1978a, 1978b)
Italy	1972	Yugoslavia	Experimental culture	Anon. (1972g)
Japan	1878	China	Culture	Kuronuma (1954)
	1943-45	China	Culture	Tsuchiya (1979)
Java	1949	China	Culture	Schuster (1952b)
Kenya	1970	?	Culture	Anon. (1970a)
Korea	1967	Taiwan	Experimental culture	Anon. (1968d)
Laos	1968	Japan	Culture	Anon. (1969o) Chanthepha (1969,1972)
Malaysia	1930	China	Culture	Gopinath (1950)
Mauritius	1977	India	Polyculture	Parameswaran et al. (1977)
Mexico	1960	Taiwan andChina	Weed control and culture	Anon. (1975b), Gandara et al. 1975, Rosas (1976), Arredondo-Figueroa unpubl. ms.
Nepal	1966-67	India and Japan	Culture	Anon. (1968d), Shrestha (1973)
	1972	Hungary	Culture	Anon. (1973b)
Netherlands	1968	Taiwan	Experimental weed control	Anon. (1969a)
New Guinea	1965	Hong Kong	Culture	Anon. (1965)
New Zealand	1966	Malaysia	Experimental weed control	Chapman and Coffey (1971), Anon. (1977d)
Nigeria	1972	?	Culture	Moses (1972)
Pakistan (West)	1964	China	Weed control and culture	Ahmed (1968), Anon. (1969o) Naik (1972), Javaid (1976)
Panama	1977	?	Culture and weed control	Panama Canal Company (1977)
	1978	United States	Weed control	Custer et al. (1978)
Philippines[2]	1966-69	?	Culture	Datingaling (1976)
Poland	1964-67	Soviet Union	Culture	Gaudet (1967), Opuszynski (1968), Anon. (1869o), Wolny (1971)
Romania	1959	China	Polyculture and weed control	Krupauer (1971)
Sarawak	?	Hong Kong, Taiwan	Polyculture	Ji (1976)

Table 2. Introductions of Grass Carp (continued)

COUNTRY	DATE	SOURCE	PURPOSE	AUTHORITY
Singapore	?	?	Culture	Ling (1977)
South Africa	1967	Malaysia	Experimental	Anon. (1968d), Crass (1969), Pike (1977)
Soviet Union[1]	1937, 19502	?	Culture and weed control	Nikolsky (1971)
European and Central Asian	1954-60	China	Culture	Verigin (1961), Ovchynnyk (1963), Vinogradov and Zolotova (1974),
Uzbekistan	1961	?	Culture	Borisovd (1972)
Sri Lanka	1949	China	Culture	Schuster (1952)
Sudan	1973	?	Culture and weed control	Anon. (1974-1975c)
Sumatra	1915	China	Culture	Schuster (1952b)
Sweden	1970	Poland	Experimental weed control	Thorslund (1971)
Taiwan[3]	?	China	Polyculture	Lin (1965); Tang 1960a, 1960b)
Thailand	?	China	Culture	Schuster (1952b)
United Arab Republic	1968	Hong Kong	Experimental culture and weed control	Anon. (1969o)
United States[4]	1963	Malaysia and Taiwan	Experimental weed control	Avault (1965b), Stevenson (1965) Guillory and Gasaway (1978)
	1963	Malaysia and Hong Kong	Experimental	Stanley (1978)
Uruguay	?	?	Experimental	Gaevskaya (1969)
Vietnam	1969	Taiwan	Culture	Anon. (1969e)
West Germany	1964	Hungary	Weed culture	Bohl (1979)
Yugoslavia	?	?	Culture	Jhingran and Gopalakrishnan (1974)

[1] Have established populations

[2] Reportedly breeding in Pampanga River

[3] Has reportedly bred in reservoirs.

[4] Reportedly breeding in Mississippi River (Conner et al. 1980)

these populations is no longer extant. Stanley et al. (1978) cite Djisalov (1978) as having reported the capture of several thousand juveniles from the flood plains of the Tisa River in Yugoslavia. Holcik (1976b) reports on the possibility of natural spawning in the Danube River. Guillory and Gasaway (1978) discuss the zoogeography and distribution of grass carp in the United States. Pflieger (1975a, 1975b, 1978) gives the occurrence of grass carp in Mississippi River basin. [Sutton (1977a) reports grass carp distribution in North America.] Larvae from natural reproduction have been recently documented from the Mississippi and Atachfalaya Rivers in Louisiana and southern Arkansas (Conner et al. 1980).

General geographical reviews of grass carp introductions include the following. Stanley (1976d, 1977) and Stanley et al. (1978) discuss the requirements for and occurrence of natural reproduction based on a visit to the Soviet Union and assessment of available world literature. Schuster (1952b) and Bailey and Haller (unpublished ms.) report on introduction in the Indo-Pacific region. Sutton et al. (1977) and Miley et al. (1979b) inspected sites of grass carp introduction in Europe and in the Soviet Union. European countries are surveyed in Blanc et al. (1971), Krupauer (1971), and von Zon (1977a).

3.3 Local occurrence

Stanley (1977) and Stanley et al. (1978) summarize the literature on habitat distribution and migration of grass carp during different life stages. Papers pertaining to spawning grounds and migration are reviewed in Section 5.4. Descriptions of movements relating to dispersal, feeding, and over-wintering may be found in Lin (1935a), Nikolsky (1963), Borbach (1966), Fischer and Lyakhnovich (1973), and Nikolsky and Aliev (1974). The grass carp dispersed through brackish water bodies in the Soviet Union (Cross 1970 citing Pavlov and Nelovkin (1963), Vinogradov and Zolotova 1974).

In aquaculture ponds, the grass carp frequents all water strata (Chen 1934, 1935, 1976), but apparently spends most of its time in the middle layers (Chow 1958). Grass carp often form schools at the water surface (Ellis 1974, Buckley and Stott 1977). When introduced into ponds, fry swim in compact schools (Shireman et al. 1978c). Telemetry studies have been accomplished with fish stocked in reservoirs and lakes (Mitzner 1975a, 1978; Nixon et al. 1977; Nixon and Miller 1978; Nall et al. 1979, Shireman and Haller 1980).

4. ENVIRONMENTAL TOLERANCE

Suitability of the environment for grass carp relates to spawning requirements, disease, food, predation, and hydrology. Suitable spawning conditions (Sect. 5.4) seem to be the primary limiting factor in most cases. Both reduction of the macrophyte food base and disease have been suggested as causes for the decrease of the introduced grass carp population in the Kara Kum Canal, Soviet Union (Stanley 1977 and Stanley et al. 1978, citing Aliev (pers.comm), and Kogan 1974). Lack of food may have contributed to decreased populations in the Khauz Khan Reservoir of Russia (Nikolsky and Aliev 1974) and in the Tone River of Japan (Bailey and Haller, Unpub. ms., Tsuchiya 1979).

The grass carp can quickly disrupt its own food supply, particularly at high densities in closed systems such as culture ponds (Vinogradov and Zolotova 1974) and small lakes (Beach et al. 1976, 1977; Gasaway 1978b). Predation (Section 9.2), especially by other fish, has hindered stocking attempts in the Soviet Union (Stanley 1977, Sutton et al. 1977, Stanley et al. 1978), United States (Gasaway 1977e, Shireman et al. 1978c), and elsewhere.

The grass carp can tolerate relatively wide ranges of hydrological conditions. Singh et al. (1967a) investigated the tolerance of fry and fingerlings for temperature, dissolved oxygen, pH, salinity, turbidity, alkalinity, ammonia, chlorine, and sulphide. The lethal limits for oxygen content and temperature depend on size and acclimatization (Opuszynski 1967a). Custer et al. (1978) determined fingerling acclimation regimes for abrupt changes in oxygen content and temperature. Negonovskaya and Rudenko (1974) discuss the effect of decreasing oxygen on fry metabolism. Leonte (1969) measured oxygen consumption of embryonic and larval stages. The level of and changes in water temperature influence egg development and larval survival to different extents (Anon. 1970i, Stott and Cross 1973). Salinity has been investigated for its effects on general adaptability of grass carp (Doroshev 1963, Cross 1970, Chervinski 1977, Kilambi and Zdinak 1980), consumption and growth rates (Kilambi 1980, Maceina and Shireman 1980a), and physiology (Maceina and Shireman 1979, Macina et al. 1980). Kilgen et al. (1975) report salinity tolerance of hybrids from crosses of male grass carp and female common carp (*Cyprinus carpio*).

5. REPRODUCTION

5.1 Maturity

Maturity occurs at ages from one to eleven years in females and at an average age of one year earlier in males (Table 3). Ling (1977) gives average ages of two years for the tropics and four to five years for temperate areas. Nikolsky (1954) sets the earliest age at six to seven years for grass carp in the Amur River of the Soviet Union, the northern limit of the range. Nutrition acts synergistically with climate to influence maturity (Bobrova 1969, Anon. 1970i, Opuszynski 1972).

Sexual dimorphism appears only in mature fish during the breeding season. Secondary sexual characters include deciduous tubercles (pearl organs) on the pectoral fins of milting males and swollen pinkish vents and soft bulging abdomens on ripe females (Table 4). Procedures for sexing immature or non-breeding grass carp without damage to specimens have been largely unsuccessful (Courtney and Miley 1973, Hong and Courtney 1973, Hong et al. 1974). Bobrova (1969) and Shelton and Jensen (1970) describe gonadal differentiation.

5.2 Reproductivity

Relative gonad weight ranges to 20% of total weight in females and to 2.5% in males. Gorback (1961, 1966) provides the best report of maturity in a natural grass carp population. In tropical Malaysia, Hickling (1967b) found little seasonal change in gonad size as is typical of the grass carp in temperate areas. Chen et al. (1969) investigated the effects of size, egg maturation stages, and diet on relative ovarian weight in cultured Malaysian fish. Slack (1962) observed ripe females to have higher gonadosomatic ratios than developing or regressing females, but egg development never advanced beyond the secondary yolk stage.

Table 3. Initial and Average Age and Size of Grass Carp at Maturity in Different Countries (Shireman and Smith 1981)

LOCATION	SEX	AGE	LENGTH (cm)	WEIGHT (kg)	AUTHORITY
China:					
Sunchow, Kwangsi Prov.	-	3(4)	-	3.5(4.1-5.9)	Lin (1935a)
Southern	-	3-4	-	-	Konradt (1968)
Yangtze River	-	5-6	-	-	Konradt (1968)
	-	4-5	-	-	Opuszynski (1972)
	-	3-4	-	-	Brown (1977)
Central and Southern	-	4	-	5	Da-Shu (1957)
Hungary	-	6-7	-	-	Opuszynski (1972)
India:					
Cuttack	male[1]	2(3)	75.2-86.0[2]	4.54-6.61	Alikunhi et al. (1962. 1963a, 1963b, 1973)
	female[1]	3	73.8-79.2[2]	4.76-7.03	Alikunhi et al. (1962, 1963a, 1963b, 1973)
	male	1	43.9-49.3[2]	0.95-1.40	Alikunhi and Sukumaran (1964)
	female	2	-	-	Alikunhi and Sukumaran (1964) Alikunhi et al. (1965)
Tamilnadu	male	1	-	-	Prabhavathy and Sreenivasan (1977)
	female	2	-	-	Prabhavathy and Sreenivasan (1977)
Israel:					
Dor	male	2	-	4.0	Yashouv (1958)
	female	4-5	-	5.0	Yashouv (1958)
Malaysia:					
Malacca	-	2	-	6.0	Slack (1962)
	male	1-2	51-60[2]	1.2-2.0(2-3)	Hickling (1976b)
	female	1-2	58-63[2]	2.3-3.2	Hickling (1976b)
Nepal	-	2	-	-	Chen et al. (1969)
	-	4	-	-	Shrestha (1973)
Poland	female	6	-	3.0-3.5	Wolny (1971)
Romania	-	6-7	-	-	Opuszynski (1972)

-continued-

Table 3. Initial and Average Age and Size of Grass Carp at Maturity in Different Countries (continued)

LOCATION	SEX	AGE	LENGTH (cm)	WEIGHT (kg)	AUTHORITY
Soviet Union:					
Amur R. (middle)	-	6-8(9-10)	54-55(68-75)[3]	-	Gorbach (1961)
	female	7-8(9-10)	60(68-75)[3]	-	Makeeva (1963)
	male	6-7(9-10)	60-65(68-75)[3]	-	Gorbach (1966)
	female	6-7(9-10)	60-68(70-75)[3]	-	Gorbach (1966)
	-	8-9	70-75[3]	-	Ko-lei-hei-chin (1966)
Amur R. (lower)	-	8-9	-	-	Ma-k'ai-yeh-wa et al. (1966)
Amur R. (upper)	-	9-10	-	-	Ma-k'ai-yeh-wa et al. (1966)
Turkmen	male	2-3	-	-	Vinogradov (1968)
	female	3-4	-	-	Vinogradov (1968)
Kiev	male	7-8	-	-	Vinogradov (1968)
	female	8-9	-	-	Vinogradov (1968)
Krasnodar	male	4	-	-	Vinogradov (1968)
	female	5	-	-	Vinogradov (1968)
	male	3-4	-	-	Anon (1970i)
	female	4-5	-	-	Anon. (1970i)
Moscow	male	9	-	-	Vinogradov (1968)
	female	10	-	-	Vinogradov (1968)
	-	10	-	-	Opuszynski (1972)
Central	male	7-8	-	-	Bobrova (1969)
	female	8-9	-	-	Bobrova (1969)
South Central	male	2-3	-	-	Anon. (1970i)
	female	3-4	60	-	Anon (1970i)
Lower Volga R.	-	5(6+)	60	-	Martino (1974)
Taiwan	male	3-4	-	-	Lin (1965), Chen (1976)
	female	4-5		3+	Lin (1965), Chen (1976)
United States:					
Alabama	male	2	-	-	Alabama Dept. of Conservation (1968)
	female	3	-	-	Alabama Dept of Conservation (1968)

-continued-

Table 3. Initial and Average Age and Size of Grass Carp at Maturity in Different Countries (continued)

LOCATION	SEX	AGE	LENGTH (cm)	WEIGHT (kg)	AUTHORITY
United States:					
Arkansas	female	4	-	-	Bailey and Boyd (1970,1973)
	-	3	-	-	Sneed (1971)

[1] Brood stock

[2] Total length

[3] Standard length

Table 4. Secondary Sex Characters and Seasonal Occurrence of Ripe Grass Carp (Shireman and Smith 1981).

LOCATION	SEX	CHARACTER	TIME OF YEAR	AUTHORITY
India (Cuttack)	Male	Roughness on pectoral fins	March - September	Alikunhi and Sukamaran (1964); Alikunhi et al. (1962, 1963a, 1963b, 1973)
	Female	Soft distended abdomen, swollen pinkish vent	June - July	Chaudhuri et al. (1966)
India(Tamilandu)	Male	Rough pectoral surfaces, serrated ridges on pectoral fin rays, thickened first pectoral ray, nuptial tubercles on head	March - August	Prabhavathy and Sreenivasan (1977)
	Female	Soft bulging abdomen, pinkish vent	May - August	Prabhavathy and Sreenivasan (1977)
Japan	Male	Pearl organs on pectoral, dorsal and caudal fins	April - August	Kawamoto (1950)
Malaysia (Malacca)	Male	Roughness on pectoral fins, thickened first pectoral fin ray, pectoral fin longer than of female	All months	Hickling (1976b)
	Female	Soft distended abdomen, vent sometimes swollen and pinkish	All months	Hickling (1967b)
Malaysia (Malacca)	Male	Roughness on pectoral fins	All months	Chen et al. (1969)
	Female	Soft bulging abdomen, swollen pinkish cloaca	All months	Chen et al. (1969)
Nepal (Kathmandu)	Male	Roughness on pectoral fins	May - June	Shrestha (1973)
	Female	Distended belly, swollen pinkish vent	May - June	Shrestha (1973)

-continued-

Table 4. Secondary Sex Characters and Seasonal Occurrences of Ripe Grass Carp (continued).

LOCATION	SEX	CHARACTER	TIME OF YEAR	AUTHORITY
Soviet Union (Ukraine)	Male	Thickened first pectoral fin ray	June	Prikhod'ko and Nosal' (1963)
Soviet Union	Male	Rough inner surface on pectoral fins	May - June	Anon. (1970i)
	Female	Soft sagging abdomen, occasional swelling of vent	May - June	Anon. (1970i)
Taiwan	Male	Deciduous serrations on pectoral fins	April - September	Lin (1965)
	Female	Distended belly, swollen pinkish vent	April - September	Lin (1965)
Taiwan	Male	Roughness on inner sides of pectoral fins	March - July	Chen (1976)
	Female	Soft distended belly, swollen pinkish vent	March - July	Chen (1976)
United States (Arkansas)	Male	Pearl organs on dorsal sides of pectoral fins	May	Bailey and Boyd (1972, 1973)
	Female	Distended abdomen	May	Bailey and Boyd (1972, 1973)
United States (Florida)	Male	Deciduous tubercles on pectoral fins, first dorsal fin ray and dorsum of caudal peduncle	May - June	Courtenay and Miley (1973)

Alikunhi et al. (1962) gives relative ovarian weights for brood stock injected with carp pituitary. Other reports of relative ovarian weight include Dah-Shu (1957) for China, Inaba et al. (1957) on one gravid female from Japan, and Makeeva (1963) on Amur basin fish, Soviet Union. Gradual increases in water temperature can induce maturation outside of the regular breeding season (Sutton et al. 1977, Huisman 1978, Shireman et al. 1978b). Working with grass carp under tropical Malaysian conditions, Hickling (1967b) presents the only direct evidence for multiple spawning by individual females in one year.

Asynchronus development of oocytes was reported in fish from China (Lin 1935a, Gorbach 1966), the Tone River, Japan (Inaba et al. 1957), Malaysia (Chen et al. 1969), the Amur River (Makeeva 1963, Ko-lei-hei-chin 1966, Ma-kai-yeh-wah et al. 1966, Gorbach 1972), and the lower Volga River (Martino 1974). The grass carp apparently spawns one to three times per year, depending on climate and seasonal conditions. Females are known to resorb eggs under adverse circumstances. Ko-lei-hei-chin (1966) claims further that intervals between spawns increase with age of the fish. Makeeva (1963) suggests that individuals may not spawn every year.

Absolute fecundity ranges from tens of thousands to two million eggs and averages 500,000 for 5 to 7 kg brood stock (Anon. 1970i). Table 5 summarizes literature reports of absolute fecundity. Konradt (1968) demonstrated that greater doses of injected hormone can increase the number of ovulated eggs. Hickling (1967b) also reports hypophysation as increasing the number of yoked ovarian eggs. Alikunhi et al. (1962)

Table 5. Absolute Fecundity of Grass Carp (Shireman and Smith 1981)

NUMBER OF EGGS ($x10^3$)	WEIGHT (kg)	TOTAL LENGTH (cm)	AGE (years)	CHARACTERISTICS OF SPECIMENS	LOCALITY	AUTHORITY
100*	7.3	-	-	wild-caught	China (West R., Kwangsi Prov.	Lin (1935a)
960*	14.6	-	-	wild-caught	China, Yangtze R.	Chang (1966)
373	4.8	73.8	3		India (Cuttack	Alikunhi et al. (1963a)
564	4.9	75.8	3			
396	5.5	78.6	3	brood stock		
618	5.7	78.9	3	after injection		
442	5.8	75.0	3			
309	7.0	79.2	3			
200-300	4.6	-	-	injected	India (Tamilandu	Prabhavathy and Sreenivas. (1977)
485*	7.1	88	-	wild-caught	Japan (Waterase R.)	Inaba et al. (1957)
816*	7.4	76[1]	7	wild-caught	Soviet Union (Amur River)	Berg (1949)
$\bar{x}$ = 470	$\bar{x}$ = 7.5	-	-	8 mg injection	Soviet Union (Lenigrad)	Konradt (1968)
$\bar{x}$ = 785	$\bar{x}$ = 7.5	-	-	24 mg injection		
237-1637 $\bar{x}$ = 820*	5.1-16.4	66-96[2]	7-15	wild-caught	Soviet Union (middle Amur R.)	Gorbach (1972)
$\bar{x}$ = 1089*	-	-	-	wild-caught	Soviet Union (Kara Kum Canal and its reservoirs)	Aliev and Sukhanova (1974)
10-700 $\bar{x}$ = 367	3.7-7.4	-	3	injected	United States (Florida)	Shireman (1975)
$\bar{x}$ = 740*	3.7-7.4	-	3	injected		

*Values with asterisks denote number of ovarian eggs and those without are the number of ovulated eggs.

[1]Standard lengths

investigated relative fecundity in fish under Indian culture. Gorbach (1972) provides the most extensive report on fecundity in a natural population and factors affecting it, including age, size, weight, condition, fat content, nutrition, and fishing pressure.

5.3 Spawning season

Lin (1935a) and Dah-Shu (1957) documented that spawning occurred from April to September in the Yangtze, Pearl, and West Rivers of China. Gorbach (1961, 1966, 1972) sets the breeding season in the Amur basin from late May to early August with peaks from late June to mid-July. Other reports of the Amur breeding season include Verigin (1961), Makeeva (1963), Ko-lei-hei-chin (1966), and Ma-kai-yeh-wa et al. (1966).

Unless maturation is artificially induced (Sect. 5.2 and 11.2), naturalized or cultured grass carp spawn at the times given in Table 6 for various localities. The climate in northern latitudes limits the breeding season and makes it more distinct compared to those under tropical conditions (Hickling 1967b). Weir or dam construction may change hydrological conditions and affect the time of grass carp reproduction (Tsuchiya 1979, Bailey and Haller, unpublished ms.).

5.4 Spawning conditions and grounds

Grass carp usually spawn their pelagic eggs in the primary channels of relatively large rivers. Water temperatures in the 15 to 17°C range apparently trigger upstream migration to the spawning grounds (Aliev 1976). The hydrological conditions cited most frequently for grass carp reproduction are a rise in water level, temperatures above 17°C, and current velocity greater than 0.6 m/s (Lin 1935a; Nikolsky 1954, 1963; Dah-Shu 1957;

Table 6. Seasonality of Maturation in Naturalized and Cultured Grass Carp Populations (Shireman and Smith 1981)

LOCATION	MATURATION SEASON	AUTHORITY
Austria	June	Brown (1977)
India (Cuttack)	May - July June - August	Alikunhi et al. (1963a)
(Tamilnadu)	May - Augst	Chaudhuri et al. (1966)
Japan (Tone River*)	June - July	Kuronuma (1955)
	June - Early August	Inaba et al. (1957)
	June - August (peaks late June-mid July)	Tsuchiya (1979)
(Shinga Prefecture)	April - July	Kawamoto (1950)
Korea	July - August	Kim (1970)
Malaysia (Malacca)	May - August[1]	Slack (1962)
	all months	Hickling (1967a)
	all months	Chen et al. (1969)
Nepal	mid May - June	Shrestha (1973)
Netherlands	July	Huisman (1978)
Soviet Union		
Astrakhan	latter June	Anon. (1970i)
Ili River*	peaks mid/late May	Nezdoliy and Mitrofanov (1975)
Kara Kum Canal*	May - June	Aliyev (1976)
Krasnodar	latter May	Anon. (1970i)
Moldavia	early June	Anon. (1970i)
Syrdar'ya River*	latter May	Verigin et al. (1978)
Turkman	early May	Anon. (1970i)
Ukraine, southern	late May-late June	Hoa (1973)
Uzbek	early May	Anon. (1970i)
Volga R. (lower)	May - mid August	Martino (1974)
Volgograd	latter June	Anon. (1970i)
Taiwan	May-early July March - July	Lin (1965)
United States		
(Arkansas)	May - July	Bailey and Boyd (1970, 1973)
	May - June	Addor and Theriot (1977)

*Asterisks indicate self-reproducing populations. All other localities relate to introduced spawning.

[1]Imported as fingerlings.

Kuronuma 1958; Verigin 1961; Makeeva 1963; Gorbach 1966; Anon. 1970i; Nezdoliy and Mitrofanov 1975; Ling 1977; Verigin et al. 1978; Miley et al. 1979b; Tsuchiya 1979). Spawning grounds occur immediately downstream of a tributary, island, or other geologic feature which causes strong vertical mixing, and have rock, gravel, or sand as a substrate (Lin 1935a; Dah-Shu 1957; Kuronoma 1955, 1958; Inaba et al. 1957; Ko-lei-hei-chin 1966; Anon. 1970i).

The most extensively investigated river with respect to grass carp spawning conditions is the Tone River of Japan where introduced fish have formed an established population (Kuronuma 1955, 1958; Inaba et al. 1957; Tsuchiya 1979). Aliev (1976) gives a thorough account of the unique spawning grounds and conditions pertaining to massive grass carp reproduction in the Kara Kum Canal of the Soviet Union. Bailey and Haller (unpubl. ms.), discuss the physiographic conditions of a Taiwan reservoir where grass carp have spawned in the past (Tang 1960a, 1960b). Rosas (1976) describes the Mexican rivers where grass carp have reproduced recently.

Many hydrologic or physiographic factors such as turbidity or river length may actually influence or merely coincide with successful grass carp reproduction, so the relative importance of many factors is unknown. Leslie et al. (unpubl. ms.) demonstrated that eggs can develop at a current speed of 0.24 m/s, and have suggested, along with Aliev (1976), that river length and current may be more important to physiological preparation of spawners than to egg development. Martino (1974) reported that grass carp reproduced in the Volga River may have occurred in adjacent flooded meadows with current velocities of 0.2 to 0.5 m/s.

Based on visits to areas with established populations, or interviews with researchers who work with introduced grass carp, and on reviews of pertinent literature, a number of reports have been published describing sites of natural spawning and summarizing habitat requirements for successful reproduction. Bailey and Haller (unpublished ms.) and Burress (1970) investigated sites in the Far East, including the Tone River, Japan. Stanley (1977), Sutton et al. (1977), Stanley et al. (1978), and Miley et al. (1979b) draw on experience gained in the Soviet Union and Europe. Stanley (1976d) reviews grass carp reproduction worldwide with emphasis on its potential in the United States. Breder and Rosen (1966) and Gerking (1978) provide miscellaneous references on grass carp reproduction.

5.5 Mating

Mating is promiscuous and has been observed in the Tone River of Japan (Kuronuma 1955, 1958; Inaba et al. 1957) and in the West River of China (Lin 1935a, Dah-Shu 1957). Natural reproduction reportedly occurs during daytime, but Tsuchiya (1979) has found greatest activity by induced spawners to take place at night.

6. DEVELOPMENT

6.1 Fertilization

Fertilization is external. Bobrova (1969) describes the syngamy and related cytology from first prematuration division to the initial cleavage division. Mantelman (1969, cited in Stanley 1976b) and Anon. (1970f) have noted three or more pronuclei in 5% of fertilized eggs, which is probably a result of polyspermy. Stanley (1976b, 1976c), Stanley et al.

(1976), and Stanley and Jones (1976) suggest that polyspermy in conjunction with exclusion of the maternal common carp (Cyprinus carpio) genome, yields androgenetic grass carp. Gynogenetic grass carp may be obtained through retention of the second polar body, equivalent to secondary nondisjunction. Using allogenic and/or irradiated milt increases the proportion of gynogenetic specimens. Mantelman (1973) reported that the cytological events of syngamy in reciprocal crosses of grass carp with silver (Hypophthalmichthys molitrix) or bighead (H. nobilis) carp take place similarly to those in homogenic crosses.

6.2 Embryogenesis

Incubation periods of 16 to 60 hours correspond with temperatures from 30 to 17°C with the optimal range from 21 to 25°C (33 to 23 hours) (Lin 1965, Vinogradov and Erokina 1967, Anon 1970). Nikolsky (1954) and Swingle et al. (1967) also reported incubation times and temperatures. The most thorough description, including figures, of embryogenesis may be found in Anon. (1970i); other accounts are given by Lin (1935a), Inaba et al. (1957), Alikunhi et al. (1962, 1963a, 1963b, 1973), Bailey and Boyd (1970), Antalfi and Tolg (1972), Soin and Sukhanova (1972), and Fischer and Lyakhnovich (1973). Konradt (1968) photographed developmental stages.

Overripe spawn and protracted ovulation can cause increased egg mortality during incubation (Makeyeva and Verigin 1971). Inadequate fertilization and various adverse incubation conditions can result in embryonic or larval deformation and death (Vinogradov and Erokina 1967, Anon. 1970i). False development of unfertilized spawn and various deformations are described in Anon. (1970i) and Shireman (1975). Stott and Cross (1973) investigated abrupt temperature drops during incubation and have illustrated resulting developmental deformations.

6.3 Larval stages

Inaba et al. (1957), Anon. (1970i), and Conner et al. (1980) discuss and illustrate the larval development period, which consists of a protolarval stage (first three days) when exogenous feeding occurs and of a mesolarval stage which normally lasts until one month of age. Conner et al. (1980) provide meristic measurements as well. Water temperatures near 30° C cause larvae to attain development states more quickly than water at lower temperatures (Alikunhi et al., 1962). Other descriptions of larval development include those of Lin (1935a), Soin and Sukhanova (1972), and Fischer and Lyakhnovich (1973).

Stott and Cross (1973) reported that 20-hour-old protolarvae are fairly resistant to abrupt temperature drops from 24.4 to 17C°. Bailey (1972a) notes a susceptibility to suffocation by silt. Growth and survival through larval stages are enhanced with the addition of zinc sulfate, which apparently participates in metabolic processes involving calcification of bony tissue (Sabodash 1974).

6.4 Postlarval stages

Developing grass carp attain the fry stage at one month of age and two cm in length, become fingerlings at 1.5 months and four to five cm, and are identical to adults by two months of age and seven cm in length. Inaba et al. (1957) and Anon. (1970i) give the best accounts and illustrations of these stages. Others may be found in Antalfi and Tolg (1972), Soin and Sukhanova (1972), and Fischer and Lyakhnovich (1973). Dah-Shu (1957) describes fry. High temperatures of 28 to 33°C permit grass carp to reach the fry stage by 18 days of age in Indian rearing ponds (Alikunhi et al. 1962, 1963a, 1963b, 1973). Doroshev (1963) and Maceina and Shireman (1980) investigate the effect of salinity on fry and fingerling growth rates.

Internal changes continue to occur during the postlarval period. The relative amount of hemoglobin increases during the first year as a result of increasing red blood cell size (Lyakhnovich and Leonenko 1971). Bobrova (1969) and Shelton and Jensen (1979) discuss anatomical and cytological differentiation of the gonads during the fingerling stage. Hoa (1973) reports some meristic biological indicators and their relation to fingerling rearing conditions. Fischer and Lyakhnovich (1973) review the relative changes in external dimensions, weight of different body parts, and intestinal length during the subadult phase. The relatively long juvenile period seems to be a time of dispersal in wild populations and is reviewed by Stanley et al. (1978).

6.5 Adult stage

Examination of scale annuli indicates that grass carp fished out of the Amur basin, Soviet Union, are typically 5 to 11 years old (Berg 1959). Specimens from 13 to 15 years of age have been taken sporadically (Gorbach 1966, 1972). A 21+-year-old individual was captured in 1958 (Gorbach 1961).

Reported maximum weights of grass carp range from 32 kg (Nikolsky 1954, Gaevskaya 1969, Fischer and Lyakhnovich 1973) to 50 kg in the Yangtze River (Dah-Shu 1957) to over 200 to 300 catties (120 to 181 kg) (Lin 1935a, citing Chen 1933). The largest specimen measured by Berg

(1949) was 110 cm standard length and 15 kg in weight. Of the hundreds of fish taken in the Amur basin and examined by Gorbach (1961, 1966, 1972), the largest ranged from 94 to 105 cm standard length and 11.9 to 16.4 kg in weight. Descriptions of reproduction, feeding, and growth of adult grass carp are discussed in appropriate sections.

7. FOOD AND FEEDING

7.1 Life stages and selectivity

Grass carp first feed exclusively on plankton but change during the first year to a diet almost entirely composed of macrophytes. Bailey (1972a) provides an extensive literature review and his own research pertaining to the life stages and selectivity of grass carp feeding. Linchevskaya (1966a) and Rozmanova (1966) report that phytoplankton dominate the exogenous food items in two-to-four day old larvae and that zooplankton occur most frequently in the gut by the fifth day. Sobolev (1970) and Tamas and Horvath (1976) have investigated the zooplankton species preference of various larval stages. Other reports on larval food items include Nikolsky (1954), Dah-Shu (1957), Inaba et al. (1957), Kuranuma (1958), Linchevskaya (1966b), Ling (1967), Lupacheva (1967), Bailey (1972a), Bardach et al. (1972), Opuszynski (1972, 1979), Woynarovich (1975), Schlumpberger and Lievenau (1978), Bohl (1979), and Miley et al. (1979b). Appelbaum and Uland (1979) have determined the appropriate food particle sizes for larvae of different ages.

At about two cm the grass carp begins to feed on macrophytes. Sobolev (1970), Opuszynski (1972, 1979), and Watkins et al. (1981) report on the increase in percent composition of plant material in the guts of fingerlings which mark the transition to phytophagy. Fingerlings initially prefer the tender species or parts of aquatic plants (Lin 1935a; Fischer 1968; Anon. 1971f; Bailey 1972a; Opuszynski 1972, 1979; Edwards 1974, 1975; Willey et al. 1974; Prabhavathy and Sreenivasan 1977; Sutton 1977b; Watkins et al. 1981).

Fingerlings also consume animals under certain conditions. Edwards (1973) and Willey et al. (1974) have documented that grass carp fingerlings in aquaria with vegetative food available, prey on many invertebrates and small fish when they are offered. Singh et al. (1976) found that 7 to 13 cm grass carp avidly eat common carp (*Cyprinus carpio*) hatchlings while 20 to 25 cm specimens refuse them. In a small pond, only trace amounts of invertebrates have been found in the stomachs of 6 to 22 cm grass carp (Colle et al. 1978b). In devegetated ponds, however, juveniles apparently resort to insects for food (Kilgen and Smitherman 1971, 1973; Forester and Avault 1978). Opuszynski (cited by Sutton et al. 1977) states that the gut contents of cultured grass carp include 75% vegetation by weight and 25% zooplankton and benthos in yearlings, 75% plants and 25% food pellets in two year old fish, and 90% plants and 10% pellets in three year old fish. Mitzner (1975c, 1978) reports only trace amounts of animal material in the gut contents of adults stocked in a lake. Gaevskaya (1969), Kilgen (1973), and Nikolsky and Aliev (1974) also comment that animals are insignificant in the adult diet and may be ingested incidentally along with plants.

Table 7 presents a cross section of the many food plants of grass carp documented in the literature. Carter and Hestand (1979) devised a key for identification of plants ingested by grass carp. Bailey (1972a) summarizes changes in selectivity as grass carp increase in size and reviews pertinent papers on the subject. Sutton et al. (1977)

Table 7. Representative Food Plants of Fingerling and Juvenile Grass Carp (Shireman and Smith 1981)

SPECIES	REF NOS.*	SPECIES	REF NOS.*	SPECIES	REF NOS.*	SPECIES	REF NOS.*
Alternanthera philoxeroides	1	Glyceria aquatica	6	Nasturtium officinale	3	P. pusillus	15
Anacharis spp.	10	G. maxima	7	Nitella hookeri	3	Ranunculus circinatus	13
Azolla spp.	15	Hydrilla spp.	9	Paspalum notatum	10	R. fluitans	6
A. rubra	3	H. verticillata	12	Phalarus arundinacea	6	Sagittaria graminea	2
Callitriche spp.	13	Lagarosiphon major	3	Phragmites communis	6,7	S. sagittifolia	7
C. stagnalis	3	Lemna spp.	7	Pithophora spp.	1,15	Schoenoplectus lacustris	7
Ceratophylum demersum	15	L. gibba	11	Polygonum spp.	10	Sirogonium spp.	15
Chara spp. 1,5,9,10,11,12,	15	L. minor	3,11,4,15	P. amphibium	6	Spirodella polyhiza	1
Eichornia crassipes	1,4	Lyngbya spp.	15	Potamogeton spp.	9	Trapa natans	6
Eleocharis spp.	2,10	Myriophyllum spp	15	P. crispus	3,15	Typha angustifolia	6
E. acicularis	1	M. brasiliense	1	P. diversifolius	1,5	T. latifolia	6
Elodea canadensis	1	M. propinquum	3	P. foliosus	15	Vallisneria spp.	9
E. densa	3,6,7,8,15	M. spicatum	1,5,12	P. illinoensis	2,12	V. americana	1,12
Eremochlea ophiuroides	5	Najas spp.	10	P. lucens	6	Wolffia columbiana	15
Fontinalis spp.	7	N. flexis	2,15	P. natans	6		
		N. guadalupensis	1,11,12	P. pectinatus		*Ref. No. Key Below	

REF. NO.	AUTHORITY	EXPERIMENTAL ENVIRONMENT	SIZE OR AGE OF SPECIMENS
1	Avault (1965b)	small pools	30-40 cm
2	Colle et al. (1978b)	small lake	6.3-22 cm
3	Edwards (1974,1975)	small ponds	0+ - 1+
4	Johnson and Lawrence (1973)	ponds	160 - 190g
5	Kilgen and Smitherman (1971, 1973)	ponds	yearlings
6	Krupauer (1971)	ponds	2+-4+
7	Opuszynski (1972, 1979)	ponds	250g
8	Pentelow and Stott (1965)	ponds	19 cm, 140g
9	Prabahavathy and Sreenivasan (1977)	ponds	30 cm
10	Stevenson (1965)	ponds	0.9 - 1.3 kg
11	Sutton (1977b)	small pools	fingerling
12	Sutton and Blackburn (1973a, 1973b)	370-l tanks small pools	3l.1.1-3.5 kg 40-400g
13	Sutton et al. (1977)	ponds	200-300 g
14	Van Dyke (1973)	55-l aquaria	225-589 g
15	Willey et al. (1974)	57-l aquaria 64-l barrels	15 cm 15 cm

discuss food selection based on information gained during a visit to various European countries and the Soviet Union. Edwards (1973, 1974) has observed that larger body size and higher water temperature broaden the species range of plant selection. Tender, succulent plants are highly preferred at all ages, but especially in young fish (Krupauer 1967, 1968b; Prowse 1971; Sutton and Blackburn 1973a, 1973b). Other investigations of plant selectivity have been carried out in the Soviet Union (Strogonov 1963, Verigin et al. 1963, Nikolsky and Verigin 1966, Zolotova 1966, Prikhodka and Lupacheva 1967, Gurova 1972), United States (Alabama Department of Conservation 1965, 1967; Stevenson 1965; Kilgen and Smitherman 1971, 1973; Johnson and Lawrence 1973; Willey et al. 1974; Sutton 1977b), India (Mehta and Sharma 1972, Mehta et al. 1976), Poland (Penzes and Tolg 1966; Opuszynski 1972, 1979), and Holland (von Zon 1974, 1979; von Zon et al. 1977). Dutha and Kilgen (1975) and Theriot and Sanders (1975) report on food selection in fingerling hybrids of male grass carp crossed with female common carp (*Cyprinus carpio*). In studies of the grass carp and other species, blood characteristics have correlated with degree of carnivory or phytophagy (Molnar 1969, Gyula 1970, Molnar and Tamassy 1970).

7.2 Feeding grounds, conditions, and behavior

In the Amur basin of the Soviet Union, grass carp feeding exhibits a marked seasonality, dependent on water temperature and inundation of terrestrial vegetation on the floodplain (Nikolsky 1963, Gaevskaya 1969). Condition and fat content are influenced by both food availability and the extent of flooding in the previous year (Gorbach 1971, 1972).

Feeding activity is directly related to water temperature and usually ceases at 10 to 14°C and below (Stroganov 1963; Beridze and

Chkhaidze, 1966; Bobrova 1966, 1968; Nikolsky and Verigin 1966; Penzes and Tolg 1966; Woynarovich 1968; Anon. 1970i; Gurova et al. 1972; Vietmeyer 1976; Colle et al. 1978b). Sudden temperature drops and windy weather also inhibit feeding (Stroganov 1963, Hickling 1966, Gurova et al. 1972). Disturbance by transplantation or fishing may cause grass carp to cease feeding for one or more days (Hickling 1962, Prowse 1966b).

Size, age, and many other factors affect feeding behavior. Fry only take inanimate food particles when they are suspended in the water column (Stevenson 1965, Appelbaum and Uland 1979). They generally feed in the lower and middle water layers (Inaba et al. 1957). The omnivorous fingerlings do not disturb the bottom while foraging (Edwards 1973). Descriptions of the buccal cavity in adults and of the process of mastication may be found in Inaba and Nomura (1956), Stroganov (1963), Hickling (1966), and Berry and Low (1970). The decrease in food selectivity with increasing size and temperature is referred to in the previous section. Relative consumption rate also decreases as grass carp grow from juvenile to adult size (Chapman and Coffee 1971). Reported observations of feeding activity indicate that any time of the day or night is suitable (Hickling 1962, Stroganov 1963, Woynarovich 1968, Anon. 1970i).

7.3 Consumption rate

Woynarovich (1968) and Vietmeyer (1976) state that daily consumption rates range from 80% to several times the body weight under optimal conditions. The daily ration for grass carp in Soviet fish culture averages 40% (Anon. 1970i). The high feeding rate is primarily due to the quick passage and imcomplete digestion (Sect. 7.4) of food in the gut (Hickling 1962, 1966; Stroganov 1963).

Body size and food type influence consumption. The effects of size on feeding rate have been investigated in fingerlings by Shireman et al. (1978a) and in juvenile to adult grass carp by Chapman and Coffee (1971) and Mehta et al. (1976). Shireman and Maceina (1980) estimated that 6+ kg grass carp stocked in a lake ate 26 to 28% of their body weight per day.

Food type affects consumption rate which is used as a primary indicator of food selectivity (Section 7.1) in grass carp. Fingerling feeding rates have been investigated with respect to various vegetable and artificial diets (Shireman et al. 1978a), to the proportion of animal or vegetable content (Fischer 1973), and to various plant species (Fischer 1968). Verigin et al. (1963), Nikolsky and Verigin (1966), Krupauer (1967, 1968), and Mehta et al. (1976) provide data on consumption rates of different plant species by juvenile to adult specimens.

Environmental factors, particularly temperature, also influence consumption. Chapman and Coffee (1971) and Edwards (1974) report seasonal variation in feeding rate. Using relative gut content weight as an index, Colle et al. (1978b) observed reduced consumption as temperature dropped, especially below 14°C, with fingerlings stocked in a pond. In a controlled experimental environment, feeding rate was highly correlated with temperature which accounted for most of the variation (Sutton and Blackburn 1973a, 1973b; Sutton 1974). In another study, temperatures of 18 and 29°C had insignificant effects on fingerling consumption rates (Kilambi and Robison 1979). Consumption can also be affected significantly by salinity (Doroshev 1963, Kilamvi 1980, Maceina and Shireman 1980) and by oxygen content (Stanley 1973a, Shireman 1975, Shireman et al. 1977a, von Zon 1977a citing van Starkenburg and van der Zweende, 1976). The effects of stocking density on consumption have been reported in Shireman (1975), Shireman et al. (1977a), and Kilambi and Robison (1979). The effects of abrupt temperature drops, wind, and disturbance (Hickling 1962, 1966; Stroganov 1963) have been mentioned in the previous section.

7.4 Food conversion

The grass carp is relatively inefficient in the utilization of food. The absence of cellulase, which consequently requires mechanical rupture of plant cell membranes for digestion, and the quick passage of food through the gut (less than eight hours at 28 to 30°C) result in assimilation of around 50%, according to Hickling (1962, 1966). Gaevskaya (1969) points out that the tightly packed bolus may be exposed to digestion only in its outer layer. Other reported digestion rates of plant material range from 50 to 70% (Stroganov 1963; Van Dyke 1973; Stanley 1974a, 1974b; Vietmeyer 1976; Van Dyke and Sutton 1977). Working with 40 to 120 g fingerlings, Fischer (1972b) reports assimilation values of 40% with animal food and 20% with plants.

Much research has investigated food conversion under various dietary conditions. Literature values of food coefficients include 14 to 54 ($\bar{x}$ = 18) in a Russian pond (Stroganov 1963), 6.9 for concentrated feed to 57 for cattail (*Typha latifolia*) in a Russian study of 2+ year old fish (Arikhod'ko and Lupaecheva 1967), 30 for Soviet fish culture (Anon 1970i) and cage culture at 30 to 34°C (Verigin et al. 1963), 48 for Napier grass (*Pennisetum purpureum*) consumed in Malaysian aquaculture (Hickling 1960), 18 to 22 in Chinese culture (Woynarovich 1968), 20 to 73 with hydrilla (*Hydrilla verticillata*) as food (Sutton and Blackburn 1973a, 1973b; Sutton 1974), and 16 to 79 in grass carp fed duckweed (Lemna spp.) under different conditions (Van Dyke 1973, Sutton 1977b, Van Dyke and Sutton 1977). Venkatesh and Shetty (1978) obtained conversion values of 27 for hybrid napier grass (Pennisetum purpureum x sajje), 94 for hydrilla, and 128 for coontail (Ceratophyllum demersum) fed to fingerlings in Indian culture. Shireman et al. (1978a) report higher conversion efficiency with duckweed than with pelleted diets. Dabrowski (1979) and Dabrowski and Kozak (1979) examine the effects of cassein, fish meal, and soybean diets of different compositions on the protein efficiency ratio and net protein utilization in fry. The energy balance and conversion of protein and other dietary constituents have been determined for grass carp fed with duckweed (Lemna spp.) (Van Dyke 1973, Van Dyke and Sutton 1977) and with egeria (Egeria densa) (Stanley 1974a, 1974b).

The relative proportions of animal and vegetable matter in the grass carp diet greatly influence food conversion and related parameters. Fischer (1970, 1972a, 1972b) has investigated the energy balance and assimilation of major dietary constituents in fingerlings and juveniles reared on lettuce (Lactuca sativa) or tubificid worms (Tubifex). He later reports that a diet with 75% animal and 25% plant material is optimal (Fischer 1973). Working with duckweeds (Wolffia, Spirodella) and invertebrates (Moina, Chryomyia) as food items, I-kuei et al. (1966, 1973) have demonstrated that a dietary animal content of 30% or more results in optimal conversion rates in fry and fingerlings.

Many factors other than diet affect food conversion in grass carp. Huisman (1978) reports that fry fed pelleted food under intensive culture steadily become less efficient converters as they grow to 300 g and lower temperatures apparently decrease efficiency as well.

The effects of body size on fingerling conversion have also been investigated for duckweed (Lemna spp.) and various pelleted diets (Shireman 1975; Shireman et al. 1977a, 1978a). Tal and Ziv (1978a, 1978b) document a decrease in conversion efficiency from one to two years of age, and Sutton (1974) reports a similar reduction from 100 g to 1 kg in weight. Seasonal variation in conversion rate has been observed with hydrilla (Hydrilla verticillata) as food (Sutton and Blackburn 1973a, 1973b; Sutton 1974). The influence of salinity (Maceina and Shireman 1980a) and the interdependent effects of density and oxygen content (Shireman 1975, Shireman et al. 1977a) on food conversion have been studied in fingerlings given duckweed. Kilambi (1980) found conversion efficiency to be negatively correlated with salinities from 3 to 9% at 18.5°C but it was unaffected by these salinities at 29.5°C. Sutton (1977b) found that underfed yearlings had the highest conversion rates in various experiments involving fingerling to adult grass carp and different feeding conditions.

8. Growth

8.1 Growth pattern

The weight-length relationship in grass carp usually does not differ significantly from the typical cubic growth equation (Table 8). Shireman and Maceina (1980) determined that females were significantly heavier than males at the same lengths and had significantly higher condition coefficients. Larger grass carp also weighed significantly more for their size than did smaller specimens. Adams and Titeko (1970) report the length and weight of grass carp from fry to 56 cm and Hickling (1960) gives the same data from 57 to 66 cm. Hoa (1973) observed that weight-length variability of juvenile grass carp increased when growth was retarded because of poor culture conditions.

Table 8. Weight-Length Relationships Reported for Grass Carp

WEIGHT-LENGTH RELATIONSHIP (W in g, L in mm)	SIZE RANGE (mm)	CONDITION FACTOR (K)	GROWTH CONDITIONS	AUTHORITY
$W = .0566 \times 10^{-5} L^{3.108}$ [$\log_{10}W = -5.247 + 3.108 \log_{10}L$	270-660	1.09 - 1.13	Hong Kong Culture ponds	Chow (1958)
$\log_{10}W = 3.484 + 2.477 \log_{10}L$	-	1.16	Temperate lake	Mitzner (1975c)
$\log_{10}W = -4.916 + 3.002 \log_{10}L$	29-252	-	Culture tanks	Shireman (1975)
$\log_{10}W = 4.821 + 3.005 \log_{10}L$	450-700	-	Temperate lake both sexes	Shireman and Maceina (1980)
$\log_{10}W = -5.239 + 3.127 \log_{10}L$	700-1,111	-	Temperate lake both sexes	Shireman and Maceina (1980)
$\log_{10}W = -5.157 + 3.101 \log_{10}L$	7,650	1.392	Females	Shireman and Maceina (1980)
$\log_{10}W = 4.367 + 2.825 \log_{10}L$	7,650	1.311	Males	Shireman and Maceina (1980)

Gorbach (1961) provides growth data of native grass carp in the Amur basin, Soviet Union. Length increases 9 to 10 cm annually in the first four or five years, 6 to 7 cm in the sixth and seventh years, and 2.5 cm after the eighth year. Growth rate by weight increases with age, particularly from the fifth to seventh years, and decreases in older fish if adverse conditions develop. No difference in growth between the sexes was noted in Gorbach's study, but Hickling (1967b) did find females to grow significantly faster than males in Malaysian culture. Reported growth rates usually range from 10 to 22 g per day for intermediate to adult size grass carp with good feeding conditions (Hickling 1960, 1967b; Alikunhi and Sukumaran 1964; Crowder and Snow 1969; Sinha 1973; Mitzner 1975c; Shireman 1975; Sinha and Gupta 1975; Mehta et al. 1976; Miley et al. 1976; Shireman et al. 1980; Shireman and Maceina 1980).

Size effects on grass carp growth have been noted most frequently in cultured or introduced populations. Huisman (1978) describes the pattern of fry growth under controlled hatchery conditions. Mehta et al. (1976) report growth rates in g/d of 0.6 in the first 6 to 7 months of Indian culture, 3 to 5 from 7 to 13 months, and 17 to 22 from 13 to 15 months of age. Chapman and Coffee (1971) found a higher growth rate in 10.2 kg specimens than in those weighing 3.3 kg. General patterns of growth, usually for the first four years of culture, have been reported for China (Dah-shu 1957, Giduma 1958), India (Jhinghran and Gopalikrishnan 1974, Prabhavathy and Sreenivasan 1977), and South Africa (Pike 1977). Linear growth has been observed in grass carp growing from 20 cm and 90 g up to 13 to 14 kg over periods of up to 4 years in temperate lakes (Gasaway 1978b, Shireman et al. 1980, Shireman and Maciena 1980). Extrinsic factors which influence growth are discussed in the following section.

8.2 Growth rate

Under optimal conditions, the grass carp may grow faster than any other fish species of comparable size. In tropical countries, specimens in fish culture have attained 7.0 to 8.5 kg in one year with rates of increase averaging 1 kg per month in the last 6 months (Anon. 1970g, Vietmeyer 1976). In the temperate Amur basin of the Soviet Union, the greatest growth rate of wild fish amounts to 2.7 kg per year and occurs in fish older than 6 years (Gorback 1961). Factors which have been demonstrated to influence grass carp growth include diet, consumption, temperature, dissolved oxygen, salinity, and density.

Many natural and prepared foods have been tested for their effects on growth in all sizes of grass carp. Appelbaum and Uland (1979) found Alkan yeast with a vitamin and protein supplement to be superior to other diets, such as *Artemia salina* nauplii, for larval rearing. A similar yeast diet proved better than ground nut oil cake, rice bran, or aquatic weeds (*Hydrilla verticillata* and *Potamogeton perfoliatus*) for fry and and fingerling culture in an Indian study (Sharma and Kulshrestha 1964). Dabrowski (1979) determined the optimal protein content of a cassein diet to be $52.6 \pm 1.93\%$ for the greatest growth and conversion efficiency in fry. Dabrowski and Kozak (1979) tested soybean and fish meal diets with fry. Meske and Pfeffer (1978) investigated different diets such as trout feed, a prepared mixture of whey powder and soybean meal, and green alga (*Scenedesmus obliquus*) meal, and obtained the best fry and fingerling growth with a combination of 80% algae with 20% of the prepared mixture.

Shireman et al. (1978a) observed faster growth in fingerlings reared on duckweed (Lemna minima) than in those given commercial or prepared pelleted diets. Another study indicated that fingerlings grew better on duckweed (Lemna gibba and minor) than on two other plant diets (Najas guadalupensis and Chara sp.) (Sutton 1977b).

Diets with varying proportions of plant and animal components also affect fingerling growth. Fischer (1972a) reported much higher growth rates with animal (Tubifex sp.) than with plant (Lactuca sativa) material. I'kuei et al. (1963, 1973) determined a proportion of 30% animal food in the diet for optimal fingerling growth, the value also reported for Soviet fish culture (Anon. 1970i).

Most diet research with regard to juvenile growth has concentrated on various plant species. Sutton and Blackburn (1973a, 1973b) investigated the growth of 40 to 616 g grass carp in outdoor pools with a variety of aquatic plants and found poor utilization of water hyacinth (Eichhornia crassipes) by small fish. Poor growth on water hyacinth, especially with small individuals, has been noted in other studies (Blackburn and Sutton 1971; Baker et al. 1973,1974). Blackburn and Sutton (1971) observed greater grass carp growth with hydrilla (Hydrilla verticillata) and southern naiad (Najas guadalupensis) diets than with commercial feed. Duckweed (Lemna sp.) also appears to be superior to pelleted feed as a diet for grass carp (Tal and Ziv 1978a, 1978b). Hydrilla promotes faster growth than either Napier grass (Pennistum purpureum) or tapioca (Manihot utilissimus) leaves (Tan 1970). Interestingly, Venkatesh and Shetty (1978) observed significantly higher growth in fingerlings given hybrid napier grass (P. purpureum x sajje) than in those fed hydrilla or coontail (Ceratophyllum demensum). Other growth studies have dealt specifically with duckweed (Van Dyke 1973, Van Dyke and Sutton 1977) and with hydrilla (Sutton 1974). Grass carp grow best in polyculture when given supplemental vegetation (Sen et al. 1978). Greatest grass carp growth occurred with high protein pellet and with manure plus grain diets in Israeli investigations involving polyculture with Tilapia and other carps (Voav et al. 1977).

The effects of consumption rate (Sect. 7.3) on grass carp growth have only been reported in a few instances. Fischer (1973) obtained the highest consumption and best growth in 74 to 235 g specimens with a mixed plant and animal diet. Fish averaging 295 g had highest consumption rates on plant material but greatest growth on the mixed diet. Growth was significantly related to hydrilla consumption but the relationship explained only 39.2% of the variation in growth, which apparently also depended upon conversion rate which fluctuated over time (Sutton and Blackburn 1973a, 1973b; Sutton 1974). With a duckweed (Lemna sp.) diet, growth in 16 to 589 g fish was highly correlated with consumption which explained as much as 84% of the variation in growth (Van Dyke 1973, Sutton 1977, Van Dyke and Sutton 1977).

A general review of reported grass carp growth rates reveals that growth is fastest in the tropics and in the warmer seasons of temperate areas. Colle et al. (1978b) observed that 48-to 186-mm-fingerlings in a pond grew slower at low temperatures, particularly below 14°C. Seasonal variation in growth rates of fingerling to adult grass carp has been documented in New Zealand studies (Chapman and Coffee 1971, Edwards 1974). Sutton (1974) determined that the growth rates of 0.1 kg individuals increased to a greater extent with a temperature change from 23 to 29°C than did those of larger 1 kg specimens. Opuszynski (1967b) observed that grass carp growth rates increased along with temperature, but Kilawbi and Robison (1979) found similar growth rates in fingerlings raised at water temperatures of 18 and 29°C.

Density and oxygen content usually act together in their effects on grass carp growth rates. Density-dependent growth has been noted for 0.1 to 0.9 kg fish at stocking rates from 49 to 3800 per hectare (Blackburn and Sutton 1971; Kilgen and Smitherman 1971, 1973). Shelton et al. (1981) observed a strong dependence of growth on density in the first year of life and a more variable relationship during the second year. Kilambi and Robison (1979) investigated the effects of stocking rates on fingerling growth. The role of density in polyculture production has been investigated by Murty et al. (1978) for fry and by Moav et al. (1977) for fingerling to harvestable sizes of grass carp. Sharma and Kulshrestha (1974) found that density and oxygen content affected the growth of fry and fingerlings. Stanley (1975) has established that grass carp cease feeding at approximately 2.5 ppm oxygen. Density did not affect fingerling growth in tanks until oxygen content approached 4 mg/l when large reductions in consumption occurred (Shireman 1975, Shireman et al. 1977a).

Depending upon the origin of the seawater used in his experiments, Koroshev (1963) observed normal fingerling growth at salinities up to 7 and 9 $^{o}/_{oo}$, but large scale mortality occurred at 10 to 14.5 $^{o}/_{oo}$. Maceina and Shireman (1980) found significant reductions in fingerling growth rate at 3 to 6 $^{o}/_{oo}$ salinity and some mortality at 12 $^{o}/_{oo}$. Kilambi (1980) determined the growth rate in fresh water to be three times greater than those at salinities from 3 to 9 $^{o}/_{oo}$. Growth was not significantly different in this salinity range.

Grass carp growth rates under numerous culture conditions have been reported in the literature. Huisman (1978) reports on intensive rearing of fish from larva to yearling in the Netherlands. Growth rates in pond culture are available for the United States (Stevenson 1965, Alabama Department of Conservation 1966, Crowder and Snow 1969), India (Alikunhi and Sukumaran 1964; Sinha 1973; Chaudhuri et al. 1975; Sinha and Gupta 1975; Mehta et al. 1976; Prabhavathy and Sreenivasan 1972, 1977), China (Dah-Shu 1957, Gidumal 1958), Fiji (Adams and Titeko 1970), Israel (Yashouv 1958), Malaysia (Hickling 1960), Poland (Penzes and Tolg 1966), Soviet Union (Bobrova 1965, Beridze and Chkhaidze 1966, Gurova 1972), and South Africa (Cross 1969, Pike 1977). Bizyaev and Chesnakova (1966) investigated the rearing and growth of fingerling and yearling grass carp in fallow and sown rice fields. Long term growth in United States lakes has been reported by Mitzner (1975c), Gasaway (1978b), Shireman et al. (1980), and Shireman and Maceina (1980). Aliev (1963a) provides grass carp growth rates in a vegetated lake of the Soviet Union.

9. INTERSPECIFIC INTERACTIONS

9.1 Parasites and disease

In both its indigenous and non-native habitats, the grass carp harbors numerous parasites (Table 9), particularly in the disease-prone conditions of dense fish culture. Riley (1978) reviews the literature on grass carp parasites and documents the occurrence of a pentastomid worm in fish introduced into the United States. Other more or less extensive discussions of symptoms and treatments of parasitic diseases in grass carp under fish culture conditions include

Table 9. Parasites of Grass Carp (Modified from Shireman and Smith 1981)

Parasite	Reference
VIRUSES	
Rhabdovirus spp.	3,9
R. carpio	9
BACTERIA	
Achromabacter spp.	28
Aeromonas spp.	28
A. punctata	
A. salmonicida	
var. achromogenes	9
Flexibacter columnaris	5
Myxoccus piscicola	19
Pseudomonas spp.	
FUNGI	
Branchiomyces sanguinis	9
Saproglenia spp.	12,13,16,24
PROTOZOA	
Apiosoma cylindriformis	17,21,25(a,b,e)
A. magna	25(f)
A. minimicro nucleata	25(f)
A. piscicola	17,21,25 (f)
Balantidium ctenopharyngododontis	5,7,21,24,25(a,b,e)
Chilodonella spp.	9,31
C. cyprini	11,17,18,21,22,24,25 (d,e)
Chloromyzum spp.	18
C. cyprini	21,25 (a,e)
C. nanum	21,25(a,e)
Costia necatrix	11,25 (b)
Cryptobia spp.	9
C. branchialis	25(a,b,e)
C. cyprini	1,21
Eimeria carpelli	25(f)
PROTOZOA, continued	
Eimeria mylopharyngodoni	17
E. sinensis	17
Entamoeba ctenopharyngodonti	25(a,b)
Epistylis spp.	25(f)
E. lwoffi	25(d)
Euglenosoma caudata	25(b)
Glaucoma pyriformis	25(b)
Hemiophrys macrostoma	25(a,b)
Hexamita spp.	25(b,g)
Icthyophthyrius spp.	9
I. multifiliis	10,11,13,17,18,19, 21, 25(b,d,e),26
Myxidium spp.	25(e)
M. ctenopharyngodonis	25(a)
Myxobolus dispar	21,25(e)
M. ellipsoides	25(a)
Sphaerospora carassii	25(e,f)
Spironucleus spp.	25(3)
Tetrahymena pyriformis	25(a)
Thelohanellus oculi-leucisci	33
Trichodina spp.	11,22,25(g)
T. bulbosa	25(b,d)
T. carasii	25(d)
T. domerguei	21,25(c,d)
T. meridionalis	21,25(d)
T. nigra	21,25(d,f)
T. nobilis	25(d)30,33
T. ovaliformis	21,25(a,b)
T. pediculus	21,25(a,b,c,f)
T. reticulata	17,25(f)
Trichodinella epiotica	21,25(c,e)

-continued-

Table 9. Parasites of Grass Carp (continued)

KEY TO REFERENCE NUMBERS:

1) Anon. 1972d
2) Anon. 1976b
3) Ahne 1975
4) Alikunhi and Sukumaran 1964
5) Astakhova and Stepanova 1972
6) Bardach et al. 1972
7) Bauer 1968
8) Bisseru 1970
9) Bohl 1979
10) Cross 1969
11) Dah-Shu 1957
12) Doroshev 1963
13) Edwards and Hine 1974
14) Faust and Khaw 1927
15) Gidumal 1958
16) Huisman 1978
17) Ivasik et al. 1969
18) Konradt and Faktorovich 1966
19) Laboratory of Fish Deseases (date unknown)
20) Laboratory of Fish Diseases 1977
21) Musselius 1969
22) Musselius and Strelkov 1968
23) Orchynnyk 1963
24) Prabhavathy and Sreenivasan 1977
25) Riley 1978 citing; (a) Bykovskaya-Pavlovskaya et al. 1962; (b) Chen 1955; (c) Ivanova 1966; Kashkovskii 1964; (e) Molnar 1971; (f) Stepanova 1971; (g) Sullivan and Rogers, pers. comm.
26) Stevenson 1965
27) Sutton et al. 1977
28) Szakolczai and Molnar 1966
29) Tomasec 1968
30) Wu 1971
31) Vanyatinskii 1978
32) Yukhimenko 1970
33) Yukhimenko 1972

Dah-Shu (1957), Stevenson (1965), Konradt and Faktorovich (1966), Bauer (1968), Musselius and Strelkov (1968), Ivasik et al. (1969), Bardach et al. (1972), Edwards and Hine (1974), Prabhavathy and Sreenivasan (1977), Sutton et al. (1977), and Bohl (1979).

The eggs, larvae, and fry are susceptible to external fungal and bacterial infections (Chen et al. 1969; Bailey and Boyd 1971; Anon. 1972e, 1972b). Adverse incubation conditions may cause dropsy which results from hydration of the body cavities (Anon. 1970i). Another developmental deformity is curvature of the spine which apparently results from imbalanced diets in some cases (Shireman 1975, Meske and Pfeffer 1978). Molnar (1971) discusses the protozoan parasites of fry. Astakhova and Stepanova (1972) and Yukhimenko (1972) have investigated parasitic infection in fingerlings and yearlings. Molnar (Anon. 1971c) described symptoms and effects of dactylogyrosis. Ahne (1975) and Bohl (1979) provide accounts of Rhabdovirus sp., the etiologic agent of "spring viremia" or acute dropsy. Bacterial gill rot has been studied by the Laboratory of Fish Disease (no date) in China and bacterial enteritis by Anon. (1971c), Wu (1971), and the Laboratory of Fish Disease (1977). The incidence and treatment of columnaris disease has been detailed in Kim (1970), Shireman (1975), Shireman et al. (1976), and Huisman (1978). Perhaps the most dangerous native grass carp parasite, which has been transplanted along with the fish, is Bothriocephalus acheilognathi (= gowkongensis) (Ovchynnyk 1963, Bauer 1968, Tomasec 1968, Yukhimenko 1970). Bohl (1979) gives a full account of this nonspecific cestode which has caused losses in European carp culture. It has been introduced into the United States along with grass carp (Anon. 1976b). The trematode, Clonorchis (=Opisthoreis) sinensis, which also parasitizes man and other mammals, uses the grass carp as an intermediate host (Faust and Khaw 192-7, Bisseru 1970). Trust et al. (1979) describe the nonpathogenic gastrointestinal bacteria found in cultured grass carp.

9.2 Predators

Many aquatic predators utilize the grass carp. Invertebrates such as copepods (especially Cyclops), belastomid and notonectid diving bugs, predaceous diving beetles and their larvae, and dragonfly nymphs attack the early life stages (Lin 1949, Dah-Shu 1957, Gidumal 1958, Anon. 1970l, Bailey and Boyd 1971, Wurtz-Arlet 1971, Bailey 1972, Boyd and Bailey 1972, Chen 1976). Voracious predation of grass carp eggs by fish has been observed in an experimental release (Leslie et al. unpubl. ms.).

Piscivorous fish in the grass carp's native China include Parasilurus asotus, Siniperca chuatsi, and Luciobrama typus (Dah-Shu 1957, Gidumal 1958). Channa (=Ophicephalus), Gobius, Elopichthys bambusa, Clarias, and Anabas cause losses in Taiwanese and Malaysian fish culture (Birtwistle 1931a, Lin 1949). In the Soviet Union, snakehead (Channa), pike perch (Lucioperca lucioperca), and pike (Esox lucius) prey on grass carp in pond culture and may limit introduced populations (Efimova and Nikanorov 1977, Stanley 1977, Sutton et al. 1977, Stanley et al. 1978). In the United States, considerable research has been directed toward the theoretical size limits of largemouth bass (Micropterus salmoides) predation on grass carp (Shireman et al. 1978c), aquarium studies of bass predatory behavior toward grass carp (Hatton 1977), and lake and pond stocking trials to determine the extent of bass consumption of grass carp (Gasaway 1977e, Shireman et al. 1978c). Shireman et al. (1978c) concluded that grass carp should be at least 450 mm TL at stocking.

Other vertebrate predators of grass carp include water snakes, piscivorous birds, and otters (Birtwistle 1931a, Gidumal 1958, Stanley 1977, Sutton et al. 1977, Stanley et al. 1978, Thomas et al. 1979). Frogs (*Rana*) have caused losses in fry rearing ponds (Sutton et al. 1977).

9.3 Competition and other indirect interactions

Grass carp competition with other species is always related to food. Grass carp fry reportedly compete with other fish species for zooplankton in polyculture rearing (Opuszynski 1968, 1979; Grygierek 1973). Sobolev (1970) determined that this competition is insignificant at reasonable stocking rates. If vegetative material is or becomes scarce, adult grass carp may prey on animals and compete with other benthophages such as common carp (*Cyprinus carpio*) and gamefish (Bobrova 1966, Gaevskaya 1969, Vinogradov and Zolotova 1974, Lewis 1978). Other studies have reported that grass carp provide little competition with carnivorous fish and may actually starve in devegetated ponds with animal food present (Kilgen and Smitherman 1971, 1973; Terrell 1975a; Terrell and Fox 1974, 1975; Terrell and Terrell 1975). Much apparently depends on the prior feeding history of the individual fish (Zolotova 1961).

Grass carp apparently competed with crayfish (*Procambarus clarkii*) for vegetative food in small culture ponds and consequently reduced crayfish production (Forester and Avault 1978). Grass carp may possibly reduce the food base of herbivorous waterfowl, especially overwintering populations (Gasaway 1977b, 1978a; Gassaway et al. 1977 unpubl. ms; Gasaway and Drda 1977; Land 1980).

Because of food selectivity, the grass carp sometimes increases in unpalatable plants at the expense of preferred species (Vinogradov and Zolotova 1974, Sutton 1975b, Fowler and Robson 1978, Koblinski et al. 1980, Miley et al. 1980, Nall and Schardt 1980a). The quick elimination of macrophytes and abrupt influx of nutrients in grass carp faeces can result in plankton blooms, especially of blue-green algae (Alikunhi and Sukumaran 1964; Opuszynski 1972, 1979; Nikolsky and Aliev 1974; Vinogradov and Zolotova 1974; Crisman and Kooijman 1980). Many studies have noted changes in the species composition as well as abundance of plankton populations in various pond and lake situations where grass carp have been introduced (Grygierek 1973, Mestrov et al. 1973; Gasaway 1977b, 1977c, unpubl. ms.; Lembi and Ritenouer 1977; von Zon et al. 1977; Gasaway Drda 1978; Lembi et al. 1978). Fry and Osborne (1980) observed no changes in the zooplankton of ponds which they felt could be directly attributed to grass carp introduction. Grass carp had no effect on algae in Polish ponds while stocking of silver (Hypopthalmichthys molitrix) or bighead (H. nobilis) increased algal populations (Januszko 1974). Bogdanovich (1970, 1974) found that grass carp increased the abundance and biomass of bacteria in the sediments of Soviet ponds.

The presence of grass carp may affect macroinvertebrate populations both positively and negatively. Increases in macroinvertebrate standing crops are generally credited to increased nutrient input via grass carp faeces (Aliey 1976, Haller and Sutton 1977, Lembi and Ritenouer 1977, Lembi et al. 1978, Kobylinski et al. 1980, Miley et al. 1980). When stocked at high densities, grass carp may eliminate vegetative refugia and decrease invertebrate diversity and numbers by exposing them to predation (Vinogradov and Zolotova 1974; Beach et al. 1976, 1977; Gasaway 1977a, 1977b; Newton et al. 1976). In other studies, no significant changes in macroinvertebrates have occurred with the introduction of grass carp (Rottmann 1976, Rottmann and Anderson 1976, Crisman and Kooijman 1980). In Russia, ectoparasitic dipterans such as mosquitoes have been controlled by stocking grass carp to eliminate vegetation used for larval development (Aliyev and Bessmertnaya 1965, Aliev 1976). Grass carp have been noted to decrease shrimp production in polyculture trials (Kuronuma and Nakamura 1957).

Stocking grass carp can have complex effects on other fish populations, a fact reflected in the conflicting literature. Reduction of vegetative refugia may lead to increased vulnerability of small fish to piscivores (Aliyev and Bessmertnaya 1965, Vinogradov and Zolotova 1974, Beach et al. 1976, Baur et al. 1979). Macrophyte removal can also reduce spawning sites for phytophilous fish (Opuszynski 1968, 1979; Krupauer 1971). After introduction of grass carp, drops in reproduction have been reported for pike and perch (Lucioperca fluviatilis) in small Russian lakes (Sutton et al. 1977) and for largemouth bass and bluegill (Lepomis macrochirus) in small American ponds (Forester 1975, Forester and Lawrence 1978). In the latter study, foraging grass carp may have interfered with reproduction by wandering onto spawning beds. Newton et al. (1976) introduced grass carp into a reservoir where they eliminated the vegetation, apparently disrupted the macroinvertebrate food base, and cut centrarchid biomass in half. With grass carp in polyculture ponds, however, production of companion species increased. Polyculture with grass carp has enhanced cyprinid and centrarchid production in other studies (Stanley 1973a, Buck et al. 1975, Chaudhuri et al. 1975, Haller and

Sutton 1977, von Zon et al. 1977) (Section 12.1).

Perhaps the most intensive studies and controversial study of grass carp effects on other fish involves several lakes and ponds in Florida, United States. Negative effects were documented for the abundance and condition of many species, especially gamefish, at most sites after grass carp were stocked (Gasaway 1977a, 1977b unpubl. ms.; Ware and Gasaway 1976). However, according to Beach et al.(1976, 1977) and Miley et al. (1979c) these results might have been affected fish populations to a significant extent (Beach et al. 1976, 1977; Miley et al. 1979e). Grass carp introductions have adversely affected pike, perch, Crucian carp (Carassius carassius), and roach (Rutilus rutilus) in the Soviet Union (Vinogradov and Zolotova 1974). In temperate United States lakes, Bailey (1978) found that grass carp controlled or eliminated vegetation but had insignificant effects on other fish populations.

10. POPULATION (STOCK)

10.1 Structure

Gorbach (1961) provides the most extensive data pertaining to sex, age,and size composition of a native grass carp population. Drawing on publications by Nikolsky (1956) and Konstantinova (1958), and on his own research, he shows that the average age and size of grass carp in the Amur River, Soviet Union, have decreased drastically from the 1930's to 1959, apparently due to overfishing of spawning individuals.

The sex ratios of catches from self-reproducing grass carp populations have been reported as female dominated in the Amur River (Borbach 1961) and in Japan (Inaba et al. 1957), while Chang (1966) writes that males comprise 75 to 80% of Chinese catches. Spawning observations indicate that one to three males accompany each female (Lin 1935a, Dah-Shu 1957, Inaba et al. 1957). Shelton and Jensen (1979) document a 1:1 ratio in young cultured grass carp.

10.2 Natality and recruitment

No information is available on natality rates or recruitment in wild populations. Hatching rates of artificially fertilized eggs range from 0.05 to 70% (Alikunhi et al. 1962, 1963b, 1973; Alabama Department of Conservation 1966; Bailey and Boyd 1970, 1971, 1973; Boyd and Bailey 1972) with an average of 40% in Soviet fish culture (Anon. 1970i), and indicate that high egg mortality occurs under natural conditions. Eggs are prone to infection by bacteria and fungi (Bailey and Boyd 1971; Anon. 1972e, 1972b; Shrestha 1973; Bohl 1979) and to attack by copepods (Anon. 1970i). Extensive predation by fish on experimentally released eggs (Leslie et al. unpubl. ms.) and the narrow hydrologic conditions required for proper development (Sections 5.4 and 6.2) also suggest that natality rates are low in the wild. Differential mortality of the life stages which influences recruitment is discussed in the following section.

10.3 Mortality, morbidity, and condition

The available information on grass carp mortality rates deals with cultured or introduced populations in closed systems. Vladimirov (1975) identifies two periods of low larval survival, the first two days after hatching and the fourth to sixth days when exogenous feeding begins. Soviet culturists obtain 50% or better survival during this period (Anon. 1970i).

Rates and sources of mortality for fingerling (monthly attrition of 3.2%) to 2 + year-old (monthly attrition of 1.9%) fish in small ponds free of fish predators are reported in Thomas and Carter (1977) and Thomas et al. (1979). Survival ranges from 30 to 40% through the larval period, 50 to 70% during the fingerling stage, and 80 to 90% in over-wintering yearlings in Russian fish culture (Anon. 1970i). Mortality rates of 40 to 50% in first-year fish and 20 to 30% in second- and third-year fish are reported for Chinese culture (Dah-Shu 1957). Introduction of fingerlings into a pond with an established largemouth bass (Micropterus salmoides) population resulted in almost total mortality (Shireman et al. 1978c, 1980). Colle et al. (1978b) observed 92.9% mortality of fingerlings in a pond poisoned to remove predators and suggested piscivorous birds as the probable cause. Survival of 0.13 to 1.9 kg grass carp varied from 1 to 96% mortality of fingerlings in a pond poisoned to remove predators and suggested piscivorous birds as the probable cause. Survival of 0.13 to 1.9 kg grass carp varied from 1 to 96% in four ponds over two years and apparently depended on the extents of predation by bass and of macrophytes for food (Beach et al. 1976, Gasaway 1978b). Colle et al. (1978a) estimated a 94.6% reduction in grass carp 2.5 years after stocking in a lake. Bird and fish predators reportedly limit naturalized grass carp populations in the Soviet Union (Stanley 1977, Sutton et al. 1977, Stanley et al. 1978).

Causes of morbidity in grass carp include disease (Section 9.1), starvation, and hydrologic conditions (Section 4). Decreased macrophyte abundance in four ponds may have increased grass carp mortality (Beach et al. 1976, Gasaway 1978b). Behavioral effects induced by morbidity are described by Opuszynski (1967a) for extreme water temperatures and by Negonavskaya and Rudenko (1974) for low oxygen content. Maceina and

Shireman (1979) and Maceina et al. (1980) investigated the physiological effects of increasing salinity. Grass carp sensitivity to rotenone and other fish toxicants is reported in Marking (1972), Henderson (1974), Willey et al.(1974), Cumming et al. (1975), Miley et al. (1976), Martin and Martin (1979), and Hardin (1980). Colle et al. (1978a) provide the most extensive data on rotenone dosage.

Gorbach (1971) describes annual variation in condition and fat content in the native grass carp population of the Amur River, Soviet Union. Mitzner (1975c, 1978) and Shireman and Maceina (1980) report condition coefficients for grass carp introduced into American lakes. Hoa (1973) found that increases in weight-length variability, increased positive skewness of distributions by weight-length classes, and decreased relative intestinal length indicated poor growth conditions for pond-raised under-yearlings.

10.4 Population dynamics

No information is available on annual cycles in the demographic parameters of self-reproducing grass carp populations. Fishery statistics provide the only information on changes in grass carp abundance over long periods of time in the Soviet Union and Japan. Gorbach (1961) documented large scale population reductions and decreases in average age, length, and weight of grass carp in their native Amur basin from the 1930's to 1959 due to fishing pressure. Variable growth rates in fish from different localities indicated the presence of several local stocks. Immature fish comprised much higher proportions of catches during the 1960's (Gorbach 1972). The annual take dropped by a factor of 15 from 1965 to 1970 due to overfishing and to large reductions in the annual population fecundity. Krykhtin (1975) observed that the youngest grass carp caught to a considerable extent in the Amur fishery were 5 to 6 years old. In the Amur region, grass carp have always been uncommon relative to most other species (Nikolsky and Aliev 1974, Miley 1980).

Small reproducing stocks of non-native grass carp occur in several Soviet river systems (Section 3.2), but establishment and dynamics are difficult to determine because of continuing introductions (Stanley 1977, Stanley et al. 1977, Sutton et al. 1978, Miley et al. 1979b). Reporting on the freshwater fisheries of Turkmenistan in general and the Khauz Khan Reservoir in particular, Aliev (1976) documented grass carp increases until 1971 when they represented 10.2% of the Reservoir catch, and decreases thereafter to 0.2 to 1.8% of the 1974 fisheries. The population reductions in the Khauz Khan Reservoir and its associated Kara Kum Canal are also discussed in Nikolsky and Aliev (1974), Stanley (1977), Stanley et al. (1978), and Miley (1980). Grass carp reportedly migrated from the Kara Kum Canal through brackish waters of the Aral Sea and established populations in freshwater lakes, dominating the fishery of at least one lake (Bykov 1970, cited in Stanley 1977 and Stanley et al. 1978). Annual grass carp catches from reservoirs associated with the Tone River in Japan declined from a high of 47 metric tons (MT) in 1959 to 0 to 9 MT from 1960 to 1975 (Tsuchiya 1979).

10.5 Relationships of population to ecosystem

A variety of environmental factors apparently affect grass carp populations. Overfishing causes large decreases in the Amur River population by reducing the average age, size, and fecundity (Gorbach 1961, 1972; K'o-lei-hei-chin 1966). Successful self-reproduction of introduced grass carp has not resulted in large populations in most Soviet river systems where predation by birds and other fish seems to limit their abundance (Stanley 1977, Sutton et al. 1977, Stanley et al. 1978, Miley et al 1979b, Miley 1980).

Predation has hindered many other stocking attempts (Sections 4 and 9.2). The interplay of stocking rates, fishing effort, establishment of self-reproduction, and extent of the macrophyte food base regulates abundance of grass carp introduced into Turkmenistan (Aliev 1976). Because of their high consumption rates, grass carp may disrupt their own food supply (Vinogradov and Zolotova 1974). Reductions of grass carp numbers in the Khauz Khan Reservoir since 1970 occurred along with decreases in macrophyte beds (Nikolsky and Aliev 1974). Stanley (1977) and Stanley et al. (1978) report that the population decline in the Kara Kum Canal since 1970 may have resulted from exhaustion of the food base (citing Kogan 1974) or from parasite disease (S.S. Aliev pers. comm.). Reduced spawning success because of dam and weir construction and decreased aquatic plants used as adult food and juvenile cover have apparently caused a decline in grass carp abundance in the Tone River, Japan (Tsuchiya 1979, Bailey and Haller unpubl. ms.). Sections 3.4 and 5.4 review accounts of areas where introduced populations have spawned successfully.

Grass carp populations can have effects on other species (Section 9) and on water quality of an ecosystem. Beach et al. (1976, 1977) and Gasaway (1977b, 1977c, unpubl. ms.) document increases in nitrate-nitrite and chlorophyll levels of four Florida, United States, ponds after stocking of grass carp. In a temperate flow-through Iowa lake, water quality showed no significant short-term effects after grass carp introduction (Mitzner 1975b) but improved in the long run as evidenced by reductions in nitrate-nitrite, biological oxygen demand, and turbidity (Mitzner 1978). Grass carp may eradicate vegetation and cause decreased dissolved oxygen and increased CO_2 as observed in Indiana ponds (Lembi and Ritenour 1977, Lembi et al. 1978) and in a Yugoslavian lake (Mestrov et al. 1973). In Missouri, grass carp ponds exhibited higher oxygen contents than did control ponds (Rottmann 1976, Rottmann and Anderson 1976). The presence of grass carp in the Kara Kum Canal and Khauz Khan Reservoir of the Soviet Union improved the oxygen level regime after they eliminated most vegetation which died off seasonally in the pond and decomposed, resulting in low oxygen levels (Aliev 1976, Stanley 1977, Stanley et al. 1978). While nutrient influx via grass carp faeces has been credited with causing phytoplankton blooms and die-offs which consequently lower oxygen levels, the simultaneous stocking of planktophagic fish with grass carp has apparently prevented this situation in the Soviet Union. Terell (1974, 1975b) also demonstrated that orthophosphate, magnesium, and iron deposited in ponds via grass carp excreta became bound in the bottom sediments and were not available to the plankton community. Other water quality changes resulting from grass carp introduction include increased turbidity and potassium levels in Indiana ponds (Lembi and Ritenour 1977, Lembi et al. 1978) and decreased pH and increased Kjedahl nitrogen in a Florida lake (Kobykinski et al. 1980). In other studies, such as that by Fry and Osborne (1980), no water quality changes occurred with grass carp stocking. Michewicz et al. (1972a) demonstrated that grass carp effects on the water quality correlated with the size of their enclosure.

11. FISHERIES

11.1 Fishing equipment and techniques

The literature describes many devices and methods for capturing larval to adult crass carp. Long, conical nets of closely woven bamboo or linen are most frequently used for collection of fry and eggs in Chinese rivers (Birtwistle 1931b, Dah-Shu 1957, Bardach et al. 1972). Dipnets, pushnets, and seines are also used (Brown 1977).

Though they are commercially important in many areas, adult grass carp rarely comprise a large proportion of the catch. Commercial gear includes gill nets, trammel nets, seines, hoops nets; trotlines, hook and line, fish traps, and rotenone are used in other applications (Vietmeyer 1976, Pflieger 1978). The Chinese fish with otters and cormorants as well as with nets (Chang 1966). Lin (1935a) describes the typical fishing vessel as a small sampan in China, but commercial operations use large motor craft today. Successful fishing of grass carp with hook and line apparently depends on bait selection and amount of aquatic vegetation present (Bailey 1972a; Terrell 1975a; Terral and Fox 1974, 1975; Terrell and Terrell 1975; Buckley and Stott 1977; Sutton et al. 1977; Wilson and Cottrell 1979).

11.2 Fishing areas

The Chinese trap fry and sometimes eggs in the lower Yangtze River from Hupei to Kian-Su Provinces and in the Pearl River complex upstream on the West River as far as Poseh (Lin 1935a, Dah-Shu 1957). Adults are harvested in the same areas as well as farther upstream. Chang (1966) reviews major phytophagous fishery areas in China. Most of the Soviet catch from the Amur River is taken in the lower part of the middle reaches (Gorbach 1961, 1966). Fisheries for grass carp are developing in a few areas where introductions have occurred. The Soviets take grass carp in the Syrdar'ya and Amudar'ya basins and in Turkmenistan, particularly the Khauz Khan Reservoir and Kara Kum Canal (Maksunov 1973, Nikolsky and Aliev 1974, Aliev 1976, Verigin et al. 1978). Significant catches are also reported from lakes bordering the Aral Sea (Stanley et al. 1978, citing Bykov 1979). In Japan, most grass carp are harvested from Lakes Kasumi and Kita near the mouth of the Tone River and eggs are collected from the Edo River (Tsuchiya 1979). Man and Hodgkiss (1977) report stocking and yield of grass carp in a Hong Kong reservoir. A potential fishery may develop in the Rio Balsas system of Mexico where thousands of fry from natural spawning have been documented (Anon. 1976c, Rosas 1976).

11.3 Fishing seasons

Adult grass carp are harvested primarily during the spawning season from May to September in the Amur basin (K'o-lei-hei-chin 1966, Gorbach 1971). In China, all life stages are taken during the warm months from early May to July on the Yangtze River and from early April to late September in the Pearl River basin (Lin 1935a, Dah-Shu 1957). Chang (1966) mentions that fishery activity during the breeding season was restricted for conservation purposes during various Chinese dynasties.

11.4 Yields and commercial importance

Though commercially exploited in a number of areas, the grass carp is almost invariably uncommon compared to other species such as common carp (*Cyprinus carpio*) or silver carp (*Hypophthalmichthys molitrix*), probably because few ecosystems can produce the macrophyte food base necessary for the support of a large population. Annual yields in the Amur basin averaged 30 metric tons (MT) in prewar years (Nikolsky and Aliev 1974), attained 110 MT in the primary fishery section of the river from 1957 to 1966 (Gorbach 1966), and dropped quickly during the late 1960's due to overfishing (Gorbach 1972). In the Khauz Khan Reservoir, the annual catch reached a high of 36.4 MT (21.2% of fisheries production) in 1970 (Nikolsky and Aliev 1974). Grass carp have never represented more than 2% of the annual catch in the freshwater Turkmenistan fishery (Aliev 1976), but they have dominated the catch in at least one lake on the Aral Sea (Stanley et al. 1978, citing Bykov 1970). In the Tone River basin of Japan, grass carp have approached 80% of the phytophagous fish catch in the past, but currently comprise less than 10% with annual production ranging from 0 to 9 MT from 1960 to 1975 (Tsuchiya 1979). Lin (1949) estimated annual harvests of 11 billion fry, including grass carp and other cultured cyprinids, from Chinese rivers, but today's induced spawning techniques have decreased demand for wild fry and depressed this fishery's activity.

11.5 Fisheries management and conservation

In the Amur basin, regulations such as size and season limits, catch quotas, and suspension of fishing have been proposed to allow rehabilitation of depressed grass carp stocks (Borbach 1961, 1972; Makeeva 1963; K'o-lie-hie-chin 1966; Ma-k'ai-yeh-wa et al. 1966). Ma-k'ai-yeh-wa et al. (1966) also pointed out that planned reservoir construction was needed to avoid negative impacts on spawning. In the Soviet Union, fishing for phytophagous species is usually prohibited until several years after stocking (Aliev 1976). Chang (1966) reviews current and past regulation of the Chinese fishery and the need for better planning of hydrological projects. Prior to development of induced spawning techniques, demand for wild-caught fry nearly caused overexploitation of Chinese stocks (Job 1952).

12 AQUACULTURE

12.1 Role and culture of grass carp in fish farming

Polyculture of Chinese cyprinids, including the grass carp, is documented as beginning in the T'ang Dynasty (618-917 AD) (Dah-Shu 1957, Lin 1965, Chang 1966, Roberts et al. 1973, Brown 1977). Chang (1966) refers frequently to the grass carp in his historical review of Chinese aquaculture. In most farm operations, grass carp are stocked in small quantities to provide weed control. They are used as the dominant species, which require supplementary feeding with terrestrial grasses or silkworm cocoon in southern China, Southeast Asia, and Malaysia (Lin 1954, Ji 1976, Anon. 1977a, Ling 1977, Tapiador et al. 1977).

Procedures for induced spawning are discussed in Section 14.1, but one of the best descriptions of artificial reproduction and rearing of grass carp is that published by the All-Union Scientific Research Institute of Pond Fishery in the Soviet Union (Anon. 1970i). Diets and controlled environments for intensive rearing of larval to fingerling stages (Sections 7 and 8) are investigated in I-kuei et al. (1966, 1973), Fischer (1970, 1972a, 1972b, 1973), Sabodash (1974), Sharma and Kulshrestha (1974), Shireman (1975), Tamas and Horvath (1978), Shireman et al. (1977a, 1978a), Huisman (1978), Meske and Pfeffer (1978), Murty et al. (1978), Venkatesh and Shetty (1978), Appelbaum and Uland (1979), Dabrowski (1979), Dabrowski and Kozak (1979), and Rottmann and Shireman (1979).

Grass carp are suitable for a wide variety of polyculture operations. They are commonly used in fish-*cum*-duck polyculture (Anon. 1969j,1971a; Ling 1971; Pekh 1971; Cheng 1976b; Sin and Cheng 1976) and on farms where livestock (especially swine) wastes are recycled for pond fertilization (Gopinath 1950; LeMare 1952; Prowse 1967b; Ling 1977; Moav et al. 1977; Buck et al. 1978z, 1978b, 1979). Grass carp tolerate high densities of

8400 to 27,000 fish per hectare (Opuszynski 1968). In Indian polyculture, their presence enhanced production of other species to the same extent as fertilization with manure (Sen et al. 1978). The grass carp makes available nutrients which are normally bound up in macrophytes (Lowe-McConnell 1971) and its presence has increased yields of other cyprinid and centrarchid species in numerous studies (Kuronuma and Nakamura 1957, Bobrova 1968, Nikolsky and Verigin 1968, Opuszynski 1968, Stanley 1973a, Buck et al. 1975, Chaudhuri et al. 1975, Rottman 1976, Rottmann and Anderson 1978, Haller and Sutton 1977, von Zon et al. 1977, Newton et al. 1976).

Results of grass carp polyculture with other Chinese and Indian major carps are reported in Chen (1934, 1935), Alikunhi and Sukumaran (1964), Alikunhi et al. (1965), Lin and Chen (1967), Rabanal (1968), Sinha (1973), Jhingran (1974), Anon. (1975c), Das et al. (1975), Raja (1967), Sinha and Gupta (1975), Chakrabarty et al. (1976), Parameswaran et al. (1977), Prabhavath and Sreenivasan (1977), Sinha (1977), and Srivastava and Chawdhary (1979). Tang (1970a) deals with grass carp in Taiwan polyculture. Tal and Ziv (1978a, 1978b) discuss its positive and negative aspects in Israeli fish culture. Bizyaev and Chesnakova (1966) describe grass carp rearing experiments in sown and fallow rice fields. Peat-hag ponds can also serve for rearing (Mints and Khairulina 1968). Table 10 enumerates other short references to grass carp culture.

The major reported disadvantage of grass carp is that, in the absence of plant food, they eat pelleted food, which they convert inefficiently, compared to other cultured species (Vinogradov and Zolotova 1974; Tal and Ziv 1978a, 1978b). Other general aquaculture references, which

Table 10. Aquacultural References on Grass Carp in Various Countries

COUNTRY	ABSTRACT OF REFERENCES	AUTHORITY
Bulgaria		
	Better growth and survival were obtained with Hypoothalmichythys nobilis x H. molitrix hybrids than with grass carp in pond culture.	Boev (1970)
	Reports induced breeding on a commercial scale.	Grozev et al. (1970)
	Improved total yields were obtained in common carp polyculture with grass carp and other herbivorous carps.	Anon. (1974a)
	Determined yields and conversion in experimental polyculture of common, grass, and other herbivorous carps.	Boyadjiev and Petrov (1977)
Burma		
	Grass carp exhibited very high growth rates in polyculture with Indian and Chinese carps.	Anon. (1970d)
China		
	General description and yields of grass carp in Chinese pisciculture.	Drews(1961), Anon. (1977a)
Cuba		
	Grass carp culture in reservoirs.	Anon. (1970b)
	High growth rates and induced breeding are reported for introduced grass carp.	Anon. (1970g)
Czechoslavakia		
	Discusses importation, transportation, rearing, feeding, weed control, and polyculture.	Krupauer (1966, 1968a)
	Reports difficulty of artificial reproduction of grass carp for culture.	Berka (1969)
East Germany		
	Prewarmed water maximizes yields in artificial reproduction.	Jahnichen (1968)
	Growth and feeding of grass carp fry in trough culture with silver carp fry.	Schlumpberger and Liebenau (1978)
	Rearing, stocking, feeding, and survival of grass and other Chinese carps.	Wolf et al. (1978)
France		
	Observations on growth under different conditions.	Wurtz-Arlet (1969)
Hong Kong		
	Reports special unit for reproduction of Chinese carps.	Anon. (1971a)
	Marketing and price of grass carp.	Cheng (1967a)
	General description of fish culture, diseases, and commercial importance.	Cheng (1976b)

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Table 10. Aquacultural References on Grass Carp in Various Countries (continued)

COUNTRY	ABSTRACT OF REFERENCES	AUTHORITY
Hungary		
	Hybrid offspring of female common carp and male grass carp have high growth rates.	Anon. (1969c)
	A hatchery for induced spawning of grass carp is announced.	Anon. (1969h)
	Polyculture of common carp with grass and Chinese carps is integrated with duck raising and farm crops.	Anon. (1969i) Pekh (1971)
	Gives anticipated yields of Chinese carps from a breeding and nursery farm utilizing heated effluent from a power station.	Pekh (1971) Thuransky (1972) Anon. (1974b)
India		
	Survival, stocking rates, production, weed control, and induced spawning of grass carp in polyculture.	Anon. (1968b)
	Successful induced spawning by hypophysation.	Anon. (1969f)
	Describes training activities of center for induced spawning of grass and other carps.	Anon. (1969j)
	Reports successful hybridization of grass carp with common and silver carp.	Anon. (1971e)
	Feeding, growth, and production in polyculture using grass carp.	Anon. (1972j)
	Growth rates, feeding, and maturation of grass carp in brackish water ponds.	Prabhavathy and Sreenivasan (1972)
	Induced spawning by fractional pituitary injection.	Sreenivasan (1972)
	Experimental polyculture of Indian and Chinese carps in sewage-fed ponds.	Anon. (1974c)
	Stocking rates, growth, and production of grass and other carps in ponds and reservoirs.	Gopalakrishnon (1974)
	A pituitary dose of 6 mg/kg was effective in inducing ovulation in grass carp.	Mathew et al. (1978)
Iraq		
	Reports feeding and initial growth of grass carp.	Anon. (1969k)
Israel		
	Attempts at acclimatization and artificial reproduction were unsuccessful.	Yashouv (1958)
	Densities, feeding, and yields in intensive polyculture of grass carp, other carps and tilapia.	Moav and Wohlfarth (1975)
Korea		
	Induced spawning, maturation, fry culture, and disease are discussed with respect to grass and silver carps.	Kim (1970)
	Induced spawning, fry culture, and yields of grass and silver carps.	Kim and Paik (1971)

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Table 10. Aquacultural References on Grass Carp in Various Countries (continued)

COUNTRY	ABSTRACT OF REFERENCES	AUTHORITY
Laos		
	Artifical breeding and reservoir stocking are planned for grass carp.	Anon. (1972a)
Malaysia		
	Inorganic fertilizers can be more economical than organic fertilizers for use in polyculture with grass and other carps.	Prowse (1962)
	Experiments indicated that growth of grass and other carps can be influenced by absolute size of their enclosure.	Prowse (1968)
	Reports successful induced spawning and suggests that nutrition may influence maturation.	Anon. (1969d)
	Gives production of Chinese carp fry at culture center.	Anon. (1973a)
	Discusses stocking rates, feeding, disease control, and marketing of cultured grass carp.	Ji (1976)
Mexico		
	Documents successful induced spawning and growth rates in different areas of the country for grass carp.	Anon. (1972i)
Nepal		
	Stock from artificial reproduction to be used in polyculture trials.	Anon. (1972l)
	Successfully induced spawning through pituitary injections.	Woynarovich (1972)
	Grass carp used in polyculture with other carps and integrated with duck farming.	Anon. (1973e)
	Reports fry distribution and use of grass carp in polyculture.	Anon. (1974-75a) (1974-75d)
	General description of grass carp and its role in polyculture as a manuring and weed control agent.	Woynarovich (1975)
	Grass carp used in polyculture integrated with duck and rice farming.	Anon. (1979g)
Nigeria		
	Introduction and breeding of grass carp are planned.	Moses (1972)
Pakistan		
	Grass carp suggested for culture and weed control.	Javaid (1976)
Philippines		
	Induced spawning and culture of grass carp in Candaba swamp.	Anon (1969b)
	Cultured grass carp successfully marketed in 1960.	Anon. (1970c)

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Table 10. Aquacultural References on Grass Carp in Various Countries (continued)

COUNTRY	ABSTRACT OF REFERENCES	AUTHORITY
Philippines (cont'd)		
	Discusses polyculture yields of grass and other carps and a commercial hatchery operation.	Anon. (1970e)
	Describes commercial polyculture of grass and other carps in rotation with melon farming.	Tang (1970b)
	Polyculture of grass and other carps in reclaimed flood lands.	Anon. (1971b)
	Development of polyculture and commercial fry production of grass and other carps.	Anon. (1972c)
Poland		
	Grass and silver carp increased yields of carp culture ponds by 25% without additional feeding.	Opuszynski (1969)
	Reports successful induced spawning of grass carp.	Balicki (1971)
	Documents second successful spawning and start of commercial culture.	Okoniewski (1971)
	Reports successful culture of grass and other Chinese carps along with weed control in heat-polluted lakes.	Thorslund (1971)
	Artificial reproduction and maturation in grass and other Chinese carps.	Wolny (1971)
	Techniques and yields of artificial reproduction in 1976.	Jachnichen and Wolf (1978)
Romania		
	Larvae and fingerlings are reared in 50 to 150 ha impoundments on the Danube delta.	Anon. (1968c) Mirica (1968)
	Four breeding stations produced 222 million larvae of grass and other Chinese carp.	Mirica (1969)
	Stocking of grass and other Chinese carps in brackish waters and reservoirs for culture and weed control is being tested.	Busnita (1970a)
	Stocking and feeding of grass carp in pond culture.	Cure (1970)
	Research on dosage and timing of hormone injections for induced spawning.	Niculescu-Davas (1970)
	Optimal time for artificial reproduction and fertility data of grass carp are given.	Popescu et al. (1970)
	Influences on maturation and induced spawning of grass carp are discussed.	Nicolau et al. (1971)
	Yields and stocking rates in polyculture of grass carp with other carps.	Teodorescu-Leonte (1971)

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Table 10. Aquacultural References on Grass Carp in Various Countries (continued)

COUNTRY	ABSTRACT OF REFERENCES	AUTHORITY
South Africa		
	Artificial reproduction and rearing of grass carp fry.	Pike (1974-75)
Soviet Union		
	Feeding, growth, and yields in pond culture.	Verigin (1961)
	Grass carp have acclimatized and are suitable culture fish in Central Asian and Kazakhstan U.S.S.R.	Aliev (1963b)
	Feeding and growth in Georgian ponds.	Beridze and Chkhaidze (1964)
	Pond production increased with less feed when grass carp were cultured with common carp.	Bobrova (1965)
	Reviews history of introduction, breeding, and culture of grass and other Chinese carps.	Babyan (1966)
	Cultured grass carp competed with common carp at high densities, increased pond production without additional food, and tolerated low oxygen levels.	Bobrova (1966)
	Suggests grass carp for weed control and increased production in Belorussian ponds.	Lyakhnovich (1966)
	Feeding, growth, and interspecific effects of grass carp in mono- and polyculture.	Bobrova (1968)
	Optimal stocking rates and yields of grass carp cultured with common carp.	Kharitonova and Tarasova(1968
	Polyculture of grass carp with other carps and trout.	Lavrovsky (1968)
	Grass carp control macrophytes, fertilize ponds, and raise production in polyculture.	Nikolsky and Verigin (1968)
	Growth and survival of grass carp in a cooling reservoir of a power station.	Zubareva (1968)
	Reports optimal stocking rates of grass and other Chinese carps for highest production and use of fallow rice fields for rearing.	Batenka and Sorokhima (1969), Chizhov and Anoshin (1969)
	Rearing grass carp in vegetated ponds with other Chinese carps increased production without additional feeding or decreasing growth of other species.	Khyng (1970)
	Rearing of grass carp larvae in cooling ponds.	Gurova et al. (1972)
	Hydrobiology of polyculture ponds with grass and other carps.	Tashpulatov (1973)
	Discusses fish farms, breeding, and use of heated effluents for culture of grass carp and other fish.	Bobrova (1977)
Thailand		
	Increased induced breeding of Chinese carps produced 150,000 fry.	Ling (1969)
	Demand and hatchery production of grass and other Chinese carp fry.	Anon. (1970a)
	Use of grass carp in aquaculture.	Anon. (1975-75b)

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Table 10. Aquacultural References on Grass Carp in Various Countries (continued)

COUNTRY	ABSTRACT OF REFERENCES	AUTHORITY
United States		
	Season and techniques of induced spawning.	Jeffrey (1970)
	Reports emphasis of and centers for research on grass carp for culture and weed control.	Burress (1972)
	Increases total polyculture yield without additional feeding.	Walsh (1978)
	Speculates on causes of unsuccessful induced spawning.	Miley and Leslie (1980)
	Describes hatchery, spawning techniques and fry rearing of grass and other Chinese carps.	Lin (unpubl. ms.)
West Germany		
	Investigation of induced spawning of Chinese carps.	Anon. (1971d)
	Induced spawning techniques for grass carp.	Meske (1974)
Yugoslavia		
	Grass carp successfully induced to spawn in 1968.	Fijan (1970).

deal with induced spawning and/or rearing of grass carp, include Dah- Shu (1957), Gidumal (1958), Hickling (1960, 1962, 1968), Lin (1965), Verigin (1966), Ling (1967), Tubb (1967), Anon. (1968b, 1970i), Chaudhuri (1968), Kuronuma (1968), Bardach et al. (1972), Roberts et al. (1973), Aquaculture Development and Coordination Programme (1976), Chen (1975), Brown (1977), Ling (1977), Gerking (1978), and Huisman (1978).

12.2 Disease control

Musselius and Strelkov (1968), Ivasik et al. (1969), Edwards and Hine (1974), and Bohl (1979) provide the most recent and complete information on the prevention and treatment of important grass carp diseases occurring in fish culture. The non-specific endoparasitic cestodes, *Bothriocephalus* and *Khawia*, are given particular attention. Lin (1954) states that grass carp are particularly susceptible to bacterial diseases and cannot tolerate foul water to the extent that other cyprinids can. Antibiotics are administered orally, in injections, or by prophylaxis to combat viral and bacterial diseases such as dropsy and gill rot (Laboratory of Fish Diseases no date, Dah-Shu 1957, Anon. 1971c, Wu 1971, Bohl 1979). Prophylactic baths with Furanace (Kim 1970, Huisman 1978) and copper sulfate (Shireman 1975, Shireman et al. 1976) have proved effective against columnaris disease. Prevention of cryptobiasis involves eradication of the hirudinean vectors in ponds (Anon. 1972d), and treatment of infected fish includes baths with copper sulfate, saline, and ammonia solutions (Dah-Shu 1957, Ivasik et al. 1969). Chemicals used to control ectoparasites and administered by prophylaxis of fish or by pond treatment are listed in Dah-Shu (1957), Gopalakrishnan (1968), Cross (1969), Edwards and Hine (1974), Ji (1976), Prabhavathy and Sreenivasan (1977), and Bohl (1979).

12.3 Yields and commercial importance

In Chinese polyculture of grass carp with other species, total annual production averages 1.5 to 3.8 metric tons per hectare (MT/ha) nationally and ranges up to 18 MT/ha on farms in the Pearl River delta (Anon. 1977g). Yashoav (1968) and Bardach et al. (1972) estimate average annual yields from 3 to 8 MT/ha in Far East polyculture. A monoculture of grass carp in a blocked-off Chinese river where supplementary plant food was given produced yearly 13 to 19 MT/ha (Dah-Shu 1957). Annual yields in Indian polyculture have ranged up to 9.1 MT/ha with grass carp contributing 19% by weight (Gopalakrishnan 1974, Jhingran 1974, Anon. 1975c, Chaudhuri et al. 1976, Sinha 1977). Section 12.1 mentions studies which detail increased production of companion species when grass carp are added to polycultures. Table 10 provides literature reports of yields in various culture operations.

Little information on national production is published, but grass carp market sales are second only to bighead carp (*Hypophthalmichthys nobilis*) in Malaysia (Ji 1976). Brown (1977) reports 20 MT per year for Austria and 0.13 to 1.8 MT annually in Korea from 1971 to 1974.

13. TRANSPLANTATION

The availability of rapid transport and induced spawning of (Section 14.1) grass carp allowed for its introduction throughout the world, whereas it was previously restricted to eastern China and adjacent areas (Huet 1970). Countries where it has been imported and the reasons for importation are listed in Table 2.

Waterproof baskets and other containers carried on foot have been used for transport over short distances (Lin 1949, Brown 1977). Flow-through barges have carried fry in freshwater waterways (Brown 1977).

Mechanically aerated wooden tubs have served in both air and sea transport (Birtwistle 1931b, Bidumal 1958). Sealed tins (Gidumal 1958, Lin 1949) and plastic bags (Brown 1977) are typically used now. A description of Soviet methods and shipping boxes for the transport of grass carp is given in Anon. (1970i). Fish may be starved beforehand and kept at low temperatures to reduce their metabolism and to slow fouling of the water (Chang 1966). The tranquilizer, MS-222, can reduce mortality during transportation (Popesca et al. 1968, Gupta and Sharma 1974). Custer et al. (1978) successfully shipped grass carp in a tank truck on a airplane and investigated procedures for acclimating fingerlings to different water conditions in short time periods with minimal mortality.

14. MANIPULATED REPRODUCTION

14.1 Induced spawning

The first instance of non-natural reproduction in grass carp is reported by Lin (1935a, 1949) who captured wild spawners, hand-stripped the eggs and milt, and hatched the fertilized eggs in boxes anchored in a watercourse. This method had little impact on the Chinese fry industry. Induced spawning techniques became commercially viable in both China and Russia during the early 1960's (Verigin 1963, Lin 1965, Kuronuma 1968, Vinogradov 1968) and greatly depressed the demand for wild-caught fry. Artificial breeding probably prevented overexploitation of Chinese stocks and permitted fulfillment of increasing demands for fry (Job 1952, Tubb 1967). Hickling (1968) and Kuronuma (1968) review the history and techniques of induced spawning in grass carp. Short references on the subject may also be found in Table 10. Table 11 summarizes the procedures and results which have been reported in the literature for successful artificial reproduction.

Table 11. Injection Procedures and Yields in Induced Ovulation of Grass Carp (Shireman and Smith 1981)

LOCALITY	NO. OF FEMALES	WEIGHT (kg)	INJECTIONS[1]	INTERVAL BETWEEN INJECTIONS (hours)	NO.[2] OF EGGS (x 10^3)	NO.[2] OF FRY OBTAINED (x 10^3)	AUTHORITY
China	-	-	2-8	-	yes*	yes*	Anon. (1978a)
	-	-	0.5 LH-RH[3], 6.5 LH-RH[3]	8	yes	yes	Anon. (1978a)
India (Cuttack)	1	6.8	3.0, 6.0	7	428	5	Alikunhi et al. (1962, 1963a, a163b, 1973)
	1	2.3	4.0,6.0	7	-	80	Chaudhuri et al. (1966)
	1	1.6	4.0,7.0	7	-	50	
	1	2.6	1.0,3.0,6.0	3	-	35	
	1	3.2	1.0,3.0,7.0	3	-	2	
	1	3.0	1.0,4.0,6.0	3	-	3	
	1	3.4	4.0,7.0	4	-	30	
	1	2.8	4.0,8.0	4	-	40	
(Tamilnadu)	-	-	2.0-3.0,5.0,8.0	4	yes*	yes*	Prabhavathy and Sreenivasan (1977)
Japan	-	-	5.0-10.0	-	yes*	yes*	
	-	-	2.5-5.0,2.5-5.0	6	yes*	Yes*	
Malayasia (Malacca)	-	-	.0-7.0,5.0-7.0	5	yes	yes	Chen et al. (1969)
Nepal	i	4.0	5.3,2.7	6	-	0.1	Shrestha (1973)
	1	4.0	3.0,2.3,2.3	3	-	0.2	
	1	6.0	3.0,3.0	6	-	3	
	1	6.0	1.0,3.5	11	-	18	
	1	6.0	0.5,3.5	14	-	9	
	1	5.0	1.6,3.5	6	-	35	
	1	4.0	1.5,3.0	6	-	30	
	1	3.5	1.7,2.6	6	-	50	
	1	5.0	1.8,3.6	7	-	55	
Soviet Union (Leningrad)	-	5-7	0.5,3-6	24	500	200	Anon. (1970i)
	3	7.5	3.7	-	156	yes	
	14	7.5	0.5,3.7	24	11000	yes	
	14	7.5	0.5,3.7	6	6600	yes	

-continued-

Table 11. Injection Procedures and Yields in Induced Ovulation of Grass Carp (continued)

LOCALITY	NO. OF FEMALES	WEIGHT (kg)	INJECTIONS[1]	INTERVAL BETWEEN INJECTIONS (hours)	No.[2] of EGGS (x 10^3)	No.[2] OF FRY OBTAINED (x 10^3)	AUTHORITY
Taiwan	-	-	1.5-2.0 +5**,1.5-2.0+10**	6	yes	yes	Lin (1965)
United States							
(Alabama)	1	4.1	0.85,2.9 + 500*	21	300-500	2	Alabama Dept. of Conservation (1966)
	1	3.4	1.0,3.5 + 500, 3.5 + 500*	21,7	2-3	0.01	
	1	3.9	Q.5,2.1 + 130*	24	yes	yes	Alabama Dept. of Conservation (1967)
	1	3.0	0.7,2.7 + 170*,3.0 + 170*	24,12	yes	yes	
	1	2.7	0.7,3.3 + 180*,3.3 + 180*	24,22	yes	yes	
	1	3.0	0.7,3.0 _ 170*	24	yes	yes	
	1	5.7	0.4,2.6 + 180*,2.6 + 180*	24,12	yes	yes	
	1	3.6	0.6,2.5 + 280*,2.5 + 280*	24,12	yes	yes	
	1	3.0	0.7,3.0 + 340*	24	yes	yes	
	-	3.7-6.8	0.3-0.5,2.2-4.0 + 1000* 2.2-4.0 + 1000*(optional)	24,12	yes	yes	Alabama Dept. of Conservation (1968)
	1	4.4	6.6,6.6	-	yes	yes	Ventura (1973)
	1	4.7	4.4	-	yes	yes	
(Arkansas)	4	5.0	220*,1870*,2.2	24	7185	270	Bailey and Boyd (1970, 1973)
	1	6.4	220*,1879*,2.2	24			
	3	-	220*,1870*,0.2,2.2	24	2500	600	Bailey and Boyd (1971)
	2	-	220*,1870*,0.2,1.3	24	600	60	
	1	-	220*,1870*,0.2,0.2,0.2	24,12	710	500	
	1	-	220*,2200*,0.2,2.2	24	350	227	
	1	-	220*,2200*,0.2,4.4	24	630	358	
	1	-	0.2,4.4	24	72	0.7	
	8	5.7,9.8	220*,1870*,2.2	24	6850	3000	Boyd and Bailey (1972)
	5	6.8-8.4	220*,1870*,2.2	24	7000	2250	
	2	6.8-7.3	220*,1870*,2.2	24,48	2700	1300	
	-	-	440*,1760*,11.0	24	yes	yes	Stanley (1975)
	-	-	100*,400*,.0-3.0	24	yes	yes	

-continued-

Table 11. Injection Procedures and Yields in Induced Ovulation of Grass Carp (continued)

LOCALITY	NO. OF FEMALES	WEIGHT (kg)	INJECTIONS[1]	INTERVAL BETWEEN INJECTIONS (hours)	NO. OF EGGS (x 10^3)	NO. OF FRY OBTAINED (x 10^3)	AUTHORITY
United States (Arkansas) - continued -							
	-	-	400*,1600*,10.0	24	yes	yes	Stanley 1967d)
	88	-	440*,1760*,3.0-5.0	12,24	46900	yes	Thomas (1977)
(Florida)	3	-	440*,1879*,9.0	16,15	1950*	yes*	Rottman and Shireman (1979)
West Germany	-	-	0.4,3.2-3.4	24	yes	yes	Bohl (1979)

[1] * Values with one asterisk denote I.U./kg of human chorionic gonadotropin.

[1] ** Values with two asterisks denote rabbit units/kg of Synahorin.

[2] Values without asterisks indicate eggs or fry obtained by hand stripping and dry fertilization. An asterisk denotes cases where eggs were collected from spawning ponds or tanks.

[3] Luteinizing-releasing hormone.

The manual published by the All-Union Scientific Research Institute of Pond Fishery (Anon. 1970i) describes the Soviet method of induced spawning which is probably the most widely used. Ripe 5- to 7-kg females are injected with a small initial dose and a larger resolving dose of pulverized cyprinid pituitary suspended in saline. Males receive a single injection. The sexual products are hand-stripped and fertilization is by the dry method. Egg incubation takes place in Weiss or similar apparatus where the proper temperatures, turbulence, and oxygen levels can be maintained. Lin (1965), Konradt (1968), Vinogradov (1968), Chen et al. (1969), Boonbrahm et al. (1970), Makeyeva and Verigin (1971), and Bardach et al. (1972) describe almost identical techniques.

Chinese researchers used intraperitoneal injections of luteinizing-releasing hormone or its synthetic analog to induce spawning in grass carp (Anon. 1978a), but Ventura (1973) was unsuccessful with luteinizing hormone. Mammalian chorionic gonadotropins have also been used to reinforce the effects of pituitary infections (Ling 1977) (Table 11). Tang (1965) more than doubled the percentage of ovulating females by giving supplemental injections of Synahorin, but Chen et al. (1969) reported no effects at all with the same gonadotropin.

A number of variations of the basic method outlined above have been used successfully. By manipulating temperature and photoperiod, grass carp can be brought into reproductive condition at any time of year (Sutton et al. 1977, Huisman 1978, Shireman et al. 1978b). Inducing ovulation appears to be less difficult in northern latitudes than in southern ones where seasonal climatic changes are lacking (Anon. 1967, Hickling 1967a). Males do not always require artificial stimulation to produce milt (Shrestha 1973). Breeders are selected on the basis of secondary sexual characters (Table 4). Ripe females may be identified by catheterization, but this technique can cause injury and other complications (Chen et al. 1969). Anesthesia with quinaldine has been used to reduce injury as a result of handling (Alabama Department of Conservation 1968; Bailey and Boyd 1970, 1973; Jeffrey 1970; Boyd and Bailey 1972; Shireman 1975; Stanley 1975). MS-222 is another promising tranquilizer for this application (Popescu et al. 1968, Gupta and Sharma 1940, Meske 1975). The non-specificity of hypophyseal hormones allows the use of many cyprinid species as donors (Alikunhi et al. 1962, 1963a, 1963b, 1973; Chaudhuri et al. 1966, 1967; Hickling 1967a; Bardach et al. 1972). Bacteriostatic or distilled water can serve as a carrier (Alabama Department of Conservation 1966, 1967; Boyd and Bailey 1972). Both intraperitoneal and intramuscular injections are used and sites include the bases of dorsal, pectoral, and pelvic fins and the tip of the caudal peduncle. Kuronuma (1968) and Chen et al. (1969) did not note any differences in effects of introperitoneal versus intramuscular injections or of the sites used.

Wet-fertilization, or spawning grass carp in ponds or tanks, could potentially decrease damage to breeders, reduce labor, improve spawn quality, and increase fertilization rates, but the technique makes environmental control and egg collection more difficult than with dry fertilization (Lin 1965, Ling 1977, Tapiador et al. 1977, Rottmann and Shireman 1979, Tsuchiya 1979). Environments used successfully for wet-fertilization include ponds (Lin 1965, Kuronuma 1968, Ling 1977, Tsuchiya 1979, Bailey and Haller unpubl. ms.), net-enclosed pond sections or hapas (Chaudhuri et al. 1966, 1967), pools (Tapiador et al. 1977), and circular 1.8 m diameter tanks (Rottmann and Shireman 1979). Tanin and formalin are used to combat bacterial and fungal infections in egg (Anon.

1972e, 1972i; Shrestha 1973; Bohl 1979). Hatching vessels include pools (Tang 1965, Tapiador et al. 1977), net or cloth containers set in streams and raceways (Lin 1949, 1965; Kuronuma 1968; Shrestha 1973; Ling 1977), circular fish tanks (Rottmann and Shireman 1979), and jars and troughs (Konradt 1968, Kuronuma 1968, Chen et al. 1969, and many others).

14.2 Hybridization

Induced spawning techniques permitted hybridization of grass carp with many other cyprinid species. The cross attracting the most interest is that with bighead (*Hypophthalmichthys nobilis*), which is reviewed in Sutton et al. (unpubl. ms.). Using bigheads as the paternal parent has yielded matroclinous (Aliev 1967) and intermediate (Andriasheva 1968, Makeeva 1969) hybrids. Triploidy has been documented in the intermediate offspring (Krasznai and Marian 1977; Marian and Krasznai 1978, 1979; Lynch 1979). Intermediate young have been obtained in the opposite cross (Makeeva 1969, Berry and Low 1970, Verigin et al. 1975). Bakos et al. (1978) report successful reciprocal crossing of these species. Andriasheva (1968) also obtained viable larvae by breeding female bigheads with male grass carp, but he gave no morphological description.

Grass carp have also been crossed frequently with common carp (*Cyprinus carpio*). Gynogenetic progeny (Section 14.3) have resulted in hybridization with male common carp (Aliev 1967, Vasilev et al. 1975). Stanley (1974c, 1975) and Avault and Merkowsky (1978) report undescribed but viable larvae from this cross. In the opposite cross using female common carp, intermediate hybrids are reported by Makeeva (1969, 1976), Stanley (1973a, 1974c, 1976b, 1976c), Makeyeva and Verigin (1974), Theriot and Sanders (1975), and Stanley and Jones (1976). Vasilev et al. (1975, 1978) found their intermediates to be triploid, and Stanley (1975) and Avault and Merkowsky (1978) determined theirs to be fertile. Matroclinous (Makeyeva and Verigin 1974, Makeeva

1976) and androgenetic (Stanley 1973a, 1974c, 1976b, 1976c; Stanley and Jones 1975) (Section 14.3) offspring have also occurred when hybridizing female common carp with male grass carp.

Aliev (1967) obtained patroclinous young in breeding female silver carp (Hypophthalmichtys molitrix) with male grass carp. Andriasheva (1968) performed successful reciprocal crosses with these species but did not describe the results. Reciprocal crosses of grass carp and goldfish (Carassius auratus) yielded intermediate hybrids (Stanley 1973a, 1974c; Stanley and Sneed 1973a, 1973b). Fertilizing female grass carp with eastern bream (Abramis brama orientalis) produced intermediate to matroclinous offspring (Ryabov 1973). Use of male black bream (Megalobrama terminalis) yielded intermediate yearlings (Aliev 1967). Other more or less successful grass carp hybridizations in which morphological descriptions have not been reported are documented in Alikunhi et al. (1962, 1963a, 1963b, 1973) for male and female rohu carp (Labeo rohita) and for male catla (Catla catla), Hickling (1968) for female mrigal (Cirrhina mrigala) and male white bream (Parabramis pekinensis), Boonbrahm et al. (1970) for male and female puntius carp or tawes [Puntius (=Barbus) gonionotus], Chen (1969) for female snail carp (Mylopharyngodon piceus), and Prabhavathy and Sreenivasan (1977) for Labeo ariza. Nikolsky et al. (1968) investigated numerous hybrids from interspecific breeding of Chinese carps.

14.3 Gynogenis, androgenesis, and sex reversal

Most of the grass carp research published by Stanley (see Section 16 APPENDIX I) has been devoted to production of gynogenetic and androgenetic fish. Thomas (1977) also describes a method for obtaining gynogenetic progeny by fertilizing grass carp eggs with irradiated common carp milt. Stanley and his associates have used irradiated milt from goldfish as well as from common carp. Attempts to increase yields with cold shocks. pressure, high incubation temperatures, or colchicine have been unsuccessful (Anon. 1975d, Stanley 1975, Stanley et al. 1975). Androgenetic offspring resulted spontaneously at very low rates when common carp eggs were fertilized with grass carp sperm. The cytological mechanisms involved in production of androgenetic and gynogenetic grass carp are discussed in Anon (1973c), Stanley et al. (1973b, 1975, 1976b, 1976e), Stanley and Sneed (1973a, 1973b), and Stanley et al. (1976). Morphological, biochemical, and cytological analyses indicate that androgenetic and gynogenetic grass carp have pure inheritance from a single parent (Stanley et al. 1976, Stanley and Jones 1976). All gynogenetic grass carp produced thus far have proved to be females, indicating sex determination through a system of female homogamety (Stanley 1976a, 1976b; Stanley and Thomas 1978).

Early experiments on sex reversal in grass carp were unsuccessful (Jensen et al. 1978, Stanley and Thomas 1978, Stanley 1979). Shelton and Jensen (1979) treated normal and gynogenetic grass carp with methyltestosterone given orally and in silastic implants, and obtained sex-reversed males (genotypic females), intersexes, females with depressed gonal development, and apparent neuters. Morphological and histological examination demonstrated the occurrence of sex reversal which was successful only with implants but did not necessarily depend on methyltestosterone administration during the period of gonadal differentiation.

15. WEED CONTROL

15.1 Applicability of grass carp to aquatic weed problems

The grass carp is valuable for macrophyte control, as evidenced by the tremendous amount of literature on the subject. Most reviews of biological and other aquatic weed control methods cite the grass carp as a promising biocontrol (Schuster 1952a; Swingle 1957; Hall 1961; Avault 1965a; Hickling 1965; Avault et al. 1968; Philipose 1968, 1976; Prowse 1969b; Huet 1970; Sills 1970; Timmons 1970; Yeo and Fisher 1970; Bohl 1971;Krupauer 1971; Wurtz-Arlet 1971; Gupta 1973; Legner et al. 1973; Andres and Bennett 1975; Dow 1975; Gandara et al. 1975; Allen 1976; Gangstad 1976; Mani et al. 1976; Pieterse 1977; von Zon 1977b; Haller 1979; Lawrence unpubl. ms.). Thermal and chemical pollution have increased aquatic macrophyte problems in many areas (Glagolev 1963, Krupauer 1967a, Liepolt and Weber 1979, Verigin 1979). Introduction of highly competitive exotic plants such as hydrilla (Hydrilla verticillata) (Miley et al. 1979c) has also aggravated the problem in the southern United States. Hall (1961), Aliev (1963a, 1976), Aliyev and Bessmertnaya (1965), Bailey (1972a), Gupta (1973), Nikolski and Aliev (1974), Burkhalter (1975), Dow (1975), Aliyev (1976), Beach et al. (1976, 1977), Pieterse (1977), Rottmann (1977), and many others describe the detrimental effects of aquatic weeds on navigation, drainage, water transport, recreation, fisheries, parasitic insect control, and other uses of water bodies.

The grass carp presents a viable alternative to other aquatic weed control measures. Using grass carp often costs less and lasts longer than other methods (Aliev 1963a, Bailey 1972a, Beach 1973, Anon. 1974d, Decell 1975, Dow 1975, Provine 1975, Aliev 1976, Aliyev 1976, Pieterse 1977, Rottmann 1977, Sutton 1977a). Chemical control leaves all the nutrients from dead plants in the water for future weed growth and may have non-specific or long term toxic effects (Schuster 1952a; Bailey 1972a; Opuszynski 1972, 1979; Walker 1972; Adamec 1973; Provine 1975; Mani et al. 1976; Guillory 1979; von Zon 1979). Chemical apolications may be severely restricted in water used for domestic and agricultural uses (Dow 1975, Kobylinski et al. 1980). Dewatering of water bodies for weed control often is not desirable or physically possible (Miley et al. 1979a). Grass carp gradually control macrophytes which prevents abrupt nutrient influxes and increased protein production (Bailey 1972a, Miley et al. 1979c, von Zon 1979). The grass carp tolerates more extreme water temperatures than any other phytophagous fish with potential for weed control (Prowse 1969b, Huet 1970, Michewicz et al. 1972b, Dow 1975, von Zon 1975, Sutton 1977a).

Some of the negative aspects of using grass carp have to do with its adverse impacts on water quality (Section 10.5) and on other species (Section 9.3). Successful weed control with grass carp depends upon its food selectivity (Section 7.1) and stocking rate (Avault et al. 1968; Killgen and Smitherman 1971, 1973; Opuszynski 1972, 1979; Chaudhuri et al. 1976; Sutton 1976b; Vietmeyer 1976, Fowler and Robson 1978, Stevenson 1980). Densities high enough for effective weed control may become prohibitively expensive (Anon. 1969e, 1969g; Stott et al. 1971).

Cagni et al. (1970), Opuszynski (1972, 1979), Vietmeyer (1976), Rottmann (1977), and Shireman (1979) provide general reviews on the grass carp and its use as an aquatic weed biocontrol. Evaluations of grass carp for macrophyte control in various countries have been done for Canada, (Fedorenko and Fraser 1978), Czechoslovakia (Krupauer 1966), England (Cross 1969; Stott 1967, 1977), India (Chaudhuri et al. 1976), Netherlands (von Zon 1973, 1974, 1977a, 1979), Phillipines (Gangstad 1976), Soviet Union (Nikolski and Aliyev 1974, Vinogradov and Zolotova 1974, Aliev 1976, Aliyev 1976), United States (Greenfield 1971, Michewicz et al. 1972b, Walker 1972, Sutton 1977a), and West Germany (Bohl 1971).

In the United States, general reviews of grass carp biology and weed control potential include those for Arkansas (Bailey 1972a), California (Pelzman 1971, Dow 1975), Florida (Sutton and Vandiver 1976, Haller 1979, Florida Game and Fresh Water Fish Commission unpubl. ms.), Louisiana (Carver et al. 1971), New York (Adamec 1973), and Texas (Provine 1975).

15.2 Applications and research

The most popular application of grass carp for weed control is in small ponds, in particular those used for culture (Schuster 1952a, Kuronuma and Nakamura 1957, Swingle 1957, Hickling 1962, Bhimacher and Tripathi 1967, Blackburn 1968, Fielding 1968, Lawrence 1968, Timmermans 1968, Anon. 1971f). Use of grass carp to control weeds and to increase fisheries production in reservoirs, lakes, canals, and rivers has also been considered or tested in the Soviet Union (Verigin 1961; Aliev 1963, 1976; Nikolsky and Aliev 1974; Nikolsky et al. 1968; Aliyev 1976) and China (Chang 1966). Grass carp have potential for culture and weed control in both active and fallow rice fields (Bizyaev and Chesnokova 1966, Yudin 1968, Batenko and Sorokhina 1969, Chizhov and Anoshin 1969, Vingradov and Zolotova 1974), and in the cooling reservoirs of power generation stations (Verigin 1969, 1963, 1979; Glagolev 1963). Aquatic plant control with grass carp in the Soviet Union reduced larval habitat for noxious insects such as mosquitoes (Aliyev and Bessmertnaya 1969, Aliev 1976, Verigin 1979). Grass carp have been suggested for weed control in enriched waters from sewage treatment plants (Sutton 1973, 1975a, 1976a, 1977b, 1978).

Various combinations of grass carp with other aquatic macrophyte control measures have been proposed or tested. Grass carp in conjunction with the mottled waterhyacinth weevil (Neochetina eichhorniae) retarded water hyacinth (Eichhornia crassipes) more than either control agent alone (Del Fosse et al. 1976). Initial removal of macrophytes by hand or with herbicides and subsequent control with grass carp has been suggested by Sutton (1974, 1975a) and others. Manual methods and grass carp gave adequate control in Indian fish ponds (Singh 1976). Results of grass carp combined with chemical treatment are reported in Sutton (1975a, 1976b), Gasaway (1977d), Shireman and Haller (1979), and Shireman and Maceina (in press).

Considerable interest exists in non-reproducing stocks of grass carp or its hybrids for weed control. Gynogenesis (see Stanley in Section 16, Sections 14.3 and 15.4) is a somewhat expensive method of producing monosex stocks due to low yields. Breeding gynogenetic fish with sex-reversed females could overcome this problem but sex-reversal is still in the developmental stage (Shelton and Jensen 1979, Sections 14.3 and 15.4). Florida Game and Fresh Water Fish Commission (1980c) reviews research on the grass carp-bighead carp (Hypopthalmichthys nobilis) hybrid for weed control in Florida. Feeding habits have been investigated for hybrids of grass carp with female common carp (Cyprinus carpio) (Dathu and Kilgen 1973; Theriot and Sanders 1975) and with male big-head carp (Cassani 1981). Both hybrids exhibited similar food preferences and were less herbivorous than grass carp.

Shireman (1979) summarizes current research and applications or grass carp as a weed control in the United States, Soviet Union, and Europe. Other reviews of grass carp as an aquatic plant management tool in Europe and the Soviet Union are provided in Krupauer (1971), Sutton et al. (1977), and Miley et al. (1979b).

A tremendous amount of research effort has been devoted to grass carp for weed control in the United States. Guscio and Gangstad (1970) and Gangstad, Raynes, and Burress (1972, 1973) review orientations and locations of research centers. Meyer et al. (1975) report on the status of grass carp and on specific research needs relative to it. Lewis et al. (1978) summarized a collection of research papers and evaluated the grass carp's potential for weed control in the United States. Most work on this subject has been done in Florida, Arkansas, and Alabama.

Numerous field tests of the grass carp for weed control in Florida have been or are being carried out. This and other research in the state are reviewed in Wallace (1970), Hudson (1973), Burkhalter (1975), Florida Department of Natural Resources (1979), and Florida Game and Fresh Water Fish Commission(unpubl. ms. 1980c). The most intensively studied and controversial investigation to date involved four ponds located throughout Florida. Martz (1973) described the study sites prior to stocking. Grass carp controlled aquatic vegetation to widely varying extents in different ponds (Beach et al. 1976, 1977; Drda 1977; Gasaway 1977b; Gasaway and Drda 1978). Substantial negative effects were observed on sportfish populations in two ponds (Anon. 1975e, Ware et al. 1975, Ware and Gasaway 1976, Gasaway 1977b). Beach et al. (1976, 1977) and Miley et al. (1979c) theorized that pre-stocking sampling methods rather than grass carp caused these effects. The ponds were also investigated for grass carp effects on water quality (Gasaway 1977c), chlorophyll contents (Gasaway and Drda 1976, Gasaway unpubl. ms.), community structure (Gasaway 1977b), benthic macroinvertebrates (Gasaway 1977a), and waterfowl habitat (Gasaway and Drda 1977, Gasaway et al. 1977). Beach et al. (1976, 1977) also provided comprehensive reports on these factors.

The U.S. Army Corp of Engineers initiated a weed control study with grass carp in Lake Conway in 1976 (Decell 1977, Aquatic Plant Control Research Program no date). Project overviews are given in Decell (1975, 1976), Addor and Theriot 1977, Hamilton (1977), Theriot (1977), Theriot and Decell (1978), and Buglewicz (1980). Ewel and Fontaine (1975, 1977, 1980) devised a theoretical model to predict grass carp effects on the Lake Conway ecosystem. Fox et al. (1977) performed a comprehensive baseline evaluation of biotic and physiochemical parameters. Specific investigations were directed at water quality (Sawicki 1977, Kaleel 1980), aquatic macrophytes (Nall et al. 1977; Nall and Schardt 1978, 1980), benthos (Chrisman and Kooijman 1980), herpetofauna (Godley et al. 1980), and fish, waterfowl, and mammals (Guillory et al. 1977, Guillory 1979, Land 1980). Anthropogenic influences on Lake Conway during the project necessitated a human factors study (Williams 1980). New methodology developed during this study included the use of a recording fathometer for determination of hydrilla distribution and biomass (Maceina and Shireman 1979b), and radiotelemetry tracking of grass carp (Nall et al. 1979, Keown 1980, Nall and Schardt 1980).

Miley et al. (1976) reviewed ongoing field tests in Florida and report successful hydrilla control and increases of eutrophication characterisitics in several lakes (Miley et al. 1979a, 1979c; Miley 1980). Kobylinsky et al. (1980) found few changes which could be attributed to grass carp in Deer Point Lake, a flow-through system where weed control was gradually attained. Nixon et al. (1977) provide a baseline analysis of this lake. Ultrasonic telemetry was used to track carp during the study (Nixon et al. 1977, Nixon and Miller 1978). During the first two years after stocking, grass carp failed to control hydrilla in Lake Wales (Montegut et al. 1976, Shireman 1976). In the third year, grass carp were the major influence on hydrilla and had caused changes in sportfish and other animal populations (Shireman et al. 1977b, 1979; Gasaway 1978a). Grass carp contributed to a decline in waterfowl by decreasing their hydrilla food base (Gasaway 1978a, Gasaway et al. unpubl. ms.). Shireman and Gasaway (1976) provide baseline information on Lake Baldwin where a combination of grass carp and chemical control proved unsuccessful in reducing hydrilla (Gasaway 1977d). A more intensive stocking of larger fish in 1978 eliminated hydrilla in less than two years (Shireman and Maceina 1980, in press). Grass carp decreased hydrilla biomass 45.7% in Little Lake Barton within two years (Osborne and Sassic 1979). Shireman and Maceina (1980) successfully measured hydrilla distribution and biomass by means of a recording fathometer in several Florida lakes.

Sutton and his colleagues in southern Florida have investigated the grass carp's weed control potential in various controlled situations. Successful hydrilla control was obtained in several small ponds by use of grass carp, sometimes supplemented with initial herbicide applications (Sutton 1975a, 1976b, 1979a, 1979b; Sutton and Vandiver 1979; Sutton et al. 1979). In earthen ponds, grass carp controlled hydrilla while permitting eelgrass (Vallisneria americana) to increase (Sutton 1972, 1975b; Haller and Sutton 1977; Sutton et al. 1979). Investigations of water hyacinth control have been carried out with grass carp (Baker et al. 1973, 1974; Sutton and Blackburn 1973a, 1973b) and in combination with the mottled water hyacinth weevil (Del Fosse et al. 1976). Sutton (1973, 1975a, 1976a, 1978) demonstrated that grass carp would efficiently utilize duckweed (Lemna minor) grown in sewage effluent.

One of the first states to import grass carp, Arkansas, began research in 1963 when Stevenson (1965) reported the grass carp's selective acceptance of different food plants. Successful weed control was attained with grass carp in Lake Greenlee in less than a year (Bailey

1972a, 1972b; Bailey and Boyd 1972), and by 1975, they were controlling aquatic macrophytes in over one hundred large lakes (Bailey 1975, 1978). Phytoplankton blooms and changes in fish populations occurred, but were either shortlived or inconsequential. Newton et al. (1976) introduced grass carp into an Arkansas reservoir where they eliminated vegetation and caused a 50% decline in centrarchid biomass. High grass carp stocking density apparently was responsible for the deleterious environmental effects. Henderson (1978) reviewed grass carp research in Arkansas.

Alabama also imported the grass carp in 1963 and numerous experiments on its plant-feeding selectivity in small pools and its weed control potential in ponds were conducted (Avault 1965a, 1965b; Swingle et al. 1967; Avault et al. 1968; Sills 1970; Kilgen and Smitherman 1971, 1973; Johnson and Laurence 1973; Lawrence unpubl. ms.). The Alabama Department of Conservation (1965-1968, 1972) has provided much information on grass carp weed control in small closed systems. Crowder and Snow (1969) demonstrated that small grass carp could control filamentous algae (*Pithophora* and *Hydrodictyon*) in ponds. Grass carp eradicated the filamentous alga *Lyngbya* in a lake within one year (Zolczynski and Smith 1980). In Alabama culture ponds, grass carp reduced water hyacinth standing crops and indirectly increased channel catfish (*Ictalurus punctatus*) and striped bass (*Morone saxatilis*) biomass (Kilgen 1978).

Mitzner (1975b, 1975c, 1978, 1979, 1980) reported that grass carp reduced aquatic plant biomass 91% over four years at Red Haw Lake, Iowa, without adversely affecting water quality. A telemetry study documented movement and activity of the grass carp (Mitzner 1975a, 1979, 1980). The positive results prompted grass carp stockings in numerous public and private waters of the state (Mitzner 1979, 1980). Grass carp quickly removed aquatic plants in Indiana ponds but caused changes in dissolved oxygen, turbidity, and potassium (Lembi and Ritenour 1977, Lembi et al. 1978). Small fish were tested for their selectivity of common Indiana aquatic plants and for potential carnivory (Doskocil et al. 1973, Willey et al. 1974). Grass carp controlled aquatic vegetation and increased total production in Illinois culture ponds with golden shiners (Notemigonus chrysoleucus) and bluegill (Lepomis macrochirus) (Baur et al. 1971, Buck et al. 1975). In ponds with bass (Micropterus), gamefish recruitment declined (Buck 1975). In Illinois hatchery ponds, grass carp controlled filamentous algae and did not prey on juvenile fish (Lewis 1978). In Missouri ponds, grass carp substantially reduced aquatic plants, improved water quality, increased total production, and apparently caused increases in fathead minnows (Pimephales promelas) and juvenile bluegills (Rottmann 1976, Rottmann and Anderson 1976). Terrell and Terrell (1975) reported satisfactory weed control with grass carp in Georgia catfish (Ictaluridae) ponds. Kansas culture ponds benefitted from weed control by grass carp (Stevens 1980). Dow (1975) describes encouraging results of stocking grass carp for weed control in California reservoirs and current studies to determine potential competition between grass carp and bluegill. Schramm (1979) devised a stocking rate model for use in grass carp control of hydrilla.

Much foreign, especially Chinese, research on the grass carp is unavailable in the U.S. The Soviet Union has a tremendous grass carp literature, but relatively few articles are translated into English. Verigin (1961) reviewed early Soviet work on grass carp introduction and potential for weed control. Stroganov (1963) and Verigin et al. (1963) carried out experiments on grass carp feeding behavior and plant selectivity. Nikolsky and Verigin (1968) reviewed these studies. By far the most successful Soviet introduction of grass carp took place in the inland waters of Turkmenistan, in particular the Kara Kum Canal, where large scale grass carp reproduction, complete weed control, and increased fisheries production were achieved (Aliev 1963a, 1976; Nikolsky and Aliev 1974; Aliyev 1976). Efimova and Nikanorov (1977) discuss the prospects of weed control with grass carp in Ivan'kovskoyo Reservoir. Other reports of weed control by grass carp in the Soviet Union include a 66% reduction in an irrigation canal within two months (Zolotova 1970) and applications in ponds (Lupacheva 1968, Zolotova and Khromov 1970). Several Soviet studies have dealt with integration of grass carp culture with weed control in rice fields (Bizyaev and Chesnokava 1966, Yudin 1968, Batenko and Sorokhina 1969, Chizhov and Anoshin 1969).

Preliminary pond experiments in England indicated that grass carp could control Elodea canadensis and Myriophyllum spicatum (Pentelow and Stott 1968, Stott 1967, Anon. 1968a, Ministry of Agriculture, Fisheries and Food 1968). Stott and Robson (1970) determined stocking densities necessary to remove specific amount of waterweeds from ponds. Stott and Orr (1970) estimated the amount of aquatic vegetation consumed by grass carp through the use of food conversion values. Fowler and Robson (1970) researched interactions between food preference and stocking rate, and found that understocking of grass carp in a mixed aquatic plant community could permit unpalatable species to increase weed biomass to pre-stocking levels, even though preferred plants were eliminated. Supplementary chemical control might be required for unpalatable plant species. Tooby et al. (1980) determined that grass carp could tolerate ten herbicides at their maximum application rate. Stott et al. (1971) showed that weed control in a pond would cost £120 per hectare annually with grass carp compared to £87 with herbicides. Moore (1979) describes a project designed to evaluate grass carp for weed control and for their effect on other fish. Behrendit (1973) reviews research progress on the grass carp in England.

Many European countries have investigated grass carp for weed control. Von Zon (1973, 1974) reported adequate aquatic weed management by grass carp in Dutch ditches. Further field tests indicated that grass carp controlled weeds with less expense and less environmental degradation than did either mechanical or chemical methods (von Zon et al. 1977). Von Menzel (1977) described grass carp use for weed control in West Germany. In northern Germany, weed control usually requires dense grass carp stocks which are uneconomical (Anon. 1969e, 1969g). Riechert and Trede (1977) found that two- to three-year-old grass carp showed promise for controlling water hyacinth. Grass carp demonstrated great potential for alleviation of aquatic plant problems in East German canals (Jahnichen 1973). They controlled a wide variety of weed species in Bulgarian (Anon. 1969e, 1969g) and Czechoslovakian (Anon. 1969c) ponds. Partial reduction of Myriophyllum and some other aquatic weeds was obtained with grass carp in a small Swedish lake (Ahling and Jernelov 1971, Thorslund 1971). Grass carp severely reduced aquatic macrophytes and negatively affected water quality and plankton populations in a Yugoslavian lake (Mestror et al. 1973).

Mani et al. (1976) and Philipose (1976) review research on grass carp as a weed management tool in India. Grass carp provided effective control of submerged plants and duckweeds in culture ponds (Singh et al. 1967b). Pond vegetation was initially removed by hand and subsequently controlled by grass carp in another study (Singh 1976). Mehta and Sharma (1972) investigated weed control with grass carp in ponds and canals. Mehta et al. (1976) determined plant feeding selectivitiy of different size grass carp and demonstrated their use for aquatic weed management in canals of the Chambal Irrigation system.

Ahmad (1968) and Naik (1972) discussed grass carp stockings in Haliji Lake, Pakistan, where it became apparent that much denser stocks were needed for effective weed control. Grass carp could not reduce water hyacinth or other floating weeds in Ubolratana Reservoir, Thailand (Bhukaswan and Pholprasity 1976a, 1976b). Prowse (1967a, 1971) reviews research on weed management with grass carp in ponds at Malacca, Malaysia. Research in Taiwan demonstrated that grass carp preferred terrestrial grass to hydrilla (Anon. 1972n). Grass carp controlled aquatic vegetation and increased fish production in Japanese farm ponds (Kuronuma and Nakamura 1957).

Chapman and Brown (1966) first suggested grass carp for weed control in New Zealand. Chapman (1970), Chapman and Coffey (1971), and Edwards (1974) performed preliminary investigations of feeding preferences on local aquatic vegetation. Differential reductions occurred with different plant species when grass carp were stocked in a drainage ditch (Edwards and Moore 1975) and a lake (Mitchell 1977). Initial feeding studies in the Rewa River, Fiji (Adams 1970, Adams and Titeko 1970), indicated the feasibility of hydrilla control by grass carp. Riverine predators precluded direct release of fingerlings even if large numbers could have been imported economically into the country. For these reasons, induced spawning and culture operations were initiated (Hughes 1971, Chaudhuri 1974).

Mexico and Panama imported grass carp for weed control. After preliminary tests demonstrated high consumption of water hyacinth by grass carp (Anon. 1972h), one million fingerlings were stocked into the Endho

Reservoir, Mexico (Anon. 1975b). Grass carp research in Mexico was reviewed by Gandara et al. (1975). The grass carp was hoped to provide hydrilla control in the Panama Canal Zone, but transport and acclimation difficulties prevented large scale field tests (Panama Canal Company 1977, Custer et al. 1978, Parris 1980).

Africa has had little experience with the grass carp; however, the species has been recommended for weed control in Kenya (Gaudet 1976), Sudan (Anon. 1974-1975c), Ethiopia (1974a), and Egypt (Bailey 1977).

15.3 Regulations on introduction

Careful evaluation should precede grass carp introduction to avoid harmful environmental effects (Nikolski and Aliev 1974, Prowse 1966a). In England importers are licensed and local laws control further distribution (Stott 1979). British Columbia, Canada, banned grass carp introduction in 1977 (Fedorenko and Fraser 1978). Austria permits purchase and stocking of grass carp by any interested party (Sutton et al. 1977, Miley et al. 1979b).

Papers discussing the introduction and control of grass carp in the United States include Lachner et al. (1970) and Rosenthal (1980). In 1969, the Conference on Importation and Use of Exotic Fishes recommended a halt to further grass carp stockings in open waters (Anon. 1969m, Northrup 1972). The Soil Conservation Service also opposed further grass carp introductions in 1973 (Anon. 1973d).

The number of states restricting possession of grass carp to those with official permits grew to 35 by 1976 (Anon. 1973d, 1977b, 1977c, 1977e, 1977f). Florida, which researched the use of grass carp for vegetation control, has fairly strict laws controlling distribution (Northrup 1972; Ogilvie 1972; Florida Game and Fresh Water Fish Commission

1980a, 1980b; Courtenay no date). Specific information on other state regulations is available for California (Anon. 1976a), Michigan (Anon. 1972o), Missouri (Anon. 1972m), and New York (Anon 1973f). Arkansas has a liberal policy which permits grass carp distribution to the public and private parties (Anon. 1972b, 1972f, 1972k). Henderson (1979) reviews the grass carp controversy and reasons for Arkansas' liberal introductions of the fish.

15.4 Control of introduced populations

Physical means of removing grass carp from a water body include nets, electroshocking, and fish toxicants. Shireman and Maceina (1980) found that electroshocking was costly and time-consuming; gill nets were a cost-effective means of removal but had to be set at night and were more effective in winter; haul-seines were effective if large groups of fish could be found; and rotenone treatment in combination with blocknets produced few grass carp but caused high mortality in gamefish. Hardin (1980) also tried selective removal with rotenone but significant largemouth bass (*Micropterus salmoides*) mortality occurred which may have been aggravated by low oxygen levels causing stress. Colle et al. (1978a) were successful in selective removal of grass carp with rotenone and caused small mortality on other species. Grass carp sensitivity to rotenone and other chemicals such as antimycin and thanite also has been investigated (Marking 1972, Henderson 1974, Willey et al. 1974, Cumming et al. 1975, Miley et al. 1976, and Lembi and Ritenour 1977). Greenland et al. (1978) describe a labor-intensive but effective method of removing grass carp from ponds with haul-seines.

Leslie et al. (unpubl. ms.) demonstrated that grass carp potential for feral reproduction might be greater than previously assumed, but reproduction could be obviated by using monosex stocks or sterile hybrids (Stanley 1973c). The food preferences of hybrids resulting from male grass carp crossed with female common carp (Cyprinus carpio) were similar to those of grass carp but tended slightly toward carnivory (Dathu and Kilgen 1975, Theriot and Sanders 1975, Avault and Merkowsky 1978). The hybrids competed with channel catfish (Ictalurus punctatus) in ponds (Merkowsky and Avault 1976, Avault and Merkowski 1978). These hybrids also turned out to be fertile (Stanley 1975, Avault and Merkowsky 1978).

The other potential grass carp hybrid for weed control involves crosses with bighead carp (Hypopthalmichthys nobilis) (Miley 1980). Hybrid fingerling food habits tended toward herbivory, but hybrids would feed on invertebrates (Cassani 1981). Research planning meetings on this hybrid have been held (Anon. 1979, 1979b). Sutton et al.(unpubl. ms.) review the literature and report observations on this hybrid.

The production of monosex stocks involves the use of gynogenesis and sex reversal (Stanley 1973c). Economical production of monosex stocks must circumvent the problem of sex identification (Courtenay and Miley 1973, Hong and Courtenay 1973, Hong et al. 1974) (Section 5.1). Stanley (1973a, 1974c) produced gynogenetic grass carp (Section 14.3) and discovered that they were all females (Stanley 1975a). Gynogenesis is uneconomical for producing large monosex stocks because of low yields in induced spawning (Stanley et al. 1975). The current strategy is to breed female fish with sex-reversed females (phenotypic males) to obtain monosex female stocks and to obviate the need to sex determination (Stanley 1973b, 1975, 1976; Thomas 1977). Sex reversal in grass carp has been mostly unsuccessful (Jensen et al. 1978, Stanley and Thomas 1978, Stanley 1979), but Shelton and Jensen (1979) recently have had positive results and are rearing sex-reversed fish to determine their fertility.

16 APPENDIX I: SCIENTIFIC LITERATURE

Important bibliographies relevant to the grass carp include Nair (1968), Weed Research Organization (1971, 1976), and Little (1979). More or less extensive literature synopses and biological reviews are Lin (1935a, 1935b), Dah-Shu (1957), Hickling (1967b), Schneider (1969), Fischer and Lyakhnovich (1978), and Shireman and Smith (1981).

Journals which frequently publish papers on grass carp are listed below.

Aquaculture

FAO Aquaculture Bulletin (FAO Fish Culture Bulletin) no longer published

Journal of Aquatic Plant Management (Hyacinth Control Journal)

Journal of Fish Biology

Journal of Ichthyology (English translation of Voprosy Ikhtiologii)

Malaysian Agriculture Journal

Proceedings of the Indo-Pacific Fisheries Council

Progressive Fish-Culturist

Sport Fisheries Institute Bulletin

Transactions of the American Fisheries Society

Important collections of papers have appeared in the following publications.

Problemy Rybokhozyaystvennogo Ispol'zovaniya Rastitel'noyadnykh Ryb v Vodoyemakh SSSR [Problems of the Fisheries Exploitation of Plant-Eating Fishes in the Water Bodies of the USSR].

T'ai-p'ing-yang Hsi-pu Yu-yeh Yen-chin Wei-yuan-hui Ti-ch'i-zz'u Ch'uan-ti Hui-i Tun-wen-chi (Collected Articles of the 7th Plenary Conference of Fishery Research of the West Pacific). Peiping, China. February 1966.

Pillay, T.V.R. (Ed.). 1967-1968. Proceedings of the World Symposium on Warm-Water Pond Fish Culture. Rome, 18-25 May 1966. FAO Fisheries Reports No. 44, Volumes 1-5.

Cherfas, B.I. (Ed.). 1969. Genetics, Selection, and Hybridization of Fish (Genetika, selektsiya i gibridizatsiya ryb). Jerusalem: Israeli Program for Scientific Translations (1972).

Gangstad, E.O. (Ed.). 1973. Herbivorous Fish for Aquatic Plant Control. Aquatic Plant Control Program. Technical Report 4. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Florida Game and Fresh Water Fish Commission. 1977. The Grass Carp: A Special Research Report to the Governor and Cabinet. Tallahassee, FL: Florida Game and Fresh Water Fish Commission.

Freeman, T.E. (Ed.). 1977. Proceedings of the 4th International Symposium on Biological Control of Weeds. Gainesville, FL: University of Florida, Institute of Food and Agricultural Sciences.

Smitherman, R.D., W.L. Shelton, and H.H. Grover (Eds.). 1978. Symposium on Culture of Exotic Fishes presented at Aquaculture/Atlanta/'78, Atlanta, Geogria, January 4, 1978.

Transactions of the American Fisheries Society. 1978. Volume 107, Number 1.

Shireman, J.V. (Ed.). 1979. Proceedings of the Grass Carp Conference. Gainesville, Fl: Aquatic Weeds Research Center, University of Florida, Institute of Food and Agricultural Sciences.

Decell, J.L. (Ed.). 1980. Proceedings, 14th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

17. APPENDIX II: POPULAR ARTICLES

Many popular publications have been written concerning grass carp. There is even a humorous song titled "Grassy Carp" sung by Dale Crider on the album Pioneer Ethics (1975; Gainesville, FL: Arhinga Roost Music). In any event, the following article citations are appended primarily to provide sources for gauging public opinion relative to grass carp use.

Anon. 1969. The weed-eating carp. Gardener's Chron. 165(21):28. Reviews value of grass carp for weed control as well as for protein production. Results of field experiments in England indicate it can control some weed species. Cites need for research on stocking rates, interspecific effects, and potential for becoming a nuisance species in open waters.

Anon. 1971. Aquatic vegetation control. Illinois Nat. Hist. Surv. Rep. 107:1-2. Discusses advantages of biological agents over chemicals for aquatic weed control. Recommends grass carp distribution be limited until potential effects of introduction into United States waters are known.

Anon. 1971. Asiatic grass carp caught in Mississippi. Springfield (Ill.) State Journal, Feb 5. Documents capture of 21-pound specimen in river near Urbana. Recommends restriction because grass carp could potentially destroy other fish habitat.

Anon. 1971. County leaders take bold step toward control of hydrilla. Winter Garden (FL.) Times, Mar. 25. Reports start of grass carp field testing for aquatic weed control in ponds.

Anon. 1971. Lack of cooperation hit in water weed control. Orlando (Fl.) Sentinel, Nov. 18. Conflicting opinions of different governmental agencies on the advisability of introducing grass carp for weed control have hindered research.

Anon. 1971. Lake Erie grass carp? Sport Fish. Inst. Bull. No. 223:5-6. Criticizes U.S. Fish and Wildlife Services' intention to study and possibly introduce grass carp into Lake Erie for weed control.

Anon. 1971. Let nature find a way. Orlando (FL.) Sentinel, Jan. 16. Compares grass carp favorably with mechanical and chemical weed control, but points out that its use is still experimental.

Anon. 1971. Tiny fish may control water weeds. The Tampa (Fl.) Tribune Times, May 2. The hydrilla problem in Florida and the advantages of control by grass carp rather than chemical or mechanical methods are discussed.

Anon. 1971. Weed-eating fish discovered to clear Florida waterways. Jacksonville (Fl.) Times-Union, Feb. 18. Documents start of cooperative research between Florida Department of Natural Resources and U.S. Department of Agriculture.

Anon. 1972. Cabinet okays weed-eating fish study. The Tampa (Fl.) Tribune, on Aug. 30. Reports authorization of research by Florida Department of Natural Resources on grass carp for aquatic weed control.

Anon. 1972. A fish story provides answer to a very weedy problem. Market Bulletin (Florida Department of Agriculture and Consumer Services), July 1. Summarizes cooperative governmental research on grass carp for weed control in Florida.

Anon. 1972. Fish that weed the water. Agric. Res. USA 20(11):6-7. Summarizes cooperative governmental research on grass carp for weed control in Florida.

Anon. 1972. Grass carp problem. Sport Fish. Inst. Bull. No. 240 (reprinted in Farm Pond Harvest Winter, 1973:18-19). Reports new restriction on grass carp introduction by several states and reviews research demonstrating grass carp feeding on animal material, selective control of water weeds, and intensive fertilization of water as a result of grass carp faeces.

Anon. 1972. Man's best friend? Time, Jan. 31. An extremely distorted and inaccurate article on grass carp.

Anon. 1972. Restoring (managing) aquatic ecosystems. Sport Fish. Inst. Bull. No. 232:1-3. Though directed primarily at common carp, this article also criticizes premature claims of the grass carp as a panacea for aquatic weed control.

Anon. 1972. Turning the tide against aquatic weeds. World Farming 14(9):18-22. Reviews aquatic weed problem and various approaches to control, including Indian, Russian, and American research on grass carp.

Anon. 1972. Weed-eating fish: Is it good or bad? Crops and Soils 25(1):27-28. Advises caution in stocking grass carp for weed control and further research on ecosystem impacts.

Anon. 1972. White amur in Arkansas. Sport Fish. Inst. Bull. No. 239:4-5. Summarizes panel discussion of researchers from various states. Calls for halt in grass carp introductions and for more investigation of its environmental effects.

Anon. 1973. IID fund research projects to solve canal weed pests. San Diego (Cal) Union, Feb. 5. Reports on a cooperative state project to investigate grass carp for weed control in irrigation canals.

Anon. 1973. White amur shows promise in biological weed control. Fla. Cons. News 9(3):1. Reviews Florida's aquatic weed problems and cooperative research on grass carp as a biocontrol.

Anon. 1974. White amur controls aquatic weeds. Illinois Nat. Hist. Surv. Rep. 136:1-2. Reports status of grass carp in Illinois and research demonstrating its ability to control weeds in ponds.

Anon. 1975. Additional experiments with the white amur. Illinois Nat. Hist. Surv. Rep. 148. Gives tentative results of experiments where grass carp successfully controlled weeds in ponds but negatively affected other fish species.

Anon. 1975. Grass carp binge. Sports Fish. Inst. Bull. No. 265. Discusses control of grass carp introduction and criticizes administrative approaches to grass carp research in Florida.

Anon. 1975. Grass carp could mean trouble. Bass Research Foundation Report No. 2:4. Reports on research in Alabama and Florida which indicates adverse impacts of grass carp on gamefish.

Anon. 1976. Good or bad? Controversy heats up over white amur/grass carp. Comm. Fish Farmer and Aquacult. News 2(5): 16-21. Presents pro and con views of grass carp for aquatic weed control.

Anon. 1976. Grass carp no panacea. Sport Fish. Inst. Bull. No. 274. Advises extreme caution in grass carp introduction for weed control and reviews potential negative impacts.

Anon. 1976 Lake Louise first for grass carp? Outdoor News 9(10). Reports upcoming test introduction of grass carp in Minnesota lake.

Anon. 1976. Status of grass carp. Sport Fish. Inst. Bull. No. 273:4-6. Reviews state prohibitions on grass carp, current research in Florida, and distribution in North America, including massive reproduction in Mexico.

Anon. 1977. Approval needed for amur use. Jacksonville (Fl) Times-Union, Jan. 26. Reports control of grass carp in Florida and research conflicts between governmental departments.

Anon. 1977. A grass carp problem. Sport Fish. Inst. Bull. No. 288:4. Records occurrence of grass carp in Indiana, Minnesota, and California.

Anon. 1977. A look at the grass carp. Grass carp fact sheet. Florida Game and Fresh Water Fish Commission. Release No. 63-1. 3pp. The Commission opposes further stocking of grass carp until ongoing research is concluded. Weed control requires large numbers of grass carp which can have adverse effects on other fish.

Anon. 1977. Weed-eating fish fails to do job in Orlando. Gainesville (Fl.) Sun, Oct. 19. Higher stocking rates would be needed to control hydrilla in Florida lakes.

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