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Scientific and Biological Basis for the Accelerated Formation of a Reproductive Stock of Silver Carp (Hypophthalmichthys molitrix Valenciennes, 1844) under Pond Aquaculture Conditions in the Tashkent Region.

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ABSTRACT: This article presents the biological and technological foundations for the accelerated formation of an early-maturing reproductive group of silver carp (Hypophthalmichthys molitrix Valenciennes, 1844) under pond aquaculture conditions in the Tashkent region. The study employed an integrated approach based on early diagnosis of sexual maturation, assessment of gonadal developmental status, monitoring of gonadosomatic index (GSI) dynamics, and the use of pituitary hormonal stimulation. Production trials were conducted during 2023–2025 in a 0.2-ha pond at the "ZAFAR ASADBEK BALIG'I" farm in the Kuyichirchik District of the Tashkent region. A total of 220 fish were maintained in polyculture, including 60 silver carp, 120 grass carp, and 40 common carp. The integrated selection and reproductive approach made it possible, under the experimental production conditions, to register a reduction in the period required to reach reproductive maturity to 24 months. In the selected reproductive group, GSI reached 16.2%, while the fertilization rate reached 86%. By the end of the production season, 810,000 standard larvae were obtained, which was 15.7% above the planned target of 700,000. Production profitability amounted to 42.1%. The results demonstrate the biological and practical importance of combining morphophysiological diagnostics, monitoring of gonadal development, and controlled hormonal stimulation when forming reproductive groups of silver carp.

Keywords: silver carp, Hypophthalmichthys molitrix, reproduction, sexual maturation, gonadosomatic index, gonads, pituitary stimulation, fertilization, larvae, pond aquaculture.

INTRODUCTION: Silver carp (Hypophthalmichthys molitrix Valenciennes, 1844) is one of the most important freshwater aquaculture species and is widely used in polyculture because of its ability to efficiently utilize the natural food resources of water bodies. Intensification of herbivorous fish culture requires not only improvements in feeding and husbandry technologies, but also the formation of physiologically complete reproductive stocks capable of providing a stable supply of high-quality stocking material [1, 6].

In the fundamental work of J.E. Bardach, J.H. Ryther, and W.O. McLarney, the efficiency of fish culture is described as being determined by the complex interaction of species-specific biological characteristics, aquatic environmental conditions, culture technology, and the organization of reproduction [1]. Accordingly, management of the reproductive cycle of cultured fish should be regarded as one of the key elements for improving the overall efficiency of aquaculture.

When forming a reproductive stock, particular importance is attached to determining the age and physiological condition at which fish are capable of producing fully developed gametes. Sexual maturation in fish is a complex multistage process involving gonadal development, gametogenesis,

changes in endocrine status, and preparation of the organism for spawning. As shown in the studies of R. Billard, the reproductive function of teleost fish is closely associated with sequential morphofunctional changes in the gonads, while gamete quality depends on their stage of development and the general physiological condition of the broodfish [2].

According to N.R. Bromage and R.J. Roberts, the efficiency of artificial fish reproduction is largely determined by the quality of the established broodstock. The authors emphasize that the age and size of broodfish alone cannot be considered sufficient criteria of reproductive readiness. A more objective assessment should take into account gonadal condition, the course of gametogenesis, gamete quality, and pre-spawning holding conditions [4]. Consequently, the formation of a reproductive group of silver carp requires the use of a combination of morphological and physiological criteria.

One informative indicator of the reproductive status of fish is the gonadosomatic index (GSI), which reflects gonadal mass relative to total body mass. Changes in this index during the reproductive cycle are associated with the growth and maturation of germ cells. Therefore, GSI, together with assessment of gonadal developmental stages, can be used to characterize reproductive status and determine the period of functional readiness for artificial reproduction [2, 4].

Environmental factors exert a substantial influence on the rate of sexual maturation and reproductive function in fish. C.E. Boyd and C.S. Tucker demonstrated that temperature and oxygen regimes, pH, concentrations of nitrogenous compounds, and overall water quality determine the intensity of metabolic processes and the physiological condition of fish in pond culture [3]. Reproductive stock formation should therefore be carried out with continuous consideration of environmental conditions, because changes in these factors can directly or indirectly affect gonadal growth and maturation.

Temperature and photoperiod are especially important environmental factors. Based on an analysis of reproductive cycles in cultured fish, N. Bromage, M. Porter, and C. Randall showed that external seasonal signals participate in the regulation of maturation through the neuroendocrine system. Photoperiod and temperature can alter the timing of sexual maturation, the seasonality of the reproductive cycle, and the functional state of the gonads [5]. This is particularly important when adapting fish reproduction technologies to different climatic zones.

Thus, the age at sexual maturity should not be regarded as an absolutely constant characteristic independent of culture conditions. Realization of reproductive potential is determined by the combined effects of genetic characteristics, temperature, photoperiod, food availability, water quality, and the general physiological condition of fish [3–5]. This provides a scientific basis for developing technological approaches aimed at managing maturation processes under aquaculture conditions.

Hormonal stimulation is an important component of controlled reproduction. In fish culture, pituitary preparations are used to induce the final stages of gamete maturation and to obtain mature gametes. However, the effectiveness of hormonal treatment depends on the initial state of the reproductive system; therefore, hormonal stimulation should be combined with a preliminary assessment of gonadal maturity and the general physiological condition of the broodfish [2, 4].

The modern concept of broodstock management involves a transition from selecting broodfish mainly by age and external characteristics toward a comprehensive assessment of their reproductive status. Combining age and morphometric characteristics with assessment of gonadal condition, GSI, and subsequent controlled hormonal stimulation makes it possible to select individuals for reproduction on a more scientifically justified basis [2, 4, 5].

The relevance of this approach is increasing against the background of global aquaculture development. According to FAO materials, sustainable growth in the production of aquatic biological resources requires greater efficiency in reproductive technologies, improved quality of stocking material, and rational use of available production resources [6]. For pond farms, this means the need to

establish a stable system of in-house reproduction and to form reproductive groups adapted to specific ecological and technological conditions.

This issue is of particular practical importance in Uzbekistan. The long growing season and regional characteristics of the temperature regime create prerequisites for studying opportunities for directed management of growth and reproductive development in herbivorous fish. At the same time, results obtained in other climatic zones cannot automatically be transferred to the conditions of the Tashkent region, which necessitates regional production studies.

Accordingly, during 2023–2025, a production-scale evaluation of an integrated approach to forming a reproductive group of silver carp was carried out at the "ZAFAR ASADBEK BALIG'I" farm in the Kuyichirchik District of the Tashkent region. The studies were conducted in a 0.2-ha pond containing 220 fish in polyculture, including 60 silver carp, 120 grass carp, and 40 common carp. These parameters correspond to the production scheme used for implementing the results of the dissertation research.

The scientific hypothesis was that the integrated application of early diagnosis of reproductive status, assessment of gonadal development, determination of GSI, and controlled pituitary stimulation could improve the efficiency of forming a reproductive group of silver carp under the specific conditions of a pond farm.

The aim of the study was to scientifically substantiate and evaluate, under production conditions, an integrated approach to the accelerated formation of a reproductive group of silver carp (Hypophthalmichthys molitrix Valenciennes, 1844) in pond aquaculture in the Tashkent region, based on assessment of reproductive status, gonadal development, the gonadosomatic index, and the application of pituitary stimulation.

To achieve this aim, the following tasks were addressed: to assess the reproductive status of silver carp; determine the diagnostic value of GSI and gonadal condition in selecting promising individuals; evaluate the effectiveness of pituitary stimulation; determine fertilization level and standard larval yield; and provide a production and economic assessment of the developed approach.

MATERIALS AND METHODS: Experimental and production studies were conducted during 2023–2025 at the "ZAFAR ASADBEK BALIG'I" farm located in the Kuyichirchik District of the Tashkent region, Republic of Uzbekistan.

The principal study object was silver carp, Hypophthalmichthys molitrix (Valenciennes, 1844). The research was aimed at scientifically substantiating accelerated formation of a reproductive group through comprehensive assessment of sexual maturation, the functional condition of the gonads, the gonadosomatic index (GSI), and the effectiveness of hormonal stimulation.

The production trial was organized in a 0.2-ha pond (20 sotix). Fish were maintained in polyculture. The total stock consisted of 220 individuals, including 60 silver carp, 120 grass carp (Ctenopharyngodon idella), and 40 common carp (Cyprinus carpio).

The choice of polyculture as the production model was based on general principles for the rational utilization of the natural food base of ponds. As noted by J.E. Bardach, J.H. Ryther, and W.O. McLarney [1], the joint culture of fish with different feeding spectra enables more complete utilization of the trophic resources of a water body. Nevertheless, the reproductive investigations in the present study focused specifically on silver carp.

Methodological framework of the study: The methodological basis of the work was developed with consideration of classical and modern concepts in fish reproductive physiology and broodstock management [1, 2, 4, 5].

According to R. Billard [2], assessment of fish reproductive status should be based on analysis of gametogenesis and the functional state of the gonads. N.R. Bromage and R.J. Roberts [4] indicate that

reproductive efficiency is determined by a combination of factors including broodfish age and physiological condition, degree of gonadal development, gamete quality, and holding conditions.

Accordingly, the methodological scheme of the present study included the following sequential stages:

1. maintenance and observation of fish under production conditions;
2. assessment of the reproductive status of silver carp;
3. determination of the degree of gonadal development;
4. calculation of the gonadosomatic index;
5. identification of individuals promising for formation of the reproductive group;
6. application of pituitary hormonal stimulation;
7. assessment of fertilization success;
8. recording the yield of standard larvae;
9. production and economic evaluation of the tested approach.

This integrated approach made it possible to consider age at sexual maturity not as the sole selection criterion, but together with indicators of the actual functional state of the reproductive system.

Assessment of reproductive status and gonadal development: When forming the reproductive group, particular attention was paid to the condition of the gonads. The methodological approach was based on the principle that the stage of gonadal development is one of the most informative biological indicators of readiness for reproduction [2, 4].

The study included assessment of gonadal condition and developmental stages, including morphophysiological monitoring and histological analysis. The use of histological assessment together with other indicators enabled a more objective characterization of the reproductive system because external morphological features do not always directly reflect the degree of germ-cell maturity. In accordance with the approaches summarized by R. Billard [2], morphofunctional changes in the gonads are associated with the sequential stages of gametogenesis and can be used to characterize the reproductive status of fish.

1. N.R. Bromage and R.J. Roberts [4] also emphasize the need for a comprehensive approach to broodfish assessment, in which gonadal condition is considered together with age, physiological, and other biological characteristics.

2. Therefore, in the present study, selection of silver carp for formation of the reproductive group was based on an integrated assessment of traits characterizing functional readiness for reproduction.

3. Determination of the gonadosomatic index: The gonadosomatic index (GSI) was used as one of the principal quantitative indicators of reproductive status.

4. The index was calculated as the ratio of gonadal mass to total fish body mass:

$$GSI = (Wg / W) \times 100,$$

where:

GSI — gonadosomatic index, %;

Wg — gonadal mass, g;

W — fish body mass, g.

5. The methodological significance of this indicator is related to the fact that gonadal mass increases relative to total body mass during germ-cell maturation. Therefore, GSI dynamics can be used as a quantitative indicator of reproductive development in combination with direct assessment of gonadal condition [2, 4].

6. In the present study, GSI was not considered an independent and absolute indicator of sexual maturity. It was interpreted together with the results of gonadal assessment and the overall reproductive readiness of the fish. This approach reduces the likelihood of incorrectly evaluating physiological status on the basis of a single relative indicator.

7. Consideration of environmental factors: A methodologically important element of the study was consideration of the effects of aquatic environmental conditions on the physiological and reproductive state of the fish.

8. According to C.E. Boyd and C.S. Tucker [3], water quality is one of the principal factors determining fish physiological well-being in pond aquaculture. Temperature and oxygen regimes, pH, and concentrations of nitrogenous compounds can affect metabolic intensity, feeding activity, and the general condition of cultured organisms.

9. Water temperature is particularly important in studies of the reproductive cycle. N. Bromage, M. Porter, and C. Randall [5] showed that temperature and photoperiod are important external signals involved in regulating maturation in cultured fish through neuroendocrine mechanisms.

Therefore, the reproductive-development indicators obtained in the production trial were interpreted in relation to the specific culture conditions of the Tashkent region rather than as universal values characteristic of silver carp in all climatic regions.

Pituitary hormonal stimulation: Pituitary hormonal stimulation was used to manage the final stages of the reproductive process.

The use of hormonal induction in artificial fish reproduction is based on the physiological principle of stimulating the final maturation of germ cells and preparing broodfish for collection of mature gametes [2, 4].

A key principle in the present study was that hormonal stimulation was not regarded as an independent method for accelerating sexual maturation, but as one element of an integrated technology.

The reproductive status of the fish and the degree of gonadal development were first assessed, after which pituitary stimulation was applied to selected individuals.

This sequence is methodologically justified because the organism's response to hormonal treatment depends on the initial developmental stage of the reproductive system [2]. Consequently, preliminary diagnosis of gonadal condition improves the justification for selecting individuals for subsequent reproductive procedures.

The specific preparation doses and administration regimen were not recorded in the original implementation act and are therefore not provided in this article in order to avoid methodologically unsupported detail.

Assessment of fertilization efficiency: Following the reproductive procedures, egg fertilization success was assessed.

GSI = (Wg / W) × 100,

The fertilization rate was expressed as a percentage and determined as the ratio of the number of fertilized eggs to the total number of eggs included in the count:

$F = (Nf / Nt) \times 100,$

where:

F — egg fertilization rate, %;

Nf — number of fertilized eggs;

Nt — total number of eggs counted.

The fertilization rate was used as one of the main criteria of the functional quality of the formed reproductive group and the effectiveness of the applied reproductive-management measures.

When interpreting the results, the position of N.R. Bromage and R.J. Roberts [4] was taken into account: gamete quality and fertilization success depend on the physiological condition of broodfish, their pre-spawning holding conditions, and the degree of gamete maturity.

Assessment of larval yield: The practical efficiency of reproduction was also evaluated by the number of standard larvae obtained.

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To determine the production effect, actual larval yield was compared with the farm's planned target.

The absolute amount by which the planned target was exceeded was calculated using the formula:

$\Delta N = Nf - Np$,

where:

ΔN — additional number of larvae obtained;

Nf — actual number of larvae;

Np — planned number of larvae.

The relative change was determined as follows:

$\Delta N\ (\%) = [(Nf - Np) / Np] \times 100$.

This approach enabled quantitative evaluation of the production effect resulting from implementation of the developed system for forming and using the reproductive group.

Production and economic assessment: Modern aquaculture technologies should be evaluated not only from biological but also from production and economic perspectives. This principle is consistent with the modern concept of sustainable aquaculture, which seeks to improve the efficiency of biological and production resource use [6].

The economic efficiency of the tested approach was evaluated on the basis of actual production volume, its internal calculated value, production costs, net profit, and profitability.

Net profit was determined using the formula:

$P = V - C$,

where:

P — net profit, UZS;

V — value of produced output, UZS;

C — total production costs, UZS.

Profitability was calculated as follows:

$R = (P / C) \times 100$,

where:

R — production profitability, %.

The economic assessment included costs associated with maintenance and feeding of the reproductive group, hormonal stimulation, reproductive and incubation procedures, water and electricity use, labor, and other production expenses.

Criteria for evaluating the effectiveness of the developed approach: Thus, the methodological evaluation of the study results was based on an interconnected analysis of biological, reproductive, production, and economic indicators.

The main criteria were:

- age at attainment of reproductive readiness;
- condition and degree of gonadal development;
- gonadosomatic index value;
- effectiveness of pituitary stimulation;
- fertilization percentage;
- number of standard larvae obtained;
- excess of actual larval yield over the planned target;
- net profit;
- production profitability.

This study design corresponds to the integrated principle of fish reproduction management, in which the biological indicators of broodfish are considered in relation to the final outcome of artificial reproduction and the production efficiency of the technology [1, 4, 6].

F = (Nf / Nt) × 100,

The obtained data are of practical interest because, in the initial production description of the species, sexual maturation of silver carp under the conditions considered was associated with a later age of 4–5 years.

At the same time, the result obtained should be interpreted specifically as the outcome of a particular production-scale evaluation of a complex of selection and reproductive measures, rather than as a universal biological age of maturation for the species in all climatic zones.

Dynamics of reproductive indicators: In the selected reproductive group, GSI reached 16.2%.

The high GSI value indicated substantial gonadal development and, together with morphophysiological assessment, was used as one of the criteria of reproductive readiness.

Following the reproductive procedures specified by the technology, the fertilization rate reached 86%.

The results confirm the need for an integrated approach to the formation of reproductive groups.

Using calendar age alone as a criterion for selecting broodfish does not fully characterize their physiological readiness for reproduction.

ΔN = Nf – Np,

In this respect, the results are consistent with the concept of Bromage and Roberts (1995), according to which reproductive success is determined by the physiological quality of broodfish and gamete maturity.

Billard (1986) likewise emphasized the need to assess the functional state of the fish reproductive system.

Consequently, combining age criteria with GSI and assessment of gonadal condition is methodologically better substantiated than selection based on age alone.

ΔN (%) = [(Nf – Np) / Np] × 100.

Significance of pituitary stimulation: Pituitary stimulation within the developed scheme was aimed at managing the final stages of the reproductive process.

Importantly, hormonal stimulation was applied as a component of an integrated technology after fish had been selected according to reproductive status. This makes it possible to interpret the observed effect not as the result of hormonal treatment alone, but as the consequence of sequential management of the reproductive group.

The fertilization rate of 86% indicates high production effectiveness of the applied complex of measures under the conditions of this farm.

Larval production: The final yield of stocking material is one of the most important practical indicators of technological efficiency.

The initial plan was to obtain 700,000 standard larvae. Actual production amounted to 810,000 larvae.

Thus:

810,000 – 700,000 = 110,000 larvae.

The relative excess over the plan was: (110,000 / 700,000) × 100 = 15.7%.

Therefore, the production result exceeded the planned target by 110,000 larvae, or 15.7%.

This result is of direct practical importance because an increase in larval yield improves the farm's self-sufficiency in stocking material.

ECONOMIC EFFICIENCY: Economic evaluation is a necessary stage in the production-scale testing of biotechnological solutions.

The internal calculated value of one standard larva was 10 UZS.

With a planned quantity of 700,000 larvae, the expected value of production was: 700,000 × 10 = 7,000,000 UZS.

In fact, 810,000 larvae were obtained, with a total calculated value of: 810,000 × 10 = 8,100,000 UZS.

Total production costs amounted to 5,700,000 UZS, including expenses for maintenance and feeding of broodfish, hormonal stimulation, reproduction, incubation, water and electricity supply, labor resources, and other production costs.

- Net profit amounted to: 8,100,000 – 5,700,000 = 2,400,000 UZS.
- Profitability:

R = (2,400,000 / 5,700,000) × 100 = 42.1%.

- Thus, each 1 UZS of production costs generated approximately 0.42 UZS of net profit, while the ratio of production value to costs was approximately 1.42.
- The biological effect of the developed approach, expressed as improved reproductive performance, was directly transformed into an economic result.
- DISCUSSION: Fish reproductive function results from a complex interaction of genetic, physiological, environmental, and technological factors. Therefore, accelerated formation of reproductive groups should be viewed not as the consequence of a single technique, but as the result of integrated management of the organism and culture conditions.
- The production results obtained are consistent with the general principles formulated by Bromage et al. (2001), according to which external environmental signals participate in the regulation of fish maturation through endocrine mechanisms.
- At the same time, practical aquaculture must distinguish between the onset of gonadal-development processes and actual readiness for successful artificial reproduction.
- For this reason, the use of GSI in combination with gonadal assessment has substantial diagnostic value.
- The GSI value of 16.2% recorded in the production trial characterizes substantial development of the reproductive system in the selected fish. However, this indicator should be interpreted together with other traits because identical GSI values do not necessarily indicate identical gamete quality.

A second important result was the achievement of an 86% fertilization rate. This indicator reflects the effectiveness of the entire set of measures, from formation and maintenance of the reproductive group to determination of readiness and hormonal stimulation.

Of particular interest is the reproductive readiness recorded at 24 months under production conditions.

Indicator	Value
Study period	2023–2025
Study site	«ZAFAR ASADBEK BALIG‘I»
District	Kuyichirchik, Tashkent region
Pond area	0.2 ha
Total number of fish	220 individuals
Silver carp	60 individuals
Grass carp	120 individuals
Common carp	40 individuals
Culture system	polyculture

The result indicates the possibility of substantially intensifying the formation of reproductive stock under the specific conditions of the farm. Nevertheless, further scientific verification of this

effect requires a larger number of observations, comparison among age groups, and long-term monitoring of offspring quality.

From a practical perspective, shortening the period required to form a reproductive group can potentially reduce the nonproductive maintenance period of replacement stock, accelerate broodfish turnover, and increase flexibility in reproduction planning.

Obtaining 810,000 larvae instead of the planned 700,000 demonstrates that biological optimization of the reproductive process can be accompanied by a direct production effect.

Consequently, the principal advantage of the developed approach is the interrelationship of three components: biological diagnostics → controlled reproduction → production and economic outcome.

This integrated principle may be considered a promising direction for improving silver carp reproduction technologies in pond farms of Uzbekistan.

CONCLUSIONS: Under the conditions of the "ZAFAR ASADBEK BALIG'I" farm in the Kuyichirchik District of the Tashkent region, an integrated approach to forming a reproductive group of silver carp was tested at production scale. The approach included early diagnosis of sexual maturation, assessment of gonadal development, determination of GSI, and pituitary hormonal stimulation.

Indicator	Result obtained
Recorded age of reproductive readiness	24 months
GSI	16.2%
Egg fertilization	86%
Planned larval production	700,000 individuals
Actually obtained	810,000 individuals
Excess over plan	110,000 individuals
Excess over plan, %	15.7%

1. Under the production trial conditions, silver carp were recorded as capable of attaining reproductive readiness by 24 months of age, indicating the potential of directed selection and management of fish reproductive status.

2. The gonadosomatic index of the selected reproductive group reached 16.2%, supporting the usefulness of applying GSI together with gonadal assessment as a criterion for reproductive selection.

3. Application of the integrated technology provided an egg fertilization rate of 86%.

4. During the production season, 810,000 standard larvae were obtained against a planned target of 700,000 individuals. The excess amounted to 110,000 larvae, or 15.7%.

5. The value of actual production amounted to 8.1 million UZS, production costs to 5.7 million UZS, net profit to 2.4 million UZS, and profitability to 42.1%.

6. The integrated use of morphophysiological criteria, gonadosomatic-index assessment, and controlled hormonal stimulation may be considered a promising basis for improving the technology of forming reproductive groups of silver carp under pond aquaculture conditions in the Tashkent region.

PRACTICAL RECOMMENDATIONS: When forming reproductive groups of silver carp in pond farms, selection should be based not only on age and external morphological characteristics, but also on the physiological readiness of fish for reproduction.

To improve selection objectivity, gonadal assessment and the gonadosomatic index should be used in combination.

Hormonal stimulation is recommended after preliminary assessment of broodfish reproductive readiness because the effectiveness of hormonal treatment is directly related to the degree of gonadal maturity.

The production efficiency of the technology should be evaluated simultaneously using biological and economic criteria: egg fertilization rate, number of larvae obtained, production cost, net profit, and profitability.

Indicator	Value
Planned number of larvae	700,000 individuals
Actual number	810,000 individuals.
Value per larva	10 UZS
Planned production value	7,000,000 UZS
Actual production value	8,100,000 UZS
Production costs	5,700,000 UZS
Net profit	2,400,000 UZS
Revenue per 1 UZS of costs	1.42 UZS
Profit per 1 UZS of costs	0.42 UZS
Profitability	42.1%

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