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Original article

Dynamics of Allometric and Weight Parameters of the Black Sea Scallop *Flexopecten glaber ponticus* (Bucquoy, Dautzenberg & Dollfus, 1889) During Cage Farming

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Abstract
The scallop *Flexopecten glaber ponticus* (Bucquoy, Dautzenberg & Dollfus, 1889), which is endemic to the Black Sea, can be classified as a mollusk species potentially cultivable in the coastal waters of Crimea. Recent data indicate emerging trends in the scallop population recovery off the Crimean coast. The scallop settles in large quantities into nursery cages together with the giant oyster *Crassostrea gigas* (Thunberg, 1793), which suggests the scallop can be reared in suspended culture due to its availability and ease of collection. We studied the seasonal dynamics of allometric growth and weight increase of the Black Sea scallop *F. glaber ponticus* during cage farming off the coast of Crimea. For the first time, a growth model is presented that adequately describes the linear growth of the mollusk. The linear relationship between shell height and age of the scallop and the exponential relationship between the total live weight and shell height were found. It was shown that the commercial quality indices of *F. glaber ponticus* – meat yield, condition index and gonadosomatic index – vary with season. The maximum values of the condition index and meat yield were noted in April, 63.40 and 33.01%, respectively. The gonadosomatic index increased from January to June (from 6.8 to 13.14%) and decreased from July to November, which trends are associated with the gametogenesis and spawning of the mollusk. The percentage of dry matter in soft tissues was 16.5%. We propose the cultivation duration (2.5–3 years) and optimal timing for harvesting marketable Black Sea scallop as a promising mariculture species. Winter and spring can be the best period for collection of the Black Sea scallop of marketable size.

Keywords: scallop *Flexopecten glaber ponticus,* growing, linear growth, condition index, meat yield, gonadosomatic index, Black Sea, mariculture, commercial mollusks

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Динамика линейных и весовых параметров черноморского гребешка *Flexopecten glaber ponticus* (Bucquoy, Dautzenberg & Dollfus, 1889) при садковом выращивании

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Аннотация

Плоский гребешок *Flexopecten glaber ponticus* (Bucquoy, Dautzenberg & Dollfus, 1889), являющийся эндемиком Черного моря, может быть отнесен к потенциальным объектам культивирования у берегов Крыма. Данные последних лет свидетельствуют о восстановительных процессах в популяции гребешка на Крымском побережье. В массовом количестве гребешок оседает в выростные садки с гигантской устрицей *Crassostrea gigas* (Thunberg, 1793), что позволяет выращивать его в подвесной культуре благодаря доступности и простоте сбора. Цель работы – изучить сезонную динамику линейного и весового роста черноморского гребешка *F. glaber ponticus* при садковом выращивании у берегов Крыма. Впервые представлена модель роста, адекватно описывающая линейный рост моллюсков. Определена линейная зависимость высоты раковины гребешка от возраста и экспоненциальная зависимость общего живого веса гребешков от высоты раковины. Показано, что индексы товарного качества *F. glaber ponticus*: выход мяса, индекс кондиции и гонадосоматический индекс – изменяются в зависимости от сезона. Максимальные значения индекса кондиции и выхода мяса отмечены в апреле и составляли соответственно 63.40 и 33.01 %. Гонадосоматический индекс увеличивался с января по июнь (от 6.8 до 13.14 %) и уменьшался с июля по ноябрь, что связано с процессами гаметогенеза и нереста моллюсков. Доля сухого вещества в мягких тканях составила 16.5 %. Рекомендована продолжительность выращивания (2.5–3 года) и сроки сбора товарной продукции черноморского гребешка как перспективного объекта марикультуры. Для сбора урожая черноморского гребешка товарного размера может быть оптимальным зимне-весенний период.

Ключевые слова: гребешок, *Flexopecten glaber ponticus,* марикультура, рост, индекс кондиции, выход мяса, гонадосоматический индекс, Черное море, промысловые моллюски

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Introduction

The mollusk aquaculture includes approximately 65 registered species represented mainly by bivalves (clams, oysters, scallops and mussels), which account for 89% of global marine aquaculture production, while 11% comes from wild capture. The largest producers of marine bivalves are Asian countries, especially China, where 85% of the world production is grown [1]. The world seafood market considers scallops, along with other commercial bivalves (mussels and oysters), to be a valuable delicacy due to their excellent taste and nutritional properties. High-quality protein, polyunsaturated omega-3 fatty acids in high concentrations necessary for human activity, as well as macro- and microelements (iodine, selenium, calcium), vitamins A and D make a major contribution to the nutritional value of the mollusk [2].

In the Black Sea, commercial harvesting and cultivation of bivalves are not particularly developed. Only five mollusk species are of commercial importance: *Mytilus galloprovincialis* (Lamarck, 1819), *Crassostrea gigas* (Thunberg, 1793), *Chamelea gallina* (Linnaeus, 1758), *Donax trunculus* (Linnaeus, 1758) and *Anadara kagoshimensis* (Tokunaga, 1906) [3]. The scallop *Flexopecten glaber ponticus* (Bucquoy, Dautzenberg & Dollfus, 1889), which is endemic to the Black Sea, can be classified as a mollusk species potentially cultivable in the Crimean coastal waters. It lives at depths of up to 30 m on the surface of silty, sandy and shelly ground, as well as on oyster beds [1)]. The scallop can attach itself temporarily to the thalli of vegetation located above the ground. The color of the shells varies from white or yellow to red and brown, the right valve is often lighter than the left one. The length and height of the mollusk shell is up to 55 mm, its width is up to 13 mm. Until recently, the Black Sea scallop was included in the Red Book of the Republic of Crimea as a subspecies declining in numbers [2)]. However, recent literature and our own data [3, 4] indicate emerging trends in the scallop population recovery off the Crimean coast. The scallop settles in large quantities into nursery cages together with the giant oyster *C. gigas*, which suggests the scallop can be reared in suspended culture due to its availability and ease of collection.

During cage farming, *F. glaber ponticus* has a relatively high growth rate in its first year of life and reaches a length of about 42 mm by the end of the second year. The largest mollusk specimens at the age of three years had a shell height of more than 55 mm. As for the scallops from natural Black Sea settlements, this size is close to the limit [3]. The scallops *F. glaber* with a shell height of more than 50 mm are considered to be commercial ones [5]. This species is promising for the Black Sea mariculture due to its high growth rate.

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1) Skarlato, O.A., 1972. [Class Bivalvia]. In: V. A. Vodyanitskiy, 1972. [*Field Guide for the Black Sea and the Sea of Azov*]. Kiev: Naukova Dumka, pp. 178–249. Vol. 3 (in Russian).

2) Ivanov, S.P. and Fateryga, A.V., eds., 2015. *Red Book of the Republic of Crimea. Animals*. Simferopol: ARIAL, 440 p. (in Russian).

The Black Sea scallop is a synchronous hermaphrodite. The gonad is two-colored: the male part of the gonad is cream-colored, the female part is orange. It reproduces in June and July. Spawning is partial. The Black Sea scallops become reproductive in the first year of their life [6].

According to N. Berik [6], the scallop *F. glaber* farmed in the Canakkale Strait (the northern Aegean Sea) also reproduces in June and July. The scallop *F. glaber* from the northwestern Adriatic Sea has two spawning periods: in April and May, as well as from June to September (with maximum gonadosomatic index values in June) [5].

The cultivation of *F. glaber ponticus* along the Crimean coast of the Black Sea is at an early stage, so the data concerning the biotechnology of cultivating this species and its nutritional properties are very little.

The paper aims at the study of the seasonal dynamics of allometric growth, determination of the relationship between the total weight and shell height and evaluation of commercial quality indices (meat yield (MY), condition index (CI) and gonadosomatic index (GSI)) of the Black Sea scallop *F. glaber ponticus* as a promising mariculture species during cage farming.

Materials and methods of study

The material of the study was the scallop spat collected in nursery cages with the giant oyster *C. gigas* grown on an oyster farm (Sevastopol Bay outer roadstead: 44°37′13.4″ N; 33°30′13.6″ E). The mollusk specimens were then grown with the use of suspended culture at a depth of 3–5 m for 2.5 years.

The growth dynamics and determination of the total weight of scallops of different ages (from 0.5 to 2.5 years) were studied over a year selecting 10 pcs. monthly. The mollusk specimens were cleaned of fouling organisms, washed in sea water and then their size and weight characteristics were determined [7]. The length (L, mm), height (H, mm), width (D, mm) of the *F. glaber ponticus* shell were measured with a digital caliper (*Zubr* ShTs-1) with an accuracy of 0.01 mm. Total wet weight of the scallop (W_{total}, g – total weight with mantle fluid), weight of soft tissue ($W_{s.t}$, g), weight of gonads (W_{gon}, g) were determined according to method [7] on electronic scales (OHAUS) with an accuracy of 0.01 g.

Dry matter of soft tissues and dry matter of gonads were determined on AXIS ANG200C electronic scales (to 0.0001 g) after drying in a thermostat to a constant dry matter at a temperature of 60 °C for 48 h. CI, MY and GSI indices (%) were calculated using formulas [8]:

$$CI = \text{meat wet weight (g)} / \text{shell wet weight (g)} \cdot 100;$$

$$MY = \text{meat wet weight (g)} / \text{total wet weight (g)} \cdot 100;$$

$$GSI = \text{gonad wet weight (g)} / \text{meat wet weight (g)} \cdot 100.$$

The moisture content of the sample was determined as the difference in weight before and after drying in a thermostat at 60 °C to constant weight and was shown as percentage. Ash content was determined by burning samples in a TEMOS-Express muffle furnace at a temperature of 600 °C for 2 h [3)]. The mean values of allometric and weight parameters and confidence intervals were calculated in Excel.

[3)] Horwitz, W., 2000. *Official Methods of Analysis of the AOAC International.* Gaithersburg, USA.

Empirical data on allometric growth were approximated with the von Bertalanffy growth model – the Ford–Walford equation [9, 10]

$$H_t = H_\infty \cdot (1 - e^{-kt}),$$

where H_t is actual size of an individual, mm, at age t, years; H_∞ is theoretically maximum shell height, mm; k is growth constant, year^{-1}; e is base of natural logarithm (2.71828…).

Results and discussion

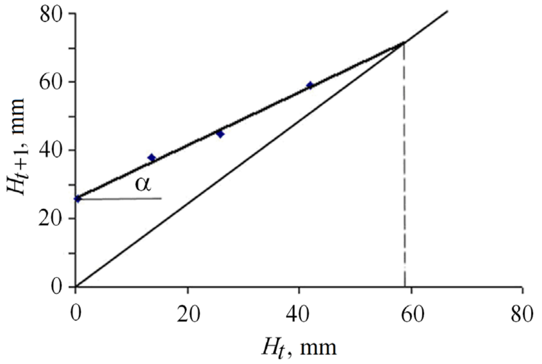
As a result of the analysis of size-frequency distributions, modal sizes of mollusk specimens in age groups of 0.5–2.0 years were obtained. They were then used to create an allometric growth model. The height of the scallop spat shell immediately after the larvae metamorphosis is 0.3 mm [4)]. The values of the parameters of this equation were found graphically. To construct the graph, the average values of the scallop shell height at age t were plotted on the abscissa axis, and at age $t + 1$ – on the ordinate axis (Fig. 1).

These points are located on one straight line. The intersection of the line with the right angle bisector determines the theoretically maximum size of an individual in the settlement. Fig. 1 shows that the line intersects the bisector at 57.0 mm. The slope angle (α = 26°) makes it possible to evaluate the growth constant:

$$k = -\lg \operatorname{tg} \alpha / \lg e,$$

where tg α is tangent of the slope angle of a straight line, which is equal to 0.4877, then k = –lg 0.4877 / 0.4343 = −03118 / 04343 = −0.718. We obtain the following relationship:

$$H_t = 57.0 \cdot (1 - e^{0.718t}),$$
$$0.5 \le t \le 2.0.$$



F i g . 1 . Graphical determination of parameters of the von Bertalanffy growth equation

Using this formula, we calculated the theoretically expected average values of the scallop shell height (Table).

The formula describes the mollusk allometric growth adequately. Thus, the theoretically expected modal classes coincide completely with the actual average values of the shell height for the age of 1.5 and 2.0 years.

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4) Zakhvatkina, K.A., 1972. [Larvae of Bivalvia]. In: V. A. Vodyanitskiy, 1972. [*Field Guide for the Black Sea and the Sea of Azov*]. Kiev: Naukova Dumka, pp. 250–270. Vol. 3 (in Russian).

Parameters of the growth equation for the scallop *Flexopecten glaber ponticus* and theoretically expected modal sizes of mollusk specimens aged 0.5–2 years

t, years	k_t	e^{-kt}	$1-e^{-kt}$	H_t (theoretically expected), mm	$H \pm i$ (actual), mm
0.5	0.359	0.698	0.302	17.21	13.71 ± 0.76
1.0	0.718	0.487	0.513	29.24	25.88 ± 0.67
1.5	1.077	0.341	0.659	37.56	37.96 ± 0.75
2.0	1.436	0.238	0.762	43.43	42.12 ± 1.02

Note: ±*i* – confidence interval, mm.

The relationship between the average value of the scallop shell height (H, mm) and age ($0.5 \geq t \geq 2.5$) is also described by a linear function with a high value of the correlation coefficient ($r = 0.9841$):

$$H = 19.514\ t + 4.8472.$$

Fig. 2 shows the graph of relationship.

As the shell height increased, the total weight of the scallop increased exponentially (Fig. 3).

The results of our studies showed that the relationship between the wet weight of soft tissues and the total wet weight of the Black Sea scallop was described by a linear function (Fig. 4).

The values of the *F. glaber ponticus* weight indicators (MY, CI and GSI) show the mollusk commercial quality. Weight indicators can vary depending on the season, presence and availability of food, reproductive cycle stages and are the result of a complex interaction among these factors [11]. These indicators reflect the mollusk ecophysiological characteristics (gametogenesis and metabolism processes) and are of great importance when harvesting marketable products.

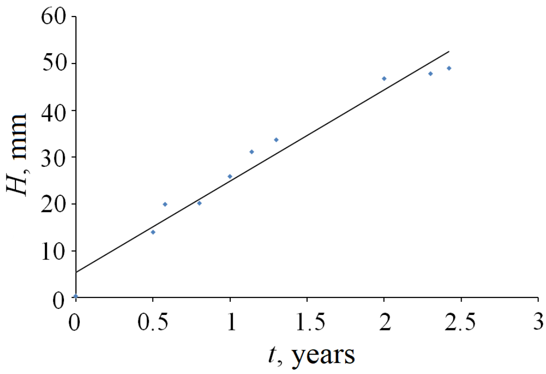
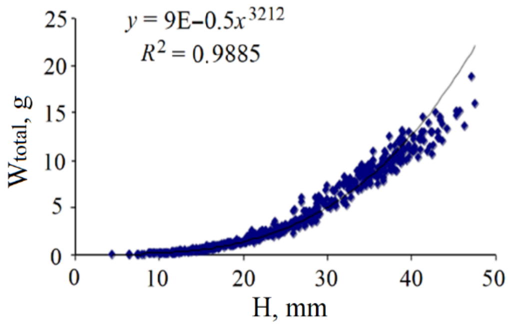
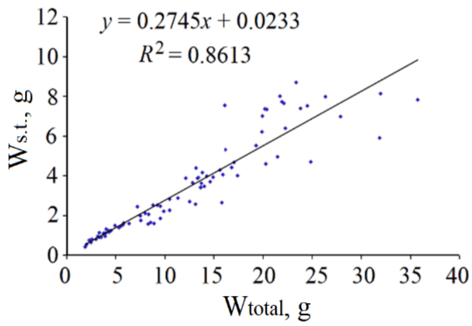


Fig. 2. Dynamics of growth of the scallop *Flexopecten glaber ponticus* during cage farming



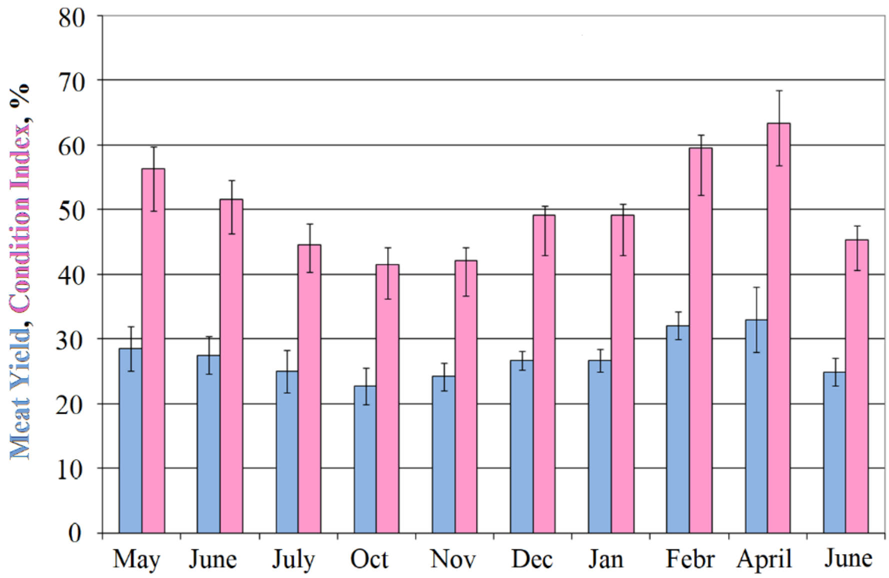
F i g . 3 . Dependence of the total weight of the scallop *Flexopecten glaber ponticus* on the shell height



F i g . 4 . Correlation of the soft tissue wet weight with the total weight of the Black Sea scallop *Flexopecten glaber ponticus*

We established that changes in the weight indicators of the scallop *F. glaber ponticus* were seasonal. The maximum CI and MY values were noted in April, 63.40 ± 6.54% and 33.01 ± 5.06% ($p = 0.05$), respectively, while the minimum values of these indicators were recorded in October: 41.39 ± 5.15% and 22.71 ± 2.80% (Fig. 5). The CI increase from January to May is obviously related to the gonad maturation dynamics. The CI values dropped sharply in June during the spawning period and remained low from July to December. The MY values increased from January to April due to an increase in somatic tissue weight. These values then decreased during the spawning period and remained low during the resting period. The processes of somatic tissue growth slowed down and the CI increased due to the increase in the weight of the gonads in April–June. For the same scallop species grown in the Çardak Lagoon on the shore of the Canakkale Strait (Turkey), similar results were obtained for MY: 39.69% in spring and 29.96% in summer [6].

It is known that the decrease in the CI and MY indices in summer and autumn is caused by unfavorable hydrological conditions, as well as a decrease in the qualitative and quantitative composition of phytoplankton necessary for somatic and generative growth [12]. Thus, the concentration of microalgae decreased in August to minimum values (26 thousand cells·L^{-1}) in the water area of the mussel and oyster farm (location of nursery cages with the scallops) with water warming up to 25 °C. It was the period of domination of large-celled forms of algae, which are not food for bivalves [13]. The maximum values of phytoplankton abundance were typical for February, when food species of microalgae predominated: the diatom *Skeletonema costatum* (Greville, 1865) and the coccolithophore *Emiliania huxleyi* (Lohmann, 1967). From April to July, the number of phytoplankton changed slightly, from 100 to 124 thousand cells·L^{-1}.

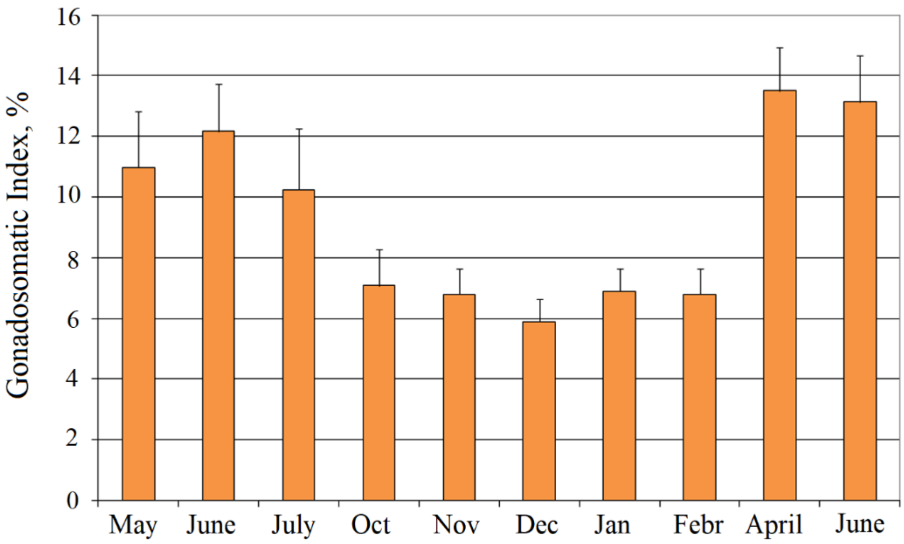


F i g . 5 . Seasonal dynamics of mean values of condition index and meat yield of the scallop *Flexopecten glaber ponticus* during cage farming

According to literature data, seasonal fluctuations in seawater parameters can affect the physiological functions and survival of the scallops negatively [14]. Due to a lack of food, metabolic energy is redirected mainly to maintaining reproductive processes, which leads to a decrease in the condition index value, while high food availability enhances tissue and gonad growth [15].

The increase in the scallop GSI values from February (6.8 ± 1.86%) to June (13.14 ± 1.52%) with its maximum in April (13.5 ± 1.44%) indicates the maturation of the gonads (Fig. 6). In parallel with the development of the gonads, the total weight of the scallop soft tissue and the CI values also increased. The Black Sea scallop spawning was noted in June – early July and the GSI value was 10.25 ± 2.0% at the end of July. From October to December, the GSI values were declining and reached their minimum in December (5.9 ± 0.74%).

Changes in the MY and GSI indices are directly related to the reproductive cycle. The weight of gonads increases before spawning, while the weight of the somatic tissue decreases. It is known that glycogen accumulated in the adductor is used as an energy source to increase the weight of gonads. Thus, reproduction affects significantly the adductor weight and, consequently, the total weight of the soft tissue [16, 17]. By the reproduction period, the relative weight of the somatic tissue decreases due to the increase in the weight of gonads [17].



F i g . 6 . Seasonal dynamics of the gonadosomatic index of the Black Sea scallop *Flexopecten glaber ponticus* during cage farming

According to our data, the weight of gonads changed insignificantly from December to February (from 0.136 g to 0.152 g). However, the weight of the gonads increased to maximum values (0.343 g) from April to June, possibly due to the accumulation of a sufficient amount of lipids [5]. Therefore, high CI values in April are stipulated by an increase in the weight of the somatic tissue, and in June – an increase in the weight of gonads. Gametogenesis processes depend on biotic and abiotic factors [18]. The mollusk gametogenesis occurs with a sufficient amount of trophic resources necessary for the energy-consuming reproduction process. With an insufficient amount of food, the mollusk experiences catabolism of such reserve tissue as the adductor [18]. According to T. Marceta [5], the tendency toward decreased weight and energy content in the somatic tissue and gonads indicates a gradual depletion of energy stored in the somatic tissue for use in the reproductive process.

The MY, CI and GSI indices reflect the ecophysiological state of bivalves. Changing the index values adjusts significantly the cultivation biotechnology and harvesting dates. The MY values of the scallop *F. glaber ponticus* increased from autumn to early spring. Therefore, the commercial value of the mollusk decreases sharply during and after the spawning period when the scallop gonads are freed from reproductive bodies and the weight of the soft tissue decreases.

The dry matter content in the soft tissue of the scallop *F. glaber ponticus* averaged 16.5% and the proportion of water was 83.5%, with its maximum content in February (83.81%). Similar values were obtained for other bivalves: *M. galloprovincialis, Limaria tuberculata* (Olivi, 1792) [19]. The water content in the soft tissue influences physical and chemical characteristics of the mollusk and is considered to be a good indicator of seafood freshness and quality. Its content depends on the physical structure since water is involved in many physiological processes such as nutrient transport, waste removal, transmission of nerve impulses and muscle contractions [20].

The relationship between the dry weight of the scallop soft tissues and the wet weight is expressed by the following linear function:

$$W_{dry\ s.t.} = 0.1601 \cdot W_{meat\ s.t.} + 0.0127,$$
$$0.18 \geq W_{meat\ s.t.}\ g \geq 4.42; \quad R^2 = 0.9912.$$

The ash content in the soft tissues of the Black Sea scallop indicating the amount of inorganic compounds in the tissues ranged from 1.85 g / 100 g to 2.36 g / 100 g. Similar average ash content values were determined for bivalves from the Adriatic Sea: *F. glaber* – 2.11 g / 100 g, *Chlamys vari*a (Linnaeus, 1758) – 2.49 g / 100 g, *Ostrea edulis* (Linnaeus, 1758) – 2.18 g / 100 g [21] and from the Mediterranean Sea: *M. galloprovincialis* – 2.62 g / 100 g [19].

Conclusion

Recently, the population of the Black Sea scallop *F. glaber ponticus* has been recovering resulting in an increase in the amount of settled spat, which makes it possible to study the allometric and weight parameters. When grown in suspended culture, the weight of the Black Sea scallop increased exponentially with its shell height. The mollusk commercial indicators varied depending on the season. The highest CI and MY values were noted from December to April (49.13−63.4 and 26.71−33.01%, respectively), and the lowest ones – in the summer months. The maximum GSI values were obtained in June during the pre-spawning period. Therefore, winter and spring can be the best periods for collection of the Black Sea scallop of marketable size.

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