ANNOTATED BIBLIOGRAPHY OF BIGHEAD (*HYPOPHTHALMICHTHYS NOBILIS*) AND SILVER (*HYPOPHTHALMICHTHYS MOLITRIX*) CARPS FROM RUSSIAN-LANGUAGE LITERATURE

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ABSTRACT

Naseka, A., and Bogutskaya, N.   2011.   Annotated Bibliography of Bighead (*Hypophthalmichthys nobilis*) and Silver (*Hypophthalmichthys molitrix*) carps from Russian-Language literature. Can. Manuscr. Rep. Fish. Aquat. Sci. 2964:vi+79p.

This annotated bibliography has been prepared to summarize the information pertaining to migration, feeding, spawning, bioenergetics and physiological limits of Bighead, Grass and Silver carps from Russian-language literature. Bighead and Silver carps, collectively known as bigheaded carps, are native to, and have also been introduced into, Russian waters. As a result, many papers have been published on life history characteristics for both species and extensive knowledge exists regarding managing native and introduced populations. As the risk of invasion by both Bighead and Silver carps into the Great Lakes region increases, the compilation of Russian information will help to educate scientists and managers, and will inform a binational Asian carp risk assessment document, a joint effort between Fisheries & Oceans Canada and the Great Lakes Fishery Commission.

Materials cited in this bibliography include books, papers published in scientific journals, as well as literature such as reports from Russian government publications and proceedings from scientific conferences.

RÉSUMÉ

Naseka, A., and Bogutskaya, N. 2011. Annotated Bibliography of Bighead (*Hypophthalmichthys nobilis*) and Silver (*Hypophthalmichthys molitrix*) carps from Russian-Language literature. Can. Manuscr. Rep. Fish. Aquat. Sci. 2964:vi+79p.

La présente bibliographie annotée offre une synthèse de l'information trouvée dans la littérature scientifique en langue russe concernant la migration, l'alimentation, la fraye, la bioénergétique et les limites physiologiques de la carpe à grosse tête, de la carpe de roseau et de la carpe argentée. La carpe à grosse tête et la carpe argentée, groupées en anglais sous l'appellation « bigheaded carps », sont des espèces indigènes en Russie, mais elles ont aussi été introduites dans certaines eaux russes. De nombreux articles sur les caractéristiques du cycle biologique de ces deux espèces ont donc été publiés en russe, et il existe dans cette langue un important corpus de connaissances en matière de gestion des populations indigènes et introduites. Vu l'accroissement du risque d'invasion des Grands Lacs par la carpe à grosse tête et la carpe argentée, la présente compilation de l'information russe sur ces espèces sera utile aux scientifiques et aux gestionnaires, et elle enrichira la documentation employée pour la rédaction du document binational d'évaluation du risque présenté par les carpes asiatiques, initiative conjointe de Pêches et Océans Canada et de la Commission des pêches des Grands Lacs.

Les ouvrages cités dans cette bibliographie comprennent des livres, des articles de revues scientifiques et divers autres documents, comme des rapports publiés par le gouvernement russe et des actes de congrès scientifiques.

1.0 INTRODUCTION

Considerable scientific information has been generated on Bighead and Silver carps based on research conducted on the species within their native and introduced ranges (e.g. Kolar et al. 2007, Chapman and Hoff 2010, Kipp et al. 2011). As a substantial portion of the native ranges of bigheaded carps are in northeastern Asia along the Amur River system on the Chinese-Russian border, a wealth of primary literature exists in the Russian language that has been inaccessible to scientists not familiar with the language.

Russian language peer-reviewed journal sources, books, government publications and additional literature were reviewed and translated individually into an annotated bibliography that summarizes key findings and conclusions from research conducted on bigheaded carps. In addition, translated species accounts from the *Fishes of Kazakhstan* for the two species are included in the appendices.

2.0 ANNOTATED BIBLIOGRAPHY

Abdullayev [Abdullaev] M.A., Khakberdiyev [Khakberdiev] B. 1989. Problems of biology and ecology of Grass Carp and Silver Carp from collecting-drainage waters of middle and lower reaches of Syr Darya. [Voprosy biologii i ekologii belogo amura i obyknovennogo tolstolobika kollektorno-drenazhnykh vod srednego i nizhnego techeniya Amudar'i.] *In:* Negonovskaya I.T. (Ed.). *Phytophagous fish in waterbodies of different types.* [Rastitel'noyadnye ryby v vodoyemakh raznogo tipa.] *Sbornik Nauchnykh Trudov GosNIORKh.* [Collected Scientific Articles of State Research Institute of Lake and River Fisheries]. No. 301. P. 113-129.

Morphological features and ecological peculiarities of Silver Carp (*Hypophthalmichthys molitix*) distributed in different waterbodies of the Middle and Lower Amu Darya River in Uzbekistan and Turkmenistan were examined. The study area has been heavily altered by the construction of a large number of artificial channels and dammed lakes, forming an extensive channel drainage system used for irrigation. The Karakum Canal is the main artery and connects directly to the Amu Darya River. Fish stocked and released in the Karakum Canal dispersed widely throughout the entire system of the Middle and Lower Amu Darya River. Channels varied by depth, water quality, current and width; however, Silver Carp inhabit all of them.

The Fulton condition factor (F_{cf}) for Silver Carp was 0.98-3.32, on average 2.29. In general, Silver Carp fed primarily on phytoplankton (up to 95.5% by weight), with diatoms comprising the dominant prey item. However, during the spring and early summer, zooplankton were the primary food source and accounted for 50.4% by weight of dietary intake. Index of fullness varied between 170-180$^{o}/_{ooo}$ (night), 139-140$^{o}/_{ooo}$ (morning), and 160-180$^{o}/_{ooo}$ (day). A substantial difference in the index of fullness was found between fish from channels (70.5$^{o}/_{ooo}$) and those from Ullishorkul Lake in summer (440-450$^{o}/_{ooo}$). In autumn, when water levels are considerably lower, the main food source was blue-green algae and *Spirogira*; however, the amount of *Fragilaria, Pediastrum* and *Melosira* consumed also increased to 45.3%.

Silver Carp females attained maturity at age 4+, at a length of 60-67 cm and a weight of 3375-4800 g. In Amu Darya River, spawning occurred in June in channels upstream from dams, when water levels rise and the water temperature increased to 19-22ºC. 16 females (60-90 cm, 3840-14600 g) with ripe ovaries were examined. Absolute fecundity varied between 308,000 and 1, 387,000. The diameter of oocytes ranged from 0.5 to 1.7 mm. Due to retention of eggs of various sizes, Silver Carp in these waterbodies may be considered batch-spawners which is indicated by eggs being released more than once during a spawning season. Young-of-the-year fish are highly abundant in rise channels, collectors and reservoirs between August and September.

Abdusamadov A.S. 1986. Biology of Grass Carp *Ctenopharyngodon idella* (Val.), Silver Carp *Hypophthalmichthys molitrix* (Val.) and Bighead Carp *Aristichthys nobilis* (Rich.) introduced in the Terek River region of the Caspian Basin. [Biologiya belogo amura *Ctenopharyngodon idella* (Val.), belogo tolstolobika *Hypophthalmichthys molitrix* (Val.) i pestrogo tolstolobika *Aristichthys nobilis* (Rich.), akklimatizirovannogo v Terskom raione Kaspiyskogo basseyna.] *Voprosy Ikhtiologii* [Journal of Ichthyology, Moscow]. Vol. 26. No. 3. P. 425-433.

Based on studies of spawning runs and migration (eggs and fingerlings), major spawning characteristics were defined for the following phytophagous fish species: Bighead Carp, (*Hypophthalmichthys nobilis*), Grass Carp, (*Ctenopharyngodon idella*); and Silver Carp (*Hypophthalmichthys molitrix).* These species have been introduced into the Terek River watershed, part of the Caspian Sea basin. Larvae and fingerlings of these species migrate downstream to coastal areas of the Caspian Sea (water salinity of 6-12‰) and remain there until maturation. Spawning occurred in upstream reaches of the Terek River; approximately 125-260 km from the river mouth. Sexual maturation varied by species and sex: Bighead Carp (male: 5, females: 6); Grass Carp (male: 4, female: 5); and Silver Carp (male: 4, female: 4-5). Spawning populations among all species were dominated by fishes aged 5-6 years. Average absolute individual fecundity also varied by species: Bighead Carp (930,000); Grass Carp (756, 000); and Silver Carp (812,000). Spawning occurred from April to July, with temporal variation by species. Mass spawning runs of Grass and Silver carps occurred in early May, whereas, the maximum spawning period for Bighead Carp occurred in June. These spawning runs coincided with flooding of the Terek River and water temperatures reaching 18-22 °C.

Akhmerov A.Kh. 1948. *Parasites of the Amur River fishes.* [Parazity ryb r. Amura.] *Izvestiya TINRO.* [Proceedings of Pacific Institute for Fisheries and Oceanography]. Vol. 27. P. 222-225.

The following parasites were found on Silver Carp in the Amur River: *Myxosporidia* (gills, kidney, bile); *Trematoda* (intestine); *Monogenea* (gills); *Cestoda* (intestine); larvae of *Diplois sphatae* (lens); metacercaria of *Metagonimus yokawai* (scales, fins); *Nematoda* (intestine, body cavity); and, *Copepoda* (gills).

Aliyev [Aliev] D.S. 1974. On feeding of the adult bighead in some waterbodies of the Karakum Canal. [O pitanii vzroslogo pestrogo tolstolobika v nekotorykh vodoemakh Karakumskogo kanala]. *In:* Nichay O. (Ed.) *Biological fundamentals of fish industry in waterbodies of Central Asia and Kazakhstan.* [Biologicheskiye osnovy rybnogo khozyaistva vodoyemov Srednei Azii i Kazakhstana], 2. Ylym, Ashkhavad. P. 9-11.

Dietary information, as well as annual and daily feeding dynamics of Bighead Carp from the Karakum Canal at Ashghabad and the Khauzkhan Reservoir were reviewed. From May to August, zooplankton (*Bosmina, Keratella, Cyclops*) was the main dietary component (up to 90% of gut contents) along with detritus. Between May and June, the index of stomach fullness reached $51^{o}/_{ooo}$, but decreased in July to $20.3^{o}/_{ooo}$ as a result of reduced detrital consumption. With a reduction in reservoir water levels (September), Bighead Carp underwent a dietary shift to primarily phytoplankton, specifically blue-green algae (*Mycrocystis, Gomphospheria, Pediastrum, Scenedesmus*) as well as detritus (up to 43.5% by weight) and a reduction in the proportion of zooplankton (only 1.3% of daily intake). Variation in the index of fullness averages $166^{o}/_{ooo}$, but varied from $24^{o}/_{ooo}$ (early morning) 34-61% (afternoon) to $26^{o}/_{ooo}$ (night).

Bagrov A.M., Chertikhin V.G. 1985. Features of maturation and spawning of the Silver Carp females in waterbodies of the tropical zone. [Osobennosti sozrevaniya i neresta samok belogo tolstolobika v vodoyemakh tropicheskoy zony]. *In*: Vinogradov V.K. (Ed.) *Phytophagous fishes and new objects of fish industry and acclimatization.* [Rastitel'noyadnyye ryby i novyye ob'ekty rybovodstva i akklimatizatsii.] *Collected Scientific Articles of All-Union Research Institute of Pond Fish Industry*. [*Sbornik Nauchnykh Trudov VNIIPRKh*]. No. 44. P. 90-96.

Phytophagous fishes from tropical regions are known to reach greater than normal sizes and weights than their more temperate counterparts. In the Pedrigal Reservoir in Cuba, young-of-the-year Silver Carp attained weights of 8-10 kg at 10 months of age, whereas, record weights of adult Silver Carp range from 47-60 kg. However, the rapid growth and absence of seasonal temperature variation in a tropical zone (annual mean temperature range 22.7-29.0ºC) may result in gonadic malformations and maturation disorders.

In Cuban populations of Silver Carp, ovaries developed quickly and in certain 1 year-old females, oocytes were identified at the vacuolisation stage. By the end of the second summer, some females had matured and spawned following hypophysial injections, while others had oocytes at the stage of vacuolisation and early vitellogenesis (yolk deposition). In general, female reproductive stages varied within age classes. Many females had vitellogenic oocytes by February-March, yet others spawned from the beginning of March to the middle of April. Average relative fecundity of the females at first maturation was 101, 200 eggs/kg of fish weight. Larval survival rate was low in these individuals (20.6%). Male Silver Carp also exhibited early onset of maturation as compared to more temperate populations.

Hypophysial injections were used to induce 2 year-old females to spawn three times during the same summer; in April, end of June, and mid-August. Absolute fecundity was up to 641,600 eggs, and was comparable to fecundities of 6-10 year-old females reared in ponds of the North Caucasus. Repeated spawning can be performed under certain conditions: 1500-2000 degree days between events and females must increase in weight by at least 0.7-0.8 kg.

Bezrukov V.F., Berdyshev G.D. 1983. The variability of muscle proteins in Grass Carp *Ctenopharyngodon idella* (Val.), Silver Carp *Hypophthalmichthys molitrix* (Val.) and Bighead Carp *Aristichthys nobilis* (Rich.) (Cyprinidae). [Izmenchivost' myshechnykh belkov belogo amura *Ctenopharyngodon idella* (Val.), tolstolobika *Hypophthalmichthys molitrix* (Val.) i pestrogo tolstolobika *Aristichthys nobilis* (Rich.) (Cyprnidae).] *Voprosy Ikhtiologii*. [Journal of Ichthyology, Moscow]. Vol. 23. No. 3. P. 502-507.

Using an electrophoretic method, myogenic activity was studied in three species of phytophagous fishes: Bighead Carp, Grass Carp; and Silver Carp. Myogens were identified as species-specific by their electrophoretic spectra. Hybrids between two carp species maintained protein fractions from both parents. The observed variability of fast myogenic fractions in phytophagous fishes was related to different ages of the studied individuals.

Bizyayev [Bizyaev] I.N. 1968. Some features of acclimatization of phytophagous fish in the Northern Caucasus. [Nekotoryye osobennosti akklimatizatsii rastitel'noyadnykh ryb na Severnom Kavkaze]. *In:* Karpevich A.F. (Ed.). *Acclimatization of fish and invertebrates in waterbodies of the USSR.* [Akklimatizatsiya ryb i bespozvonochnykh v vodoyemakh SSSR]. Nauka, Moscow. P. 112-115.

Spawning of phytophagous fishes in the Kuban River commenced when water temperatures reach 20-23°C; feeding behaviour occurred between 5 to 35°C. Every year, a proportion of introduced fishes migrated to the Azov Sea estuarine zone, where salinity reached 11.5 ‰. Aside from temperature, stream characteristics largely influenced spawning success in the Kuban River. Unlike the majority of cyprinids, Far-East carps preferred spawning in turbid waters, which enabled eggs to be suspended in the water column during the entire period of embryonic development. Investigations of reproduction in phytophagous fishes in the Kuban River indicated that spawning was not influenced by water level, but rather by turbidity. The relative egg density decreased through a hydration process in the perivitelline space and approached the relative density of turbid water. Under natural conditions, reproduction of Far-East carps occurred where water turbidity parameters reach 1.2 kg sediment/m^3 of water during the spawning period and include the Amu Darya, Terek, Kura and Kuban rivers. In contrast, rivers with low turbidity such as the Don, Volga, and Dnieper, as well as many lakes, reservoirs and ponds, natural spawning of phytophagous fishes was improbable. Spawning of phytophagous fishes in the Kuban River took place at channel bars with small gravel substrate and having flow velocities higher than in silted, broad, and deeper sectors of the river. Hydrological conditions at the bars (high flow velocity, rough pebbly riverbed, and numerous vertical vortices) maintained suspension in the water column of the released eggs until the hydration process had finished.

Borutskiy E.V. 1950. The data on feeding of Amur Silver Carp (Hypophtalmichthys molitrix.Val.). [Materialy o pitanii amurskogo tolstolobika (*Hypophtalmichthys molitrix* Val.).] *In:* Nikol'skiy [Nikolskiy], G.V. (Ed.). *Proceedings of the Amur Ichthyological Expedition in 1945-1949.* [Trudy Amurskoy Ikhtiologicheskoy Ekspeditsii 1945-1949 godov.] Vol. 1. P. 287-302.

An extensive study on feeding behaviour by Silver Carp in the Amur basin was conducted on 61 individuals ranging from 14 to 78 cm. Silver Carp greater than 15.5 mm in length consumed mostly phytoplankton. Intestinal length varied with body length: in fish ~14 cm long, intestine was 6-7 times longer than body length, in fish 60 cm long, intestinal length was 8-9 times longer, and in fish greater than 62 cm, intestinal length was 10-11 times longer. Gill rakers were modified to filter phytoplankton, which enabled fish to feed passively while swimming. However, fish could intensify feeding behaviour by increasing frequencies of opercular movements without additional locomotory expense.

Daily variation in intestinal contents/volume (index of fullness as Silver Carp do not have stomachs) was observed. At night, the index of fullness was approximately 565 $^{o}/_{ooo,}$ and the majority of food is located in the anterior part of the intestine. By morning, the index had decreased to 440 $^{o}/_{ooo}$ and food became more evenly distributed along the intestine. The index of fullness increased slightly (464 $^{o}/_{ooo}$) by the evening and food was distributed uniformly along the length of the digestive tract.

Taxonomic composition of the diet was dependant on relative prey abundance and availability. In spring, when phytoplankton were scarce, detritus represented a greater proportion of the diet, which indicated that fish fed off the bottom; however, the index of fullness was low (57-91 $^{o}/_{ooo}$). By the beginning of summer, the dietary proportion of detritus decreased and the amount of zooplankton consumed increased to 26%. During algal blooms, Silver Carp fed primarily on phytoplankton. Digestion occurred in the posterior half of the intestine where approximately half of algal cells are destroyed.

Burlakov A.B. 1985. Activity of gonadotropins in the hypophysis and blood serum of Silver Carp females *Hypophthalmichthys molitrix* (Val.) (Cyprinidae) during different stages of their reproductive cycle. [Aktivnost' gonadotropinov v gipofize i syvorotke krovi samok tolstolobika *Hypophthalmichthys molitrix* (Val.) (Cyprinidae) na raznykh stadiyakh reproduktivnogo tsikla]. *Voprosy Ikhtiologii*. [Journal of Ichthyology, Moscow]. Vol. 25. No. 3. P. 494-504.

Gonadotropin activity (GTA, hCG-affine) in the pituitary gland/hypophysis and blood serum in Silver Carp females was examined at varying stages of the reproductive cycle. Results indicated that gonadic development is accompanied by a marked increase in GTA level, both in the hypophysis, as well as blood serum. An increase in gonadosomatic index (GSI) from 0.14 to 28 units resulted in a 53-fold increase of the blood serum GTA, and a 5-6- fold increase in the hypophysis GTA. Fish of different size and age groups with similar physiological status (identical maturity stage) displayed unequal gonad weights (GSI) and varying degrees of hypophysis development (in relation to the brain, HBI). This variability also occurred for GTA levels in the hypophysys and blood serum. Accelerated ovary maturation (at ovulation), induced by hCG injection, resulted in an increase in the blood GTA and GSI and a 30% reduction in the hypophysis GTA as compared to intact females (maturity stage IV). The second maturation of females revealed higher GTA levels in blood and in the hypophysys, as well as higher HBI and GSI values, compared with the respective figures at first maturity.

Burlakov A.B. 1995. Changes in hormonal status of females of Silver Carp *Hypophthalmichthys molitrix* during the prespawning period. 2. Morpho-functional state of the neurosecretory cells of the preoptic and lateral nuclei of the hypothalamus. [Izmeneniye gormonal'nogo statusa samok belogo tolstolobika *Hypophthalmichthys molitrix* v posleneresstovyy period. 2. Morfofunktsional'noye sostoyaniye neyrosekretornykh kletok preopticheskogo i lateral'nogo yader gipotalamusa]. *Voprosy Ikhtiologii*. [Journal of Ichthyology, Moscow]. Vol. 35. N 6. P. 811-821.

The morpho-functional status of neurosecretory cells of female Silver Carp in pre-optic and lateral hypothalamic nuclei was discussed along with variable endocrine sensitivity of ovarian follicles during the pre-spawning period. An increase in follicle sensitivity was followed by an increase in functional activity in both pre-optic and lateral hypothalamic nuclei. This was evidenced by the expanded cell area and nuclear volume, removal of neurosecretory granules from the cells of pre-optic nuclei and transfer along the pre-optic-hypophyseal tract, appearance of large Herring bodies around the area of pre-optic-hypophyseal tract entering the lateral nucleus, as well as decreased somatostatin content in the hypothalamus. The loss of sensitivity to hormones in the ovarian follicles was accompanied by a decrease in functional activity of the investigated hypothalamic nuclei and reduces somatostatin content in the hypothalamus.

Burlakov A.B., Belova N.V., Emel'yanova N.G. 1987. The activity of the blood plasma gonadotropin and the quality of eggs of Silver Carp *Hypophthalmichthys molitrix* in the process of artificial propagation. [Aktivnost' gonadotropina v syvorotke krovi i kachestvo ikry belogo tolstolobika *Hypophthalmichthys molitrix* pri ego isskustvennom vosproizvodstve]. *Voprosy Ikhtiologii*. [Journal of Ichthyology, Moscow]. Vol. 27. No. 6. P. 962-970.

An investigation of gonadotropin activity in Silver Carp during ovulation under hatchery conditions was conducted. Injections of human chorionic gonadotropin (hCG) were used for hatchery propagation and the breeding quality of carp eggs was estimated. GTA level in the blood serum of females varied (3-50 IU*ml^{-1}) after egg removal. A high, positive correlation between the blood GTA in post-ovulated females and hatchery indicators of oocyte quality (ratios of fertilization, normally developing embryos and hatching success) was detected. Structural differences between oocytes of high and low hatchery quality were identified using an electron microscope. The importance of the neuroendocrine system in the expected quality of hatchery-produced sperm and eggs in relation to hatchery breeding of Silver Carp was also discussed.

Burlakov A.B., Belova N.V., Godovich P.L., Tsibezov V.V. 1991. The role of the endocrine system for the development of egg quality in Silver Carp *Hypophthalmichthys molitrix* in the process of artificial propagation. [Rol’ endokrinnoy sistemy v formirovanii kachestva ikry belogo tolstolobika *Hypophthalmichthys molitrix* pri isskustvennom vosproizvodstve]. *Voprosy Ikhtiologii*. [Journal of Ichthyology, Moscow]. Vol. 31. No. 5. P. 839-850.

The endocrine system in Silver Carp plays an important role in the quality of hatchery-produced sperm and eggs. Development of eggs and sperm was examined in relation to artificial breeding and the use of human chorionic gonadotropin (hCG). Researchers described how, under exogenous, hormone-induced maturation of females, various parts of the endocrine system were involved in the regulation of pre-reproduction processes and their role in biological quality of developing mature oocytes. The resulting biological response of the reproductive system subjected to the same dose of exogenous hormone was dependant on the involvement of the recipient’s endocrine centers to regulate final stages of maturation. The extent of such involvement was determined by the level of functional activity of the endocrine system prior to hormonal stimulation.

Burlakov A.B., Emel’yanova N.G., Godovich P.L. 1995. Changes in hormonal status of females of Silver Carp *Hypophthalmichthys molitrix* during the prespawning period. [Izmeneniye gormonal’nogo statusa samok belogo tolstolobika *Hypophthalmichthys molitrix* v prednerestovyy period. 1. Chuvstvitel’nost’ ovarial’nykh follikulov k gormonam]. *Voprosy Ikhtiologii*. [Journal of Ichthyology, Moscow]. Vol. 35. N 1. P. 105-113.

The hormonal variation of female Silver Carp during pre-spawning and spawning periods was examined with respect to the quantitative parameters of oocyte maturation, consistency of individual response if exposed to a range of steroid hormones, degree of the nuclei shift in the oocytes, location of the nucleoli in the nuclei, and the presence or absence of early malformation signs in the oocytes. Research included *in vitro* sensitivity of ovarian follicles to various estrogens, progestins, androgens, and corticosteroids, as well as examinations of the morphology and endocrine function of gonads expressed during production of sex steroid hormones. Female fish differed in individual sensitivity of ovarian follicles to *in vitro* hormone exposure and were divided into 4 groups: initially low-sensitive; mid-sensitive; high-sensitive; and, recurrently low-sensitive (displaying the signs of loss of sensitivity to hormones). Females with varying degrees of endocrine follicle sensitivity to hormone exposure also differed in morphology and function of follicular epithelium. Increased sensitivity of ovarian follicles to hormones was accompanied by hormonal changes in the blood plasma. These changes included a significant decrease of estradiol (by 109%) and testosterone (by 250%) levels, and increase in progesterone (by 180%). Reseachers concluded that the variable hormonal status of females kept in ponds during the prespawning and spawning periods should be considered when carrying out hatchery breeding and application of hormone- stimulated maturation.

Burlakov A.B., Khapchayeva E.V. 1983. Ripening of the oocytes of Silver Carp *Hypophthalmichthys molitrix* (Val.) (Cyprinidae) influenced by estrogens, androgens and gestagens *in vitro* depending on different sensibility of the fish *in vivo* to chorionic gonadotropin. [Sozrevaniye ootsitov tolstolobika *Hypophthalmichthys molitrix* (Val.) (Cyprinidae) pod deystviyem estrogenov, androgenov i gestagenov in vitro v svyazi s raznoy chuvstvitelnost'yu ryb in vivo k khorionicheskomu gonadotropinu]. *Voprosy Ikhtiologii*. [Journal of Ichthyology, Moscow]. Vol. 23. No. 4. P. 652-660.

Sensitivity of Silver Carp oocytes, exposed to *in vitro* steroid hormones of various functional groups was examined in contrast with *in vivo* sensitivities of fish exposed to human chorionic gonadotropin (hCG). The experiments indicated that under hatchery breeding, female Silver Carp differed both in egg quality and sensitivity to hCG (*in vivo)* as well as to all tested steroid hormones (*in vitro).* In this regard, assessment of female sensitivity to hCG injection *in vivo* may be conducted through a comprehensive simultaneous analysis of the follicle reactivity *(in vitro)* to a number of steroid hormones of different functional groups.

Danchenko E.V., Zhiteneva L.D., Guseva S.S. 1980. Nutrition and feeding interactions of two-year Bighead Carp and Silver Carp in different climate conditions by example of the Rostov Province and Krasnodarskiy Kray. [Pitaniye i pishchevyye vzaimootnosheniya dvukhletok belogo i pestrogo tolstolobikov v raznykh zonal'nykh usloviyakh na primere Rostovskoy oblasti i Krasnodarskogo kraya]. ***In:*** **Kamilov G.K. (Ed.).** ***Phytophagous fishes in industrial fish culture. Book of Abstracts of the 9th All-Union Conference.*** **[Rastitel'noyadnye ryby v promyshlennom rybovodstve. Tezisy dokladov IX Vsesoyuznogo Soveshchaniya.] Izdatel'stvo AN UzSSR, Tashkent. P. 43-44.**

Feeding behaviour of Bighead and Silver carps was examined over a 10 year period (1969-1979) in the Rostov Province and Krasnodar Kray, South Russia. In all locations, Silver Carp fed on phytoplankton in the second year of life. Taxonomic composition and quantity of consumed algal species depended on seasonal availability and abundance of algal species. Phytoplankton comprised 10-90% by weight of total diet. The balance of the diet was represented by a combination of detritus and mineral particles, which could supply up to 90% of the diet during low algal periods. Silver Carp fed on benthic sediments rich with epiphytes, protozoans and microflora. During the mass development period of the rotifer *Keratella,* these zooplankton organisms could account for up to 5% of the total food weight consumed by Silver Carp. Feeding was accomplished by way of passive consumption, through filtering of the phytoplankton.

The diet composition of Bighead Carp at age 1+ was determined by the abundance and availability of food objects and was characterized by a wide spectrum of species. However, unlike Silver Carp, during periods of low zooplankton production Bighead Carp did not compensate by feeding on detritus. Interestingly, the species never consumed phytoplankton, even during periods of abundance or algal blooms. Digestive tract examinations in Bighead Carp were conducted every 4 hours and revealed that the species fed constantly and the index of fullness varied (47-104 $^{o}/_{ooo}$) with the minimum index occurring at 05:00h.

Doroshev R.I. 1964. Salinity tolerance of some species of fish recommended for introductions to the Sea of Azov. [Soleusto'chivost nekotorykh vidov ryb, rekomendovannykh dlya vseleniya v Azovskoye more]. *In:* Karpevich A.F. (Ed.) Acclimatization of fish and food organisms in seas of the USSR. [Akklimatizatsiya ryb i kormovykh organizmov v moryakh SSSR.] *Trudy VNIRO.* [Proceedings of All-Union Institute for Fisheries and Oceanography]. Vol. 55. No. 2. P. 97-107.

The survival rates of Far-East carps fry were examined from waters of varying salinity levels. For the study, carp fry were infected with ectoparasites (*Trichodina*) to illicit a suppressed physiological status. The average daily mortality rate in the control tank (freshwater) accounted for 1% of total mortality. Exposure to the 2.5 and 5‰ Azov sea water resulted in reduced mortality (0.5-0.3%), and almost complete elimination of parasites. At 7.5‰ salinity, the average daily mortality increased to 1.4% as compared with the control group. However, salinity levels of 10‰ resulted in complete fish mortality within 7 days, with an average daily mortality of 14.6%. During this period, the fry ceased both feeding and locomotory activities. Partial mortality was observed at 12‰ salinity (Aral Sea), whereas, total mortality occured at a salinity level of 14.5‰, with an average daily mortality of 7%. The upper salinity threshold for Far-East carp fry was estimated at 7-8‰ (Azov Sea) and 10-11‰ (Aral Sea) with a chloride concentration of approximately 4%.

Emel'yanova N.G. 1985. Seasonal changes of the cytoplasm of previtellogenic oocytes in Silver Carp *Hypophthalmichthys molitrix* (Val.) (Cyprinidae). [Sezonnyye izmeneniya tsitoplazmy ootsitov perioda previtellogeneza u tolstolobika *Hypophthalmichthys molitrix* (Val.) (Cyprinidae)]. *Voprosy Ikhtiologii*. [Journal of Ichthyology, Moscow]. Vol. 25. No. 2. P. 248-255.

The most significant seasonal variations in oocyte cytoplasm of Silver Carp were observed as changes to the morphology of the Golgi complex, the clustering of mitochondria and hypertrophied endoplasmic reticulum. Low metabolic rate at low temperatures may be adaptive for cytoplasmic organelles in germ cells in an effort to minimize metabolic costs. The process of yolk granule formation in late pre-vitellogenic oocytes revealed seasonal differences; formation of yolk granules in winter were followed by active pinocytosis in the form of coated vesicles during oocyte metabolism. The process of vitellogenin influx into the gonads starts in the winter, but occurred primarily during the spring (pre-spawning period).

Emel'yanova N.G., Makeyeva A.P., Mikodina E.V. 1980. Data on the ontogenetic development of Silver Carp. [Materialy po oogenezu belogo tolstolobika]. *In:* Kamilov G.K. (Ed.). *Phytophagous fishes in industrial fish culture. Book of Abstracts of the 9th All-Union Conference.* [Rastitel'noyadnye ryby v promyshlennom rybovodstve. Tezisy dokladov IX Vsesoyuznogo Soveshchaniya.] Izdatel'stvo AN UzSSR, Tashkent. P. 160-161.

The developmental process to mature ova from oogonia was described for Silver Carp. Oogonia and pre-vitellogenetic oocytes were characterized by weak development of the cytoplasmic organelles, nucleoli and cell membrane. These organelles were commonly few in number. The nucleolus often had a fibrillose structure, indicating a slight synthesis of the RNA. The cell membrane was slightly sinuous. Immediately following onset of vitellogenesis, the number of nucleoli increased and their granular components developed quickly. The nuclear membrane formed numerous projections into the cytoplasm. Oocytes grew quickly and the synthesis of yolk granules, cortical alveoli and material of the cell membrane was quite rapid. At the end of vitellogenesis, the nucleus became smooth again, fewer nuclei were present and had a less granular component, and the structure of the mitochondria became simpler.

The eggshell of ovulated oocytes was represented by a three-layered zona pellucida and a narrow chorion. The outer layer of shell originated in oocytes in the latest period of pre-vitellogenesis. The intermediate and inner layers were formed at the beginning of vitellogenesis, while the chorion developed during the period of intensive vitellogenesis. While the egg was ripened, the inner layer became fibrous. The exfoliation of fibers during the formation of the perivetelline space contributed to a considerable enlargement of the eggshell. Oocytes in the ripening period experienced a disintegration of the nucleus and the porous plates, which appeared in the cytoplasm at the end of the oogenesis. As porous plates were absent in normal ovulated oocytes, their presence may indicate abnormalities during oogenesis.

Fulga N.I., Statova M.P. 1992. Features of oogenesis in Silver Carp *Hypophthalmichthys molitrix* during the period of sexual maturation in waterbodies of different types in Republic of Moldova. [Osobennosti oogeneza belogo tolstolobika *Hypophthalmichthys molitrix* v period polovogo sozrevaniya v raznotipnykh vodoyemakh respubliki Moldova.] *Voprosy Ikhtiologii*. [Journal of Ichthyology, Moscow]. Vol. 32, No 2. P. 99-106.

Over the 30-year period of domestication and hatchery breeding of Silver Carp, no significant changes were observed during oogenesis under pond conditions with the exception of an extended length of vitellogenesis. In all seasons, development of pre-vitellogenic oocytes in the cooling tanks was characterized by the lack of a pause in the C-phase and de-synchronized transition to vacuolization of the cytoplasm. Age of first maturity in females was determined by a different rate of oocyte development during vitellogenesis. Transition to this developmental period was observed in spring and in summer, resulting in the completion of the IV maturity stage in these seasons. At this stage, females possessed a single generation of yolk-filled oocytes.

Gorbach E.I., Krykhtin M.L. 1980. Optimal parameters of the main factors determing maturation and reproduction of Grass Carp and Silver Carp in the Amur. [Optimal'nye parametry osnovnykh factorov, opredelyayushchie sozrevanie i razmnozhenie belogo amura i tolstolobika v Amure]. *In:* Kamilov G.K. (Ed.). *Phytophagous fishes in industrial fish culture. Book of Abstracts of the 9th All-Union Conference.* [Rastitel'noyadnye ryby v promyshlennom rybovodstve. Tezisy dokladov IX Vsesoyuznogo Soveshchaniya.] Izdatel'stvo AN UzSSR, Tashkent. P. 152-154.

To attain sexual maturity in the Amur River region, Silver Carp and Grass Carp required an annual accumulated heat of 2655-3111 degree-days (ºd) (mean 2865 ºd). Of these, 565 ºd must immediately precede the pre-spawning period (before the 15th of June). Under favourable thermal conditions, the value of this parameter increased to 650 ºd (approximately 20 days of water temperatures between 15-20 ºC), and maturation accelerated considerably. An estimated 50% of the population reached maturity at the age of 4 + to 5 + years (males) and 5 + to 6 + years (females). In colder years, (only 10 days when water temperatures reached 15-20 ºC before the

15th of June), the amount of accumulated heat did not reach 500 ºd. This resulted in a two-year delay in maturity for both males and females.

Spawning began when water temperatures rose above 17 ºC. Below this threshold, spawning activity stopped and eggs that had already been laid perished. The period of most intensive spawning behaviour usually took place in late June and early July, when water temperatures ranged from 21-26 ºC. However, the dates and intensity of spawning were highly correlated to fluctuations in water level; even if favourable water temperatures were reached, spawning only occurred when water levels were high and ceased if levels dropped. Spawning also stopped if waters became rough. Spawning was most successful when there were 2-3 periods of rising water levels (increases of 1-2 meters) that were maintained for a period of 1 to 2 weeks. Even under favourable conditions, 23% of females had unlaid eggs, and in unfavourable years, as many as 70% of females did not spawn.

Among other hydrological requirements for successful spawning, water velocities of 0.7-1.4 m/s and a minimum 600 km length of river stretch between spawning sites and nursery areas were necessary. This distance may differ in rivers other than the Amur; however, stream length must be at least 100 km as a 0.3 m/s decrease in water velocity caused eggs and embryos to thicken and die on the substrate before they reached the active stage.

Gorbach E.I., Krykhtin M.L. 1981. Rate of maturation in Grass Carp *Ctenopharyngodon idella* (Val.) and Silver Carp *Hypophthalmichthys molitrix* (Val.) in Amur River. [Temp sozrevaniya belogo amura *Ctenopharyngodon idella* (Val.) i tolstolobika *Hypophthalmichthys molitrix* (Val.) v reke Amur.] *Voprosy Ikhtiologii*. [Journal of Ichthyology, Moscow]. Vol. 21. No. 5. P. 835-843.

Variation in age, length, and weight at first maturity was described for Grass Carp and Silver Carp in the Amur River. Male Grass Carp matured at 7-13 years (majority 7-9 years), females at 8-14 years (majority 9-11 years). For Silver Carp, males matured at 4-10 years (majority 5-7 years), females at 6-10 years (majority 7-8 years). Rate of maturation was dependant upon annual water supply and flood volume. In low-water years, maturation in

Grass Carp occurred 3-4 years earlier (males at 7-8 years, females at 8-10 years); whereas, Silver Carp matured 1-3 years earlier (males at 5-6 years, females at 6-7 years). In years with varying water levels, changes in maturation rates of both species were related to differences in the thermal constant (accumulated heat degree-days) during the pre-spawning period and accumulated fat stores in individual fishes. Maturation in Silver Carp was also highly dependant on the food supply and fish growth rate. Mass maturation of these species in the Amur River was dependant on the average pre-spawning thermal constant of 919±29 degree days and exposure to warm water for 29±2 days.

Gorbach E.I., Krykhtin M.L. 1988. Migration of the Grass Carp, *Ctenopharyngodon idella*, and Silver Carp, *Hypophthalmichthys molitrix* in the Amur basin. [Migratsii belogo amura *Ctenopharyngodon idella* i belogo tolstolobika *Hypophthalmichthys molitrix* v basseyne Amura. *Voprosy Ikhtiologii*. [Journal of Ichthyology, Moscow]. Vol. 28. No. 4. P. 619-625.

The main spawning grounds for Grass Carp and Silver Carp were syntopic, located in the lower sections of the Middle Amur River and the Songhua (Sungari) River. Total spawning area of Silver Carp was double the amount used by Grass Carp and included the upper section of the Lower Amur River. Periods of mass spawning were common to both species, and occurred from the second half of June to the first half of July. The majority of larval and post-larval Grass and Silver Carp resided in the Middle Amur lowland where the floodplain is well-developed. The lower reaches of the Amur River were populated by juvenile fishes, at least 1 year of age. Juveniles gradually moved downstream to enter subsidiary waterbodies and, in some years, the freshened part of the Amur Liman and the estuarine zone. Juveniles of both species occupied in the lower reaches of the Amur River until reaching the age of 4-5 years. At this point they began the 500 km upstream migration, approaching the Malmyzh area in 2 years. Further migration from Malmyzh, to the main spawning sites took at least 1 year for Silver Carp, and 2 years for Grass Carp. A small number of Silver Carp migrated to the main spawning grounds in the lower section of the Amur River and remained in the Malmyzh area for feeding and spawning.

Brooders of both species over-wintered in deepwater pockets located in the lower section of the Middle Amur River and the upper section of the Lower Amur River. A large number of brood fishes moved into boundary waters of the lower Middle Amur in late May–June to spawn in the warmer Sungari waters. During the second half of July, the post-spawn fishes gradually returned to the Amur River to feed and overwinter. The majority of post-spawn brooders undertook small-scale migrations of approximately 100 km; however, analysis of fish size, maturity stage, and tag return, indicated that a small number of post-spawn fishes did undertake a more lengthy feeding migration.

Isuyev L.R., Musayev B.S. 1989. A comparative description of the lipoacidic content during the early stages of development of carp, bighead, Siberian salmon, Caspian salmon and Russian sturgeon. [Sravnitel'naya kharakteristika zhirokislotnogo sostava lipidov na rannikh stadiyakh ontogeneza karpa, pestrogo tolstolobika, kety, kaspiyskogo lososya i russkogo osetra]. *Voprosy Ikhtiologii*. [Journal of Ichthyology, Moscow]. Vol. 29. No. 2. P. 342-345.

Hatchery-produced eggs, embryos, and early larvae of *Acipenser gueldenstaedti, Cyprinus carpio, Hypophthalmichthys nobilis, Oncorhynchus keta,* and *Salmo trutta caspius* were studied in Daghestan. The composition of fatty acid lipids in eggs and larvae of *Cyprinus carpio* remained consistent during development, except for a small increase in the proportion of stearic acid and lower content of palmitic-olein acid. Eggs and larvae of the Silver Carp experienced an increase in $C_{16:0}$, $C_{16:1}$, and $C_{18:1}$ acids and a decrease in $C_{20:5}$, $C_{22:6}$ acids.

Kamilov B.G. 1984. Morphological features of the registering structures of Silver Carp *Hypophthalmichthys molitrix* (Val.) (Cyprinidae) with regard to the determination of the age and growth rate. [Morfologicheskiye osobennosti registriyruyushchikh struktur belogo tolstolobika *Hypophthalmichthys molitrix* (Val.) (Cyprinidae) v svyazi s opredeleniem vozrasta i tempa rosta.] *Voprosy Ikhtiologii* [Journal of Ichthyology, Moscow]. Vol. 24. No. 6. P. 1003-1013.

Morphological features of age determination structures were studied in Silver Carp. Results indicated that the tapered sclerite band in the scales of Silver Carp should be considered a morphological indication of annulus. Age determination can be verified by using the first ray of the pectoral fin, vertebrae, and pterygiophore of the first dorsal fin ray. The presence of surface sculptures and the solid structure of gill covers, as well as blurred annuli displayed on otoliths, made them unreliable as tools for age determination.

Kamilov B.G. 1986. State of the gonads in females of Silver Carp *Hypophthalmichthys molitrix* (Val.) depending on growth rate under conditions of Uzbekistan. [Sostoyaniye gonad u samok belogo tolstolobika *Hypophthalmichthys molitrix* (Val.) v zavisimosti ot tempa rosta v usloviyakh Uzbekistana.] *Voprosy Ikhtiologii*. [Journal of Ichthyology, Moscow]. Vol. 26. No. 6. P. 1033-1036.

Under climatic conditions of Uzbekistan, a positive correlation was found between gonad development and growth of Silver Carp, which indicated that fish with faster growth rates had more developed gonads. Among similar-sized individuals of different ages, older fish had more developed gonads. The age of first maturity was strongly dependent on the growth rate during the first year. Silver Carp in Uzbekistan pond farms matured in 3 years, provided that they reached at least 17 cm in body length, and a weighed between 100-120 g during the first year.

Kamilov B.G., Salikhov T.V. 1996. Spawning and reproductive capability of Silver Carp *Hypophthalmichthys molitrix* in Syr Darya River. [Nerest i vosproizvoditel'naya sposobnost' belogo tolstolobika *Hypophthalmichthys molitrix* reki Syrdar'i.] *Voprosy Ikhtiologii* [Journal of Ichthyology, Moscow]. Vol. 36. N 5. P. 631-637.

The spawning cue observed for Silver Carp in the Syr Darya River was a combination of rising water temperature and level during the spring flood. These conditions coincided with large irrigation discharges into the river channel from the reservoir. The spawning run began in late March to early April, when water temperatures reached 13-16 °C, and lasted until the end of May. In cold-winter years, spawning migration was delayed, and lasted until mid-June. During one spawning season, several approaches of brood fishes to the spawning grounds were recorded. The most abundant approach was comprised of joint shoals of fishes, including Bighead and Grass Carp. Silver Carp were the dominant species in spawning shoals, representing up to 70-85% of the total number of fishes. Larger fishes (92-126 cm TL, 18-47 kg) arrived on spawing sites first, followed by progressively smaller fishes over the next 5-15 days, and large-scale spawning activities commenced. In some years, a sharp decrease in water level during the spawning season interrupted the spawning run and fishes became concentrated in the deeper parts of the river channel. However, once water levels resumed, spawning migration continued. The brood of Silver Carp traveled in the surface layers and leapt out of the water if disturbed by noise or vibration.

The spawning area was situated between the Gul village and the Farkhad dam; however, the precise location of spawning grounds varied from year to year depending on flood water volume and velocity. Spawning took place at narrow stretches or bends of the river characterized by vertical vortices and flow velocities of 0.5-2.0 m sec^{-1}. Silver Carp spawned in small groups of 15-25 fish near the surface. Ideal spawning conditions included clear weather and water temperature of 18-20 °C. Spawning often took place during evening and morning hours. Post-spawning downstream migration was observed from late May to late June.

The spawning population included fishes aged 3-10 years. Long-term observations, from 1970-1990, revealed a trend towards diminishing proportions of older brood fishes. In the 1970's, females aged 5-7 years accounted for 83% of the total population, whereas, in the 1990's, that proportion decreased to 67%. Growth rate in females was rapid throughout the studied period and no interannual variability was detected. In the Syr Darya River, Silver Carp matured at 3-4 years, at a length of 50-55 cm and weight of 4000 g in males, 54-59 cm and 5000 g in females. Sex ratio was approximately 1:1, as estimated for spawning stock in 1978-1979 and 1990-1993.

In the 1970's, average length and weight measurements were higher in females than in males, especially in body weight. By the 1990's, males and females were quite similar in the average length, with slightly increased body weight in females. The gonad weight in brood females ranged from 250-6000 g, absolute fecundity varied between 299,000 and 5,400,000 eggs, relative fecundity ranged from 79-392.3 eggs per 1 gram of body weight, and maturity index varied between 5.0 and 29.7%. These reproductive parameters increased concurrently with increasing fish size.

Karpov V.E. Bayekeshev A.Sh., Glukhovtsev I.V., Shapovalov M.V., Pichkily L.O. 1989. Characteristics of self-sustained stocks of Grass Carp and Silver Carp in the Balkhash-Ili basin. [Kharakteristika samovosproizvodyashchikhsya stad belogo amura i belogo tolstolobika Balkhash-Iliyskogo basseyna.] *In:* Negonovskaya I.T. (Ed.). *Phytophagous fish in waterbodies of different types.* [Rastitel'noyadnye ryby v vodoyemakh raznogo tipa.] *Sbornik Nauchnykh Trudov GosNIORKh.* [Collected Scientific Articles of State Research Institute of Lake and River Fisheries]. No. 301. P. 86-112.

Silver Carp populations in the Ili River, including Balkash Lake and the Chardara Reservoir, were examined in this study. Although this population is established, natural reproduction was limited and likely hindered due to unsuitable conditions for larval development (requires a short distance for downstream drift and sufficient zooplankton and phytoplankton abundance for feeding). In this region, adult Silver Carp were an average of 68.0-83.0 cm long, weigh 6.0-12.0 kg, had a Fulton condition factor (F_{cf}) of 1.66-1.96, and Clark condition factor (C_{cf}) of 1.49-1.66. Gonadosomatic index (GSI) of four females was between 0.57-1.51 (late April) but increased to 14.55 (early May). In late May, the four captured females displayed significant variation in GSI, ranging from 4.14 to 17.7. Absolute fecundity was estimated at 1,576,000 to 2,184,000 eggs, and relative fecundity ranged from 131-195. The fecundities were reported without specifying size or age of females.

In June 1987, three larvae (6.0-7.2 mm TL) were sampled in the upper section of the Ili River. Information was not given regarding the spawning possibility in the downstream area, outside the Kapchagay HEPS dam. Juvenile Silver Carp have been recorded in the upper section of the reservoir, and had a low-abundance spawning run which started in late April. The diet of young-of-the-year Silver Carp (August, 1986) consisted of 126 species, including 58 species of green algae, 34 of diatoms, and 21 of euglenophytes. The dominant blue-green algae species was colonial *Merismopedia punctata*, which accounted for 63% of the total algal species. Pyrrophyte algae (particularly, *Gymnodinium* sp. and *Peridinium inconspicum*) accounted for the 51% of the total diet, while diatoms and green algae comprised 9 to 14%.

Indices of consumption and gut fullness were very high during this period, 900.24$^{o}/_{ooo}$ and 580.52$^{o}/_{ooo}$. In October, algal diversity decreased to 108 taxa, however, the number of green algae species increased (67 species), diatoms decreased (25 species), and 7 species of blue-green algae were present. Quantatively, green and blue-green algae were the predominant dietary components. Green algae species were represented mainly by *Scenedesmus quadricauda* and *Binuclearia lauterbornii*; which accounted for 55% of the total algae species and 42% by weight. *Aleristopedia punctata* and *Gomphosphaeria lacustris* were the dominant species of blue-green algae, 21 and 36%, respectively. Indices of consumption and gut fullness in that period declined to 142.69 and 94.48$^{o}/_{ooo.}$ F_{cf} for fingerlings in late August declined to 1.38-1.79, with an average of 1.54; C_{cf} ranged from 1.10 to 1.36. By the end of the growing season, these values increased up to 1.9-1.95 F_{cf} and 1.57-1.69 C_{cf}. After wintering, yearlings displayed a range of values of condition factor: 1.45-1.92 F_{cf} and 1.14-1.52 C_{cfc} with an increase in values as the season progressed (1.96-2.32 F_{cf} and 1.69-1.92 C_{cfc}).

Khalmatov N. 1974. Changes of morphological features of the blood in fish depending on seasons and conditions of rearing. [Izmeneniye morphologicheskikh pokazateley krovi ryb v zavisimosti ot sezonov goda i usloviy vyrashchivaniya.] *In:* Nichay O. (Ed.) *Biological fundamentals of fish industry in waterbodies of Central Asia and Kazakhstan.* [Biologicheskiye osnovy rybnogo khozyaistva vodoyemov Srednei Azii i Kazakhstana], 2. Ylym, Ashkhavad. P. 91-92.

Blood chemistry (numbers of erythrocytes, leucocytes, hemoglobin and hematocrit levels, and total protein) were examined in Common Carp, Gibel or Prussian Carp (*Carassius gibelo*), Grass Carp, and Silver Carp from an artificial pond in the Ferghana Province. In Silver Carp, blood chemistry varied strongly with seasons, the number of erythrocytes ranged from 1.3 million mm^{-3} (spring) to 1.8 million mm^{-3} (autumn), the number of leucocytes fluctuated from 19,800-23,000 mm^{-3}, and the erythrocyte sedimentation rate was 4.5-3.5 mm/hour. For other species, variation in blood chemistry was present as well.

Kirilenko N.S., Chigrinskaya Yu.N. 1983. Activity of peptic enzymes in Silver Carp *Hypophthalmichthys molitrix* (Val.) (Cyprinidae) during its consumption of green-blue algae. [Aktivnost' pishchevaritel'nykh fermentov tolstolobika *Hypophthalmichthys molitrix* (Val.) (Cyprinidae) pri potreblenii sinezelenykh vodorosley.] *Voprosy Ikhtiologii*. [Journal of Ichthyology, Moscow]. Vol. 23. No. 6. P. 969-973.

Daily consumption of blue-green algae by 2 year-old Silver Carp depended on the background algal concentration in the water, was greatest at algal concentration levels of 1.334 g l^{-1}, and accounted for 9.8% of body weight. A further increase in blue-green algae concentration led to a reduction in daily consumption. The distribution of amylolytic, proteolytic, and lipolytic enzymes along the digestive tract of the Silver Carp was characterized by a distinct proximo-distal gradient, indicating that digestive activity declines towards the end of the digestive tract. The digestive tract responded to an increase in the amount of consumed algae, through redistribution of enzymatic activity responsible for cavity and membrane hydrolysis of carbohydrates, proteins, and lipids.

Koblitskaya A.F. 1981. Key to young of freshwater fishes [Opredelitel' molodi presnovodnykh ryb]. Moscow, Liogkaya i pischevaya promyshlennost'. 208 pp.

A key is presented to identify pre-larval, larval and juvenile stages of common freshwater fishes of the Volga basin including introduced Grass Carp (*Ctenopharyngodon idella)* and, Silver Carp (*Hypophthalmichthys molitrix)* based on stages of ontogenetic development as identified by Vasnetsov (1953). Characteristics used to distinguish pre-larval Silver Carp from Grass Carp include*:* trunk myomeres (26 or less in Silver Carp, 30-32 in Grass Carp); tail length in Silver Carp is twice the body length (2.5 times greater in Grass Carp); and, pigmentation of the pre-anal fold is present only in Silver Carp. Pre-larval Silver Carp hatch at 5.2-6.0 mm body length and are characterized by having 24-26 trunk segments and 14-19 caudal segments, dorsal fin branched rays 7; anal fin branched rays 12-14; lateral line 110-124 scales (Figure 1a). At this stage, pigment is absent from eyes and body. the fin fold large and wide and the caudal notch is absent. The head is small with a wide mouth. Early pectoral fins appear 2 days post-hatch, at body length of 7 mm. In later pre-larval stages, the yolk sac begins to dissolve and eyes become fully pigmented. Large, star-like melanophores appear on head, back and intestine and the swim bladder lacks air.

At the larval stage (Figure 1б, 1в), the swim bladder fills with air and the yolk sac is completely dissolved. The mouth is terminal and pigment is concentrated in three lines along the body and in the pre-anal fin fold. The primordial dorsal fin appears and is located at the 6th myomere anterior to the anus and extends over three segments. The early anal fin is also present and is located over five myomeres. Caudal fin rays are present; whereas, dorsal and anal fin rays begin to appear at a length of 9 mm. At 10 mm, the first chamber of the swim bladder has filled with air and the pre-pelvic fin appears. Pectoral fin rays are present at a length of 11-12 mm, and the pre-anal fold is very large and well pigmented (Figure 1в). At the end of the larval period, pelvic fin rays are present, dorsal and anal fins are completely developed and have separated from the caudal fin.

Juvenile Silver Carp have complete fin development between 13-15 mm (Figure 1г). Lateral line scales are present once juvenile fish reach 22-25 mm in length. The head is large and retains a terminal mouth. The pre-anal fold persists and, by 50 mm in length, the entire body is covered with scales and the eyes have moved to the lower position on the head.

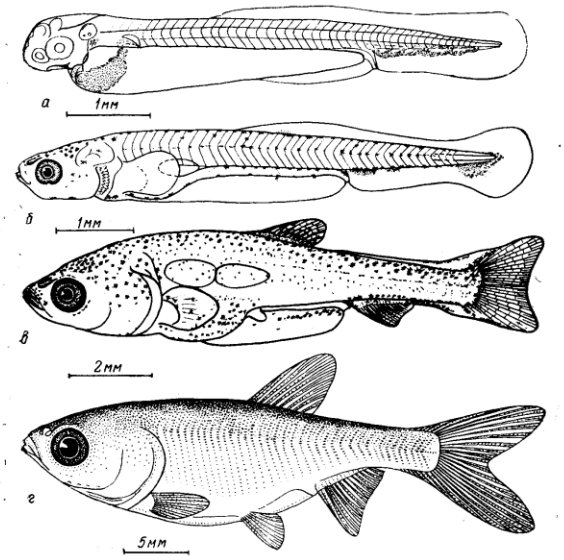

Рис. 74. Hypophthalmichthys molitrix (Val.):
а — предличинка длиной 6,2 мм; б — ранняя личинка длиной 6,3 мм; в — поздняя личинка длиной 11 мм; г — малек длиной 25 мм.

Figure 1. Developmental stages of *H. molitrix* (after Vasnetsov 1953).

Krykhtin M.L., Gorbach E.I. 1981. The breeding ecology of the Grass Carp *Ctenopharyngodon idella* (Val.) and Silver Carp *Hypophthalmichthys molitrix* (Val.) in the Amur River basin. [Ekologiya razmnozheniya belogo amura *Ctenopharyngodon idella* (Val.) i belogo tolstolobika *Hypophthalmichthys molitrix* (Val.) v basseyne Amura.] *Voprosy Ikhtiologii* [Journal of Ichthyology, Moscow]. Vol. 21. No. 2(127). P. 317-330.

Pre- and post-spawn female Silver Carp were found primarily in the Leninsky and Golovino districts with single individuals also found in the Ussuri and Lower Amur rivers in the Malmyzh district. Downstream-migrant eggs were recorded primarily in samples from the Leninsky and Golovino districts. Early larvae (2-4.5 days old) were sampled from the Leninsky – Malmyzh area at densities approximately 70 times smaller than that of deposited eggs. Eggs and larvae were not found downstream of these areas.

Silver Carp eggs dispersed to the Leninsky and Golovino districts both from the Amur and Sungari streams and were more abundant in the latter. The majority of eggs were carried in the surface water layer, located midstream and in the channels, where flow velocity reached 0.7-1.4 m sec^{-1}. In the nearshore sites, where the flow velocity slows to 0.3-0.4 m sec^{-1}, eggs occured more frequently in the water column and in the bottom layer. Egg membrane diameters measured 4.2-5.0 mm, and yolk diameters measured 1.15-1.25 mm; however, larger egg sizes were also found. These results are consistent with samples taken in 1977 and 1978 (membrane diameter of 6.0 mm, yolk diameter 1.4 mm). In the Leninsky and Golovino districts, dispersed eggs represented many age classes, from 1 hour post-fertilization to more than 1.5 days of age. The stage of embryonic development ranged from blastodisc cleavage to rotating embryo. The majority of embryos were between 10-20 hours old (between gastrulation and organogenesis).

Kryzhanovskiy S.G., Smirnov A.I., Soin S.G. 1951. Data on development of fishes in the Amur River. [Materialy po razvitiyu ryb v reke Amur]. *In:* Nikol'skiy, G.V. (Ed.). *Proceedings of the Amur Ichthyological Expedition in 1945-1949.* [Trudy Amurskoy Ikhtiologicheskoy Ekspeditsii 1945-1949 godov.] Vol. 2. P. 5-233 [Hypiphthalmichthys molitrix, pages 79-84].

Embryological development in Silver Carp was described from samples collected in the Amur River during the Amur Ichthyological Expedition (1945-

1949). Eggs and larvae (0.5-10 days old) drifting downstream were collected in the main river stream. Silver Carp spawned from about 300 km upstream from the mouth of the Sungari down to the mouth of the Ussuri River. Eggs and larvae (up to 7.8 mm long, 8 days old) were primarily drifting in the main current, whereas, older larvae (greater than 8.0 mm, 8 to 18+ days old) were found along the river banks. Larger larvae were likely able to swim against the current and approach the bank to look for slow-current backwaters and floodplain lakes where they formed small schools and remained to forage for the remainder of the season. In the lower Amur, where most floodplain lakes are found, larvae entered lakes through channels after substantial flooding events and subsequent inflow of lake water. When the current changed direction (moving downstream), migrating larvae were not found. Upstream from the Sungari mouth, drifting larvae up to age 6-7 days were found. Larvae greater than 15 mm were collected only in lakes.

Silver Carp eggs were typically pelagic, with a large cavity under the egg membrane. The membrane diameter of eggs varied from 3.5 to 4.5 mm, the diameter of the yolk sac was 1.2 mm or less. Species identification was possible only at the tail segmentation stage. At earlier stages, Silver Carp eggs looked very similar to those of other pelagophilous fishes. Hatching took place at water temperatures of about 25ºC, at an age of 2 days post-fertilization. Embryos rested on the bottom, rarely entering the water column. Embryo length at hatching measured approximately 6 mm and Silver Carp were easily distinguishable from Grass Carp embryos. Although morphologically very similar, Silver Carp had a smaller eye and different numbers of abdominal and caudal segments than did Grass Carp (Silver Carp: 24-26 abdominal and 14-17 caudal segments; Grass Carp: 28-32 and 12-16, respectively). Pigment appeared at 4 days post-hatch. Embryos were very slow-moving until 7 days of age (6.35-8.0 mm long) following which embryos became much more mobile, and developed further pigmentation. Air bubbles first appeared in the swim-bladder, and the yolk sac was considerably reduced. Larvae were able to swim, but occasionally fell to the bottom. A large pre-anal fold formed when larvae reached 12 mm in length and could be used to differentiate Silver Carp from all other fishes. At this stage, larvae fed on zooplankton, and developed a single intestinal loop; however, by the time larvae reached 18 mm in length, the intestine had developed many loops.

Litvinov K.V., Podolyako S.A. 2012. Fishes in the Astrakhan' Nature Reserve. *In*: Bogutskaya N.G., Kiyashko P.I., Orlova M.I., Naseka A.M. Key to fishes and mollusks of the Caspian Sea. (in press).

Larval and juvenile Silver Carp (6.7-22 mm, developmental stages B to G (Figure 2)) were collected in a channel (Bystraya) of the Volga Delta in the Astrakhan' Nature Reserve (Damchik District of the reserve). This channel is located in the western part of the Volga Delta (45.8ºN, 47.9ºE). Collected individuals were determined to be from naturally reproducing populations of Silver Carp, as hatchery-released fish of this species requires later stages of development prior to stocking. This represents the only naturally occurring spawning and development of Silver Carp from the Volga Delta since 1980.

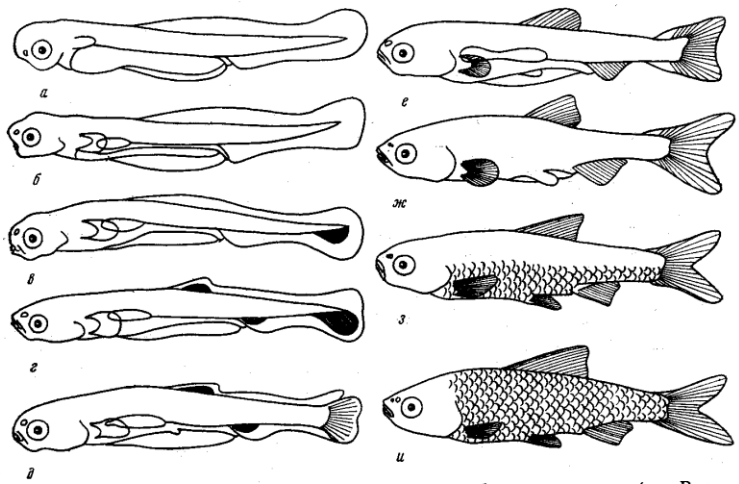

Рис. 1. Схематическое изображение развития воблы по этапам (по Васнецову, 1957):
а—этап A; *б*—этап B; *в*—этап C_1; *г*—этап C_2; *д*—этап D_1; *е*—этап D_2; *ж*—этап E; *з*—этап F; *и* — этап G.

Figure 2. Developmental stages of *Rutilus caspicus* (after Vasnetsov 1953).

Makeyeva [Makeeva] A.P. 1963. On maturation of females of Grass Carp and Silver Carp and reproduction of these fishes in the Amur basin. [O sozrevanii samok belogo amura i tolstolobika i razmnozhenii etikh vidov v basseyne Amura.] *In:* Tashliyev A.O. (Ed.). *Problems of industrial use of phytophagous fishes in waterbodies of the USSR.* [Problemy rybokhozya'stvennogo ispol'zovaniya rastitel'noyadnykh ryb v vodoyemakh SSSR.] Izdate'lstvo AN Turkmenskoy SSR, Ashkhabad. P. 76-83.

Female Silver Carp in the Amur River attained sexual maturity at a minimum age of 7 years and a size of at least 60 cm. Spawning occured once per year as evidenced by most post-spawning females having only pre-vitellogenetic oocytes (stage VI-II, Sakun and Butskaya, 1968). However, histological examination revealed some asynchronicity of oocyte maturation in a few individuals and the presence of a second generation of vitellogenetic ocytes. This may indicate repeat spawning activity; however, it is more likely that some females did not spawn annually or that the development of vitellogenic oocytes may take more than one year.

Makeyeva [Makeeva] A.P., Belova N.V., Emel'yanova N.G., Verigin B.V., Ryabov I.N. 1996. On the state of the reproductive system of bighead *Aristichthys nobilis* from the cooling pond of the Chernobyl' Nuclear Power Station during the post-catastrophe period. [Materialy po sostoyaniyu vosproizvoditel'noy sistemy pestrogo tolstolobika *Aristichthys nobilis* v vodoeme-okhladitele Chernobyl'skoy AES v posleavariynyy period]. *Voprosy Ikhtiologii*. [Journal of Ichthyology, Moscow]. Vol. 36. No. 2. P. 239-247.

Reproductive systems of Bighead Carp from the cooling tanks of Chernobyl Atomic Power Station were examined after having been subjected to nuclear radiation in 1986, at the age of 1-2 years. The gonads of mature females did not display specific malformations commonly attributed to radiation exposure, except for some cytoplasm vacuolization in previtellogenic oocytes and were capable of producing eggs of high aquaculture quality. Males, on the other hand posessed a number of malformations in their reproductive systems, including unicellular sclerosis in the gonads, lower sperm concentration in the ejaculate, and the emergence of a large number of abnormal germ cells.

Makeyeva [Makeeva] A.P., Emel'yanova N.G. 1990. A cytological examination of the preovulation oocyes in Silver Carp *Hypophthalmichthys molitrix* and the use of the method of biopsy for the evaluation of their state. [Tsitologicheskoye issledovaniye predovulyatsionnykh ootsitov belogo tolstolobika *Hypophthalmichthys molitrix* i ispol'zovanije metoda biopsii dla vyyavleniya ikh sostoyaniya]. *Voprosy Ikhtiologii*. [Journal of Ichthyology, Moscow]. Vol. 30. No. 3. P. 469-477.

The process of oocyte maturation proceeded asynchronously in individual Silver Carp. Six hours following a second injection, an individual displayed variability in oocyte development (expressed as % of total egg number): 26% of the eggs had the nucleus positioned below the egg membrane at the animal pole; 6% had formed an encapsulated karyosphere; and, 68% experienced mixing of karyoplasm and cytoplasm (nuclear structures were no longer visible). In a second individual, at 5 hours post-second injection, initiated disintegration of the nuclear membrane was observed in 33% of oocytes, whereas, in 67% of oocytes, this process was fully completed. The data on asynchronous development in pre-ovulatory oocytes confirmed that ovulation of oocytes in individual females occurs over a fixed time length, rather than simultaneously.

Makeyeva [Makeeva] A.P., Emel'yanova N.G., Belova N.V., Ryabov I.N. 1994. Radiobiological analysis of Silver Carp *Hypophthalmichthys molitrix* from the cooling pond of the Chernobyl' Nuclear Power Station during the post-catastrophe period. 2. Development of the reproductive system in offspring of the first generation. [Razvitiye vosproizvoditel'noy sistemy u potomstva pervogo pokoleniya.] *Voprosy Ikhtiologii*. [Journal of Ichthyology, Moscow]. Vol. 34. No. 5. P. 681-696.

Anomalies in the reproductive systems of Silver Carp were examined following the Chernobyl disaster. On average, 20.2% of fish were affected; 9.4% of females and 25.8% of males. The most severe effects of exposure included the occurrence of sterile individuals in 5.6% of fish. Gonad asymmetry was also observed in 9.4% females and in 16.1% males (Belova *et al*., 1993). In addition, developmental anomalies were identified in the first generation progeny of the post-disaster period. The number of fish with gonad mutations increased from 0 to 26% in the 1989 generation, and from 0 to 12% in the 1990 generation. In the second year of life, emergence of bisexual individuals was observed in 17% of females, while in the third year, sterility was found in 6% of females and 17% of males. Juveniles also exhibited other cytological disturbances that were absent in pre-exposure parent fish.

Makeyeva A.P., Soin S.G. 1963. Importance of the Middle and Upper Amur for the reproduction of commercial pelagophilous fishes. [Znacheniye srednego i verkhnego Amura v vosproizvodstve promyslovykh pelagofil'nykh ryb.] *Voprosy Ikhtiologii* [Journal of Ichthyology, Moscow]. Vol. 3. No. 4(29). P. 688-697.

A key to the pelagic fish eggs in the Amur rivershed was developed. The following characteristics were used to identify Bighead Carp eggs: eggshell diameter 4.0-5.0 mm; yolk sac diameter 1.1-1.2 mm; 24-26 trunk myotomes; and, 14-17 caudal myotomes. Grass Carp eggs were distinguished by: eggshell diameter 4.2-6.0 mm; yolk sac diameter 1.2-1.3 mm; embryos had 28-32 trunk myotomes; and, 12-14 caudal myotomes.

Miroshnichenko L.M., Kamenetskaya I.L. 1978. An observation on maturing and spawning migration of phytophagous fishes in Syr Darya. [Nablyudeniye za sozrevaniyem i nerestovoy migratsiye' rastitel'noyadnykh ryb v Syrdar'e. *In:* Konurbaev A.O. (Ed.) *Biological fundamentals of fish industry in the republics of Central Asia and Kazakhstan.* [Biologicheskiye osnovy rybnogo khozya'stva respublik Sredney Azii i Kazakhstana.] Ilim, Frunze. P. 367-368.

Observations of spawning migrations were made in the Syr Darya River, the Chardara Reservoir and upstream in Uzbekistan, from May to July 1977. The spawning run started May 20, and was associated with an abrupt rise in water level and water temperature of 20ºC. Three peaks were observed in the downstream drift of Silver Carp eggs (May 27, June 1 and June 4) at an average water temperature of 23.5 ºC. Ripe males were observed on May 23 at Chinaz, 35-40 km upstream from the reservoir. Their gonadosomatic index reached 2.56. On May 30, two ripe females were caught and measured up to 1 m long and 18 kg weight. One female was a Silver Carp with a gonadosomatic index of 35 and the other female was a Bighead Carp with a gonadosomatic index of 22.55.

Sex ratios were approximately 1:2, which was confirmed by fishermen at the spawning site, where a single female being followed by two males was observed. A second spawning site was located at the Dshidali Peninsula at a confluence of two riverine branches. The site was located 110 km upstream from the Chardarinskoye (Chardara) Reservoir, at a depth of 2m with a sandy-pebble substrate. A high rate of mortality, up to 100 females per day, was reported at this spawning site due to significant habitat alteration as a result of temporary dam construction. Significant differences in the values of gonadosomatic index were recorded, although this could be attributed to the concurrent presence of individuals at the II, III, and IV stages of maturity in the spawning stock. Some females did not take part in spawning activity due to disturbance or rapid changes in the river water level and later demonstrated resorption of eggs; histological examination did not reveal any disorders of gametogenesis.

Mukhamedova A.F. 1977. The level of standard metanolism of young Silver Carp *Hyphthalmichthys molitrix* (Val.). [Uroven' standartnogo obmena molodi belogo tolstolobika *Hyphthalmichthys molitrix* (Val.)]. *Voprosy Ikhtiologii*. [Journal of Ichthyology, Moscow]. Vol. 17. No. 2(103). P. 330-337.

Standard metabolic rate in Silver Carp fingerlings varied by stage of development. During the period of yolk feeding through larval transition to active/external feeding, gaseous metabolism was characterized by an increased level and intensity of oxidative processes related to morpho-physiological differentiation. After completing the transition into a larval organism, gaseous metabolism shifted to the general biological patterns and was dependent on body weight (expressed by the power function equation). At stages III - IV of larval development, larvae fed primarily on zooplankton and respiration rate and weight were linked by the equation $Q = 0{,}240\ w^{0.89}$. At the fry stage, when the diet shifts to planktonic algae, the equation became, $Q = 0{,}217\ w^{0.83}$. The expected standard metabolism rate in Silver Carp fingerlings (0.003-30 g) was calculated using the formula $Q = 0{,}224\ w^{0{,}85}$.

Mukhamedova A.F., Kalinina S.G. 1986. The feeding features and potential productivity of Silver Carp in the Tsymlyansk Reservoir. [Pishchevaya obespechennost' i potentsial'naya produktivnost' belogo tolstolobika v Tsimlyanskom vodokhranilishche.] *In:* Negonovskaya I.T. (Ed.). *Factors underlying fish production formation in reservoirs and ways for its increase.* [Faktory formirovaniya ryboproduktivnosti vodokhranilishch i puti eye uvelicheniya.] *Sbornik Nauchnykh Trudov GosNIORKh* [Collected Scientific Articles of State Research Institute of Lake and River Fisheries, Leningrad]. No. 242. P. 42-49.

Trophic characteristics of Silver Carp were presented. The study was based on long-term data collected from 1976 to 1984 on feeding habits of different age groups, as well as food supply in non-native waters. Data collection included 419 phytoplankton samples to examine dietary species composition and quantitative parameters, 213 seston samples, and 152 counts of primary production. Gut content analysis of 58 individuals aged 1 to

6+ years was assessed. 47 of these samples were subjected to differentiated analysis using separate treatments for subsamples of three sections of digestive tract.

Results revealed no age- or sex-related differences in dietary preferences of Silver Carp. Variation in the diet was attributed to seasonal changes and algal development in the waterbody. Silver Carp have adapted a non-specific, broad dietary spectrum which enables the species to exploit any readily abundant food sources. Average seasonal index of gut fullness was estimated at $211\ ^{o}/_{ooo}$. In spring, during periods of high diatom abundance, gut content analysis revealed a high prevalence of *Melosira* and *Stephanodiscus*. Phytoplankton accounted for 55.9%, followed by diatoms (42%) of total diet by weight. Approximately 20% of the diet was represented by detritus, semi-fermented algal cells of mixed composition and mucus.

In summer, dietary composition changes considerably. In early summer, a high proportion of mineral particles (up to 50%) was present in gut analysis. This was likely due to increased deposition of seston mineral suspension carried with the spring flood waters. Up to 30% of the diet (by weight) was represented by phytoplankton, a mixture of different algal groups that included diatoms as well as green and blue-green algae. During this period, phytoplankton underwent a characteristic seasonal change in abundance, transitioning from spring-specific diatoms to an early-summer composition of mixed species. The most frequently occurring species, both in the ecosystem as well as in the diet of Silver Carp, were predominantly summer species including *Melosira*, *Oscillatoria*, *Anabaena*, *Coelastrum*, and *Crucigenia*.

Detritus accounted for up to 5.3% of the diet by weight. The remainder was represented by zooplankton, primarily rotifers and copepods. By mid-summer, blue-green algae became the dominant fauna, both in the water as well as in the gut contents, representing 49-63% of the diet (by weight). The proportion of diatoms subsequently decreased to 9-11% of the diet. Large, colonial forms of algae with mucous membranes (e.g. *Microcystis*, *Gomphosphaeria*, *Merismopedia*) were the preferred algal species of Silver

Carp; *Microcystis* represented up to 75% of the dietary algae, whereas, *Aphanizomenon* accounted for only 5-10% despite having a similar abundance. By late summer and in autumn, the proportion of algae in the diet increased to 70% primarily due to *Microcystis.* Interestingly, this species was often the only food item found in digestive tracts of Silver Carp. Detritus was a less important food source than phytoplankton, usually represented only 15-20% of diet (by weight); however, during certain periods this proportion increased to nearly 100%.

Comparisons of food items distributed in different regions of the digestive tract did not provide resolution on feeding patterns or digestibility of various dietary items and may only give partial information on indirect indicator; in particular, the ratio of live and fermented algal cells along the digestive tract. In May, the ratio of live:fermented algal cells was 70:30 in the anterior section of the digestive tract with a shift to 40:60 in the posterior section. During the summer period, mucus-encapsulated colonies of blue-green algae were more frequent in the anterior and middle sections of the gut, whereas, mucus-free, scattered, single cells of blue-green algae occurred mostly in the posterior regions. This observation corresponded with conclusions made by Tseeb *et al*. (1976) and Vovk and Stetsenko (1985) that the digestive tract of Silver Carp was largely capable of digesting mucus of blue-green algae colonies that were rich in polysaccharides and associated bacteria.

Negonovskaya I.T., Rudenko G.P. 1974. Oxygen threshold and features of respiration exchange of the young phytophagous fish – Grass Carp *Ctenopharyngodon idella* (Val.) and Bighead Carp *Aristichthys nobilis* (Rich.). [Kislorodnyiy porog i osobennosti dykhatel'nogo obmena molodi rastitel'noyadnykh ryb - belogo amura *Ctenopharyngodon idella* (Val.) i pestrogo tolstolobika *Aristichthys nobilis* (Rich.).] *Voprosy Ikhtiologii*. [Journal of Ichthyology, Moscow]. Vol. 14. No. 6(89). P. 1111-1117.

Fry of phytophagous fishes (70-100 mg) had a very low oxygen threshold. Lethal oxygen concentrations for the most vigorous individuals ranged from 0.33 $mg*l^{-1}$(Bighead Carp) to 0.44 $mg*l^{-1}$(Grass Carp). The authors concluded that phytophagous fishes, which lived in extensively overgrown ponds with an unstable gaseous regime, were characterized by an extended lability in respiration metabolism in comparison with fish species from a more stable oxygen environment. Respiration lability in phytophagous fishes was expressed as a reduction in the respiration rate in response to deteriorating oxygen conditions and a decline in oxygen threshold.

Negonovskaya I.T., Rudenko G.P., Tereshenkov I.I. 1975. The impact of adverse environmental factors on the young phytophagous fish [Original translation: The effect of adverse environmental factors on the phytophagous fish fry]. [Vozdeystvie otritsatel'nykh faktorov sredy na molod' rastitelnoyadnykh ryb.] *In:* Rudenko G.P. (Ed.) *Biological bases of farm-market fish industry in small lakes of the North-West of the USSR.* [Biologicheskie osnovy tovarnogo rybnogo khozyaistva na malykh ozerakh Severo-Zapada SSSR]. *Izvestiya GosNIORKH*. [Proceedings of the State Research Institute for Lake and River Fisheries, Leningrad]. No. 99. P. 214-227.

Effects of adverse environmental conditions such as hypoxia (0.33-0.57 mg/1 O_2), low temperatures, starvation, and increased pH values (9-10) were examined on juvenile Bighead and Silver carps (age 1.0-1.5 months). Both species were highly sensitive to a rapid decrease in water temperature (reduction from 20-24° C to 12-14° C), which caused a decrease in feeding activity by 50% and an observed reduction in growth rate. Reduced mobility was observed with a decrease in temperature (from 10°C to 6°C), and a further drop in temperature resulted in a noticeable shift in equilibrium and death in smaller individuals. Decreased feeding intensity at low temperatures resulted in starvation of individuals which, if maintained even over a short period of time, was attributed to the death of all experimental subjects. During the autumn-winter season, phytophagous fishes were more susceptible to predation than native lake fishes due to a higher resistance to temperature fluctuations. Bighead Carp displayed a greater sensitivity to reduced oxygen levels and higher pH values, whereas, Silver Carp exhibited greater tolerance to a range of temperatures.

Nuriyev [Nuriev] Kh. 1969. On the biology of Grass Carp and Silver Carp in the Tudakul' Reservoir. [K biologii belogo amura i obyknovennogo tolstolobika v Tudakul'skom vodokhranilishche.] *Uzbekskiy Biologicheskiy Zhurnal*. [Uzbek Biological Journal]. No. 6. P. 37-39.

Growth and nutritional status (Fulton condition factor, F_{cf}) of Grass Carp and Silver Carp were studied in the Tudakul' Reservoir of Uzbekistan. In the reservoir, characterized by high water temperatures and a long vegetation growth season, fishes grew faster than in their native habitat in the Amur River or in the Aral Sea. Silver Carp in the Tudakul' Reservoir reached 18.8 cm by age 1+, 35.6 cm by age 2+ and 47.0 cm by age 3+ as compared to 11.7 cm, 24.3 cm, and 35.7 cm in the Amur River, and 12.4 cm, 24.7 cm, and 37.8 in the Aral Sea. Average measurements for Silver Carp were: at age 1+- body length=30.8 cm, weight =437 g, F_{cf}=1.43; at age 2+- body length=45.5 cm, weight=1449 g, F_{cf} =1.51 (1.39-1.60); and, at age 3+- body length=58.0 cm, weight=2860 g, and F_{cf} =1.48 (1.38-1.58).

Omarov M.O. 1970. Daily diet of Silver Carp *Hypophthalmichthys molitrix* (Val.). [Sutochnyy ratsion belogo tolstolobika *Hypophthalmichthys molitrix* (Val.).] *Voprosy Ikhtiologii* [Journal of Ichthyology, Moscow]. Vol. 10. No. 3(62). P. 580-582.

The diet of 2 year-old Silver Carp (body weight= 320-370 g) was estimated by measuring the rate of food passage along the digestive tract, adjusted to diurnal feeding patterns. Experiments were conducted in fish cages installed along the shoreline of a pond experiencing an algal bloom, to ensure persistent phytoplankton concentration for the duration of the experiment. Fish were fed with manufactured feed, floured prior to fish treatment. To determine the rate of food passage, fish were removed from cages at 15, 30, 60, and 120 minutes post-feeding and were subjected to laboratory analysis.

Assessments of diurnal feeding rhythm were based on daily fish samples taken at 4 hour intervals. Experiments were conducted in June (1966) at water temperatures of 23 °C and dissolved oxygen concentration of 4.23 $ml*l^{-1}$. Rate of food passage, reported as a percentage of the total digestive tract length, was 6.5% after 15 minutes, and 50% after 2 hours. Therefore, total gut transit time was 4 hours, allowing for 6 full cycles per day. Results indicated that Silver Carp fed primarily in daylight (84.9%), the period of most intensive feeding occurred between 16:00-20:00 and accounted for up to 23.3% of the daily food intake. Lowest feeding rate was observed from

20:00-0:00 (8.1%). Maximum value for index of stomach fullness was 403 $^{o}/_{ooo}$ (08:00) and minimum value was 142 $^{o}/_{ooo}$ (0:00). Daily food intake was estimated at 58g or 17.2% of the total fish weight; however, actual value may be even higher, since experimental conditions tend to reduce feeding activity of Silver Carp.

Panov D.A., Sorokin Yu.N., Motenkova L.G. 1969. Experimental study of feeding of the young Bighead and Silver Carp. [Eksperimental'noye izucheniye pitaniya molodi tolstolobikov.] *Voprosy Ikhtiologii*. [Journal of Ichthyology, Moscow]. Vol. 9. No. 1(54). P. 138-152.

Feeding and dietary requirements of Bighead Carp and Silver Carp fry were examined at different stages of *in vitro* development using radioactive carbon technique. At very early life history stages, minute zooplankton forms are considered the only complete food for the larvae. The optimum concentration of these forms was approximately 1,000 individulas l^{-1}. For fry aged 1.5 months, a number of algal species were identified as critical food items and the optimum concentration should be approximately 20 mg l^{-1}, threshold value of 4.2 mg l^{-1}.

Pavlov D.S., Aliyev D.S., Shakirova F.M., Nezdoliy V.K., Ostrovskiy M.P., Dzhemileva T.G., Malakhova T.V., Nikolayev A.A., Sukhanova A.I. 1994. *Biology of fishes of the Saryyazyn Reservoir.* [Biologiya ryb Saryyazynskogo vodokhranilishcha]. Gidroproekt, Moscow. 150 pp.

The Saryyazyn Resevoir is unique due to its ability to support a self-sustaining population of introduced Silver Carp. Adult Silver Carp migrated upstream, entering the Murhab River and continued approximately 150 km upstream to spawn. Both males and females matured at an age of 4 years; at a length of 50.5-55.0 cm in males and 52.2-65.0 cm in females. Absolute fecundity ranged from 135,800 to 552,500 eggs in fish measuring 46.0-79.0 cm (approximately 1.8-8.5 kg). Researchers found some heterogeneity of oocytes in the ovaries. A number of fish had larger than average eggs, which measured 1.11-1.32 cm in diameter and accounted for 59.4-100% of gonad weight. Others had smaller than average eggs, which measured 0.7-1.06 cm in diameter and accounted for 40.6% of gonad weight. Observed heterogeneity may indicate that Silver Carp are a portion spawner in this reservoir; however, other possible explanations include egg heterogeneity reflects unsatisfactory environmental conditions, such as limited food resources, in the reservoir.

Silver Carp fed on zooplankton until they reached a length of 10-15 cm; after which they switched to primarily phytoplankton and detritus (45.4-97.2% of the total gut content). Food composition included 76 species of algae, two species of rotifers (*Keratella cochlearis* and *K. quadrata*), one cladoceran species (*Bosmina longirostris*), and seeds of higher order plants. A tapeworm (*Ligula intestinalis*) was present in body cavities of 5-15.1% of individuals and is known to inhibit host gonadal development.

Payusova A.N., Tselikova T.N. 1981. The differences and differentiation between stockes of different origin of Grass Carp, *Ctenopharyngodon idella* (Val.), Silver Carp, *Hypophthalmichthys molitrix* (Val.) and Bighead Carp, *Aristichthys nobilis* (Rich.) carps based on electrophoretic spectra of miogens. [Razlichiya i differentsiatsiya stad raznogo proiskhozhdeniya belogo amura *Ctenopharyngodon idella* (Val.), belogo *Hypophthalmichthys molitrix* (Val.) i pestrogo *Aristichthys nobilis* (Rich.) tolstolobikov po elektroforeticheskim spectram miogenov.] *Voprosy Ikhtiologii*. [Journal of Ichthyology, Moscow]. Vol. 21. No. 4. P. 608-615.

An electrophoretic study of water-soluble muscle proteins revealed differences in the myogenic spectra of Bighead Carp, Grass Carp, and Silver Carp. Results indicated that the myogenic spectra were monomorphic and species-specific. Hybrids between Bighead Carp and Silver Carp were similar to Bighead Carp in coloration, but featured the myogenic spectra characteristics of both parental species. Species-level geographic variation in myogenic spectra from the Yangtze and Amur rivers were established for Grass Carp and Silver Carp. Hybrids, crossing Silver Carp from different geographic regions had myogenic spectra attributes from both source regions. Examination found no individual or interpopulation differences in myogenic spectra in Yangtze River carps introduced over broad geographic areas, ranging from the Moscow region to waterbodies of Central Asia, which confirmed strong inheritance of this physiological attribute.

Radenko V.N., Alimov I.A. 1991. The importance of temperature and light for the growth and survival of larvae of Silver Carp *Hypophthalmichthys molitrix.* [Znacheniye temperatury i sveta dla rosta i vyzhivayemosti lichinok belogo tolstolobika *Hypophthalmichthys*

***molitrix*.] *Voprosy Ikhtiologii* [Journal of Ichthyology, Moscow]. Vol. 31. No. 4. P. 655-663.**

Different thermal and photic preferences of Silver Carp larvae at stages I-IV of development were tested under experimental rearing conditions. Results indicated that water temperature of approximately 32 °C, an emission peak in the blue-green spectrum range, and luminous flux density of about 100 flux at the surface enabled optimal growth and survival of larvae.

Rykova T.I. 1964. On the salt tolerance of the Chinese phytophagous fishes during the early developmental stages. [O soleustoychivosti kitayskikh rastital'noyadnykh ryb na rannikh stadiyakh razvitiya.] *In:* Karpevich A.F. (Ed.) Acclimatization of fish and food organisms in seas of the USSR. [Akklimatizatsiya ryb i kormovykh organizmov v moryakh SSSR.] *Trudy VNIRO.* [Proceedings of All-Union Institute for Fisheries and Oceanography]. Vol. 55. No. 2. P. 195-196.

Salt tolerance of eggs and larvae of Grass Carp and Silver Carp was tested at varying salinities in water from the Black and Caspian seas. Egg development of both species in water from the Black Sea (1.9-4.9 ‰ salinity) was relatively normal; however, as salinity approached 6.3‰ or higher, egg development ceased at the blastodisc stage of cell division. All eggs undergoing gastrulation were destroyed at 9.4‰ salinity. Embryos successfully hatched at 3.2-4.9‰ salinity in water from the Black Sea. In freshwater, embryos survived the duration of the experiment (4 to 9 days post-hatch). Eggs reared at 6.3‰ salinity had limited hatching success and all hatched embryos died within a few hours. Silver Carp larvae had a slightly higher salinity tolerance than did Grass Carp; however, onset of mortality began at 6.3‰. In water from the Caspian Sea, a greater range of tolerance was observed. Normal development and hatching of eggs was observed at 4.2-5.9‰ salinity. Higher saline concentrations resulted in developmental abnormalities and, at 11.5‰ salinity, resulted in complete mortality of all embryos (either at the moment of hatching or within 24hours). Silver Carp larvae were able to survive in Caspian Sea water up to a salinity of 6.0‰.

The process of absorption of water by the membrane was also examined. Results indicated that the volume of the perivitelline space increased from 0 to 20-30 mm^3 in freshwater at a temperature of 19.4-20.6 ºC, 90 minutes post-fertilization. Eggs that developed in a more saline environment had a lower water volume in the perivitelline space. After incubation for 3.5 hours, Grass Carp eggs exhibited a perivitelline space volume of 16.403 mm^3 in freshwater, 2.053 mm^3 in Black Sea water (9.0‰ salinity), and 0.718 mm^3 in Caspian Sea water (11.7‰ salinity). Data were not provided for Silver Carp.

Rykova T.I. 1980. The influence of water salinity on the development of eggs of Grass Carp, Silver Carp, and Bighead Carp. [Vliyanie solenosti vody na razvitie ikry belogo amura i tolstolobikov]. *In:* Kamilov G.K. (Ed.). *Phytophagous fishes in industrial fish culture. Book of Abstracts of the 9th All-Union Conference.* [Rastitel'noyadnye ryby v promyshlennom rybovodstve. Tezisy dokladov IX Vsesoyuznogo Soveshchaniya.] Izdatel'stvo AN UzSSR, Tashkent. P. 191-192.

Fertilization of Bighead Carp, Grass Carp, and Silver Carp occurred both in fresh- and brackish water, at a salinity threshold of 7.5 ‰, above which resulted in a delayed cortical reaction, increased sperm activity, and feasible polyspermy. Normal larval and egg development occured below 5‰. Increased salinity resulted in decelerated embryonic development and delayed hatching attributed to an increase in membrane density. Increased salinity during egg incubation resulted in various morphological defects and developmental abnormalities including decreased body length of hatchlings. A high threshold for salinity tolerance combined with a narrow optimum salinity range for embryos of the Far-East carps was likely determined by their developmental adaptation (maximum egg hydration with water content of 99%). In brackish water environments (salinity ≥5 ‰), embryos of the Far-East carps developed under strained osmotic conditions as a result of high membrane permeability to water and salt ions. Level of egg hydration was not the most significant factor in embryonic development; instead, the concentration of monovalent chlorine and sodium ions and their subsequent impacts were more critical. Embryonic defects in embryos of the Far-East carps that occurred during exposure to seawater were attributed to the effects of sodium (the dominant seawater cation) and associated osmotic forces.

Shakirova F.M. 1985b. On the feeding of Silver Carp in Khauzkhan and Saryyazyn reservoirs in Turkmenistan. [Materialy po pitaniyu belogo tolstolobika Khauzkhanskogo i Saryyazynskogo vodokhranilishch

Turkmenistana.] ***Izvestiya AN Turkmenskoy SSR. Seriya Biologicheskiykh Nauk*****. [Proceedings of the Academy of Sciences of the Turkmenskaya SSR, Biological Series.] No. 4. P. 9-13.**

Silver Carp in the Khauzkhan and Saryyazy Reservoirs fed on many species of plankton and algae, but often consumed a larger proportion of zooplankton. Silver Carp exhibited opportunistic feeding behaviour and began to feed on detritus when preferred food sources were not readily available. Analysis of daily feeding behaviour revealed two peaks in feeding behaviour, one in the morning and another in the evening.

Shcherbina M.A., Giryayev A.S. 1990. Influence of the joint wintering of carp *Cyprinus carpio* and Bighead Carp *Aristichthys nobilis* on their survival and metabolism. [Vliyaniye sovmestnoy zimovki na vyzhivayemost' i obmen veshchestv u karpa *Cyprinus carpio* i pestrogo tolstolobika *Aristichthys nobilis*.] *Voprosy Ikhtiologii*. [Journal of Ichthyology, Moscow]. Vol. 30. No. 2. P. 347-350.

Estimation of the lowest thresholds for metabolism and survival rates of Bighead Carp during overwintering in ponds (6.5 months of the cold season, water temperature 1-8 ºC) were discussed. During the cold season, average individual weight decreased from 40.6 to 36.6 g (9.9% reduction), body condition index decreased from 2.1 to 1.7, and survival rate was 77.4%. Autumn body composition was determined to be 80.0% water, 20.0% dried substance, 11.8% wet protein, 2.7% carbohydrates, 2.2% lipids, 3.3% mineral substances, and 96.9 kkal/100 g total energy. Spring body composition was reported as 83.3%, 17.0%, 9.0%, 2.4%, 1.8%, 3.8%, and 76.5 kkal/100 g, respectively, which indicated that overwinter starvation resulted in a considerable increase in total body water and a loss of organic substances.

Shchechka E.I. 1980. Growth of Silver Carp in ponds with different water mineralisation. [Rost belogo tolstolobika v prudakh s povyshennoy mineralizatsie' vody]. ***In:*** **Kamilov G.K. (Ed.).** ***Phytophagous fishes in industrial fish culture. Book of Abstracts of the 9th All-Union Conference.*** **[Rastitel'noyadnye ryby v promyshlennom rybovodstve. Tezisy dokladov IX Vsesoyuznogo Soveshchaniya.] Izdatel'stvo AN UzSSR, Tashkent. P. 90-91.**

Effects of mineral concentrations on the growth of Silver Carp were examined. Fish were raised in ponds with mineral concentrations of 1 to ≥8.0 g/l. Young-of-the-year fish exhibited variable growth rates and accumulated body mass based on environmental conditions: 16.9-42.0 g body weight (mineral concentration 2 g/l), 13.6-20.8 g (2-5 g/l), 11.5-31.5 g (5-8 g/l), and 27.0 g (≥8 g/l). Body weights of 2 year-old fish ranged from 292-323 g at a mineral concentration ≤2 g/l, 520-680 g at 2-5 g/l, and 510-711 g at 5-8 g/l. Survival and growth rates varied significantly amongst individuals and were highly correlated to environmental conditions in the ponds and food availability rather than mineral concentration.

Shubnikova N.G. 1979. On sexual dimorphism in Silver Carp. [O polovom dimorfizme u belogo tolstolobika.] *Voprosy Ikhtiologii* [Journal of Ichthyology, Moscow]. Vol. 19. No. 3. P. 555-558.

Sexual dimorphism in Silver Carp was examined. Male fish were distinguished by the presence of notches (visible once males reached 20 cm TL) on the inner surface of the first pectoral fin ray, a character absent in females. Notable differences in morphometric characteristics were found between male and female fish of 60-70 cm TL. At an average size of 65.9 cm TL in males and 67.4 cm TL in females, sexual dimorphism was identified in 6 of 19 morphological features. Males exhibited longer pectoral and pelvic fins, whereas, females had longer postdorsal, pelvic-anal fin distances, and a greater body depth. However, as with other size groups, these differences had low statistical reliability (M_{diff} 3.0 to 4.9, P> 0.999). Comparison of statistical reliability for Silver Carp of different size groups, revealed that no differences were sustained through the entire life cycle with the exception of postdorsal distance in fish of size I and III classes. Many significant differences among spawning-age fish were hypothetically correlated to gonadal development and reproductive maturity, since egg presence and development greatly influenced abdominal morphology (maximum body depth, postdorsal, pelvic-anal fin distances).

Sobolev Yu.A. 1970. Feeding interactions of the young of Grass Carp, Bighead Carp and Silver Carp during the joint rearing in ponds in Belorassia. [Pishchevyye vzaimootnosheniya molodi belogo amura, obyknovennogo tolstolobika i karpa pri sovmestnom vyrashchivanii v prudakh Belorussii]. *Voprosy Ikhtiologii*. [Journal of Ichthyology, Moscow]. Vol. 10. No. 4(63). P. 711-718.

Methods for rearing young-of-the-year phytophagous fishes in polyculture were described. Stocking densities of 30-50 000 individuals ha^{-1} of Grass Carp, 20-30 000 individuals ha^{-1} of Bighead Carp, and 60 000 individuals ha^{-1} of Silver Carp were reported. Stocked densitities resulted in insignificant food competition and low strain on food resources between species during feeding activities. Reduced resource competition for food and a transition to species-specific food items were thought to promote growth among fishes. Silver Carp began consuming phytoplankton 18 days post-hatch and Grass Carp switched to macrophytes at 35 days. Grass Carp fry displayed distinct food preferences, selecting for *Daphnia longispina*, *Poliphemus pediculus*, *Bosmina longirostris*, and *Scapholeberis mucronata* while selecting against *Copepoda*, *Chydorus* and *Ceriodaphnia*.

Soin S.G. 1963. Morpho-ecological features of the Grass Carp and Silver Carp development. [Morfo-ekologicheskiye osobennosti razvitiya belogo amura i tolstolobika.] *In:* Tashliyev A.O. (Ed.). *Problems of industrial use of phytophagous fishes in waterbodies of the USSR.* [Problemy rybokhozya'stvennogo ispol'zovaniya rastitel'noyadnykh ryb v vodoyemakh SSSR.] Izdat. AN Turkmenskoy SSR, Ashkhabad. P. 100-137.

A detailed description of embryonic and larval development of Grass and Silver Carp was provided. This report provided a preliminary introduction to the subject area and an enhanced understanding of terminology used on the subject and in subsequent publications. Good quality drawings were provided that were useful for identification of embryos and larvae.

Developmental processes of Grass Carp and Silver Carp were divided into periods, further divided into stages, and each stage subdivided into phases. 30 phases of development were described, beginning at fertilization and proceeding to development at 13-15 mm in length.

Soin S.G., Sukhanova A.I. 1972. A comparative morphological study of White and Black Amur, Silver Carp, and Bighead Carp (family Cyprinidae). [Sravnitel'no-morfologicheskiy analiz belogo i chernogo amurov, belogo i pestrogo tolstolobikov (sem. Cyprinidae)]. *Voprosy Ikhtiologii*. [Journal of Ichthyology, Moscow]. Vol. 12, No 1(72). P. 72-83.

Morphological features observed in the development of embryos, larvae, and fry of Grass, Bighead, Black and Silver Carps were discussed. These pelagic species were characterized by early hatching, underdeveloped embryonic respiratory structures, delayed onset of pigmentation, and accelerated development. Additionally, a number of significant species-specific differences in size of eggs and embryos, number of myotomes, pattern and degree of pigmentation, ratio of jaw development, location of unpaired fins, development of keel and scales, as well as other morphological characters were presented.

Sukhanova A.I. 1966. Embryonic development of Bighead Carp, *Aristichthys nobilis* (Rich.). [Razvitiye pestrogo tolstolobika *Aristichthys nobilis* (Rich.).] *Voprosy Ikhtiologii.* [Journal of Ichthyology, Moscow]. Vol. 6, No 2(39). P. 264-276.

Adult Bighead and Silver carps share a number of morphological features. Bighead Carp were distinguished by having darker body coloration, different spatial location of the keel and eyes, and possible differences in gill structures. Relative to Silver Carp, Bighead Carp eggs were larger with an average diameter of 1.46 mm, as compared to 1.16 mm. Average diameter of fully hydrated eggs was also larger in Bighead Carp (4.98 mm vs. 4.03 mm in Silver Carp). Bighead Carp embryos were larger than those of Silver Carp, hatchlings measured 5.5-6.0 mm in total length (TL) as compared to 4.5-5.5 mm TL for Silver Carp. Development and morphology of embryos and larvae were very similar in both species. Length of embryonic stages were consistent between species and varied with water temperature.

Interspecific differences were observed based on the number of myotomes present. Development of the gill apparatus was not described for Silver Carp, therefore, could not be compared between species. The pattern and degree of pigmentation was similar between Bighead and Silver carps, with the exception of minor differences in pigmentation observed of the preanal fold and the area between the notochord and intestine. Morphological differences in more developed larvae were observed between species. Bighead Carp larvae displayed a protruding lower jaw that extended beyond the upper jaw, as compared to a non-protruding lower jaw in Silver Carp.

Insertion of the pectoral fin base in relation to the pelvic fin base also varied and was posterior in Bighead Carp but anterior in Silver Carp. Additionally, the location of the pre-anal fold was located between the pelvic fin and anus in Bighead Carp, whereas, it originated from the pectoral fin base in Silver Carp.

Sukhanova E.R. 1968. A role of Cyclops (*Acanthocyclops vernalis* Fisch.) for the survival of Silver Carp. [Rol' tsiklopov (*Acanthocyclops vernalis* Fisch.) v vyzhivanii lichinok belogo tolstolobika.] *Voprosy Ikhtiologii* [Journal of Ichthyology, Moscow]. Vol. 8, No 3(50). P. 584-586.

Cyclops, *Acanthocyclops vernalis*, is one of the most abundant and dangerous predators to early Silver Carp larvae. Rate of larvae predation was dependant on the stage of development and relative density of Cyclops. *In vitro*, with a Cyclops density of 1500 individuals/litre, 86.6-100% of Silver Carp larvae at the 23th, 24th and 25th stages of development (Soin 1963) were consumed in 1.5-2 hours. After reducing the abundance of Cyclops to 111 ind/l, predation pressure resulted in the elimination of 32.4% of larvae in 4 days. Following development to the 27th larval stage, Silver Carp larvae were able to avoid predation, even with increased cyclops density (618 ind/l). In Krasnodar Kray, Silver Carp larvae reached the 27th stage of development at 14 days post-hatch.

Sysoyeva T.K. 1958. Age and growth of the Amur Silver Carp. [Vozrast i rost amurskogo tolstolobika.] *In:* Nikol'skiy, G.V. (Ed.). *Proceedings of the Amur Ichthyological Expedition in 1945-1949.* [Trudy Amurskoy Ikhtiologicheskoy Ekspeditsii 1945-1949 godov.] Vol. 4. P. 141-147.

Analysis of data collected from 605 Silver Carp between 1945 and 1948 was presented. Based on results of this study, Silver Carp should be included in the group of Amur River fish species with the highest growth rates. Growth rates of Silver Carp were consistent across geographic distribution along the lower reaches of the Amur River. Two growth phases of Silver Carp were identified: the first phase occurred until sexual maturation is reached; and, the second phase was initiated when gonadal development began. Growth rates varied seasonally, as evidenced by yearly growth increments on body scales that appear in June and July. Fish grew rapidly most notably in

July and August and a sharp decline in growth rate occurred during winter months. Silver Carp eggs were carried downstream once water temperatures reached 17°C with the majority of eggs migrating between 21 and 26 °C. A sharp decrease in water temperature (≤17 °C) terminated migration and caused mortality in a proportion of fertilized eggs.

The Amur River was characterized by various abiotic conditions that remained constant despite water level fluctuations: dissolved oxygen of approximately 10 mg*l^{-1}; pH 6.2-6.4; and, free carbon dioxide concentration of 10.3 mg*l^{-1}. Turbidity and water transparency were highly correlated to water levels. In the Sungari River, water transparency ranged from 10-65 cm, whereas, in the Amur River, values were reported between 30 and 90 cm and did not affect downstream migration of Silver Carp and Grass Carp embryos. Water level was determined to be the most significant factor affecting spawning success in Silver Carp following observations of spawning activity and downstream migration of embryon. Migration of embryos was consistent in both in high- and low-water years, regardless of the relationship between the rise in water level and previous water mark during summer months. However, this relationship was affected when water temperatures dropped below 17 °C and high waves were present.

Spawning success in Silver Carp varied greatly between years. Observations were based on analysis of spawning females of varying maturity indices (4-10%) and total lengths (58-78 cm TL). The proportion of females with unreleased eggs varied from 4-70% and was highest when water conditions during the peak spawning period were unfavourable. In years when 2-3 cycles of water level increases occurred (rise in water level by up to 2 m for 1-2 weeks duration/cycle), favourable conditions existed for spawning activity in the Amur River. Thermal constant/accumulated heat during pre-spawning (476-660 degree-days) and the main spawning time (515-685 degree-days) were not a determining factor for the spawning success of Silver Carp.

Varaksa E.S. 1980. An experiment of the polyculture of buffalo, Silver Carp and carp in the water of increased mineralisation. [Opyt

polikul'tury buffalo, belogo tolstolobika i karpa pri vysokoy mineralizatsii vody]. *In:* Kamilov G.K. (Ed.). *Phytophagous fishes in industrial fish culture. Book of Abstracts of the 9th All-Union Conference.* [Rastitel'noyadnye ryby v promyshlennom rybovodstve. Tezisy dokladov IX Vsesoyuznogo Soveshchaniya.] Izdatel'stvo AN UzSSR, Tashkent. P. 40-41.

Experiments on survival and growth of Silver Carp and other fish species in ponds with a high mineral concentration (2 to 12.5 g/l) were conducted. Young-of-the-year Silver Carp demonstrated good growth rates with an average weight of 50 g and high survival rate (66.7%).

Vechkanov V.R. 1975. The intensity of respiration in Silver Carp (*Hypophtalmichthys molitrix* (Val.). [Intensivnost' dykhaniya belogo tolstolobika *Hypophthalmichthys molitrix* (Val.).] *Voprosy Ikhtiologii*. [Journal of Ichthyology, Moscow]. Vol. 15. No. 4(93). P. 720-724.

Experiments were conducted from mid-June to mid-July on Silver Carp weighing 60-240 g, with an index of stomach fullness between 500-600%oo. Experimental water conditions ranged from 21-26 °C with little fluctuation (± 0.2 °C). Initial concentration of dissolved oxygen was 8-10 mg*l^{-1}, and the average seston concentration was 50 mg of dry matter/liter which decreased the threshold oxygen concentration required for respiration by less than 10% during the experimental period. Results indicated that an increase in body weight, from 63 to 240 g, resulted in an increase in oxygen consumption from 16.57 to 55.2 ml*h^{-1} and a decreased in respiration rate (*Q/W*) from 0.197 to 0.173 ml*g^{-1} h^{-1} (values are adjusted to 20 C°).

In subsequent experiments, a broader range of study weights were included. Juvenile carp (0.6-8.2 g) and 2 year-old fish (67-195 g) exhibited a significantly reduced index of gut fullness (80-300‰) during this period (mid-late September). Initial concentration of dissolved oxygen was 10 mg*l^{-1}. Under experimental conditions of water at 14-16 °C, an increase in body weight from 0.8 to 195 g resulted in an increase in oxygen consumption from 0.239 to 23.6 ml O_2*h^{-1} and decreased respiration rate from 0.299 to 0.121 ml O_2*g^{-1} h^{-1}(or 0.459 to 0.189 ml O_2*h^{-1} at 20°C). At water temperatures of 11-13 °C, an increase in individual weight from 0.6 to 195 g resulted in a decrease in oxygen consumption from 0.361 to 0.066 ml O_2*h^{-1} (0.723 to 0.131 ml O_2*h^{-1} at 20°C).

Verigin B.V. 1950. Age-dependent variability in young Silver Carp (*Hypophtalmichthys molitrix* Val.) depending on its biology. [Vozrastnyye izmeneniya molodi tolstolobika (*Hypophtalmichthys molitrix* Val.) v svyazi s eye biologiyey.] *In:* Nikol'skiy, G.V. (Ed.). *Proceedings of the Amur Ichthyological Expedition in 1945-1949.* [Trudy Amurskoy Ikhtiologicheskoy Ekspeditsii 1945-1949 godov.] Vol. 1. P. 303-318.

Morphological changes were described for Silver Carp larvae, 7-52 mm long. Development of body shape, fins, digestive tract, and size and position of the eye were examined. The developmental process, growth up to 52 mm in body length, was subdivided into 7 stages. Stage 1, from hatching, was characterized by the absence of a swim-bladder, a non-differentiated fin fold, and feeding exclusively on yolk. Stage 2 began with the filling of the swim-bladder and the differentiation of the fold into dorsal, caudal, pre-anal and postanal fin folds. The caudal fin fold was especially well-developed. Pigmentation was absent or, by the end of the stage, very light. The yolk sac was reduced and the embryo started active feeding, turning into the larva. Stage 3 started at a length of 7.5 mm, when the larva had completed its pelagic life stage and actively migrated to river banks. Yolk was completely resorbed and the larva was dependant on external feeding only. The body, fins and pre-anal fold were pigmented. The dorsal fin appeared and the caudal fin was rounded and skeletal elements formed in other fins. The posterior end of the notochord was straight and the intestine was only slightly curved. Stage 4 occurred between 9-11.5/12 mm body length. The end of the notochord had curved upwards, the caudal fin was forked, and the first pair of intestinal loops had appeared. Precursors of the pelvic fins were visible, but had not emerged. Stage 5 was characterized by active swimming and predation upon relatively large and mobile prey (*Daphnia* and *Bosmina*). A second pair of intestinal loops had appeared and eye diameter increased considerably. Body width also increased, from 21% to 25-26% of body length. Dorsal and anal fins had become separated from the fin fold, and the pelvic fins had developed, increasing ease of maneuverability. Stage 6 occurred at length of about 15 mm. The length of the intestine had doubled previous length. Head size had increased from 30-32% to 35-36% of body length. The relative size of the eye became smaller and the eye moved to a lower position on the head. The pre-anal fold became the abdominal keel as it filled with muscular and lipid elements. Onset of crosspiece development between the gill rakers had begun at a length of about 12 mm. This stage was long, and terminated once larvae had attained 52 mm in body length. During stage 7, fish attained adult morphological features. Juveniles were similar in appearance to the adults, demonstrated a lower position of the eye relative to the mouth, and exhibited a decurved lateral line. At this stage, young fish migrated from river banks to open areas of waterbodies.

Verigin B.V. 1957. Structure of the gill apparatus and epibranchial organ in Silver Carp. [Stroyeniye zhabernogo apparata i nadzhabernogo organa tolstolobika.] *Zoologicheskiy Zhurnal* [Zoological Journal, Moscow]. Vol. 36. No. 4. P. 595-602.

The gill apparatus of Silver Carp was decribed within the context of trophic biology. Filter feeding of phytoplankton and detritus is a critical attribute of Silver Carp, which has promoted the adaptive success of the species. The principal feature of the gill apparatus was the large number of gill-filaments, 13-14/mm of the arch length. The gill-filaments were interconnected by transverse bridge-like anastomoses, which enabled each row of gill-filaments to form a single network. Each network consisted of two sections: the internal filtration section, comprised of fine (0.05 mm) filaments; and, the external section that consisted of thickened filaments and functioned as a support structure for the filtration section. Each branchial arch supported one paired structure that formed a longitudinal groove into which palatal folds extended. The suprabranchial organ consisted of 8 close-set hollow spirals, located in the thickness of palatal tissue under the skull base. The skeleton of the suprabranchial organ in Silver Carp was cartilaginous and represented a prolongation of branchial archs, with gill-filaments hanging down into the cavity of the curl beneath the skull base. Two rows of gill-filaments, one row of two adjacent branchial archs, entered each curl. The external row of gill-filaments of the first branchial arch did not enter the organ. The skeleton of the suprabranchial organ was made of two types of cartilage: principal cartilages, on which gill-filaments are arranged; and, covering cartileges, arranged between the curls and covering their anterior wall. Each fourth curl had a single cartilage. The suprabranchial organ arose when larvae reached

8-11 mm body length and the first "bridges" between the gill-filaments appeared at 18 mm.

Verigin B.V., Makeyeva A.P., Shubnikova N.G. 1979. A case of natural hybridisation *Hypophthalmichthys molitrix* and *Aristichthys nobilis* (Pisces, Cyprinidae). [Sluchay estestvennoy gibridizatsii tolstolobikov *Hypophthalmichthys molitrix* x *Aristichthys nobilis* (Pisces, Cyprinidae).] *Zoologicheskiy Zhurnal* [Zoological Journal, Moscow]. Vol. 58. No. 2. P. 190-196.

Broad-scale hybridization occurred between Bighead and Silver Carps in the Syr Darya River in 1977. Parental species differed from each other in 11 of 21 characteristics. Hybrids occupied an intermediate position between the parental species, but shared more features with Bighead Carp than Silver Carp. Researchers postulated that intensive hybrid introgression occurred between Bighead and Silver Carp in the Syr Darya River.

Voropayev N.V. 1975. Features of biology and industrial value of hybrids between Bighead Carp and Silver Carp. [Osobennosti biologii i khozyaistvennaya tsennost' gibridov tolstolobika]. *In*: Vinogradov V.K. (Ed.) *Polyculture of phytophagous fishes in pond fish industry and in natural waterbodies.* [Polikul'tura rastitel'noyadnykh ryb v prudovom khozya'stve i estestvennykh vodoyemakh.] *Collected Scientific Articles of All-Union Research Institute of Pond Fish Industry*. [*Sbornik Nauchnykh Trudov VNIIPRKh*]. No. 15. P. 19-42.

Embryonic and post-embryonic development was examined in Bighead and Silver Carps as well as their reciprocal hybrids. Morphological characters, survival rate, and timing of major developmental stages in parental species and both hybrids were reviewed. Hybrids more closely resembled maternal species in many attributes; however, growth and survival rates of hybrid individuals exceeded those observed in Bighead Carp. Dietary preferences at varying stages of development and growth in larval and 2+ hybrids were also examined. Reproductive traits of hybrids were reviewed, with good survival rates seen amongst progeny. Morphological characters and trophic attributes of second generation hybrids were also investigated.

Voropayev N.V. 1975b. A comparative characteristics of the gonad development in Silver Carp and Bighead Carp hybrids. [Sravnitel'naya kharakteristica razvitiya gonad gibridov belogo i pestrogo tolstolobikov.] *In*: Vinogradov V.K. (Ed.) *Polyculture of phytophagous fishes in pond fish industry and in natural waterbodies.* [Polikul'tura

rastitel'noyadnykh ryb v prudovom khozya'stve i estestvennykh vodoyemakh.] ***Collected Scientific Articles of All-Union Research Institute of Pond Fish Industry*. [*Sbornik Nauchnykh Trudov VNIIPRKh*]. No. 15. P. 87-93.**

Morphological and histological development of the reproductive system in reciprocal hybrids of Bighead and Silver carps was examined. Ovaries and testicles were studied at various stages of development, from larvae to sexual maturity. In the Krasnodar Kray Resevoir, females reached maturity at age of 4+ years, and males at 3+. No gonadal abnormalies were noted and both male and female individuals were fertile.

Vovk P.S., Stetsenko L.A. 1985. *Phytophagous fishes in the ecosystem of water reservoirs.* [Ryby-fitofagi v ekosisteme vodokhranilishch.] Naukova Dumka, Kiev. 136 pp.

Biological characteristics of Bighead Carp and Silver Carp from their original geographic distributions were reviewed, as well as a brief discussion of their role in fisheries in the region. Variations in biology of Far-East carps inhabiting both pond and reservoir habitats were discussed. Physiological and biochemical characteristics of Bighead and Silver Carp were examined within the context of long-term seston consumption and toxicological evaluation. Other areas of discussion included the utilization of seston components, biochemical characteristics of Silver Carp feeding on seston, and a toxicological evaluation of tissues of carp that fed on seston and blue-green algae.

Vybornov A.A. 1989. The impact of Silver Carp *Hypophthalmichthys molitrix* on the productivity parameters of phyto- and zooplankton in experimental conditions. [Vliyaniye belogo tolstolobika *Hypophthalmichthys molitrix* na produktsionnyye pokazateli fito- i zooplanktona v eksperimental'nykh usloviyakh.] *Voprosy Ikhtiologii* [Journal of Ichthyology, Moscow]. Vol. 29. No. 5. P. 874-878.

This study examined the effect of Silver Carp on phytoplakton and zooplankton development. The presence of Silver Carp in waterbodies reduced the biomass of phytoplankton and zooplankton and increased primary production of the waterbody as a result of increased photosynthetic activity of algae. Fish densities in the waterbody were directly correlated to the magnitude of changes seen in phytoplankton and zooplankton.

Zambriborshch F.R. 1957. Structure and function of the epibranchial organ in Silver Carp [Stroyeniye i funktsiya nadzhabernogo organa tolstolobika.] *Zoologicheskiy Zhurnal* [Zoological Journal, Moscow]. Vol. 36. No. 4. P. 587-594.

Historically, Silver Carp were raised in aquaculture in the Far East but have since dispersed into waterbodies in the European region of the Soviet Union. Silver Carp fed primarily on phytoplankton and exhibited morphological adaptations for this trophic specialization. The suprabranchial organ formed a spiral of upper elements of epi- and pharyngo-branchialia with their branchial filaments strongly reduced and arranged in spiral canals. The number of “dead-end” canals corresponded to that of the branchial arches (4 on each side). Each canal, with its mucous membranes on lateral and internal surfaces, was encircled in muscles attached to the skeletal base (infrapharyngobranchiale) which formed the external canal wall. Two rows of shortened gill-filaments were arranged in the canal, dividing it into larger, internal helicous canals and smaller external canals.

Gill-filaments densely set on the arch were interconnected by means of transverse anastomoses which resulted in a dense, porous filter with a diameter (on examined specimens) not more than 20 μm. Gill-filaments were arranged on each branchial arch at an acute angle, such that the distal ends protruded into the fissures of the dorsal wall of the pharynx. In contrast, palatal folds protruded out into the grooves formed by the filamental rows of each arch. Food particles that accumulated on the filaments couldnot directly reach the pharynx and were first suctioned dorsally towards the region of the epibranchia. The movement of filtered food particles to the pharynx was achieved by the cochlear canals. As the canals increased in volume, food particles accumulated on the filaments were moved posteriorly along the grooves. With the subsequent volume reduction, particles were swept from the water, off the cochlear canals to the floor of the pharynx and inhibited the possibility of a blockage in the filamentous sifting apparatus due to food or silt. The suprabranchial organ was the most important component of the pharyngeal filtering apparatus.

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Kolar, C.S., Chapman, D.C, Courtenay, W.R., Housel, Jr.C.R., Williams, J.D., and Jennings, D.P. 2007. Bigheaded carps: a biological synopsis and environmental risk assessment. American Fisheries Society Special Publication 33. Bethesda, MD.

Appendix 1. Annotated extracts on Bighead Carp, *Hypophthalmichthys nobilis* from: Mitrofanov V.P., Dukravets G.M., Sidorova A.F. et al. 1992. *Fishes of Kazakhstan.* [Ryby Kazakhstana.] Vol. 5. *Introductions, fisheries*. [Akklimatizatsiya, promysel.] Gylym, Alma-Ata. 464 pp.

DISTRIBUTION

Bighead Carp are a species included in the China Plain ichthyo-faunistic complex. Previously, Bighead Carp had only been recorded from Chinese waters south of the Amur River drainage (Nikolskiy, 1983); however, by the late 1950-early 1960’s, flooding events in the Songhua River system (the Sungari River), enabled the species to disperse from pond farms to the lower section of the Miºdle Amur River (Krykhtin 1972). Bighead Carp were reared under aquaculture programs in 32 countries in Asia, Europe, North and South America, as well as throughout the Union of Soviet Socialist Republics (USSR), and in drainage basins of the Volga, Kuban, Amu Darya, and Syr Darya rivers (Jennings 1988). In Central Asia and Kazakhstan, this species became established in both the Amu Darya and Syr Darya basins. Bighead Carp were introduced from the People’s Republic of China (PRC) in 1958-1960 into the Alma-Ata (Kazakhstan) and Karametniyaz and Akkurgan (Uzbekistan) fish pond farms.

Bighead Carp are more thermophilic than Silver Carp which enabled significant dispersal from fish farms throughout the southern region of the Aral Sea basin (Verigin and Makeyeva 1980). Since 1967, they have been observed regularly in the Syr Darya River (Bykov 1968). It has been postulated that Bighead Carp arrived concurrently with juvenile Silver Carp in a number of waterbodies in Kazakhstan; however, its simultaneous arrival has not been reported from any other regions.

DESCRIPTION

Bighead Carp are similar in body shape to Silver Carp, with darker body color and mottled blotches. The head is larger than that of the Silver Carp, and the lower jaw protrudes slightly further than the upper jaw. Bighead Carp have thin lips and lack a labial fold. Eyes are located below the mouth corners and the lateral line is complete. The pectoral fins protrude beyond the base of pelvic fins, and are slightly darker than the overall body color.

While there are no definitive morphometric descriptions of the introduced Bighead Carp from waters in Kazakhstan, within its natural geographic range, the species is characterized as follows: D-II-III 7-8, A II-III 12-14, VI 8-9; 98-100 scales in the lateral line count, 26-28 scales above, 16-19 scales below. Pharyngeal teeth are unilateral (4-4), their grinding surface is not striated. Average body measurements (expressed as a % of standard length) are: head length: 36.4% (35.2-38.0); snout length: 12.1% (11.9-12.2); eye diameter: 7.0% (6.4-7.5); postorbital distance: 18.5% (17.5-19.1); and, maximum body depth: 32% (29.8-34.2) (Jennings 1988).

REPRODUCTION

In the waters of South China, female Bighead Carp reach sexual maturity at the age of 3-4 years, one year earlier for males, at weights of 5 -10 kg; whereas in Central China, females mature at 4-5 years (3-4 years for males) but at the same weight range. In North-Eastern China, maturation is delayed by 2-3 years as compared to southern populations and is attained at 6-7 years in female fish, 5-6 years in male fish, and at a greater range of body mass (5-15 kg). Earliest onset of maturity was observed in India and Israel, where males are sexually mature at 2 years (3 years in females) at a lower body mass (4.7-6.0 kg) (Jennings 1988).

Despite inhabiting broad geographic regions of the USSR, Bighead Carp in this region mature at similar time frames; the earliest occurring in Turkmenistan (the Amu Darya River basin) at 2-4 years in males and 3-5 years for females (Sukhanova 1966). Slightly later age at maturity is observed in the Syr Darya River and waterbodies of Krasnodar Kray, where males mature at 3-4 years, and females at 4-5 years (Yakubovskiy 1984). In the Terek River basin, males mature at 5-6 years of age, at an average body length of 77 cm, and weight of 7.6 kg; while females mature at 85 cm in total length (TL) and 10.3 kg in weight (Omarov and Abdusamadov 1988). In the Dnieper River, male fish mature at 7-8 years, and 8-9 years for females. Onset of maturity is influenced by climatic conditions and growth rate in the first year of life, and also determines length and the nature of spawning behaviour (whether repeat spawning will occur, as well as number of egg released) (Verigin and Kamilov 1984, Krivtsov et al. 1988). Sexual maturation of Bighead Carp is highly dependant on thermal constant values (accumulated temperatures during the pre-spawning period), requiring approximately 1356 ± 47 degree days (ºd), which exceeds those required by Silver Carp (300 ºd). (Omarov and Abdusamadov 1988). Under Nuclear Power Station (NPS) conditions, thermal constants are approximately 5000-6000 ºd, which enables sexual maturity to be attained by four years of age (Krivtsov et al. 1988).

Fecundities of up to 1.1 million eggs were reported for native Bighead Carp (Yangtze River), with an average body mass of 18.5 kg and average ovarian weight of 1.96 kg. For the majority of mature females from this waterbody, ovarian weight accounts for 17-20% of the total body weight. Fecundity of a single female (9 years, 12.42 kg) from the Amur River was estimated at 332.9 thousand eggs. Absolute fecundities were reported for Bighead Carp (age unspecified) from various regions as: 1,600 thousand eggs (Dniester River watershed), 769.1 thousand eggs (Khauzkhan reservoir, Amu Darya River) and 1,226 thousand eggs (Terek River). When manually stripping eggs from brood stock reared in ponds, fecundity varied from 478 to 549 thousand eggs (Salikhov 1966, Krykhtin 1972, Badareu and Fulga 1988, Omarov and Abdusamadov 1988). The relative individual fecundity from the previously listed waterbodies ranged from 54 to 121 eggs, and averaged 86 (Khauzkhan Reservoir) to 115 (Terek River) eggs. These fecundity values are considerably less than those observed for Silver Carp. Increased fertility in Bighead Carp is correlated with fish age, body weight, and body length/size.

Spawning activity for Bighead Carp in Chinese rivers lasts for approximately three months (April–June), with a peak in late May (Jennings 1988); as compared to spawning which lasts only 1 month in the Amu Darya River (Aliyev et al. 1986), 100 days in the Karakum Canal (April 1-20 through late July) (Sukhanova, 1981), or 1-1.5 months in the Syr Darya River (early/mid-May-mid-June) (Verigin and Makeyeva 1980). As seen in Silver Carp, spawning activity by Bighead Carp is characterized by a multi-peaked pattern which coincides with a rise in water level and optimum temperature. Water characteristics of suitable riverine systems in China during the spawning period range from 18 to 30 °C, water levels vary between 0.4-1.4 m, and flow velocities fluctuate from 0.8-2.26 m/sec. Spawning temperatures in introduced waters range from 18.5-26 °C (Miroshnichenko and Kamenetskaya 1978, Sukhanova 1981, Yakubovskiy 1988).

The spawning migration of Bighead Carp from the Chardara Reservoir to the Syr Darya River starts in April-May, once water temperatures reach 20 °C and water levels have risen abruptly. The GSI of spawning fish is 22.55 and the ratio of females to males is 1:2 (Miroshnichenko and Kamenetskaya 1961).

Spawning for both species generally occurs in the same river areas and within the same time period; however, downstream migration of Bighead Carp embryos often occurs slightly later than other species. According to Nikolskiy and Verigin (1966), spawning takes place in deep water which is different than in Silver Carp; however, other researchers (Chang 1966, in Jennings 1988) have observed Bighead Carp spawning in the rivers of China at both surficial and deeper water layers. Spawning patterns also differ among species, where both single and repeat spawning strategies have been observed in Chinese rivers (Jennings 1988). Among introduced carp populations, a single-spawning strategy is most common among both species (Zaki Mohamed 1978). For the Karakum Canal and Chinese rivers, rising water levels are not an essential cue for the spawning process (Makeyeva 1974, Aliyev and Sukhanova 1978); whereas, it appears to be critical for populations from the Syr Darya River (Miroshnichenko and Kamenetskaya, 1978, Salikhov 1981, Verigin and Makeyeva, 1983).

Spawning sites in the Syr Darya River are located approximately 110 km upstream of the Chardara Reservoir, as estimated by the developmental stages of downstream-migrant embryos sampled from the Chinaz district. Of the total migrating Bighead Carp eggs and embryos, 30-50% were dead, and developmental pathologies were observed in 2-3%. Silver Carp contributed 70-80% eggs of those migrating downstream; whereas, Bighead Carp eggs represented the second most. Hybrids between Bighead and Silver carps were also observed (Verigin and Makeyeva 1980).

Bighead Carp eggs are bathypelagic, with an egg diameter (including membrane) and yolk size of 4.98 and 1.46 mm, respectively (Sukhanova 1968). Eggs exhibit negative buoyancy and settle to the substrate in stagnant water. Buoyancy in the water column is established by an increased absorption of water through the membrane, thus increasing the perivitelline space and reducing the specific gravity of the eggs. During the process of water accumulation within the perivitelline space, the dense egg membrane becomes stratified. Incubation lasts 24-30 hours in water temperatures of 23-28 °C. Embryos are released from the membrane after approximately 24 hours; however, this timing is dependant upon water temperature. Juvenile fish congregate in floodplain lakes and reservoirs where they feed until reaching maturity.

AGE AND GROWTH

Growth rates of Bighead Carp in stages of early development are fairly consistent across their geographic range: 5 mm TL hatchlings/free embryos, 5.5-6.0 mm for three-day-old larvae, 8.5-9 mm for four-/five-day-old larvae, and 10.5 -12.5 mm for larvae at 16 days (Sukhanova 1966, Soin and Sukhanova 1972). From different waterbodies, young-of-the year fish are 8.3-16 cm TL and weigh 25-84 g (Moskul et al. 1982).

Maximum weight possible for Bighead Carp varies and ranges from 18-23 kg (Henderson 1978 in Jennings 1988), greater than 40 kg in the Ukraine (Baltadzhi 1979), and possibly up to 75 kg (age 15 years) in the Syr Darya watershed (Rudov 1988). However, these values are likely an overestimation of true maximum limits for this large, fast-growing fish, and far exceed the maximum weight of the Silver Carp from all introduced regions. A maximum age of 14+ years and maximum length of 1.3 m TL for a Bighead Carp was recorded from waters in the Kazakhstan Republic (former Kazakh SSR) (Yakubovskiy 1988).

Two year-old Bighead Carp can reach body weights of 0.75-1.5 kg and up to 4.3 kg by 3+ in some waterbodies in China. Fish that were introduced in the Amur River required 4-5 years to attain similar body masses. Growth rates of Bighead Carp in the Dniester Reservoir and Volga river systems are more similar to those observed in the Chinese populations. Individuals gain 0.5-1.9 kg by two years of age and exhibit a slower growth rate during the third year, attaining total body mass of only 0.9-3.2 kg by age 3+ (Negonovskaya 1980). Among other introduced populations of Bighead Carp, the greatest body mass increases were observed from the Chardara

Reservoir, and were considerably higher than growth rates from other regions. Fish of age 4+ to 6+ years weighed 9.4-15 kg, and 8-9 year-old fish weighed 17-21.5 kg.

Total length growth rates of Bighead Carp from the Amur River vary considerably, both in expected and observed data. This trait is most notable among the age classes (5 - 5+), (9 - 9+), (10 -10+), where the annual total length growth rates may differ by 3-10 cm with a size class. Total length growth rates are more consistent among fish from introduced populations despite broad geographic ranges. In many age classes, total length growth rates of fish from the Amur River exceeded those recorded among fish from the Chardara Reservoir. The age 1+ group exhibits accelerated growth in the reservoirs, attaining 19.2-37.0 cm TL as compared with 6.6 cm TL in fish from the Amur River. Other age classes from the Amur River show similar variation in annual growth rates.

Among fish from all reservoirs, maximum rates of growth in total length were recorded for the age class 3-5+ years, with the notable exception of rates reported for young-of-the-year fish from the Chogray (19.2 cm) and Chardara (37 cm) reservoirs.

Individuals from the Amur River grew at a reduced rate as compared to conspecifics from other regions of the country. In the Chogray, Shengzhi, Chardara, and Khauzkhan reservoirs, average growth rates from age 1–4+ were recorded at 4-32.6 cm; up to 44.2 cm in fish at ages 6–8+. In all examples, Bighead Carp from the Chardara Reservoir exceed growth rates of fish of similar age from other reservoirs. For example, four year-old individuals from the Chardara Reservoir reach an average body length of approximately 70 cm, similar to the total length observed in fish from the Amur River at age 7+, and from the Khauzkhan, Shengzhi, and Chogray reservoirs at age 6+.

Growth rates of Bighead Carp compared across habitat types such as natural waterbodies, reservoirs, and in ponds (aquaculture populations) indicate that the rate of body weight increase in Bighead Carp under pond conditions are similar to those observed from the Shengzhi Reservoir, but exceeds rates seen from the Chardara and Chogray Reservoirs by 1-2.8 kg in 2+ year-old fish (Vinogradov 1985). In all subsequent age classes, fish from aquaculture ponds attained greater body masses than those from the Amur River (6.6 kg increase by age 4+, and 3-11 kg increase by age 6-8 years). Among fish from the Chogray Reservoir, body mass increases of 2.3-4.8 kg by age 4-5+ were observed over those from the Amur River. In the Chardara Reservoir, Bighead Carp achieve greater annual body mass growth rates across all age groups (with the exception of age 1-2+ group) than do farmed fish from aquaculture ponds. Female fish exhibit higher growth rates than do males and is a characteristic, fairly pronounced among older age classes, used to distinguish between natural and aquaculture stocks. Until fish attain 4+ years, the difference in growth rates is almost negligible (only 0.1–0.4 kg variation); however, this gradually increases among older fish, from 2.3 kg (age 6+) to 4.1 kg (age10+).

Commercial catches in the Chardara Reservoir are predominately 4-7 year-old fish which measure approximately 57-90 cm TL (max. 122 cm), and 45-64 kg (Yakubovskiy 1988).

FEEDING HABITS AND CONDITION FACTOR

Bighead Carp feed on both phytoplankton and zooplankton in equal quantity (Nikolskiy and Verigin 1966). Its gill rakers are free, lack transverse septae, and are surrounded by a mucous membrane which promotes feeding on microscopic food items (as small as 20 microns (µm) in size). Mucous structures are also used to enhance selective feeding behaviour. Large food particles (up to 50 µm), such as zooplankton and colonial algae, are of sufficient mass to pass through the upper section of gill rakers and directly enter the esophagus. Smaller particles are deposited on the mucus layer which is formed into a larger aggregation, and is then “pushed” into the esophagus for consumption. Pharyngeal teeth crush the plankton, which promoted enhanced protein utilization.

Larvae, 7-9 mm TL, preferentially consume protozoans and zooplankton (nauplial and copepodite stages of crustaceans, as well as *Bosmina* and *Moina*). Upon reaching 18-23 mm, larval diets expand to include cladocerans, and by 24-30 mm TL, phyto-and zooplankton can be digested (Chang 1966, Ling 1967).

Among young larvae from waterbodies in the USSR, phytoplankton, *Protococcales*, blue-green algae, diatoms, and ciliates of the genus *Infusoria* were consumed. Once larvae are 9-15 mm TL, zooplankton (nauplial rotifers and *Cyclopodinae*) account for nearly 100% of the diet; whereas, phytoplankton (diatoms) only account for 0.1%. Dietary proportions of zooplankton consumed by fingerlings (10-47 mm) are reduced to 69%, having nauplial stages of crustaceans be replaced by copepodites (*Cyclops*, cladocerans). Smaller chironomids were also observed in the diet, and the proportion of phytoplankton increased by 2-18%. As the larvae continued to grow and develop (from 14 to 125 mm) the proportion of dietary phytoplankton increased while zooplankton decreased to 39%. Periods of highest feeding activity for 13-day-old larvae occurred around 6 pm; whereas, lowest feeding activity was observed from 4-6 am (Lazareva et al. 1977). Diurnal feeding activity is influenced by photic conditions, level of oxygen saturation, and water temperature.

Among fish from Chinese waterbodies, daily feeding activity is estimated to occur for 18 hours per day, with a peak in activity between 12-8 pm where up to 6.6% of the total body weight is consumed. As compared to dietary composition of larval fish, young-of-the-year carp consume less zooplankton and its dietary proportion is influenced by the seasonal abundance. Zooplankton account for 0.7-5.5% of the diet when zooplankton biomass is 1 $g*m^{-3}$; and increases to 14-25% at biomass of 2-3 $g*m^{-3}$. Preferred species include *Cyclops*, various cladocerans, and *Chydorus*. When zooplankton concentrations decline to 0.5 $g*m^{-3}$, the juvenile fish become dependent on detritus and phytoplankton, which can account for up to 87-97% and 0.1-1.0% of the diet respectively. Of the available phytoplankton species, Bighead Carp yearlings preferentially consumed diatoms; as a diet of blue-green algae in a laboratory setting promoted a reduction in growth rate (Verigin 1963, Lazarev et al. 1977).

In the lower reaches of the Volga River, detritus accounts for a major dietary component among adult Bighead Carp. During the spring, detritus comprises 47% of gut contents; whereas, this proportion increases to 89-92% in the summer. In secondary waterbodies (backwater pools), high concentrations of bacteria (6.4-11.5%) and phytoplankton (38-97%) are observed. In spring, dominant algal groups are represented by diatoms and blue-green algae; whereas, diatoms, blue-green, and green algae are all common during the summer. Average annual food intake in Bighead Carp exceeds body weight by 260-770%, and may vary by 6-10 units among individuals who weigh approximately 5 kg.

Seasonal variability in feeding intensity is quite pronounced; in spring months, approximately 30% of observed fish had empty stomachs; whereas, the maximum index of stomach fullness (at 343 $^{o}/_{ooo}$), is often observed during summer months (Korolevskaya and Belotserkovsky 1984).

Dietary composition of adult fish in pond farms of the Syr Darya River basin consists of 38 algal taxa: 14 green algae species (36%), 12 blue-green algae species (31%), 8 species of diatoms (21%), 2 species of euglenophytes (5.2%), and 1 species of pyrrophytes (2.6%) with frequent occurrence of rotifers (Khakimova 1972). In the reservoirs of the Karakum Canal, dietary composition is significantly influenced by seasonality. In spring and early summer, the majority of prey consumption is represented by zooplankton; whereas, in later summer and autumn, this changes to phytoplankton. In May and June, 86% of diet is composed of *Cyclops*, *Bosmina*, and detritus with insignificant amounts of phytoplankton. By mid-summer, dietary zooplankton increases and accounts for 98.3% of the prey items consumed. However, by September, this proportion decreases to 1.3% due to the presence of available phytoplankton and detritus (Aliyev 1974).

For most populations of Bighead Carp in waters of the USSR, a shift to feeding on phytoplankton and detritus occurs as a result of decreased zooplankton biomass (Lazareva et al. 1977). This trend has also been observed in reservoirs of Russia (Veselovsky and Proletarsky reservoirs), Kazakhstan, and Uzbekistan; where zooplankton contents of the diet may vary from 30-100%, provided sufficient biomass exists (Volvovich et al. 1980, Yakubovskiy 1984).

Preferential feeding is closely correlated to available biomass. When plankton concentrations exceed 5 $mg*l^{-1}$ and are composed of larger aquatic organisms, zooplankton represents the preferred food item. At the same plankton biomass, when larger organisms are unavailable, Bighead Carp do not exhibit preferential feeding behaviour, and switch to a more opportunistic approach.

Bighead Carp are commonly used to suppress algal blooms and improve water quality (Tarasova and Muschak 1984). Maximum feeding activity is observed at 20-22 °C, decreases by 50% at 12 °C, and ceases entirely at 10 °C (Negonovskaya 1980).

Information on condition factors among Bighead Carp populations is limited; from the Chardara Reservoir, 2.2-2.5 F_{cf}; and 1.8-2.1 C_{cf} have been reported (Yakubovskiy 1984), and 2.82 F_{cf} (age 2+) and 2.36 F_{cf} (age 6+) from the Volga River basin (Kushnarenko et al. 1974).

Appendix 2. Annotated extracts on Silver Carp, *Hypophthalmichthys molitrix* from: Mitrofanov V.P., Dukravets G.M., Sidorova A.F. et al. 1992. *Fishes of Kazakhstan.* [Ryby Kazakhstana.] Vol. 5. *Introductions, fisheries*. [Akklimatizatsiya, promysel.] Gylym, Alma-Ata. 464 pp.

DISTRIBUTION

Originating from China in 1958-1960, Silver Carp, *Hypophthalmichthys molitrix*, were imported into Russia as larvae to be used in pond fish farms in Kazakhstan and Central Asia (Karametniyaz farm in Turkmenistan, Akkurgan farm – in Uzbekistan, Alma-Ata farm – in Kazakhstan). In these areas, Silver Carp became established primarily in the southern regions, in the Amu Darya and Syr Darya rivers, and subsequently spread into the northern regions of the Republic which includes the Irtysh, Tobol, Ishim, Chu, and Sarysu river basins.

Silver Carp acclimated and established a population in the Syr Darya River basin as a result of self-colonization from adjacent pond farms (Verigin and Makeyeva 1980) and by 1964, had dispersed into the southern part of the Aral Sea (Muinak Bay) (Markov 1968). Establishment of Silver Carp in the Balkhash-Ili basin was delayed, arriving in 1975 after the systematic introduction of a multi-age stocking program.

Researchers began monitoring Silver Carp in the Kapchagay Reservoir in 1973 and individual collections were recorded from 1974-1976 (Ereshchenko et al. 1977). In subsequent years (1978-1986), the number of fish caught by researchers varied from 5-12 individuals, whereas between 30 and 40 were collected in commercial catches (Mel'nikov 1984). In Kazakhstan (1965-1972), 7,700 000 Silver Carp fry and larvae were introduced into natural waters, including nine lakes and two reservoirs (Tyutenkov 1972); however, no persistent or viable populations have been identified as a result of this stocking process. From 1972-1978, 15 million fingerlings (young-of-the-year) were stocked into the region. Silver Carp were observed at various times in almost all waterbodies following the stocking process; however, establishment of a self-sustaining population has only been documented in the Chardara and Kapchagay reservoirs.

MORPHOLOGY

Sexual dimorphism in Silver Carp develops once fish reach 20 cm in total length (TL). Gender is determined by the presence of a coarse inner surface of the pectoral fins in males, as well as differences between the ante-anal and post-dorsal distances and inter-orbital width. Most sexually dimorphic features are observed among large-size brooders, 60-70 cm TL. At this size, males exhibit longer pectoral and pelvic fins; whereas, females are characterized by longer post-dorsal, pecto-ventral, and ventro-anal distances, as well as having a greater body depth. Four types of age and sex-related characteristics have been identified in Silver Carp. Constant characters are unrelated to age and include minimum body depth, ventro-anal and inter-orbital distances, and fin length (with the exception of except pelvic and caudal). Age-related characters where the value decreases with advancing age include head length, eye diameter, maximum body depth, ante-dorsal distance, and depth of dorsal and anal fins. Age-related characters whose values increase with advancing age include snout length as well as post-orbital and post-dorsal distances. Age-related characters with fluctuating patterns during the life cycle, which may include an increase in the value during earlier developmental stages followed by a decrease at the later stages such as the length of the pectoral fins and caudal peduncle, or vice versa, (ante-ventral and pecto-ventral distances) may also be observed (Shubnikova 1980).

Significant differences (6 of 16 characters) between fry originating from natural waterbodies and hatchery-produced fry were observed (Shubnikova 1980). Differences were noted in head length, forehead width, ante-dorsal, ante-ventral and ventro-anal distances, and length of dorsal fins.

REPRODUCTION

Silver Carp in the Amur River mature at an age of 5+, body length 50 cm, with males maturing slightly earlier than female fish (Nikolskiy 1956); however, contrasting studies indicate that maturity may not be reached until 7-8 years, body length 60-62 cm, but this difference is likely attributed to development under variable thermal conditions (Krykhtin et al. 1966). Normal maturation of Silver Carp in the Amur River requires an annual accumulated heat within the range of 2655-3111 degree-days (ºd), with an average of 2865 ºd, of which 565 ºd should immediately precede the pre-spawning period (prior to June 15) (Gorbach and Krykhtin 1980). Under favourable thermal conditions (650 ºd), the developmental rate increases rapidly, and approximately 50% of the population can reach maturity as early as 4 years of age.

Upon reaching maturity, spawning fish migrate from feeding grounds (the lower part of the Miºdle Amur River) to the upper reaches of Bolon Lake and the Sungari River. Information on spawning behaviour of Silver Carp in the Amur River appears to be contradictory and may reflect ongoing changes in the spawning activities. Identification of spawning grounds from Blagoveshchensk to Khabarovsk, and upstream from this area are based upon age-specific evidence of downstream-migrant eggs, embryos and larvae (Nikolskiy 1956); however, other studies suggest that the majority of spawning fish lay eggs outside the USSR territory, in Chinese waters, with only 5-20% of the total spawning population residing in Russia (Gorbach and Krykhtin 1988).

Spawning amongst Silver Carp begins in May to early June. Spawning grounds are located on sand or mud bars, often at the junction of two streams or rivers or near islands, where the flow velocity is ≥ 0.8-1.0 $m*sec^{-1}$ (Nikolskiy and Verigin 1966). Spawning in the Amur River begins later, usually in early June, and lasts for 1.5-2 months; whereas, in the Yangtze River, spawning begins in the latter third of April, and lasts for 4-5 months (Makeyeva 1974). In Chinese rivers, preferred spawning temperatures range from 26-30 °C. Minimum spawning temperature in the Amur River must be at least 17 °C (Nikolskiy 1956), with the optimal temperature range from 21-26 °C (Gorbach 1980, Krykhtin 1980).

Understanding of cues to elicit spawning behaviour in Silver Carp is not well known. Some studies emphasize the synergistic role of environmental factors, such as rising water levels in spawning rivers, which should coincide with the optimal spawning temperature. During instances where water level and temperature do not coincide, spawning is terminated and a proportion of females retain unreleased eggs. This proportion of gravid, but non-spawning, females in the Amur River may reach 50-70% under unfavourable abiotic conditions; whereas, when spawning conditions are more conducive, this number is reduced to 4-23% (Gorbach 1980, Krykhtin 1980). Other studies have disregarded synergistic effects of environmental factors contributing to spawning success as confirmed by spawning processes in the rivers of China (Makeyeva 1974).

Consensus on repeat or batch spawning in Silver Carp is also unresolved. Data on early-spawning females from the Amur River report a lack of asynchronous vitellogenesis in oocytes, which is attributed to simultaneous/single batch spawning of the first maturing fishes and implies that older individuals exhibit a similar pattern (Krykhtin and Gorbach 1966). Soin (1959) and Makeyeva (1963) suggest an alternate spawning strategy with the existence of two groups of fish in the Amur River. The first group are characterized by repeat spawning, whereas the second group exhibit only single/fractional spawning. Repeat spawning of Silver Carp in Chinese waters was observed (Nikolskiy 1956, Chen and Lin 1935); however, this periodicity was attributed to timing of the brooders' arrival on the spawning grounds rather than a repeat spawning characteristic since eggs developed synchronously, although the possibility of multiple-batch spawning does exist (Nikolskiy and Verigin 1966).

Inter-annual gaps in Silver Carp reproduction were identified among factors which inhibit spawning success in the Amur River. Following completion of egg-laying and resorption, the ovaries do not progress to phase II-III, but instead to II-nd post-spawning stage. Eggs produced by these females are unable to attain maturity in time for the following spawn, which inhibits their ability to reproduce for that season. It should be noted that despite favourable conditions, a proportion of Silver Carp still experience this reproduction gap (Krykhtin and Gorbach 1966).

Spawning typically occurs in the early morning, in surface waters, and is accompanied by noisy leaping and splashing. A male fish, often two, follows a female and presses his head on the female's abdomen to stimulate egg release (Chen and Lin 1945, Nikolskiy 1956). After spawning, brooders migrate to the lower parts of the Amur River, a distance of approximately 100-500 km, to feed in the floodplains.

Silver Carp eggs are bathypelagic, with a large perivitelline space. In the Amur River, eggs have a diameter of 3.5-4.5 mm (including the membrane) and a yolk diameter of 1.2 mm. Eggs are deposited on the bottom, when water flow velocity does not exceed 0.7 m/sec. At temperatures of 25°C, hatching occurs two days following egg deposition. Hatched embryos are approximately 6 mm with an un-pigmented body, although blood circulation is active. Gill-filaments appear four days post-hatch, yet remain uncovered. Transition to the larval phase typically occurs on the seventh day, at 6.35-8 mm TL. At this stage, pigmentation and a small yolk sac are present, and are accompanied by the disappearance of embryonic respiratory organs and the development of an air-filled swim bladder (Kryzhanovski et al. 1951; Nikolskiy 1956). Eggs, embryos and larvae are carried 500-600 km downstream in the Amur River following spawning and development. This is considered the minimum distance required for normal development of eggs and larvae prior to their transition to external feeding and settling in the floodplains of the waterbodies (Gorbach and Krykhtin 1988). The absolute fecundity of Silver Carp in the Amur River basin (based on 3 individuals) ranged from 493,000 to 541,800 eggs (fish 60.7-62.5 cm TL, 4.8-5.0 kg) and relative fecundity was 111-113 eggs.

Self-sustaining populations of Asian carps have been recently established in at least six rivers in the USSR: the Amu Darya; Syr Darya; Ili; Terek; Volga; and, Kuban rivers (Nikolskiy and Aliev 1974). Intensive study on spawning behaviour in Silver Carp from the Syr Darya and Amu Darya rivers in Kazakhstan and adjacent territories of Central Asia has been reported. The first case of natural reproduction was registered in the Karakum Canal (Aliev and Sukhanova 1978). Spawning starts when water temperatures reach 18.5-20.4 °C. Spawning was also recorded in the Murgab River (Aliev and Sukhanova 1984, 1986), and in the main channel of the Amu Darya River (Zholdasova and Guseva 1986). Spawning season in this region lasts for one month in the Murgab River in April-May (Aliev and Sukhanova 1986), and up to 3 1/2 months in the Karakum Canal in April/May through to late July (Aliev and Sukhanova 1977, Sukhanova 1981). In the Murgab River, the peak spawning season occurs over ten days in late April when water temperatures are between 22.8-23.8 °C. If the average daily temperature falls below 17.0°C, spawning behaviour ceases until water temperature returns to 19.8 °C. The spawning in the Karakum Canal extends for a lengthier time, up to 100 days, and can have up to five spawning peaks that may last for four days.

50.7-56.8% of laid eggs travel downstream during the first spawning month, 35.3-48.7% during the second, and 7.2% in the third month. Embryonic downstream migration has a sinuous peaked pattern. Migrating embryos are at the morula-gastrula stage of development and include eggs of both Bighead and Silver carps which typically comprise 45% of the total amount of pelagic, migrant eggs.

Embryos of Bighead and Silver carps can be distinguished from each other by a number of features. The oocytes of Silver Carp are smaller on average than those of Bighead Carp (3.18-4.70 mm in diameter, as compared to 4.03- 4.98 mm). Yolk diameters of Silver Carp are also smaller than those of Bighead Carp (1.03-1.30 mm, vs. 1.16-1.46 mm). Additionally, the hydration process in Silver Carp oocytes is not accompanied by membrane stratification, as is seen with Bighead Carp. No differences were found in the number of trunk and caudal segments in developing embryos between these two species (Sukhanov 1968).

Reproductive ecology of Silver Carp in introduced waterbodies has not changed significantly from that seen in native populations, although the timing of maturation and spawning and fecundity are correlated to regional climatic conditions. Developmental time to maturation in phytophagous fish species depends on the duration of early oogenesis stages and various environmental temperatures (Krivtsov et al. 1988). At high latitudes (such as the Moscow region and Amur River) where thermal constants range from 2200-3000 ºd, I/II maturation stages last for 6-7 years. In addition to this latitudinal influence; in warm waters associated with thermal and nuclear power plants (having a thermal constant of 5000-6000 ºd), females spawn as early as three years of age. In the south of Kazakhstan and Central Asia, where climatic conditions are close to the thermal constant value of 4000-6000 ºd, maturity age varies between 2-3 years (Karakum Canal), 3-5 years (Syr Darya River), and 4-5+ years (Balkhash-Ili basin) at a body length of 49-78 cm, and occurs one year earlier than their conspecifics (Nikolskiy and Verigin 1966, Igamberdiev and Agzamhodzhaev 1980, Salikhov 1981, Yakubovskiy 1982, Verigin and Kamilov 1984, Melnikov 1984, Karpov et al. 1989). Fish from these regions mature 1-4 years earlier, and at a larger size, than those from the Amur River. A strong correlation exists between age at onset of maturity and growth rate in the first year of life (Verigin and Camilov 1984). In Uzbekistan, fish with growth increments between 17 and 20 cm attained maturity in three years; whereas, individuals with lower growth rates required a fourth year for maturation.

Gonadosomatic indices (GSI) of Silver Carp during pre-spawning and spawning migrations vary widely, and may be independent of the spawners' age. In the Syr Darya River, amongst fish aged 3-11 years, GSI ranged from 0.55-2.2 in males to 11.8-34.6 in females (Salikhov 1981). In the Amu Darya River, GSI varied from 13.03-17.96 (female, age 3+), 11.8-19.5 (age 4+), 8.24-7.7 (age 5+) and 16.2-19.3 (age 6+) (Igamberdiyev and Agzamkhodzhaev 1980). In the Balkhash-Ili basin (Ili River), GSI among female fish ranged from 0.57-1.51 in late April to 14.55 in early May; however, these indices were calculated from limited data. In late May, the four captured females displayed high levels of variability in GSI, ranging from 4.14 to 17.7 (Karpov et al. 1990). Significant differences are attributed to the simultaneous presence of individuals at II, III, and IV maturity stages in the spawning group, similar to the Syr Darya River spawning population (Miroshnichenko and Kamenetsky 1978).

The spawning stock in the Syr Darya River is typically comprised of nine age groups (from 3 to 11 years), size ranging from 61-120 cm TL and 4-43 kg. The majority of spawning individuals were males, age 4-6, and females, age 4-5, which ranged from 61-92 cm TL (Salikhov 1981). In the Ili River, migrating individuals aged 5-7+ years were observed.

Fecundity in Silver Carp from Kazakhstan and Central Asia varies widely and is reported in both absolute (ova per gonad) and relative (eggs/g fish weight) values. In the southern Aral Sea basin (Tolimarjon Reservoir), 312,400-541,200 eggs were found in fish aged 3+. Fecundity in fish of other age groups varied: 424,100-718,400 (age 4+), 601,300-941,300 (age 5+), and 847,500-1,379,000 (age 6+) (Igamberdnev and Agzamhodzhaev 1980). In the Khauzkhan Reservoir, minimum fecundity of 356,000 eggs was observed in a female of 104 cm TL, 9.7 kg body weight. In comparison, maximum fecundity observed for a specimen of the same size (103 cm), but greater weight (12.9 kg), was 2.5 million eggs. In the Karakum canal area, these figures were slightly lower; 538,000-1,600,000 eggs in fish of 93-103 cm TL. Relative fecundity was 43-265 eggs, with an average of 135 (Shakirova 1980). From the Kairakkum Reservoir on the Syr Darya River, absolute fecundity of females 66-83.5 cm TL (6.4-12.1 kg), ranged from 596,900-4,329,600 eggs, average=1,541,200 eggs.

A direct relationship between fecundity and linear dimensions of females was hypothesized; for the size class 65-70 cm, average number of eggs was 723,300, as compared with 2,196,900 for the 80-85 cm group. Relative fecundity ranged from 87.8 to 470.6, with an average value of 201.3 (Karimov 1980). However, this relationship may not always be exact. In the Khauzkhan Reservoir, a difference in fecundity of more than 2 million eggs was observed in females of the same size, and it is possible that such a correlation is observed only before attaining a certain size. Absolute fecundity appears to vary by growth increments; with each 1-cm length increase in body length resulting in an increase in fecundity by 43,700 eggs. Gain of 1-kg body weight results in an increase of 141,400 eggs, and each 1-year age increment produces 18,800 more eggs (Omarov and Abdusamadov 1988).

In the Chardara Reservoir, fecundity of Silver Carp is also very high. Among females of 71-87 cm TL, 3.4-16.7 kg; fecundity ranges from 142,700 to 442,200 eggs, with an average of 339,200. The average relative fecundity is 248.2 (Yakubovskiy 1982). Fecundity of females in the Chardara population varies from 1.35 million eggs among 4+ year-olds, to 4.6 million eggs in 8+ year-old fish (Salikhov et al. 1986). Fecundity of Silver Carp from the Ili River is significantly lower: absolute fecundity (estimated from 4 females without specifying size and age) ranges from 157,600-218,400; whereas relative fecundity was determined to be 131-195 (Karpov et al. 1989). In some introduced systems, for example; the Tolimarjon Reservoir, the reproductive capacity of females is compromised due to pathologies of the reproductive system. Ovarian developmental anomalies, such as unequal ovary sizes (weight and number of eggs is 4 times greater in one ovary than the other), or the complete lack of an ovary have been observed (Igamberdiev and Agzamhodzhaev 1980).

Long-term observations on the reproduction of phytophagous fishes in the Karakum canal and other waterbodies revealed that the primary factor for spawning success was the availability of reservoirs around the spawning streams which provide suitable feeding conditions for migrating fingerlings. In source waterbodies, such as the Amur and Yangtze Rivers, this is achieved by the numerous flooded territories that form during the spawning period. Water level fluctuations, flow velocity, capacity, and other hydrologic attributes are not critical factors for ensuring reproductive success in native Silver Carp habitats (Aliev and Sukhanova 1978).

Spawning behaviour of introduced Silver Carp in the Syr Darya River is similar to that observed among native populations. The spawning process is characterized by peaks of activity which are closely linked to fluctuations in water levels. Spawning does not occur at low water levels, even if temperatures are ideal (Miroshnichenko and Kamenetskaya 1978, Verigin and Makeyeva 1980, 1983, Salikhov 1981, Yakubovskiy 1984, Salikhov et al. 1986). Three spawning populations of Silver Carp exist in the Syr Darya River: the Chardara, Farkhad and Kairakkum groups. No information is available on spawning success of Silver Carp in the lower reaches of the river.

The Chardara Reservoir spawning stock starts its run to the upper part of the reservoir between the end of February and early March. In late March to early April, when water temperatures reach 15-16 °C, Silver Carp migrate 110 km upstream and may enter other waterbodies such as the Akhangaran, Chirchik, and Keles Rivers. At the end of spawning season in late May, fish migrate back downstream into the reservoir (Yakubovskiy 1988). The spawning run may occur when conditions are not at optimal levels (can occur at 13-20°C (Salikhov 1984) and last until mid-June (Miroshnichenko and Kamenetskaya 1978)), but in all cases, spawning is initiated when optimal temperatures coincide with an abrupt rise in water level (Verigin and Makeyeva 1980). Spawning usually last for one month. The first brooders to enter the spawning territories are single, large individuals. 5-10 days following this initial arrival, mass migration ensues, with brooders of various sizes arriving. Late arrivals tend to be those individuals with reproductive anomalies (Salikhov 1981).

Researchers observed that spawning shoals contain individuals at different stages of gonad maturity (II, III, and IV) with a sex ratio of 1 male to 2 females (Miroshnichenko and Kamenetskaya 1978). Spawning grounds were observed to be 110 km upstream from the reservoir, near whirlpools, at river bends, and at major tributaries. Downstream migration of eggs peaked in late May and is closely linked with the rise of river water levels. At this time, eggs are typically between the morula and active embryo developmental stages (Vershin et al. 1978). In 1977, 36% of migrant eggs were at the gastrula stage, 24% were at the stage of embryo onset, and 20% were at the organogenesis stage which indicates considerable length of the spawning sites and variation in spawning period (Zaki Mohamed 1978). Silver Carp account for up to 80% of phytophagous fish eggs and, therefore, are most prevalent among migrant eggs (Verigin et al. 1978, Verigin and Makeyeva 1983). The presence of hybrids between Bighead and Silver carps was noted in downstream-migrant eggs and was confirmed following incubation of the eggs.

Migration of Silver Carp eggs in the Kairakkum Reservoir was observed from late May to mid-June. Peak egg migration occurred from May 29-31 (up to 200 eggs) in the early part of the day (0700-1200); all eggs were at the active embryo stage. Spawning grounds in this region are located 60-70 km from the "Friendship between Peoples" (HEPS) dam (Karimov 1988); and, therefore, downstream-migration by embryos is significantly shorter than those in native populations such as the Amur River.

The diameter of Silver Carp eggs varies from 4.5-5.1 mm (Karimov 1988). Considerable egg mortality (up to 50%) and malformations in the embryos have been observed (Verigin et al. 1978; Verigin and Makeyeva 1978) and up to 10-15% of the spawning population retains unreleased eggs (Yakubovskiy 1988). Additional characteristics of Silver Carp in the Syr Darya River include both fractional, as well as single-event, spawning (Zaki Mohamed 1978; Karimov 1980). Silver Carp fry migrate to the Kairakkum Reservoir to feed.

A proportion of eggs and embryos also drift to the estuarine zone of the Aral Sea, where water salinity is higher. As Silver Carp is generally regarded as a freshwater species, the possibility of fertilization and survival of eggs and fry under saline conditions is of particular interest (Karpevich 1966, Rykova 1980). Fertilization of eggs may occur both in fresh- and saltwater, up to 7 ‰ salinity. Beyond this concentration, conditions are unfavourable for fertilization due to the delay of cortical reaction in eggs and increased sperm activity which may contribute to fertilization by polyspermy. Development of fertilized eggs can proceed normally at salinity concentrations of 5 ‰, or less; whereas, increased salt concentration inhibits embryonic development and delays hatching due to increased stability of the membrane. Normal development of eggs occurs at 2.1-4.6 ‰ salinity, while embryonic mortality at hatching is increased in water above 4.6 ‰ (Karpevich 1966). At 6 ‰ salinity, egg development is affected and the majority of eggs do not survive through the gastrula stage. Survival of eggs and embryos also differs depending on the composition of salts. Juveniles are more salt-resistant than embryos and are able to survive and develop normally in water up to 10.5 ‰ salinity. Eggs developed normally in water from the Caspian Sea (1-6 ‰ salinity) and hatching was observed in water from the Sea of Azov (0-7.5 ‰ salinity) and Aral Sea (0-10.5 ‰ salinity).

Little is known about the breeding of Silver Carp in the Balkhash-Ili basin. Three larvae sized 6.0-7.2 mm TL were sampled in the upper section of the Ili River in June (1987). There is no information about potential spawning in the downstream area outside the Kapchagay HEPS dam. Juvenile Silver Carp were recorded earlier in the season in the upper section of the reservoir. A spawning run, with only a few participants, was observed in this region in late April (Karpov et al. 1989).

AGE AND GROWTH

Among Silver Carp from natural waterbodies, maximum length is reported to be 1 m TL, at a maximum weight of 16 kg (Animal Life, 1983). In the Chardara Reservoir, individuals were recorded at 1.25 m TL and 36 kg (Yakubovskiy 1988b). In the Amur River, fingerlings/young-of-the year reach 2.6-8.4 cm TL by August (Bogaevsky 1948, Sysoeva 1958), whereas, fish at age 1+ measured between 10.6 and 12.4 cm (Sysoeva 1958). Fingerlings from introduced populations grew faster than did fish from native populations and were able to reach 4.0-12 cm TL and 1.65-66.1 g in the Murghab River;

9.6-12.5 cm TL, 15.7-31.02 g in the Karakum Reservoir; 19-31 cm TL, 384-507 g in Khauzkhan Reservoir; and 250-300 g in the Karakum Canal (Aliev 1965, 1977, Karimov 1980, Aliev and Sukhanova 1984). Among commercial catches from the Amur River, individuals of 20-70 cm TL were recorded at an average body length of 39 to 51.6 cm, and weight of 1.2-5.6 kg (Nikolskiy 1956). In Kazakhstan, 3-6 year-old fish were measured at 45-75 cm TL, 1.8-8.0 kg in the Kapchagay reservoir; and 50-125 cm TL, 4-36 kg in the Chardara Reservoir (Yakubovskiy 1988, Leonov 1990).

Linear growth of Silver Carp from native and introduced waterbodies is influenced by annual variability in feeding conditions. In the Amur River, this trend was clearly observed among younger fish (9.7-27.7 cm for yearlings, and 25.4-38 cm among the 2 year-old fish). Among older age groups (4-7 years), growth rates stabilized across all regions with 10-year-old Silver Carp measuring 67-69 cm TL.

Growth rates of Silver Carp from introduced waterbodies, starting at age 3, are higher than in native populations from the Amur River. Yearlings and 2 year-old fish from the Amur River experience significantly higher growth rates than fish from all reservoirs, with the exception of Krasnodar Reservoir. Growth rates in the Krasnodar Reservoir are considered minimum values for growth among introduced Silver Carp. Although growth rates among year 1+ fish approaches that of fish from the Chogray and Kapchagay reservoirs, measured fish are 1-25 cm smaller than specimens from other reservoirs. This trend persists across the 0-3 year-old age group. Growth rates slow amongst native populations in older age classes (4+ to 10+ years) as compared with fish from introduced populations. In the Chardara and Kapchagay reservoirs, 5 year-old Silver Carp are typically 60-68.5 cm TL; whereas, in the Amur River, fish do not reach this size until age 7-10. In introduced waters, the largest size ranges in body length were observed in younger age classes, measuring 6.45-32 cm at age 1+, 21.5-46.7 cm at age 2+, 30.6-60.1 cm at age 3+, and 40-68.5 cm age 4+. Similar patterns exist in older size classes; however, the ranges are less pronounced and generally do not exceed 8-16 cm at age 8+ and 2-7 cm at age 9+.

Optimal feeding conditions for juvenile fish exist in the Krasnodar, Kakhovka, Tsimlyansk, and Chardara reservoirs, where 2 year-old fish attain

26-32 cm TL, and 3-4-year-old fish measure 35.8-57 cm TL. The lowest growth rate among yearlings and 2 year-old fish was registered in 1983 from the Kapchagay and Chogray reservoirs, at 6.45-7.1 cm TL. In both the Amur River and the reservoirs, the growth rate of fish in older age classes eventually plateaus and is characteristic of Silver Carp growth, regardless of the growth rate during the first year. In the Kapchagay Reservoir, yearlings experience slower growth rates, reaching an average of 6.45 cm in the second year and beginning to slow by year 5. In comparison, juveniles of similar age from the Kakhovka and Tsimlyansk Reservoirs, increase body length by 400%, attaining up to 26 cm in length by year two.

The highest growth rate for Silver Carp was recorded in Turkmenistan, in the Khauzkhan Reservoir; year 1+: 15-40 cm TL, year 2+: 56-60 cm TL, year 4+: 72-80 cm, and year 5+: 83-93 cm (Aliev 1977). Growth rates of Silver Carp feeding in the bays of the Aral Sea (7.74-10.6 ‰ salinity) was also relatively high; attaining 28-47 cm over the first four years (year 1+: 12.4 cm, year 2+: 24.7 cm, year 3+: 37.8 cm, year 4+: 42 cm (Markov 1968)).

While differing growth rates are expected for fish from different areas and waterbodies, differences have also been observed based on annual variation within the same systems. In the Kapchagay and Chardara Reservoirs, Silver Carp have attained up to 30 cm in length per year in some age groups, likely due to feeding conditions in a given year and may not be a typical growth rate for this species. Another reason for the increased length may be hybrid “contamination”, as hybrids tend to exhibit a higher growth rate than the parental species. Differences in apparent growth rates between male and female fish appears to be negligible.

Differences in body weight measurements of Silver Carp from different waterbodies are considerably greater than variation in body length. In the Amur River, Silver Carp have a very low rate of weight gain across all age groups. Rate of body weight gain was classified into three groups: 1) waterbodies supporting fish with poor weight gain (the Amur River); 2) waterbodies supporting fish with medium weight gain (Kakhovka, Tsimlyansk, and Chogray reservoirs); and, 3) waterbodies supporting fish with good weight gain (Chardara, Kapchagay, and Krasnodar reservoirs and also the reservoirs of Turkmenistan and Uzbekistan). In the Khauzkhan Reservoir, the average weight of 2 year-old fish is 3.1 kg, 4 year-old fish weigh 6.4-10.1 kg, and 5 year-old weigh 13.1 kg (Aliev 1977). In the Karakum canal, 2 year-old fish can grow up to 1.5 kg and up to 8.6 kg by age 3 (Aliev 1965). In regions of high salinity (Aral Sea), weight gain was also relatively high with fish age 5+ weighing 11.8 kg (Markova 1968).

FEEDING HABITS AND CONDITION FACTOR

Silver Carp are typically phytophagous and planktophagous, but can also exploit many available food sources. In the Amur River, Silver Carp larvae begin actively feeding at 7 mm TL. Primary food sources of larvae are rotifers, some small crustaceans, and algae (e.g. *Euglena, Pandorina, Eudorina*). Dietary preferences for juveniles (13-15 mm TL) are crustaceans (e.g. *Daphnia, Alona, Bosmina*) and, occasionally, chironomid larvae. The length of the intestine in juvenile Silver Carp (8-10 mm TL) is 50% of the total body length. Among older fish (13-15 mm TL), the intestinal length is equal to body length. By 15-16 mm TL, Silver Carp transition to an exclusively phytoplankton-based diet, a change which is reflected by the development of an intestine that is nearly double the total body length (Nikolskiy 1956). Adult Silver Carp from the Amur River feed almost exclusively on phytoplankton (95%), preferentially selecting diatoms (21-100% of the intestinal contents), green algae (7-66%), and blue-green algae (2-20%). Zooplankton accounted for only 2% of intestinal contents. When phytoplankton availability decreases, detritus is consumed.

Dietary specialization by Silver Carp is possible as a result of a modified gill apparatus to form a "plankton net". Thin gill rakers are joined by transverse septae and form a screening apparatus to filter plankton (Nikolskiy 1956; Animal Life 1983). It was previously thought that Silver Carp employed a passive feeding strategy which relied on opercular flaring associated only with breathing; however, further observations revealed increased rates of gill cover movement during feeding activity in comparision to simply breathing (Nikolskiy and Verigin 1966). Additionally, Silver Carp exhibit dietary selectivity and filter out preferred algae species, particularly diatoms, which promotes optimal growth for the fish. Algae filtered by the "gill sieve" are compressed into a bolus by the interaction of strongly laterally compressed pharyngeal teeth and the grinding plate. Compressed food then enters the lengthy intestine (nearly 1000-1300% longer than TL).

In the Balkhash-Ili basin, dietary preferences of fingerlings (young-of the-year) consisted of 126 components, predominantly 58 species of green algae, 34 species of diatoms, and 21 euglenophytes. The proportion of dietary blue-green algae, predominantly the colonial *Merismopedia punctata*, accounted for 63% of the total algal species ingested. The majority of the food bolus was represented by pyrrophyte algae, particularly *Gymnodinium* sp. and *Peridinium inconspicum*. Diatoms and green algae represented 9-14% of the diet by weight. Indices of consumption and stomach fullness had very high values in August, $900.24^{o}/_{ooo}$ and $580.52^{o}/_{ooo}$, respectively (Karpov et al. 1989). By October, algal diversity in the diet of fingerlings had decreased to 108 taxa; however, green algae increased to 67 species, diatoms species decreased to 25 and 7 species of blue-green algae were observed. Quantitatively, green and blue-green algae comprised the greatest biomass of the diet. Green algae species accounted for 55% of the total number of species and 42% by weight were represented mainly by *Scenedesmus quadricauda* and *Binuclearia lauterbornii*. Dominant species of blue-green algae were *Aleristopedia punctata* and *Gomphosphaeria lacustris* which accounted for 21% of the total species and 36% by weight. Indices of consumption and stomach fullness in that period declined to $142.69\ ^{o}/_{ooo}$ and $94.48^{o}/_{ooo}$ respectively (Karpov et al. 1989). Seasonal and interannual variability in dietary composition among Silver carp exists in other age groups as well. Diets of yearlings in April (1986 and 1988) revealed algal variability in both number of species (124–133) as well as relative dietary proportions. Annual species diversity was fairly constant; diatoms (in 1986: 37, in 1988: 63), green algae (35, 37), and the dominant group present in the diet was euglenophytes (42 species). Green algae represented 39% of the total diet, euglenophytes accounted for 23%, whereas, blue-green algae and pyrrophytes made up 12-16%. Indices of consumption and stomach fullness in that period were high, $1216\text{-}1500\ ^{o}/_{ooo}$ and $829.71^{o}/_{ooo}$, respectively. In 1988, green (48%) and blue-green algae (47%) species were prominent in the diet. The proportion of diatom species was unremarkable; however, diatoms accounted for a substantial proportion of the food bolus weight (47%). Green and blue-green algae were nearly equal in weight (24% of food mass). Dietary changes of yearlings were reflected in consumption and stomach fullness indices, exhibiting lower values in 1986 than in 1988, (92.11 $^{o}/_{ooo}$ as compared to 137.31$^{o}/_{ooo}$).

Dietary preferences of adult fish (age 6+) from Kapchagay Reservoir represent 46 algae species, of which 27 species were diatoms, 16 were green algae, and 3 were pyrrophytes. Dietary selection for diatoms was observed, both in number of species (93%), and proportion of food weight (90%), predominantly represented by the genus *Cyclotella* (Karpov et al. 1989). In fish from the Aral Sea basin, diatoms composed 100% of the diet (Aliev 1974; Yakubovskiy 1982). In the Chardara Reservoir, 95% of Silver Carp diet is composed of green algae (*Scenedesmus, Staurastrum, Melosira, Binuclearia, Zygnema, Pediastrum,* and *Oocystis*), blue-green algae (*Oscillatoria, Gloeocapsa, Mycrocystis,* and *Merismopedia*), and diatoms (*Diatoma, Synedra,* and *Cyclotella*). Zooplankton were also included (up to 30%) and included *Cyclopoida, Daphnia, Sida,* and *Rotatoria*. Index of stomach fullness content varied from 38-321$^{o}/_{ooo}$ (Yakubovskiy 1982). Algae predominated in diets of fish from waterbodies in Central Russia, Moldova, and Ukraine; however, detritus, zooplankton, and other dietary components were observed depending on food availability and seasonal abundance (Naberezhny and Yarovetskaya 1972, Buryudzha 1984). Phytoplankton was also observed to represent a primary dietary component in fish from a variety of regions in some years (Yakovchuk 1968, Kovorotnaya 1970, Tarasova 1972, Vovk 1976, Tarasova et al. 1981).

Blue-green algae may be poorly digested, and preferentially excluded, by young-of-the-year fish. Among 11 different algal species, diatoms were consumed at a rate of 47-1300 million individuals/hour (*Cyclotella*), *Euglena* at a rate of 100-1200 individuals/hour, and *Protococcus* at 7-500 million individuals/hour. In contrast, blue-green algae were consumed with the lowest frequency, and previously ingested/filtered blue-green algae was observed to be “spat” out more frequently than any other groups of algae. Blue-green algae remained undigested in feces, unlike *Protococcus* and diatoms, which were well-digested (Savina, 1966).

Daily intake and seasonal fluctuation in algae consumption vary significantly (6.1-15.2% of body weight) depending on water temperature, fish age and phytoplankton concentration (Dzhemileva 1984, Kirilenko et al. 1988); however, mature Silver Carp in the Tsimlyansk Reservoir do not display sex- or age-related differences in feeding patterns (Mukhamedova and Kalinina 1986).

The Fulton condition factor (F_{cf}) for Silver Carp fingerlings in the Balkhash-Ili basin was 1.38-1.79, and the Clark condition factor (C_{cf}) was 1.10-1.36 in late August and increased to 1.9-1.95 F_{cf} and 1.57-1.69 C_{cf} by the end of the growing season. Following the winter period, condition factors ranged from 1.45-1.92 F_{cf} and 1.14-1.52 C_{cf} and further increased to 1.96-2.32 F_{cf} and 1.69-1.92 C_{cf} (Karpov et al. 1989). Average condition factor values for fish aged 2+ and 4+ were similar to those reported for fingerlings: 1.8-2.5 F_{cf} and 1.6-2.2 C_{cf} (Mel'nikov and Yakubovskiy 1984).

In the Chardara Reservoir, F_{cf} ranged from 2.0 to 2.34 and C_{cf} - from 1.69 to 2.03 in different years, along with a high oil content of 4-5 marks (Yakubovskiy and Vasiliev 1983). In the lower reaches of the Amu Darya River, condition factors of 1.66 F_{cf} to 152 C_{cf} were reported (Shamshetov and Tleuov 1972). Of particular interest are Silver Carp from the Aral Sea, where feeding behaviour occurred in water salinity up to 10.6 ‰ and resulted in relatively high values of F_{cf} in autumn, between 1.41-2.06 in fish aged 1+ to 4+ (Markova 1968).