Quantitative Splanchnological Study of Sterlet (*Acipenser ruthenus*) Reared in a Recirculating Aquaculture System

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Abstract

Natural populations of sturgeons have dramatically declined in recent decades due to anthropogenic pressures such as overfishing, habitat degradation and pollution. Sterlet (*Acipenser ruthenus*) is a species of particular interest due to its high-quality meat, economic value and remarkable ability to adapt to recirculating aquaculture systems (RAS). This study aimed to describe the anatomical and morphological characteristics of the internal organs of 1.5-year-old sterlet specimens reared in intensive indoor systems, using specific quantitative splanchnological methods. The anatomical examination revealed an abdominal cavity with reduced perivisceral fat and a simple digestive tract composed of a short esophagus, a well-developed stomach, and a middle and posterior intestine. The latter was provided with a spiral septum on the inner surface. At the junction between the stomach and the intestine, pyloric ceca were grouped into a spongy-like structure. The liver displayed a clearly lobed structure. The pancreas, with a diffuse structure, was difficult to delimit macroscopically from a morphometric point of view. The gonads, at an early stage of development, were well individualized and covered by a thin layer of fat. The biometric analysis revealed uniform body development and a good physiological condition, typical of fish reared under controlled environmental parameters, confirming their efficient adaptation to intensive rearing conditions. The measurements revealed an average total length of 59.0 ± 0.4 cm and a mean body mass of 862.6 ± 24.9 g. The Fulton condition factor (K = 0.82) confirmed the overall healthy state of the specimens and their harmonious body growth. The digestive tract showed a mean stomach length of 13.1 ± 0.9 cm, an intestinal length of 22.9 ± 0.9 cm and a liver mass of 24.0 ± 1.0 g, indicating proportional organ development and a good nutritional status. The results highlight a normal morphological development and good physiological adaptation of *Acipenser ruthenus* to the conditions of recirculating aquaculture systems, confirming the strong biological, adaptive, and economic potential of this species in intensive aquaculture. The quantitative splanchnological data obtained in this study contribute to a better understanding of the internal morphology of the sterlet and represent a useful foundation for future research on growth physiology and aquaculture improvement in sturgeon species.

Keywords: internal organs, intensive rearing, quantitative splanchnology, RAS

1. Introduction

Natural populations of sturgeons (Acipenseridae) have undergone a marked decline in recent decades as a result of pressures exerted by human activities, such as overfishing (both legal and illegal), degradation and fragmentation of aquatic habitats caused by dam construction, and pollution associated with industrial, agricultural, and urban activities [1-5]. In the context of this dramatic reduction in stock size, all sturgeon species have been included, since 1998, in the CITES Convention on International Trade in Endangered Species [6, 1, 4]. As a consequence, in order to maintain production and reduce pressure on wild populations, a distinct branch of aquaculture dedicated to the controlled rearing of sturgeons has developed [7, 8].

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At present, sturgeons are regarded as some of the most valuable commercial fish species, being highly appreciated for caviar, meat, and, in some cases, ornamental value. Given the restrictions imposed on the exploitation of natural resources, reproduction and rearing under controlled conditions have become essential both for ensuring production and for conserving these species [9].

Within modern aquaculture, the sturgeon farming sector continues to expand due to the high economic interest, superior nutritional value of the products, and the capacity of these species to adapt to different environmental conditions [5, 10]. Among these species, sterlet (*Acipenser ruthenus*) occupies an important place in Central and Eastern Europe, being valued for the quality of its meat and roe [11, 12, 13]. In addition, the species is frequently used as an experimental model in physiological and nutritional studies due to its relatively rapid growth rate and its adaptation to freshwater environments [14, 15, 16].

The predominantly carnivorous feeding habit of the species requires a high protein intake to support growth, making sterlet suitable for the evaluation of modern nutritional strategies and alternative protein sources [17, 18]. Moreover, sterlet is frequently reared in recirculating aquaculture systems (RAS) due to its adaptability to controlled conditions and relatively early sexual maturation [19, 20, 21]. However, the physiological and morphological mechanisms involved in adaptation to the specific parameters of these systems are not yet fully understood [22, 23, 24]. In this context, the quantitative assessment of internal organs may provide valuable information regarding metabolic adaptation, nutrient utilization efficiency, physiological status, and the overall capacity of the species to adjust to intensive rearing conditions.

Therefore, the analysis of internal organ development represents an important tool for assessing physiological status, degree of adaptation, and growth efficiency under intensive rearing conditions. Consequently, the present study aims to provide a quantitative characterization of the internal organs of sterlet (*Acipenser ruthenus*) reared in a recirculating aquaculture system through the use of splanchnological and morphological analysis methods.

2. Materials and methods

The study was conducted in October 2025 at the Pădurea Verde Fish Farm, belonging to the Timișoara Didactic Station of the University of Life Sciences "King Michael I" from Timișoara. The experiments were carried out in a recirculating aquaculture system (RAS) consisting of four interconnected tanks, each with a volume of 18 m³. The system was equipped with all the components necessary to ensure optimal rearing conditions, including mechanical and biological filtration units, water recirculation and aeration equipment, as well as supplementary oxygenation systems designed to maintain fish welfare and safety.

The biological material consisted of sterlet (*Acipenser ruthenus*) specimens reared under intensive conditions in the above-mentioned recirculating aquaculture system. The physicochemical parameters of the water, like temperature, dissolved oxygen, pH, and total ammonia concentration, were monitored daily and maintained within the optimal ranges recommended for the species [11]. Fish were fed ad libitum with SUPREME 10 pelleted feed (Alltech Coppens, Germany), administered through FIAP semi-automatic feeders adjusted according to fish body weight.

For the quantitative splanchnological analysis, five clinically healthy sterlet specimens, aged 1 year and 6 months, were randomly selected. All individuals originated from the same generation and exhibited similar body dimensions, thereby ensuring the homogeneity of the experimental group. At this developmental stage, sex could not be determined due to the absence of secondary sexual characteristics.

Prior to dissection, the fish were stunned using a FIAP Mini #1986 electric device (Germany). The following biometric parameters were recorded for each specimen: total length (TL), standard length (SL), maximum body height (H), body circumference (P), and body weight (BW).

Biometric determinations were performed according to the standard methodology used in ichthyological studies [25, 26]. Based on the recorded values, the profile index (Ip = SL/H), where SL represents standard length (cm) and H

maximum body height (cm), and Fulton's condition factor ($K = BW \times 100 / SL^3$), where BW represents body weight (g) and SL standard length (cm), were calculated.

After evisceration, carcass weight was recorded for the calculation of slaughter yield. Biometric measurements were carried out using an ichthyometer, measuring tape, caliper, and a precision balance (±1 g). The obtained data were compiled and statistically processed using Microsoft Excel in order to calculate mean values and variation indicators required for the characterization of the experimental group.

Following the completion of body measurements, the specimens were dissected using a standard set of anatomical instruments (scalpel, surgical scissors, forceps). The internal organs were identified, anatomically described, removed, and subjected to morphometric and gravimetric measurements (Fig. 1). At the level of the internal organs, the main dimensions and masses of the different anatomical structures were determined. For the digestive tract, pharynx length, esophagus length and diameter, as well as stomach and intestine weight, length, and volumetric capacity, including those of the pyloric appendages, were evaluated. For the liver, total weight and the dimensions of the hepatic lobes were recorded, while for the kidneys, heart, spleen, swim bladder, and gonads, the main morphometric and gravimetric traits were determined.

Organ lengths, widths, and diameters were measured using a caliper or measuring tape, while organ weights were determined using a precision balance (±1 g). The volumetric capacity of the stomach and intestine was evaluated after emptying and washing the organs, followed by filling them with water using a graduated syringe.

The primary data obtained from the quantitative splanchnological analysis were statistically processed using Microsoft Excel to calculate mean values and variation parameters. The results are presented as mean values ± standard error of the mean.

Figure 1. Sterlet specimen prepared for quantitative splanchnological analysis

3. Results and discussion

Biometric analysis of the body

Following stunning, the sterlet specimens were subjected to biometric analysis. During this stage, the main morphometric dimensions were measured, and the obtained data were compiled and statistically processed, the results being presented in Table 1..

Table 1. Biometric parameters of sterlet specimens from the analyzed group (n = 5)

Specification	Total length (cm)	Standard length (cm)	Maximum body height (cm)	Body circumference (cm)	Body weight (BW) before evisceration (g)	Body weight (BW) after evisceration (g)
Mean	59.00	47.26	8.02	19.25	862.60	734.40
SD	0.88	1.11	0.36	0.71	55.76	36.92
SEM	0.39	0.50	0.16	0.32	24.94	16.51
CV	1.49	2.35	4.44	3.71	6.46	5.03

SD – standard deviation, SEM – standard error of the mean, CV – coefficient of variation

The recorded values indicate a uniform and harmonious body development of the analyzed specimens. Thus, the mean total length was 59.00 ± 0.39 cm, while the maximum body height averaged 8.02 ± 0.16 cm, corresponding to a profile index of 5.9. The mean body weight before evisceration was 862.60 ± 24.94 g, reflecting a harmonious and balanced growth of the individuals included in the experimental group.

Fulton's condition factor (K = 0.82) confirmed that the sterlet specimens were in good condition, the obtained value indicating harmonious growth and a favorable overall physiological status.

The analysis of body weight also showed that the mean fish weight before evisceration was 862.60 ± 24.90 g, while after viscera removal, the mean carcass weight reached 734.40 ± 16.51 g. Based on these values, the slaughter yield was calculated at 85.14%, indicating a high proportion of muscle tissue and confirming the good physiological and nutritional condition of the analyzed specimens.

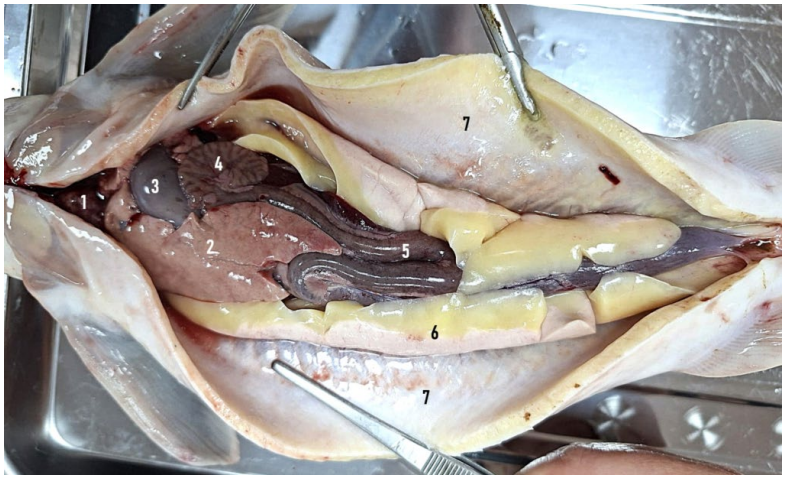

Figure 2. Internal organs visible after opening the abdominal cavity of sterlet:
1 – pericardial cavity; 2 – right liver lobe; 3 – stomach; 4 – pyloric appendages; 5 – intestine; 6 – gonads; 7 – abdominal wall

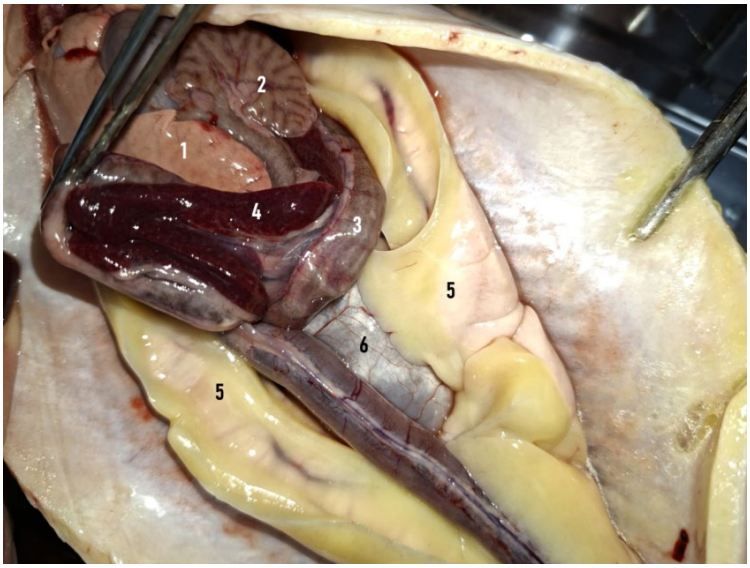

Figure 3. Internal organs identified in the abdominal cavity of sterlet:
1 – right liver lobe; 2 – pyloric appendages; 3 – intestine; 4 – spleen; 5 – gonads; 6 – swim bladder

Results of the Anatomical Study and Quantitative Splanchnological Analysis

As part of the anatomical study and quantitative splanchnological analysis, the sterlet specimens were dissected, and the internal organs were identified prior to removal in order to allow their quantitative assessment (Fig. 2, 3, 4).

After opening the abdominal cavity, the sterlet specimens were found to have a low amount of perivisceral fat, which provided excellent visibility of the internal organs. This feature allowed a clear and accurate examination of organ arrangement, with the heart, liver, spleen,

pancreas, stomach, intestine, swim bladder, and gonads being readily distinguished.

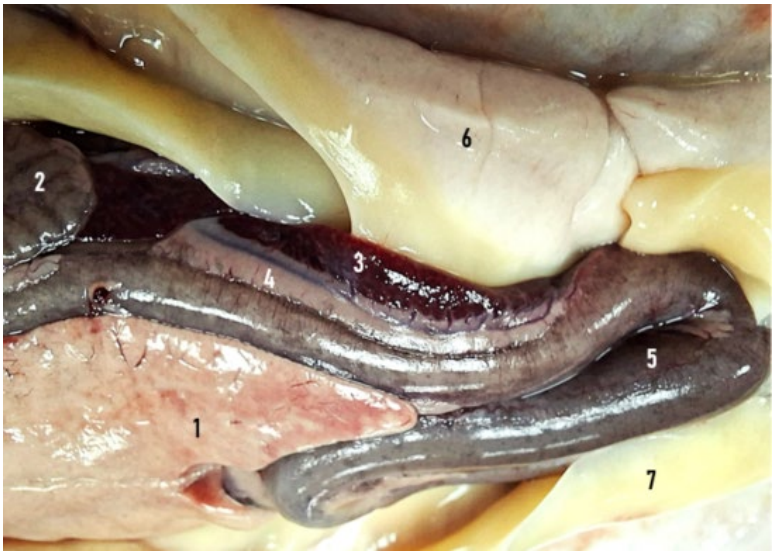

Figure 4. Internal organs identified in the abdominal cavity of sterlet:
1 – right liver lobe; 2 – pyloric appendages; 3 – spleen; 4 – pancreas; 5 – intestine; 6 – left gonad; 7 – adipose tissue

Digestive tract

The digestive tract (Fig. 5) of sterlet (*Acipenser ruthenus*) reared in a recirculating aquaculture system is relatively simple, consisting of a short esophagus, a well-developed stomach, and a relatively short intestine adapted to the digestion of pelleted feed commonly used in fish nutrition. The main anatomical components of the digestive tract are described below.

Pharynx

In the analyzed specimens, the pharynx had a mean length of 2.68 ± 0.08 cm (Table 2). From a morphological point of view, this region is characterized by a complex internal structure involved simultaneously in both respiratory and feeding functions. Of the five pairs of branchial arches, the first four bear gill filaments on the external (convex) surface and short but robust gill rakers on the internal (concave) surface, oriented in a craniocaudal direction (Fig. 6).

Figure 5. Digestive tract in sterlet

Table 2. Results of the quantitative splanchnological study of the digestive tract (n = 5)

Trait	Mean	SD	SEM	CV
Pharynx length (cm)	2.68	0.18	0.08	6.69
Esophagus length (cm)	2.84	0.24	0.11	8.48
Esophagus diameter (cm)	0.79	0.05	0.02	6.93
Stomach length (cm)	13.08	1.92	0.86	14.67
Posterior intestine length (cm)	22.94	2.06	0.92	9.00
Stomach volume (ml)	11.00	1.17	0.53	10.68
Posterior intestine volume (ml)	17.50	1.58	0.71	9.04
Stomach weight (g)	4.20	0.84	0.37	19.92
Intestine weight including pyloric appendages (g)	8.22	1.28	0.57	15.59
Pyloric appendage length (cm)	2.28	0.68	0.30	29.65
Pyloric appendage height (cm)	1.66	0.48	0.21	28.76
Stomach diameter (cm)	0.87	0.11	0.05	12.59
Posterior intestine diameter (cm)	0.96	0.15	0.07	15.80

SD – standard deviation, SEM – standard error of the mean, CV – coefficient of variation

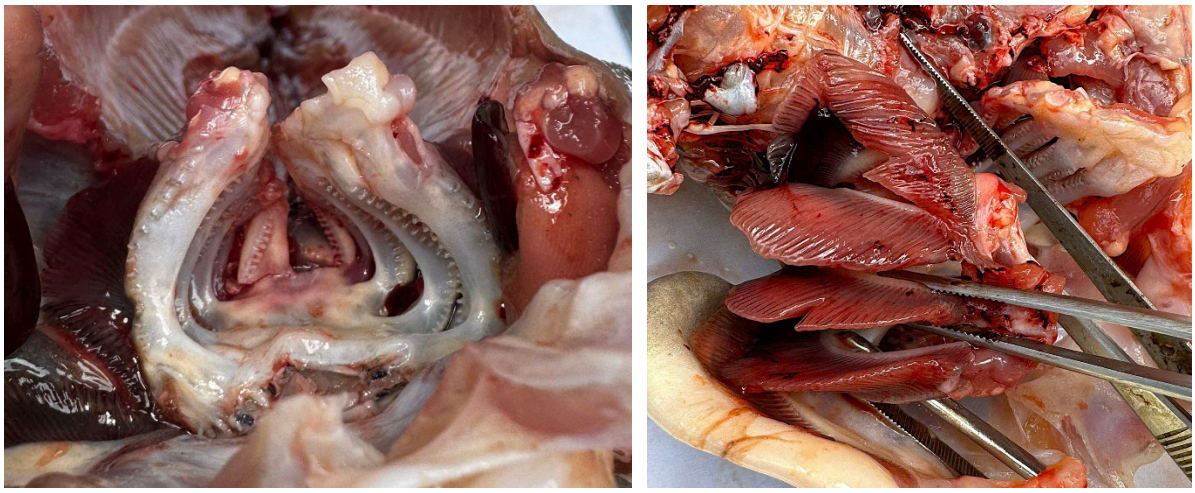

Figure 6. Pharynx in sterlet. Arrangement of the branchial arches: gill rakers located on the concave surface (left) and gill filaments on the convex surface (right)

Esophagus

The esophagus appears as a short tubular structure, with a poorly defined boundary toward the stomach. In the analyzed specimens, the mean esophagus length was 2.84 ± 0.11 cm, while the mean diameter was 0.79 ± 0.02 cm. It is located between the pharynx and the stomach, establishing the direct connection between these two segments of the digestive tract (Fig. 7).

Stomach

In sterlet, the stomach represents a major segment of the digestive tract (Fig. 8). It is provided with numerous well-developed pyloric appendages located near the junction with the posterior intestine. The stomach has an elongated and slightly enlarged shape, with thick and well-defined walls that facilitate the homogenization and progression of the food content toward the intestine.

Based on the measurements performed on the analyzed specimens, the mean stomach length was 13.08 ± 0.86 cm, with a mean diameter of 0.87 ± 0.05 cm, a mean volumetric capacity of 11.00 ± 0.53 mL, and a mean weight of 4.20 ± 0.37 g. Distally to the stomach, the pyloric appendages appeared as well-developed structures, with a mean length of 2.28 ± 0.30 cm and a mean height of 1.66 ± 0.21 cm.

Figure 7. Esophagus in sterlet

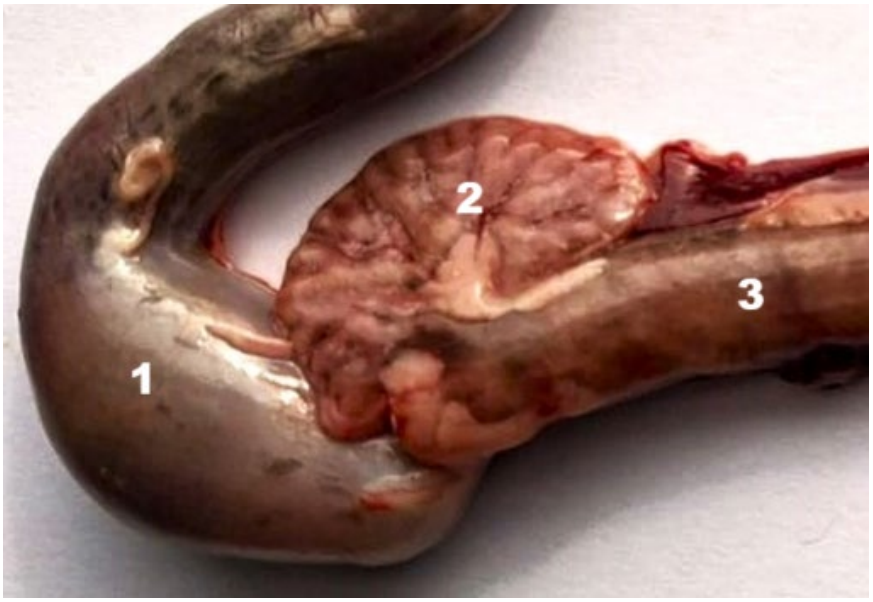

Figure 8. Pyloric appendages highlighted within the digestive tract:
1 – stomach; 2 – pyloric appendages; 3 – anterior intestine

Posterior intestine

The posterior intestine appears as a tubular structure extending from the pyloric opening of the stomach to the anal opening. The inner wall of the intestine presents a fold arranged spirally along the intestinal lumen, known as the spiral valve, which increases the absorptive surface area and prolongs the passage of food through the intestinal lumen (Fig. 9). Based on the measurements performed on the analyzed specimens, the posterior intestine showed a mean length of 22.94 ± 0.92 cm and a mean volumetric capacity of 17.50 ± 0.71 mL. The total weight, together with the pyloric appendages, was recorded at 8.22 ± 0.57 g, while the mean intestinal diameter was 0.96 ± 0.07 cm.

Figure 9. Spiral valve

Liver

In sterlet, the liver (Fig. 10) is a well-developed and relatively large organ located in the abdominal cavity, in close proximity and caudal to the heart. It has a lobed structure, consisting of two main lobes: right and left. The total liver weight in the analyzed specimens was 24.00 ± 0.97 g.

Based on the obtained data, the right liver lobe was larger than the left lobe. The mean length of

the right lobe was 10.23 ± 0.37 cm, whereas the left lobe showed a mean length of 7.93 ± 0.32 cm. Similarly, the right lobe also showed a greater width a mean value of 2.33 ± 0.16 cm, compared with 1.60 ± 0.04 cm in the left lobe (Table 3).

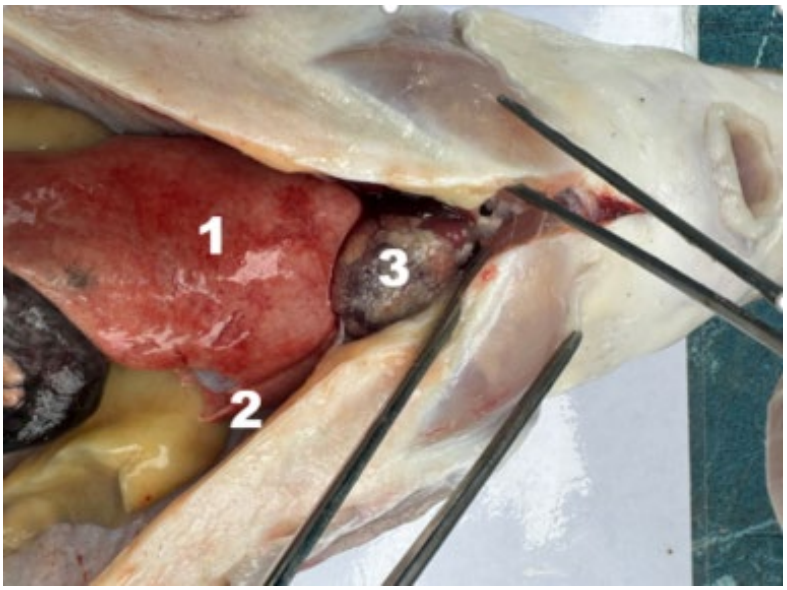

Figure 10. Liver in sterlet:
1 – right lobe; 2 – left lobe; 3 – heart

Table 3. Results of the quantitative splanchnological study performed on the liver (n = 5)

Specification	Left lobe length (cm)	Right lobe length (cm)	Left lobe width (cm)	Right lobe width (cm)	Liver weight (g)
Mean	7.93	10.23	1.60	2.33	24.00
SD	0.71	0.83	0.08	0.36	2.16
SEM	0.32	0.37	0.04	0.16	0.97
CV	8.97	8.08	5.10	15.46	9.00
SEM%	4.01	3.61	2.28	6.91	4.03

In addition to the digestive tract and liver, the quantitative splanchnological analysis also included other internal organs, such as the spleen, kidneys, gonads, heart, and swim bladder. Due to its diffuse structure and distribution throughout different tissues of the body cavity, the pancreas could not be morphometrically evaluated as a distinct organ (Fig. 4). The quantitative data corresponding to the internal organs are presented in Table 4, while their graphical representation is illustrated in Figures 11–14.

Table 4. Results of the quantitative splanchnological study performed on the organs of the abdominal cavity (n = 5)

No.	Spleen length (cm)	Kidney length (cm)	Gonad weight (g)	Heart length (cm)	Swim bladder length (cm)	Swim bladder weight (g)
Mean	7.88	18.62	36.00	1.92	8.88	5.60
SD	0.78	0.65	12.63	0.19	0.97	0.89
SEM	0.35	0.29	5.65	0.09	0.43	0.40
CV	9.85	3.47	35.08	10.02	10.90	15.97
SEM%	4.40	1.55	15.69	4.48	4.87	7.14

Figure 11. Arrangement of the kidneys (1) and the imprint of the swim bladder (2) within the abdominal cavity in sterlet

Within the abdominal cavity, *the swim bladder*, being firmly attached to the abdominal walls, could not be removed intact and collapsed during detachment. For this reason, the measurements were performed based on the impression remaining after its removal.

Following the removal of the digestive organs and the swim bladder, *the kidneys* became clearly visible, being positioned on both sides of the vertebral column. They could not be completely separated due to their adhesions to the vertebral structures, and dimensional measurements were performed directly on the carcass after removal of the internal organs.

The heart is located on the ventral side of the body, immediately posterior to the branchial arches and above the pectoral fins. It is enclosed within a structure known as the pericardial cavity. Structurally, the fish heart is composed of two chambers: a thin-walled atrium and a ventricle (Fig. 12). In sturgeon species, the ventricle is followed by a well-developed contractile muscular region called the conus arteriosus, which is provided with several rows of valves. In the analyzed specimens, the heart showed a mean length of 1.92 ± 0.09 cm.

Figure 12. Heart in sterlet

The spleen is a small organ situated between the stomach and the intestine (Fig. 4). Although relatively small in size, it performs important functions, contributing both to the formation of blood cells and to the removal of aged blood cells.
The gonads (Fig. 13), paired and elongated organs located in the abdominal cavity on both sides of the intestine, showed a mean weight of 36.00 ± 5.65 g. Considering that the analyzed specimens were 1.5 years old, anatomical sexual differentiation could not yet be clearly identified.

Figure 13. Gonads in sterlet

4. Conclusions

The biometric analysis performed on the sterlet specimens revealed a uniform body development, with a mean total length of 59.00 ± 0.39 cm and an mean body weight of 862.60 ± 24.94 g. The profile index (5.9) and Fulton condition factor (K = 0.82) confirmed harmonious growth and a good body condition of the analyzed individuals. The slaughter yield of 85.14% indicates a high proportion of muscle tissue and a favorable physiological condition.
The anatomical examination revealed an abdominal cavity with a low amount of perivisceral fat, which allowed a clear observation of the internal organs. The digestive tract exhibited a relatively simple structure, consisting of a short esophagus (2.84 ± 0.11 cm), a well-developed stomach (13.08 ± 0.86 cm), and a posterior intestine measuring 22.94 ± 0.92 cm, provided with a well-developed spiral valve.
The liver, with a mean weight of 24.00 ± 0.97 g, displayed a clearly lobed structure, with the right lobe being larger than the left one. The heart, located ventrally and composed of two chambers, had a mean length of 1.92 ± 0.09 cm, and a well-developed conus arteriosus was observed. Although relatively small in size, the spleen was easily identified between the stomach and the intestine.
Due to its diffuse structure, the pancreas could not be morphometrically evaluated as a distinct organ. The gonads, which appeared as paired and elongated organs, had a mean weight of 36.00 ± 5.65 g; however, due to the relatively young age of the specimens (1.5 years), anatomical sexual differentiation could not be identified.
Overall, the obtained data indicate a good physiological status, balanced growth, and normal internal organ development in the analyzed sterlet specimens, confirming the suitability of recirculating aquaculture systems for the intensive rearing of this species.

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