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ABSTRACT

of the dissertation for the degree of Doctor of Science

HERRING FISHES OF THE CENTRAL AND SOUTHERN CASPIAN SEA (SYSTEMATICS, ECOLOGY, DISTRIBUTION AND RESERVES)

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INTRODUCTION

The relevance of the topic and its applicability. The Caspian Sea, abundant in unique natural resources, is the largest inland brackish body of water on Earth. It lacks currents and is not connected to the oceans, yet it possesses all the characteristics of a sea.

Throughout different geological periods, the physiographic, hydrochemical, and hydrobiological features of this water basin have changed over time. The geographic and climatic conditions of various parts of the Caspian Sea during these periods led to the distinct formation of their ecosystems. Consequently, the Caspian Sea stands out from other seas in terms of species composition, bioecological characteristics, and the number of hydrobionts, including herring (*Alosa*).

In the Caspian Sea, herring is one of the most important and abundant fish species. Known for its remarkable plasticity in morphology, ecology, physiology, and evolution, herring populations exhibit a range of distinguishing characteristics.

Over the past 30-40 years, the ecosystem and fauna of the Caspian Sea, particularly the morphological and bioecological characteristics of herring populations, have been negatively affected by several factors. These include fluctuations in sea levels, increased anthropogenic environmental impact, global climate change, and the introduction of new organisms from other bodies of water, such as the Tentaculata *Mnemiopsis leidyi*.

It should be noted that extensive research has been conducted on the population structure of transit spawning herring in the Northern Caspian, the northern part of the Central Caspian, and the Volga River, focusing on their catch dynamics and stock formation. However, there are very few scientific studies addressing the systematics of herring populations in the waters of the Central and Southern Caspian Sea, particularly regarding endemic species, their bioecological characteristics, and resources. These data are general or incomplete, primarily covering the 1940s and 1950s, and often only pertain to parts of the Caspian Sea or specific gulfs. In recent decades, natural and anthropogenic factors have caused significant changes in the ecosystem of the Central and Southern Caspian Sea. These new environmental conditions underscore the importance and relevance of

studying the ichthyofauna, particularly herring, which reflect these changes. Research on their bioecological characteristics is crucial from both scientific and practical perspectives. Such studies will aid in restoring the fish stocks of the Caspian Sea, protecting their genetic diversity, and ensuring effective utilization. Furthermore, this research will enable the prediction of future changes, the preparation of scientifically based measures to mitigate expected negative consequences, and the timely prevention of these impacts.

The object and subject matter of the study.

Herring species inhabiting the Central and Southern Caspian Sea. To determine the species composition, morphometric and bioecological characteristics of herring fish, their distribution areas, reproductive migration patterns, and the positioning of ichthyoplankton within the plankton community in the Central and Southern Caspian.

The objectives and tasks of the study. The main goal of the research is to clarify the status (location) of herring fish living in the Central and Southern Caspian Sea in modern taxonomy, to understand their interspecific and intraspecific variability, and to study and evaluate their bioecological characteristics. This includes their connection with planktonic communities and their place and importance in the ecosystem. To achieve this goal, the dissertation work plans to explore the following questions:

1. Study the seasonal distribution of herring in the open parts of the Central and Southern Caspian Sea, as well as in coastal zones, and analyze their behavioral characteristics;

2. Clarify their systematic status through a comparative analysis of the morphometric and environmental characteristics of herring;

3. Use DNA analysis to clarify the position of the subspecies (Dolgin, Agrakhan, Sara and Hasangulu) belonging to the species *Alosa braschnikowi* (Borodin, 1904);

4. Determine the changes that have occurred in the migrations of herring in the Central and Southern Caspian Sea;

5. Investigate the current state of herring reproduction and nutrition biology;

6. Determine the place of herring in the planktonic community;

7. Analyze the dynamics of the herring fishery to determine the current state of their stocks and identify ways to increase, use, and protect them.

Research methods. The collection and processing of material for studying the morphobiological and ecological characteristics of fish were conducted using general methods commonly adopted in ichthyological studies. In the laboratory, indicators of the morphometric characteristics of fish were processed using the variation-statistical method. To assess herring stocks, E.M.Aksyutina's[1] method was employed. For the population genetic analysis of the studied Brazhnikov herring *Alosa braschnikowi* (Borodin, 1904), a standard method was utilized.

The main provisions presented for defense:

1. While the herring populations in the Central and Southern Caspian Sea share some morphological similarities, the Sara herring displays significant morphological and biological differences from these other herrings;

2. Genetic analysis of herring populations reveals that the Dolginsky, Agrakhansky and Hasangulu subspecies exhibit very similar characteristics. However, notable diversity is observed in the Sara herring, classified as a separate species - *Alosa sarensis* (Mikhailovskaya, 1941);

3. The horizontal and vertical distribution of herring in the Caspian Sea is directly proportional to the density of their food sources (plankton);

4. Forecasting the nesting migrations of herring in the Caspian Sea has shown that the primary external environmental factor triggering migration is not temperature but sex hormones, which become active at a certain stage of sexual product development;

5. The state of ichthyoplankton, meso- and meroplankton is influenced by various climatic, hydrological, and anthropogenic factors, as well as the seasonal and long-term population dynamics of

[1] Аксютина, Э.М.Элементы математической оценки результатов наблюдений в биологических и рыбохозяйственных исследованиях / Э.М.Аксютина. – М.: Пищ. промышленность, – 1968. – 289 с.

the invasive species *M. leidyi*;

6. Due to the impact of anthropogenic and environmental factors, herring fish stocks in the Caspian ecosystem have declined. To regulate these stocks, it is necessary to develop a scientific basis for establishing a fishing regime and general fishing rules in the Caspian Sea.

The scientific novelty of the study. For the first time, changes in the morphometric and bioecological characteristics of herring populations in the Central and Southern Caspian Sea have been comparatively characterized, revealing that these changes are adaptive in nature. Morphometric and DNA analyses have led to the taxonomic reclassification of Sara herring from the subspecies *Alosa braschnikowi* (Borodin, 1904) to the species *Alosa sarensis* (Mikhailovskaya, 1941). Additionally, the distribution areas and reproductive migration routes of herring populations have been identified for the first time. The horizontal and vertical distribution and behavioral parameters of Alosa herring in the Central and Southern Caspian Sea have been studied, and the position of ichthyoplankton within the plankton community of these regions has been determined.

The conceptual and practical significance of the study. The dissertation provides a comprehensive review of the taxonomy, morphology, bioecology, migration, planktonic communities, and resources of herring in the Central and Southern Caspian Sea. It includes detailed information essential for the planning, implementation, and analysis of future ichthyology and hydrobiology research. This material can also be used in conducting courses and preparing educational resources for higher and secondary education in these subjects.

The research results provide insight into the state of herring stocks in the Caspian Sea, particularly in the Central and Southern regions. These findings can serve as a biological basis for developing measures aimed at restoring and effectively managing fisheries, including short-term and long-term fishery forecasts. Additionally, the observed patterns in the horizontal and vertical distribution of herring, along with their behavior, can be used as a baseline for planning and monitoring activities in this region.

Approval and implemantation of the study. The key provisions of the study were undergone detailed discussion process at annual reporting meetings, scientific seminars hosted by the Laboratory of Hydrobiology at the Institute of Zoology of the Ministry of Science and Education of the Republic of Azerbaijan, as well as the following Republic and International scientific-practical conferences:

- III International Scientific and Practical Conference "Problems of preserving the Caspian ecosystem in the conditions of development of oil and gas fields" (Ashtarkhan, 2009).
- All-Russian scientific and practical conference "Ecology, evolution and taxonomy of animals" (Ryazan, 2009).
- International scientific and practical conference "Modern problems of biology and ecology" (Makhachkala, 2011).
- Conference of "Protection and restoration of biological resources of the Caspian Sea", dedicated to the 110th anniversary of the Azerbaijan Research Institute of Fisheries (Baku, 2013).
- At the "International Congress of Applied Sciences Gobeklitepe-II" (Turkey, 2021).
- International scientific conference on "Current problems of modern natural and economic sciences" (Ganja, 2022).

Based on the research materials, 41 articles have been published both domestically and internationally, reflecting the main content of the dissertation. Six of these articles were published in journals indexed in international databases. Additionally, three theses were produced.

Name of the organzation where the study was conducted. The dissertation was conducted in the Laboratory of Hydrobiology of the Institute of Zoology of the Ministry of Science and Education of the Republic of Azerbaijan.

The structure and extent of the dissertation. The study comprises 400909 (four hundred thousand six hundred forty-four) characters. It is organized into an introduction (9677), 8 chapters (384461 symbols), a conclusion (5114 symbols), practical proposals (1657 symbols), a list of 332 references in Azerbaijani, Russian and English languages, Appendices, abbreviations and list of conventional symbols. The thesis includes 78 tables and 7 figures, and 14 tables in Appendices.

CHAPTER 1. REVIEW OF LITERATURE ON THE STUDY OF HERRING FISH IN THE CASPIAN SEA

In this cahapter, extensive research has been conducted on the systematics, population structure, deep distribution, migration, stocking, and effective utilization of herring (Clupeidae), primarily inhabiting the Caspian Sea and partially found in oceans and seas worldwide. Noteworthy expeditions aimed at studying the species composition, distribution, and stocks of herring fish in the Northern and Central Caspian Sea occurred in 1904, 1912-1913, and 1930. It is important to highlight that the early 21st century marks a pivotal period for the comprehensive investigation of the Caspian ecosystem.

CHAPTER 2. OVERALL CHARACTERISTICS OF THE CASPIAN SEA

This chapter provides an overview of the hydrological, hydrochemical, hydrobiological, and ichthyological characteristics of the Caspian Sea, drawing from both literary sources and our own data.

The Caspian Sea is divided into three main parts – the Northern, Central, and Southern Caspian – based on its physical and geographical features, relief nature, and hydrological characteristics. The border between the Northern Caspian and Central Caspian is demarcated by the Mangyshlak threshold, which extends from Tsesen Island to Cape Tyub-Karagan. Meanwhile, the Central and Southern Caspian Seas are separated by the Absheron threshold, spanning from Chilov Island to Cape Kiu. The area south of the Absheron threshold is recognized as the Southern Caspian Sea.[2]

CHAPTER 3. THE MATERIALS AND METHODOLOGY OF THE STUDY

Materials for the study were collected from the shelf and coastal zones of the Central and Southern Caspian Sea between 2002 and 2012. Subsequently, from 2013 to 2020, collection efforts were focused solely on coastal zones (Fig. 1).

[2] Məmmədov R.M. Xəzər dənizinin hidrometeoroloji atlası, / R.M.Məmmədov. – Bakı:Nafta-Press, –2014, –300 s.

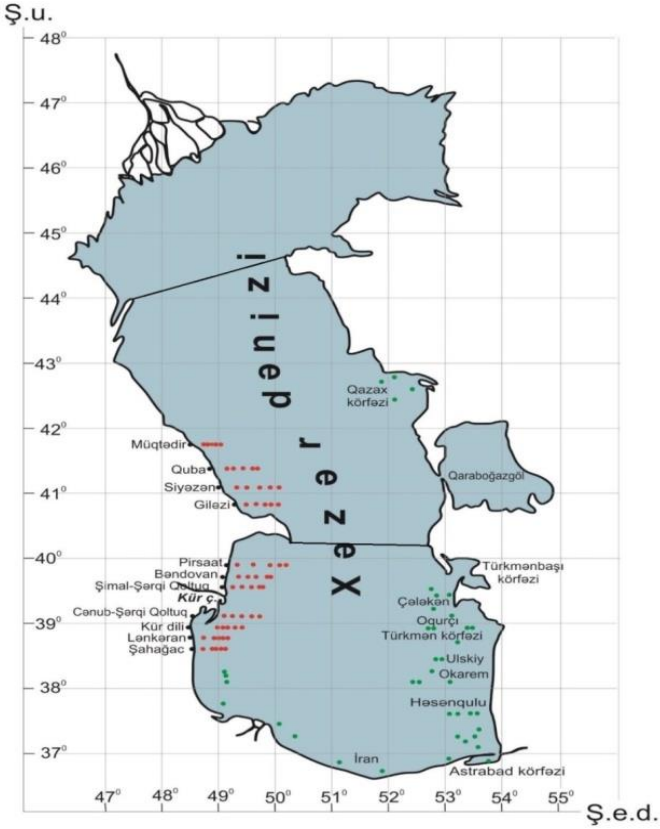

Figure 1. Schematic map of the locations for the cross sections and monitoring stations in te Central and Southern Caspian Sea.
● – permanent stations for the cross sections; ● – stations for taking samples along the coast**.**

In the open sea, fishing activities were conducted for no more than 0.5 hours using a bottom trawl (24.7 m) aboard the research vessels "Caspian Researcher" and "Alif Hajiyev". In coastal zones, fishing was carried out using sets (30x30, 40x40, 60x60 mm) and fine-mesh trawling with nets (10x10 mm). A total of 11940 herring fish were caught during the study period. From this catch, 527 specimens were selected for morphometric analysis (comprising 5 meristic and 23 plastic characters), while 5386 specimens were used to assess their bioecological characteristics (Table 1).

Table 1

The number of herring fish studied in the Caspian Sea during 2002-2020 and the character of the study

Fish name, indicators	Morphometric values	Biological values	Distribution and density
Saposhnikovi shad	51	1022	2438
North Caspian shad	50	1551	3116
Dolgin herring	100	990	1976
Agrakhan herring	25	60	60
Sara herring	50	879	2200
Big-eyed herring	45	89	89
Hasangulu herring	25	151	151
White-headed herring	15	44	44
Krasnovodsk herring	20	79	79
Eastern herring	-	3	3
Kura herring	50	77	77
Caspian anadromous herring	79	424	1690
Volga herring	17	17	17
Total:	527	5386	11940

To assess the dynamics of the abundance and stock of individual species and subspecies within herring populations, the quantity of herring fish caught per trawl and net was determined; they were handed over to the appropriate organizations. The collected materials were studied in the Laboratory of Hydrobiology of the Institute of Zoology of the Ministry of Science and Education of the Republic of Azerbaijan.

The collection and processing of materials for studying the morphobiological and ecological characteristics of fish were conducted using standard methods commonly adopted in ichthyological research[3,4]

[3] Плохинский, Н.А. Математические методы в биологии / Н.А.Плохинский. – М.: МГУ, – 1978. – 264 с.

[4] Правдин, И.Ф. Руководство по изучению рыб / И.Ф.Правдин. – М.: Пищепромиздать, – 1966. – 375 с.

The collection of herring eggs, larvae, and fry was performed using the method of T.S. Russ and I.I. Casanova, while their identification was carried out according to the method of A.F.Koblitzkaya.[5,6]

The study of the qualitative and quantitative composition of herring feed was conducted based on generally accepted methods.[7]

The method of E.M.Aksyutin was used to assess herring stocks in the Caspian Sea.

For genetic research in the Caspian Sea, material from the subspecies of hawk moth herring - Dolginsky, Agrakhansky, Hasangul, and Saraysky was collected. Fresh samples were taken from various fish tissues (liver, muscle, and dorsal fin rays) and stored in 90% ethanol to extract genomic DNA. At that time, the standard method involved using a phenylchloroform mixture.[8]

To perform DNA analysis, the isolated genomic DNA was used as a template for PCR amplification with RAPD primers obtained from Operon Technologies, USA. Initially, 20 primers were tested, and 10 of these primers successfully amplified 72 bands on an agarose gel. The 4 best amplifying primers were selected for further research. The RAPD profiles generated by each primer set were examined for amplification products using an agarose gel. If a band is formed in the gel, it is designated as 1; if there is no band, it is designated as 0. A cluster analysis was conducted, and a dendrogram was constructed according to M. Nei et al. using the UPGMA method.

Pairwise genetic distances were calculated using the POPGENE computer program (version 1.32).[9]

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[5] Расс, Т.С. Методическое руководство по сбору икринок, личинок и мальков рыб / Т.С.Расс, И.И.Казанова. – М.: Пищ. пром., – 1966. – 35с.

[6] Коблицкая, А.Ф. Определитель молоди пресноводных рыб /А.Ф.Коблицкая. – М.: Легк. и пищ. промышленность, – 1981. – 208 с.

[7] Методическое пособие по изучению питания и пищевых отношений рыб в естественных условиях / Е.В.Боруцкий. – М.: Наука, – 1974. – 254 с.

[8] Molecular cloning. A laboratory manual / I.Sambrook, D.W.Russell. – New York: Col Spring Harbor Laboratory Press, –Vol.3. 1989. – 2028 p.

[9] Nei, M. Estimation of average heterozygosity and genetic distance from a small number of individuals // – Bethesda: Genetics, – 1978.Vol.89, №3, – pp. 583-590.

CHAPTER 4. MOPHO-ECOLOGICAL CHARACTERISTICS OF HERRING FISH IN THE CENTRAL AND SOUTHERN SEA

Analysis of long-term studies conducted between 2002 and 2020 in the waters of the Central and Southern Caspian Sea revealed the presence of 5 species and 8 subspecies of sea herring. These belong to a single order (*Clupeiformes*), family (*Clupeidae*), and genus (*Alosa*) (see Table 2).

Table 2

Classification list of herring fish living in the Central and Southern Caspian Sea

Class: Osteichthyes Huxley,1880 - Bony fishes	
Order: Clupeiformes Bleeker,1859- Clupeiformes	
Family: *Clupeidae* Cuvier,1816- Herrings	
Genus **:** *Alosa* Linck,1790- Aloza	
1	2
1	*Alosa saposchnikowii* (Grimm,1887) - Saposhnikovi shad
2a	*A. caspia caspia* (Eichwald,1838) – North Caspian shad
3a	*A. braschnikowi braschnikowi* (Borodin,1904) - Dolgin herring
3b	*A.b.agrachanica* (Mikhailovskaya,1941) – Agrakhan herring
3c	*A.b.autumnalis* (Berg,1915) – Big-eyed herring
3d	*A.b.grimmi* (Borodin,1904) – White-headed herring
3e	*A.b.kisselewitschi* (Bulgakov,1926) – Hasangulu herring
3f	*A.b.nirchi* (Morosow,1928) - Krasnovodsk herring
3g	*A.b. orientalis* (Mikhailovskaya,1941) – Eastern herring
4	*A. sarensis* (Mikhailovskaya,1941) - Sara herring
5	*A.curensis* (Suvorov,1907) - Kura herring
6	*A.kessleri* (Grimm,1887) – Caspian anadromous herring
7	*A.volgensis* (Berg,1913) - Volga herring

Endemic herring of the Caspian Sea are represented by saline (Saposhnikovi shad and Northern Caspian shad, Dolgin herring, Agrakhan herring, Sara herring, Big-eyed herring, White-headed herring, Saposchnikowii shad, Hasangulu herring, Krasnovodsk herring, Eastern herring and Kura herring) and transient (Caspian anadromous herring and Volga herring) ecological groups. Most of these taxa are found in the Central and Southern Caspian Sea.

4.1. Saposchnikowii shad - *Alosa saposchnikowii* (Grimm, 1887)

Research over the years has shown that during winter, Saposhnikovi shad predominantly prefer the Southern Caspian. Specifically, they favor 25-33-meter-deep areas near the Kura River, where water temperatures range from 7.1 to 9.6°C, as well as 30-40-meter-deep areas in the Shagagach-Lankaran region. In February 2003, trawl fishing in the Gazakh Bay (eastern part of the Caspian Sea) revealed that Saposhnikovi shad prefer depths of 35-40 meters in the bay and 22-27 meters in the Okarem region of Turkmenistan's Caspian waters.

It should be noted that the spawning migration herring in the Central and Southern Caspian Sea concludes in the second half of May. On the eastern coast of the Caspian Sea, whitefish preferred depths of 18-26 meters in the Gazakh Gulf in March, and in early April, depths of 10-20 meters in the Okarem and Ulskiy regions of the Turkmenistan waters of the Caspian Sea.

In April of the same year, during our research in the waters of the Islamic Republic of Iran in the Caspian Sea, we observed that these herring were distributed at a depth of 15-25 meters. After spawning, saposhnikovi shad prefer water layers of 10-25 meters along the western shores of the Central Caspian, especially in the Guba traverse during the summer. In August-September, saposhnikovi shad were caught in small quantities on the eastern shore of the Caspian Sea, at depths of 26-30 meters in the Gazakh Gulf and 30-35 meters in the Chelakan and Ogurchi areas.

The main meristic signs of studied saposhnikovi shad were as the following: *D* III (IV) 13-15, in general 16-18 (16,6±0,04), *A* III 16-19, generally 19-22 (20,4±0,07), *sp.br*. 25-39 (29,4±0,41), *squ*. 49-57 (53,2±0,27), *sp.V*. 30-34 (31,7±0,11). The gill teeth are dense, short, and pointed, matching the length of the gill leaflets. The teeth are well-developed on both jaws. The head of the saposhnikovi shad is large and high, elongated from the bottom to the sides.

The body length of the saposhnikovi shad we caught from the constructed net ranged from 15.0 to 29.3 cm, with a total mass of 38.4 to 376.5 g. The Fulton’s condition coefficient ranged from 0.91

to 1.66. The body length of the analyzed males was 15.0 to 28.4 cm, with a body weight of 38.4 to 278.0 g, and Fulton's condition coefficient ranged from 0.91 to 1.38. For females, these indicators were 17.0 to 29.3 cm, 62.3 to 376.5 g, and 1.03 to 1.66, respectively. Females grow faster than males. Starting from the age of three, no significant increase in size was recorded for either sex.

The individuals participating in spawning migration were categorized into six age groups (2-7). First-time spawners comprised an average of 32.0% of the population, while those that spawned multiple times made up 68.0%. These findings indicate that, due to the lack of intensive herring fishing in the Caspian Sea, the majority (57.2%) of the Saposhnikovi shad spawning population consists of 4-5-year-old individuals engaging in repeated spawning. The average number of spawnings for saposhnikovi shad was 67907.

In spring, saposhnikovi shad ascend to the water's surface to feed and spawn, migrating to depths of 15-20 meters in areas adjacent to the Kura River. Consequently, in mid-March, the primary diet of individuals caught in the Kura and Shikh districts consisted mainly of common kelp *C. caspia* at 38.5% and mullet *Neogobius fluviatilis* at 23.6%. After spawning in July, saposhnikovi shad migrate from the coastal zone to the open sea to access the maximum number of food organisms available there. During the summer season, 70.5-65.8% of the main diet of saposhnikovi shad caught at depths of 25-30 meters in the Muktadir and Khachmaz areas comprised sprats, with 13.7-9.2% being herring fish.

4.2. North Caspian shad - *Alosa caspia caspia* (Eichwald, 1838)

For wintering, North Caspian shad mainly prefer the Lankaran and Kura-Dashi areas of the Southern Caspian at depths of 27-40 meters. During this period, it was observed that these fish favored the depths of 18-24 meters in the Gazakh Gulf, 17-27 meters in the Hasangulu and Okarem areas, and 18-20 meters in Iranian waters. The spawning migration of North Caspian shad typically begins in April and ends in early May. During this time, the greatest concentration of the North Caspian shad is found at 14–20-meter depths in the Kura outfall region of the Southern Caspian, the coastal waters of Chilov Island, and the border waters of the Central and Southern Caspian

Seas. By the second half of April, these fish had migrated from the northern part of the South Caspian and concentrated in the northern part of the Central Caspian at depths of 15-25 meters.

In March-April 2002, these fish were observed to prefer depths of 12-18 meters in the Gazakh Bay of the Caspian Sea, 10-20 meters in the Hasangulinsky, Okaremsky, and Ulsky regions of Turkmenistan, and 16-25 meters in the waters of the Islamic Republic of Iran. Following the spawning of North Caspian anadromous shad in July-August, they mainly favored depths of 25-75 meters off the western coasts of the Central Caspian, particularly in the Muktadir and Siyazan areas. In August-September, on the eastern coast of the Caspian Sea, North Caspian anadromous shad were found to prefer depths of 21-35 meters in the Gazakh Gulf and 30-33 meters in the Chelakan area.

The main meristic signs of studied Northern Caspian anadromous shad were as the following: *D* III 12-15, in general - 15-18 (17,0±0,09), *A* III (IV) 16-19, in general - 19-22 (20,44±0,07), *sp.br*. 85-123 (102,5±1,34), *squ*. 50-56 (53,7±0,16), *sp.V*. 29-35 (32,7±0,08). The gill incisors are extremely thin, dense, and long. The teeth are very poorly developed, with those on the lower jaw being almost undeveloped.

The body length of individuals participating in the spawning migration ranged from 14.6 to 27.1 cm, with a body weight of 39.3 to 190.4 g and a Fulton's condition coefficient of 0.98 to 1.26. During the hunting seasons from 2012 to 2020, male individuals with a body length of 17-19 cm and a body weight of 70-100 g predominated, while female individuals with a body length of 20-22 cm and a body weight of 100-130 g were most common. The Northern Caspian anadromous shad reaches sexual maturity at the age of 2 years. The individuals participating in the spawning migration belonged to six age groups (2-7 years), with most of the population (73.1%) being 3-4 years old. Individuals participating in spawning for the first time accounted for 34.6% of the population. Most first-time spawners (54.2%) were 3 years old, while the bulk of individuals participating in spawning more than once (52.8%) were 4-5 years old. Our results indicate that older individuals predominate over younger ones in the spawning stock of Northern Caspian anadromous shad. The total

number of spawns of Northern Caspian anadromous shad averaged 37778 individuals.

Copepods (46.5-71.3%) were the primary food source for the North Caspian shad hunted in the Lankaran and Kura Spit regions during the winter. However, the diet of the North Caspian shad caught in the Khudat region of the Central Caspian during spring was notably different. In this case, the fish primarily consumed Cumacea (39.3%) and Copepoda (34.1%). During the summer, the diet of the North Caspian shad from the Muktadir region of the Caspian Sea was dominated by Copepoda (74.5%), followed by Mysidacea (15.1%) and Amphipoda (6.2%). By July, Copepoda (58.2-82.5%) continued to be the dominant food item in the diet of the North Caspian shad caught in the Khachmaz and Gilazi regions of the Caspian Sea.

4.3. Sara shad - *Alosa caspia knipowitschi* (İljin, 1927)

The Sara shad, an endemic species of the Caspian Sea, exhibits a semi-transitional form. However, during the course of our research from 2002 to 2020, we did not encounter this species.

4.4. Astrabad shad - *Alosa caspia persica* (İljin, 1927)

The Astrabad shad, which is considered one of the endemic fish of the Caspian Sea basin, has a semi-transitional form. During the years of our research (2002-2020), we did not encounter this fish.

4.5. Dolgin herring - *Alosa braschnikowi braschnikowi* (Borodin, 1904)

Our extensive research, conducted over an 18-year period (2002-2020), revealed an uneven distribution of Dolgin herring during the winter months along both coasts of the Middle and South Caspian regions. From November to February, these herring predominantly occupied depths of 30-35 meters in the western Caspian, particularly within the Sumgait region and the Shah-Dili, Kur-Dili, and Lankaran areas. Concurrently, they were observed at depths of 24-30 meters in the Gazakh Gulf, while preferring shallower depths of 10-20 meters in the Hasanguli and Ulsky regions. By the end of March, these fish were observed moving toward the western shores of the Central Caspian. In contrast, on the eastern shores of the Caspian Sea, they were found in smaller numbers at depths of 15-20 meters in the Ogurchi area. After spawning, it was noted that these fish migrate

in the opposite direction along the western shores of the Central Caspian. By late summer, they favor depths of 20-25 meters in the areas of Nabran, Khachmaz, Shabran, and Siyazan. Meanwhile, on the eastern shores of the Caspian Sea, the majority of Dolgin herring fry were located within the 10-meter water layer in the Turkmen Gulf.

The main meristic signs of Dolgin herring studied by us in the Azerbaijan sector of the Southern Caspian were as the following: *D* III 13-15, in general - 16-18 (17,1±0,08), *A* III 17-19, in general - 20-22 (21,2±0,08), *sp.br*. 27-44 (33,0±0,05), *squ*. 50-56 (53,6±0,21), *sp.V*. 31-34 (32,5±0,15). Unlike other species, the gill denticles of this fish are exceptionally smooth, thick, and short, gradually tapering toward the tips. The teeth on both the upper and lower jaws are notably well-developed.

The body length of Dolgin herring, which we studied in the Western part of the Caspian Sea ranged from 10.6 to 40.0 cm, with a body weight of 15.0 to 1226.0 g and a Fulton's condition coefficient of 0.90 to 1.92. The average body length (32,5±0,28 cm) and weight (566,4±10,34 g) indicators of the female individuals were greater than average length (30,10±0,23 cm) and weight (475,0±8,63 g) values of male individuals. The Dolgin herring caught in the southeastern part of the Caspian Sea measured between 16.5 and 34.0 cm in body length, with weights ranging from 32.0 to 415.0 g and a Fulton's condition coefficient (F) of 0.71-1.34. On average, the body length of females was 26.0±0.20 cm, with a weight of 189.6±7.04 g, while males averaged 24.7±0.17 cm in length and 173.0±6.36 g in weight. It was observed that the Dolgin herring grows more rapidly during its first two years, with growth slowing down after the age of three. When comparing the growth rates of Dolgin herring populations along the western and eastern coasts of the Central and Southern Caspian, no significant differences in growth intensity were found. The herring involved in spawning in the western part of the Caspian Sea belonged to six age groups (2-7 years), with the majority (64.4%) being 3-4 years old. In the southeastern Caspian, the herring belonged to five age groups (1-5 years), with 50% being 2-3 years old. First-time spawners constituted 50.8% of the population, while repeat spawners made up 49.2%. These findings suggest that,

in the absence of industrial herring fishing, the spawning population of Dolgin herring is primarily composed (64.4%) of 3-4-year-old individuals. The average spawning population was estimated to consist of 193,324 individuals.

In the spring season, the primary diet of Dolgin herring caught in the Kuratrafi and Shykh areas consisted mainly of sea fish (43.0-48.4%), including Caspian goby (25.2-21.4%). After spawning, Dolgin herring caught by us from depths of 20-25 meters in the Muktadir and Khachmaz areas of the Central Caspian during July-August had a diet predominantly composed of sprats (65.2-71.3%). Similarly, in the winter season (January-February), the main food source for Dolgin herring caught in the Lankaran and Kuratrafi areas remained sprats, making up 57.9-68.0% of their diet.

4.6. Agrakhan herring - *Alosa braschnikow agrachanica* (Mikhailovskaya, 1941)

In recent years, the Agrakhan herring, one of the rarer herring species, has shown a preference for the western part of the Middle and Southern Caspian during the winter season. In particularly harsh winters, the range of these fish becomes restricted, leading them to favor depths of 20-25 meters near the Absheron Peninsula and the islands of Khara-Zira and Zanbil in the Caspian Sea. It should be noted that from the second half of April, as coastal water temperatures rise to 10-11°C, the Agrakhan herring that winter in these areas migrate to depths of 20-25 meters in the Kura and Kuratrafi regions of the South Caspian. By early May, they have been observed preferring shallower depths of 15-20 meters along the coast of the Absheron Peninsula in the Central Caspian. After spawning, the Agrakhan herring moves to the western shores of the Central Caspian to feed during the summer months. In July and August, these fish were observed at a depth of 25 meters in the Gilazi and Siyazan areas. In the autumn season, our research found the Agrakhan herring at a depth of 37 meters in the Kura-Dash area of the South Caspian, and at a depth of 32 meters in the Lenkoran area.

The main meristic characteristics of the Agrakhan herring, studied by us during nesting migration from the Azerbaijani sector of the South Caspian, were as follows: *D* III-IV 13-15, in general 16-19

(17,3±0,17), *A* III 17-20, in general 20-23 (21,4±0,15), *sp.br*. 25-42 (33,2±0,84), *squ*. 52-59 (55,6±0,49), *sp.V*. 30-36 (32,2±0,32). Unlike other species, the gill teeth of this fish are notably coarse, sparse, flat, and curved with pointed tips. The teeth are also well-developed.

The body length of Agrakhan herring found during the studies conducted by us was 18,0-38,4 cm, weight 76,3-560,0 g, and Fulton's condition coefficient (F) was 0,95-1,3. Biological indicators of female individuals were greater than the values of male individuals. The average body length and weight of the captured females were 29.2±0.92 cm and 308.2±25.5 g, respectively, with a condition coefficient (F) of 1.10±0.01. For males, the average body length was 26.5±0.99 cm, the weight was 176.1±31.0 g, and the condition coefficient was 1.11±0.01. Despite late spawning, the Agrakhan herring was observed to grow intensively. The studied population was found to consist of five age groups (2-6 years), with the majority (55.0%) comprising 3-4-year-old individuals. Sexual maturity in Agrakhan herring is typically reached at 3-4 years of age. Notably, 58.3% of the examined herring showed no evidence of previous spawning activity on their scales. Among the 2-3-year-olds, 82.9% had no spawning marks and were participating in spawning for the first time. These findings suggest that the spawning migration of the Agrakhan herring population is primarily driven by first-time spawners.

It has been determined that the number of spawnings in Agrakhan herring increases with both length and age. For instance, individuals measuring 26.8 cm in length and weighing 199.6 g were found to contain 44600 eggs, while those measuring 38.0 cm and weighing 560 g had 352.3 thousand eggs. On average, during the spawning migration period, these fish produced 197.7 thousand eggs.

4.7. Sara herring - *Alosa* (*b.*) *sarensis* (Mikhailovskaya, 1941)

Our research has confirmed that the Sara herring in the Caspian Sea does not migrate, and its distribution area is quite limited. The species is most commonly found in the coastal waters of the western part of the South Caspian, where it winters and reproduces. During the winter, the Sara herring is most concentrated at depths of 26-40 meters in the Lankaran and Kura regions of the South Caspian. Notably, during the winter of 2003, our trawl fishing research in the Iranian waters of the

Caspian Sea recorded two Sara herring at depths of 44-50 meters. Since the second half of March, Sara herring have been observed spawning along the southwestern shores of the Caspian Sea. Our studies indicate that after spawning, Sara herring migrate from the coastal zones to the open sea during June and July, where they distribute unevenly. For example, in the Lankaran and Kura Spit regions, Sara herring caught at depths of 50-25 meters accounted for 34.6% of the total herring catch, while in the South-East Armpit section of the Kura, they made up 66.7% of the fish caught at a depth of 10 meters.

The main meristic characteristics of the Sara herring, studied by us from the Azerbaijani sector of the South Caspian, were as follows: *D* III-IV 13-16, in general 16-19 (17,6±0,13), *A* III 17-20, in general 20-23 (21,2±0,13), *sp.br*. 24-33(28,1±0,31), *squ*. 48-60 (55,9±0,47), *sp.V*. 30-34 (31,4± 0,18). Unlike other species, the gill teeth are sparse, thin, straight, and increasingly pointed at the tips. In older individuals, the gill teeth may sometimes curve, with tips that are crushed or broken. The teeth remain well-developed.

Body length of Sara herring participating in the spawning population was 19,3-37,0 cm, weight 90,0-803,0 g, the condition coefficient (F) is 1,27-1,59. Average body length of caught female individuals was 29,3± 0,19 cm, body weight - 376,5±7,58 q, the condition coefficient was 1,46±0,09; for the male individuals, these indicators were 27,2±0,14 cm; 282,1±5,43 g; and 1,36±-0,07, respectively. Sara herrings grow most intensively between the ages of 1 and 2 years. It has been established that the spawning migration of Sara herring includes seven age groups (2-8 years), with most of the population (70.8%) consisting of 3-4-year-old individuals.

Analysis of the spawning marks revealed that 47.8% of the Sara herring population consists of individuals participating in spawning for the first time. Our findings indicate that the spawning migration of this population is largely driven by first-time spawners. There was no significant difference observed between the number of young and older individuals involved in the spawning process. Spawning begins in May and continues through June, with Sara herring spawning in stages at depths of 1-10 meters in the sea, where the water tempera-

ture ranges from 15.6 to 17.5°C. The number of eggs produced by these fish ranged from 23.9 to 254.6 thousand.

In spring, sprat played a significant role in the diet of herring caught at depths of 10-15 meters in the Lankaran and Kura Spit areas of the Caspian Sea, comprising 67.1-82.5% of their diet. In summer, kelp, particularly anchovy-like species such as *C. engrauliformis* (46-63%), and atherina (10.3-5.7%) were predominant in the diet of Sara herring caught in the Bandovan and Pirsaat areas. In winter 2010, the stomach index of Sara herring caught in the Lankaran and Kura Spit areas was low (69-91.5). The high percentage of empty stomachs (65-75%) indicates poor nutrition among Sara herring during this time. Across all regions where we conducted research, atherina was the primary food source, making up 36.8-62.2% of the diet.

4.8. Big-eyed herring - *Alosa braschnikowi autumnalis* (Berg, 1915)

Our research has shown that the Caspian marine shad is more commonly found in the western part of the South Caspian, though it is also more widespread there than in the eastern part. During the autumn-winter seasons, the most concentrated habitats for big-eyed herring in the western South Caspian are the islands of the Baku Archipelago, the Kura Spit, and the Lankaran regions, at depths of 22-36 meters. In the winter of 2003, these herring were also found, albeit in small quantities, at depths of 20-30 meters in the Hasangulu region. Starting in April, big-eyed herring have been observed approaching depths of 20-27 meters in the Bandovan and Northeastern Armpit areas of Kura for spawning. In the spring of 2002, in the Turkmen waters of the Caspian, the big-eyed herring was primarily distributed in the Hasangulu region at depths of 10-17 meters.

It has been established that after spawning, big-eyed herring migrate from coastal zones of the sea to the open sea and in June-July they settle unevenly. In the summer months, it has been noted that they prefer depths of 25-30 m in the Lankaran and Shagagach regions of the Caspian Sea. In the summer of 2003, in the eastern part of the Caspian Sea, these herring were observed to spread to a depth of 30 m in the area of Ogurchi Island and 11 m in the Turkmen Gulf.

The main meristic characteristics of the big-eyed herring, studied by us were as follows: *D* III-IV 13-15, in general 16-19 (17,3±0,13), *A* II-III 16-20, in general 19-23 (20,7±0,15), *sp.br*. 25-34 (28,6±0,30), *squ*. 48-56 (51,3±0,25), *sp.V*. 28-35 (31,5±0,25). Unlike those of other species, the gill teeth are very coarse, flat, and curved, and they are slightly longer than the gill rakers. The teeth are well developed.

Body length of big-eyed herring obtained during our research in the western part of the Central and Southern Caspian Sea was 13,5-35,5 cm, body weight - 22,6-525,0 g, the condition coefficient (F) was. The body length of caught female individuals was 21,0-35,5 cm, body weight - 86,0-525,0 g, condition coefficient - 0,88-1,35; while in male individuals, these values were 18,0-31,0 cm; 69,0-382,7 g; and 0,92-1,31 respectively.

The body length of the big-eyed herring caught on the eastern coast of the South Caspian Sea in 2002-2003 was 12,2-31,0 cm, body weight - 20,0-324,0, and the condition coefficient was 0,60-1,10. The average body lenght of analysed female individuals was 26,9±1,41 cm, body weight - 132,7±40,21 g, and condition coefficient was 0,92± 0,05; in male individuals, these values were 17,0±1,29 cm; 46,0±10,95 g; and 0,88±0,08, respectively. The caught fish belong to age group 5 (1-5). The main part of the population (83.3%) were fish aged 1-3 years.

It was determined that the big-eyed herring population in the western part of the South Caspian consists of six age groups (1-6 years), with the majority (57.3%) being 3-4 years old. big-eyed herring exhibit more intensive growth compared to other herring species due to their rapid spawning. For instance, the average sizes of the fry are 16.3 cm at one year, 20.9 cm at two years, 25.4 cm at three years, 29.3 cm at four years, 31.5 cm at five years, and 34.8 cm at six years. Research indicates that big-eyed herring reach sexual maturity at age 3, with males maturing at this age and females maturing between 3 and 4 years. Starting in early April, big-eyed herring migrate towards the southwestern shores of the Caspian Sea for spawning, as their gonads reach maturity stages III and III-IV. Observations reveal that, unlike the eastern coast, spawning in the northeastern Armpit and

Bandovan regions of the Kura River begins in early May. Notably, 57.3% of the studied big-eyed herring showed no spawning marks on their scales. Among the analyzed fish, 28.1% had one spawning mark, 13.5% had two, and 1.1% had three spawning marks. These findings suggest that recent spawning populations are predominantly comprised of individuals participating in spawning for the first time, with younger individuals significantly outnumbering older ones. The average number of eggs produced by the big-eyed herring was 143460.

4.9. Hasangulu herring - *Alosa braschnikowi kisselewitschi* (Bulgakov, 1926)

Based on our studies, it was determined that Hasangulu herring is more commonly found in the eastern part of the South Caspian. During the winter of 2003, our research in the Turkmen waters of the Caspian Sea revealed that the Hasangulu herring, along with other herring species, was most concentrated at depths of 20-25 meters in the Hasangulu area and at 10-21 meters in the Okarem and Ulsky districts. These observations suggest that, due to the decrease in water temperature during winter, local herring forms such as the Hasangulu herring migrate south, while northern forms like the Dolgin herring take their place. Additionally, in November-February, the Hasangulu herring was also found at depths of 10-15 meters in the Lankaran and Bandovan areas. During the spring months from 2002 to 2020, Hasangulu herring were observed at depths of 10-16 meters around the islands of the Lankaran, Pirsaat, and the Baku Archipelago (Khara-Zira and Zanbil). Most of the captured fish were from the younger age groups (1+, 2+, 3+). Starting in March, a significant portion of the herring migrates from depths of 20-25 meters in the Hasangulu area to depths of 10-15 meters in the Ulsky and Ogurchinsky districts for feeding in the Turkmen waters of the Caspian Sea. On April 2-3, some of these herring were noted migrating back to depths of 20-25 meters in the Chelakan area. In early April, a small number of Hasangulu herring were also found in the Iranian waters of the Caspian Sea. It was determined that the majority of herring caught during this period were young individuals, favoring sea depths of 13-23 meters.

During the summer season, small numbers of Hasangulu herring were observed at depths of 25-30 meters in the South Caspian region and at 20-25 meters around the Baku Archipelago islands. In August 2003, our research in the eastern part of the South Caspian revealed that Hasangulu herring primarily prefer the coastal waters of Ogurchi Island at depths of 18-33 meters. It appears that Hasangulu herring migrate from coastal areas to deeper parts of the sea for feeding after spawning.

The main meristic characteristics of the Hasangulu herring, studied by us in the Azerbaijan sector of the Southern Caspian Sea were as follows: *D* III-IV 13-14, in general 16-18 (16,7±0,18), *A* II-III 16-17, in general 19-20 (20,4±0,25), *sp.br*. 30-44 (36,5±1,12), *squ*. 51-54 (52,2±0,27), *sp.V*. 31-33 (31,9±0,19). This fish differs from other herrings, such as *A. braschnikowi*, by having a larger number of gill teeth. These teeth are coarse, flat, and pointed, and the gill rakers are of equal length. The teeth are well developed.

The body length of Hasangulu herring caught on the western coast of the South Caspian Sea ranged from 20.0 to 36.9 cm, with weights from 84.0 to 594.0 g and a Fulton condition coefficient ranging from 0.78 to 1.26. Female herring exhibited higher biological parameters compared to males. The average body length of females was 28.5±0.68 cm, with an average weight of 285.6±22.0 g and a condition coefficient of 1.11±0.02. In comparison, the average body length of males was 27.3±0.61 cm, with an average weight of 233.3±8.71 g and a condition coefficient of 1.08±0.02.

The body length of Hasangulu herring caught by trawl in the eastern part of the South Caspian ranged from 7.8 to 35.5 cm, with body weights from 30.0 to 555.0 g. Males had body lengths ranging from 7.8 to 30.6 cm and weights from 30.0 to 372.5 g, while females ranged from 15.8 to 35.5 cm in length and from 32.0 to 555.0 g in weight. The condition coefficient (F) of the fish obtained ranged from 0.83 to 1.35.

Comparing the population structure of Hasangulu herring on the western and eastern coasts of the Caspian Sea, there is no significant difference in growth rates between the two regions. In the eastern South Caspian, 58.9% of the Hasangulu herring were 2-3 years

old, whereas 66.7% of the fish caught in the western South Caspian were 3-4 years old. No spawning marks were observed on the scales of 37.9% of the Hasangulu herring participating in the spawning population on the western coast. Similarly, spawning marks were not found for 49.4% of the Hasangulu herring caught off the eastern shores. These results suggest that the spawning migration of the Hasangulu herring population on the western coast primarily involves individuals participating in their first and second spawning events. The average number of large fish eggs caught was 34062, while medium and small eggs averaged 59273.5.

According to our observations, starting in the second half of March, the majority of Hasangulu herring migrate from the Hasangulu area to depths of 10-20 meters in the Ulsky and Ogurchinsky areas. During this period, they feed intensively on swimming crabs, common crabs, anchovies, as well as kelpies, silversides, and Caspian goby.

4.10. White-headed herring - *Alosa braschnikowi grimmi* (Borodin, 1904)

During the years of study when we conducted research, white-headed herring was not encountered in the western part of the South Caspian. We found that in the winter season, the most concentrated area for white-headed herring in the Caspian waters of Turkmenistan is at depths of 45-50 meters in the Hasangulu area. Starting in March, these fish begin to migrate along the eastern coast of the South Caspian. By April, the areas of greatest concentration are at depths of 10-12.5 meters in the Turkmen Gulf and 17-20 meters in the Hasangulu area, where the water temperatures are higher. According to our observations, white-headed herring spawn mainly in May-June at depths of 4 meters in the Astrabad Gulf, 10 meters near Ogurchi Island, and 16 meters in the Hasangulu area. In August, white-headed herring predominantly preferred depths of 11 meters in the Chelakan area, 15-25 meters in the coastal waters around Ogurchi Island, and 45 meters in the Okarema area. It appears that due to the high abundance of Caspian goby fish in these regions, white-headed herring migrate from coastal areas to deeper parts of the sea for more active feeding following spawning.

The main meristic characteristics of the white-headed herring we obtained on the eastern coast of the South Caspian were as follows: *D* III-IV 13-15, in general 16-18 (16,7±0,17), *A* III 15-18, in general 18-21 (19,3±0,22), *sp.br*. 20-26 (23,0±0,55), *squ*. 49-55 (51,0±0,41), *sp.V*. 30-33 (31,3±0,22). The number of gill teeth in this species of herring is fewer compared to other forms of *A. braschnikowi*. The teeth are coarse, dense, and curved, with blunt and crossed ends. They are well developed.

The body length of the white-headed herring we collected ranged from 15.3 to 34.0 cm, with weights from 28.0 to 385.0 g and a fatness coefficient (F) ranging from 0.73 to 1.28. When comparing biological parameters, females exhibited slightly higher values than males. The average body length of females was 24.6±1.08 cm, with an average weight of 177.8±22.0 g and a Fulton's condition coefficient of 0.95±0.03. For males, the average body length was 20.6±0.99 cm, with an average weight of 99.7±13.0 g and a fatness coefficient of 0.95±0.03.

It has been established that the growth rate of white-headed herring on the eastern shores of the South Caspian lags behind other local herring forms due to the later onset of the spawning process. These herring grow more rapidly between the ages of one and two years, but growth slows significantly from the age of five onwards. Over the course of our research, we found that the herring population caught on the eastern coast of the South Caspian includes five age groups (2-6), with the main age group (68.1%) consisting of individuals aged 2-3 years. white-headed herring reaches sexual maturity between the ages of 2 and 6 years, with males maturing at 2-3 years and females at around 4 years. Spawning traces were absent on the scales of 50% of the white-headed herring we studied. Spawning marks were observed as follows: one mark in 29.6% of the fish, two marks in 11.1%, three marks in 4.5%, and four marks in 4.5%. Most of the spawning individuals were 2-3 years old. Our results suggest that the spawning migration of the white-headed herring population on the eastern coast of the South Caspian primarily involves individuals participating in spawning for the first time. To study the fertility of this subspecies, we used females caught in the Turkmen Gulf and

Hasangulu regions, whose gonads had reached stages III-IV of development. The length of the caught fish ranged from 31.0 to 34.0 cm, with weights from 290 to 385 g. The weight of the gonads ranged from 14.0 to 34.0 g. The number of large eggs varied between 69,420 and 176700, with an average of 123170 eggs.

4.11. Krasnovodsk herring - *Alosa braschnikowi nirchi* (Morozov, 1928)

In early February, it was found that Krasnovodsk herring, along with Hasangulu herring, were most concentrated in the Hasangulu, Okaremsky, and Ulsky districts at depths of 10-21 meters, and occasionally as deep as 40-60 meters. Starting in March, these fish began moving north, approaching the eastern coast of the South Caspian for spawning. By late March and early April, the areas of greatest concentration for Krasnovodsk herring were at depths of 10-11 meters in the Turkmen Gulf and the waters of Chalekan. Our research indicated that by summer (August), Krasnovodsk herring were most concentrated at a depth of 10 meters in the Turkmen Gulf, favoring depths of 8-20 meters in the Hasangulu area. It appears that after spawning, Krasnovodsk herring migrate from coastal regions to deeper parts of the sea to feed more actively, likely due to the abundance of food organisms in these areas. Notably, for the first time in August, we caught two specimens of Krasnovodsk herring at a depth of 25-30 meters in the Lankaran section of the South Caspian and the northeastern arm of the Kura River.

The main meristic characteristics of the Krasnovodsk herring analysed by us were as follows: *D* III 12-14, in general 15-17 (15,4±0,14), *A* III 15-18, in general 18-21 (19,2 ±0,21), *sp.br*. 20-28(23,9±0,56), *squ*. 46-53 (49,6±0,36), *sp.V*. 28-31 (29,3±0,22). It differs from other *Braschnikowi* herrings by having a smaller number of gill teeth. The teeth are rough, dense, with tips that do not cross, and are shorter than the gill leaves. The teeth are well developed.

The body length of the Krasnovodsk herring we caught on the eastern coast of the South Caspian ranged from 15.8 to 36.0 cm, with a weight of 38.0 to 500.0 g, and a condition coefficient (F) of 0.70 to 1.29. The length and weight indicators of the caught females were higher than those of the males. The average body length of females

was 24.6±0.76 cm, with a body weight of 172.0±16.8 g, while males had an average length of 21.5±0.66 cm and a body weight of 111.1±8.16 g. The Fulton condition coefficient of males (0.97±0.03) was slightly higher than that of females (0.94±0.02). The body length of this herring was found to be between 23.6 and 24.8 cm, with a body weight of 147.0 to 174.0 g, a condition coefficient of 1.11-1.14, and an age of 2+, at maturity stage II.

It was established that due to the early start of the spawning process, the local Krasnovodsk herring living in the eastern part of the South Caspian Sea has a higher growth rate compared to other local forms of herring in these areas. Specifically, at two years of age, the herring measured 15.8-24.5 cm, with an average of 19.6 cm; at three years, they measured 23.0-29.0 cm, with an average of 25.8 cm; at four years, they were 29.0-33.0 cm, with an average of 30.6 cm; and at five years, they reached 35.0-36.0 cm, with an average of 35.5 cm. The growth of Krasnovodsk herring is more intensive in the early years, with a notable slowing of growth starting at age four. Among individuals of the same age group, females had an advantage over males in both average length and weight. The population of Krasnovodsk herring caught in the fishery was characterized by four age groups (2-5 years). Since Krasnovodsk herring, like other forms of the Braynikov species, reaches sexual maturity at an early age, the majority of the caught fish (83.6%) were 2-3 years old. This species reaches sexual maturity at the age of two years. The scales of 67.1% of the Krasnovodsk herring we studied did not have spawning marks. Of the analyzed fish, 25.3% had one spawning mark, 6.3% had two, and 1.3% had three spawning marks. Therefore, the spawning migration of the population is primarily driven by individuals participating in spawning for the first time, who have a significant advantage over those that have spawned multiple times. The average spawning abundance of Krasnovodsk herring was estimated to be 72000 individuals.

4.12. Eastern herring - *Alosa braschnikowi orientalis* (Mikhailovskaya, 1941)

Eastern herring, one of the endemic fish species of the Caspian Sea, exhibits an intransitional form. These herrings are primarily distributed along the eastern shores of the Caspian Sea, from the Astra-

bad Gulf to the Kara-Bogaz-Gol Gulf. During winter, they migrate to the southeastern part of the Caspian Sea for overwintering. In the winter of 2003, Eastern herring were observed in the waters of the Hasangulu region at a depth of 45-50 meters, where the water temperature was 7.6°C. These herring are known for their short migration distances. Starting in March, they move toward the coastal waters of the Hasangulu, Chikish, and Ogurchi Island regions, with some entering the Turkmenbashi Gulf. From the second half of April, the majority of these fish are found in the Hasangulu-Chikish regions. For spawning, they migrate to the Garadashli regions of the South Caspian, as well as the Chelakan and Turkmenbashi Gulfs. After spawning, the Eastern herring disperses during the summer and fall, moving farther from the shore in search of food. Notably, in the summer of 2004, Eastern herring were caught at a depth of 10 meters in the Turkmen Gulf.

The Eastern herring caught during the winter season at a depth of 45-50 meters in the Hasangulu area had a body length ranging from 31.5 to 34.5 cm and a body weight between 335.5 to 600.0 g. The Fulton condition coefficient for these fish was observed to be between 1.12 and 1.52, with their ages ranging from 4+ to 6+. The gonads of these shad were in the II-III maturity stages. During the summer season, Eastern herring caught at a depth of 10 meters in the Turkmen Gulf had a body length of 33.0 cm, a body weight of 400.0 g, a Fulton condition coefficient of 1.11, and an age of 5+. The gonads of these fish were in the III maturity stage. It has been established that in this area of the Caspian Sea, Eastern herring reaches sexual maturity at the age of 2-3 years.

In winter, the main diet of the Eastern herring consists of shellfish and shrimp. Notably, during the winter of 2003, an Eastern herring caught at a depth of 45-50 meters in the Hasangulu region was found to have 15 pieces of Amphipod weighing 2.9 g in its stomach.

4.13. Kura herring – *Alosa curensis* (Suvorov, 1907)

The population of Kura herring has significantly declined in recent years, leading to its inclusion in Azerbaijan's "Red Book" of endangered species. Research has identified that during the winter season, the Kura herring is most concentrated at depths of 21-32 me-

ters in the Lankaran and Kura Spit areas, where the bottom water temperature ranges from 6.9 to 8.4°C. As the gonads mature and feeding intensifies, starting from the end of February, Kura herring gradually rises from the bottom layers of the water. During this period, it shifts to a semi-pelagic lifestyle, preferring to inhabit coastal waters at depths of 10-15 meters, where the water temperature is slightly warmer, ranging from 8.6 to 10.3°C. In April, observations indicated that the Kura herring was more concentrated at depths of 9-11 meters in the Lankaran, Kura Spit, and the North-Eastern Armpit of the Kura River. However, during the summer months, it became difficult to catch Kura herring. This is likely due to the fact that a small number of these herring migrate from coastal zones to the open sea in June-July after spawning. Their uneven distribution and smaller size likely prevented them from being caught in the nets.

The main meristic characteristics of the Kura herring, studied by us during nesting migration in the Azerbaijani sector of the South Caspian, were as follows: *D* III-IV 13-16, in general 16-19 (17,4±0,12), *A* III 16-21, in general 19-24 (21,5±0,21), *sp.br*. 30-47 (38,8±0,68), *squ*. 45-54 (48,8±0,34), *sp.V*. 27-34 (30,0±0,24) [17,s.153]. The gill teeth of the Kura herring are notably longer than the gill leaves. Unlike other species, these teeth are thick, rough, and sparse, with a curved shape. Additionally, the mouth of the Kura herring is equipped with well-developed teeth, which are located in the jaw, palate, and jawbones.

The body length of the Kura herring ranged from 13.1 to 23.5 cm, with a weight between 25.3 and 145.0 g, and a condition coefficient (F) of 1.08 to 1.23. Female Kura herring exhibited higher biological parameters compared to males. The average body length for females was 18.6±0.31 cm, with an average body weight of 80.5±4.40 g and a condition coefficient of 1.15±0.01. For males, the average body length was 17.0±0.37 cm, body weight was 58.3±3.80 g, and the condition coefficient factor was 1.14±0.01.

The Kura herring exhibits a notably slow growth rate compared to other forms of the species *A. braschnikowi* with fewer gill teeth, but it surpasses the local fathead minnow in the South Caspian. The sizes of the caught Kura herring were: At two years: 13.1–16.6 cm

(average: 15.1 cm); at three years: 15.5–19.5 cm (average: 17.5 cm); at four years: 18.4-22.0 cm (average: 20.2 cm); at five years: 22.5-23.5 cm (average: 23.0 cm) (Table 3). This indicates that growth retardation in Kura herring begins around one year of age and becomes more pronounced with age. The Kura herring population is comprised mainly of 3-4-year-old individuals (74.0%) and belongs to 4 age groups (2-5). Spawning occurs from late April to late June, primarily at depths of 4-10 m in areas such as Lenkoran, the Sara Peninsula, and the Kura Spit area, where the water temperature ranges from 17 to 28°C.

Table 3

The dynamics of length-weight indicators of Kura herring depending on the age

Sex	Age groups				Average
	2	3	4	5	
♀	16,1 / 48,1	17,9 / 66,1	20,3 / 99,2	23,0 / 141,3	18,6 / 80,5
♂	14,6 / 36,1	17,1 / 57,3	20,0 / 93,6	-	17,0 / 58,3
♀♂	15,1 / 39,6	17,5 / 62,2	20,2 / 97,1	23,0 / 141,3	17,9 / 70,4
n	17	36	21	3	77

The Kura herring population, which reaches sexual maturity at 2 years of age, shows the following spawning characteristics:

No spawning traces: 36.4% of the studied fish; One spawning mark: 40.2%; Two spawning marks: 19.5%; Three spawning marks: 3.9%. No spawning signs were observed in 2-year-old individuals. This indicates that the spawning population largely comprises individuals participating in spawning for the second time, with both young and older individuals contributing to the spawning process. In terms of egg production: Individuals measuring 18.6 cm in length and weighing 76.6 g laid approximately 23.7 thousand eggs; Individuals measuring 23.5 cm in length and weighing 148 g laid about 51.2

thousand eggs. The average number of eggs laid by the Kura herring is around 38.6 thousand eggs per producer.

4.14. Caspian anadromous herring - *Alosa kessleri* (Grimm, 1887)

Since the Caspian anadromous herring is a thermophilic fish, it has been noted that in the winter season these fish mainly prefer depths of 30 m in the Shagagach area, 40 m in the Lankaran area and 33 m in the southeastern area of Kura Armpit. During the studies conducted in the Iranian waters of the Caspian Sea in winter 2003, it was found that Caspian anadromous herring prefers depths of 30-35 m in these areas and layers of water with a bottom temperature of 8.7-9.7 ^{0} C. Beginning in mid-March, at a water temperature of 6-7 ^{0}C, the gonads are in the II-III, III stage of development, mainly approach the western shores of the South Caspian to carry out spawning migration to the north from wintering grounds. Spawning migration of these fish lasts almost three months. During spawning migration, these fish rarely approach the shallows of the sea, mainly moving to the deep layers of the sea, away from coastal waters. In the second half of April, it was observed that these fish migrated from the northern part of the South Caspian and preferred depths of 20-25 m in the Gilyazi and Muktadir areas of the Central Caspian. After spawning in the summer months, Caspian anadromous herring prefers the western shores of the Middle Caspian, especially depths of 75-50 m in the Muktadir and Guba areas, rather than the North Caspian. It should be noted that in summer, young Caspian anadromous herring were found at depths of 25-50 m in the Kura region of the South Caspian, and the southeastern Armpit and Bandovan areas of the Kura. During this period, a small number of young Caspian anadromous herring were found at depths of 10-20 m in the Hasangulu area.

The main meristic characteristics of the Caspian anadromous shad, studied by us were as follows: *D* III 13-15, in general 16-18 (16,7±0,06), *A* III 17-19, in general 20-22 (20,5±0,06), *sp.br*. 59-88 (70,3±0,70), *squ*. 51-58 (54,5 ±0,10), *sp.V*. 30-35 (32,4±0,10). The gill teeth of the Caspian anadromous herring exhibit noticeable variation based on the size of the individuals: Small Individuals: The gill teeth are fine. Large Individuals: The gill teeth become dense and

coarse, with broken tips. Additionally, the jaws are generally of equal length, though the lower jaw can sometimes protrude slightly forward and feature a projection under its front side. These characteristics help differentiate the Caspian anadromous herring from other species and forms.

The body length of analyzed Caspian anadromous herring ranged from 16.8 to 43.6 cm, and the body weight varied from 58.8 to 1160 g, the Fulton's condition coefficient fluctuated between 0.91 and 1.84. The body length of male individuals was 22,4-36,3 cm, body weight - 142,0-754,0 g, and Fulton's condition coefficient - 0,99-1,67; in female individuals, these values were 24,5-43,6 cm, 163,0-1160,0 g, and (F) 1,02-1,84 respectively.

It was found that Caspian anadromous herring generally reach sexual maturity at the age of 3-4 years, with some individuals maturing at 5-6 years. Up to the age of four, there is no significant difference in the growth dynamics between males and females. However, starting from the age of five, females exhibit noticeably more intensive growth compared to males.

The population of black herring caught during the study was categorized into six age groups, ranging from 2 to 7 years. The majority of the population (69.7%) consisted of 3-4-year-old individuals. Interestingly, 64.9% of the herring did not display any spawning marks, indicating they had not yet participated in spawning. For those participating in spawning for the first time, the majority (86.5%) were 3-4 years old. In contrast, among those that had spawned multiple times, the majority (45.1%) were 5-6 years old. This suggests that the spawning population is primarily composed of 3-4-year-old individuals, participating in spawning for the first time. The average absolute fecundity of the studied herring was found to be 208524 eggs, reflecting their reproductive potential.

4.15. Volga herring - *Alosa volgensis* (Berg, 1913)

The Volga herring, a transitional fish species, has experienced a sharp decline in population over recent years, leading to its inclusion in the Red Books of both the Russian Federation and the Republic of Azerbaijan. This herring species primarily overwinters in the South Caspian, particularly in the eastern part of the South Caspian

and the southern part of the Central Caspian Sea. Unlike other herring species, Volga herring undertake a unique migration pattern, moving northward to spawn in the waters of Azerbaijan and Dagestan, far from the coast and in the deep layers of the sea. They primarily enter the Volga River for spawning, with smaller numbers also entering the Ural and Terek rivers. During research conducted in February in the Turkmen waters of the Caspian Sea, Volga herring were caught at depths of 22-27 meters in the Okareminsky district and 10-20 meters in the Okareminsky and Ulsky districts. In the same month, they were also caught at depths of 26-50 meters in the Gilazi and Shabran areas of the Central Caspian. In the summer, Volga herring were found at shallower depths of around 15 meters in the Khachmaz and Siyazan areas.

The main meristic characteristics of the studied Volga herring were as follows: *D* III-IV 13-15, in general 16-19 (16,2±0,17), *A* III 15-19, in general 18-22 (19,9±0,23), *sp.br*. 97-149 (121,1±0,71), *squ*. 49-54 (51,6±0,46), *sp.V*. 28-35 (31,5±0,25). The Volga herring has gill teeth that are thin and long, typically about 1.5 times longer than the gill leaves. These teeth are less developed when compared to those of the Caspian anadromous shad but are more pronounced than those found in the Northern Caspian shad.

In 2002-2003, the Volga herring caught in the Turkmen waters of the Caspian Sea had a body length ranging from 19.6 to 30.2 cm and a body weight between 83.4 and 289.0 g. The Fulton condition coefficient for these fish varied from 0.81 to 1.53. The specimens studied were primarily between 2 and 5 years old, with the majority (62.5%) being 3-year-old individuals. The caught fish were at the I-II and II-III stages of maturity, indicating varying levels of reproductive readiness during the time of capture.

In February, the Volga herring caught in the Gilyazhi and Shabran areas had a body length of 20.0-21.1 cm, a body weight of 92-104 g, and a Fulton's condition coefficient of 1.11-1.15, with an age of 2+ years. The gonads of these fish were in the I-II stages of maturity. During the summer months from 2007 to 2016, Volga herring caught with trawls and nets in the western part of the Central and Southern Caspian had a body length of 16.7-25.6 cm, a body

weight of 60.5-179.8 g, and a Fulton's condition coefficient ranging from 1.02 to 1.26. These fish were 2-3 years old, and their gonads were at the stage of sexual maturity.It has been established that in the first two years of life, the Volga herring experiences a significant increase in length, accounting for 64.6% of its total length increase by age 5 (Table 4). In contrast, the weight increase during these first two years is only 30.7% of the average weight that the fish will reach by age 5. After this period, the growth in weight becomes more intensive compared to the earlier years. In terms of growth in length, there is almost no difference between male and female Volga herring. However, in all age groups, males lag behind females in weight growth. The productivity of the studied Volga herring population varied between 123000 and 217000 individuals, with an average productivity of 163700 individuals.

Table 4

The variation of length-weight indicators of Volga herring depending on the age

Sex	Age groups				Average
	2	3	4	5	
♀	21,0 / 100,1	22,5 / 136,4	28,7 / 245,1	30,2 / 289,0	24,1 / 174,3
♂	18,6 / 77,4	21,6 / 108,3	26,2 / 190,0	-	21,8 / 108,6
♀♂	19,5 / 88,8	22,0 / 122,3	27,8 / 217,6	30,2 / 289,0	22,3 / 134,1
n	8	5	3	1	17

CHAPTER 5. REGARDING THE FORMATION OF SPECIES OF HERRING FISH IN THE CASPIAN SEA

Among the Ponto-Caspian fishes that inhabit the Caspian Sea, herring is notable for its species and intraspecific variability. The Caspian Sea itself has undergone numerous geological, physical-geographical, and hydrological changes throughout its history, which have influenced the evolution of its fish species. Caspian herrings,

which are of autochthonous origin, trace their lineage back to ancient forms that once lived in the Sarmatian, Pontic, and Agchagyl basins.

In the study of the intraspecific variability of Ponto-Caspian herring, it has been observed that the degree of variability differs among species. Some species exhibit a high degree of variability in certain traits, while in others, these traits remain relatively stable. Based on this variability, Ponto-Caspian herring species in the Caspian Sea can be categorized into two groups: relatively stable species and changeable (or plastic) species. This distinction highlights the diverse evolutionary adaptations and responses of herring species to the changing environmental conditions of the Caspian Sea.

A small portion of the herring species inhabiting the Caspian Sea, such as Saposhnikovi shad and Agrakhan shad, as well as Kura herring, can be classified as relatively stable species. These species are unique in that they do not have subspecies, indicating a lower level of intraspecific variability compared to other herring species. The spawning grounds of these species are distinct: the Agrakhan shad spawns primarily in the eastern part of the Northern Caspian Sea, while the Saposhnikovi shad utilizes both the eastern and western parts of the Northern Caspian for spawning. Kura herring, on the other hand, spawns mainly in the Lankaran region and the Sara peninsulas at depths of 4-10 meters.

Towards the end of the 20th century, researchers such as N.G. Bogutskaya and others made significant taxonomic revisions based on the morphological and biological differences observed between the subspecies of Caspian anadromous herring and Volga herring. As a result of these differences, each was reclassified and described as a separate species: *Alosa kessleri* and *A. volgensis*.[10]

These observations suggest that certain herring species, such as Agrakhan shad, Saposhnikovi shad, Kura herring, Caspian anadromous herring and Volga herring, have demonstrated remarkable ge-

[10] Богуцкая, Н.Г. Каталог бесчелюстных и рыб пресных и солоноватых вод России с номенклатурными и таксономическими комментариями / Н.Г. Богуцкая, А.М.Насека; – М.: Товарищество научных изданий КМК, – 2004. – 389 с.

netic stability within the Caspian Sea. This stability has allowed them to maintain their species status in taxonomy over the course of a century, highlighting their resilience and consistent genetic makeup.

On the other hand, some species exhibit significant intraspecific changes, leading to the formation of different subspecies. These are classified as unstable or "plastic" species. A notable example of this group in the Caspian Sea is Brashnikovi herring. Despite the extensive research conducted over the years, no subspecies have been identified within the Caspian Sea shad population, except for Northern Caspian shad - *Alosa caspia*. Further studies, such as those conducted by A.Bani et al.,[11] involved the analysis of subspecies related to *A. caspia* in the Southern Caspian. Using morphometric and molecular methods, their research confirmed the absence of subspecies within this species. The authors attributed the phenotypic differences observed to varying environmental conditions rather than genetic divergence, reinforcing the notion that *A. caspia* is a genetically stable species with phenotypic plasticity influenced by its environment.

The research indicates significant differences in spawning timings and locations among subspecies of the Brashnikovi herring: Dolgin herring - spawning begins in the eastern part of the Northern Caspian from late April to early May. Agrakhan herring - spawning starts later, at the end of May, in the western part of the Northern Caspian. In contrast, the western part of the Southern Caspian, notable for large local populations of Sar and Big-eyed herring, is characterized by more synchronized spawning. Both subspecies of herring in this region spawn almost simultaneously, in early May, at depths of 5-15 meters. This pattern reflects a high degree of local adaptation and environmental influence on their spawning behaviors.

The research into Caspian herring has revealed significant insights into the diversity and variability of these fish. Four distinct forms of herring in the Caspian Sea – Dolgin herring, Agrakhan her-

[11] Bani, A. The taxonomy of *Alosa caspia* (Clupeidae: Alosinae), using molecular and morphometric specifications, in the South Caspian Sea / A.Bani, S.Khataminejad, H.R.Vaziri [et al.] // The European Zoological Journal, – Oxford: – 2019. Vol.86, №1, – pp.156-172.

ring, Sara herring, and Big-eyed herring - show reliable differences in both morphometric and biological indicators. These variations are significant enough to classify each as an independent subspecies. In the eastern South Caspian, five local populations of Brashnikovi herring are identified: White-headed herring, Big-eyed herring, Hasangulu herring, Krasnovodsk herring, and Eastern herring. Although these populations inhabit the same regions year-round, their spawning periods differ. The Big-eyed herring spawns from late March to early April at depths of 10-17 meters in the Hasangulu and Chikish areas. The Krasnovodsk herring begins spawning in mid-April at depths of 10-11 meters in the Turkmen Gulf and Chalekan. The Eastern herring spawns in late April to early May, preferring depths of 10-13 meters in the Caspian Turkmen Gulf and 17-20 meters in the Hasangulu area. The Hasangulu herring, known for its preference for hot temperatures, starts spawning later, from late May at depths of 20-25 meters. Morphometric comparisons have revealed that while the Krasnovodsk herring shows no significant difference from the White-headed herring, indicating that Krasnovodsk herring (A.b.nirchi) is likely a race of the White-headed herring rather than a separate subspecies, significant differences are found when comparing Hasangulu herring with the Big-eyed herring and White-headed herring. This indicates that the Hasangulu herring is distinct from these other forms.

Overall, the Caspian herring exhibits a complex pattern of intraspecific and interspecific variability, reflecting their adaptation to different environmental conditions and spawning schedules.

Based on extensive research, it has been established that Brashnikovi herring is endemic to the Caspian Sea and exhibits considerable ecological plasticity and a high rate of morphological evolution. Within this group, several forms of Brashnikovi herring, such as Dolgin, Agrakhan, and Hasangulu herring, share some morphological characteristics. However, the Sara herring is distinct both morphologically and biologically from these forms (Diagram 1). Given these findings, it is appropriate to recognize the Sara herring as an independent species, designated as *A. sarensis*.

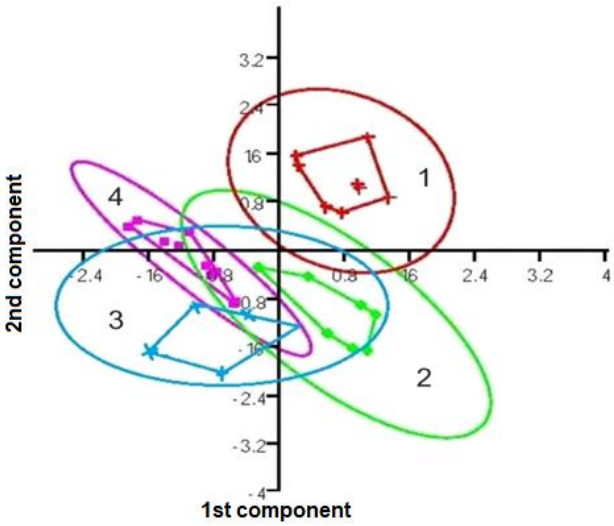
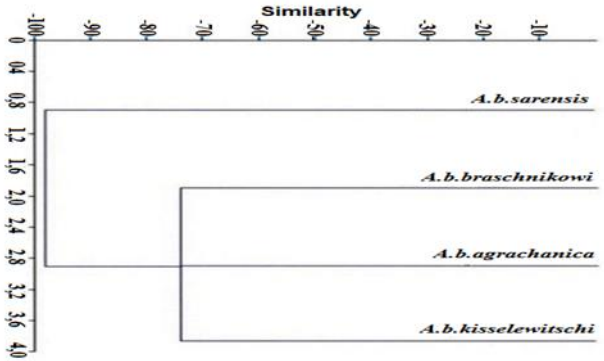


Diagram 1. Diagram of Primary Components Analysis (PCA) distribution illustrating variation of 4 subspecies of Brajnikovi herring. 1 – Sara herring; 2 – Dolgin herring; 3 – Hasangulu herring; 4 – Agrakhan herring.

The conducted cluster analysis also showed the same results (Graph 1).



Graph 1. Cluster analysis of 4 subspecies of Brashnikovi herring: Sara, Dolgin, Hasangulu and Agrakhan herrings.

Morphometric parameters alone are insufficient to accurately determine the genetic structure of a population, as they can often lead

to taxonomic uncertainty. Recognizing this limitation, studies were expanded to include an analysis of genetic variations within species. During these studies, an optimal amount of DNA was successfully extracted from all four fish subspecies (Dolgin, Agrakhan, Hasangulu, and Sara herring) using various primers. To ensure the homogeneity of the DNA, PCR amplification was performed on DNA fractions isolated from three different tissues: liver, muscles, and dorsal fin rays (Figure 2). Pairwise comparisons of the genetic distances between the four subspecies revealed that Dolgin, Agrakhan, and Hasangulu herring are more similar to each other in terms of morphological parameters and exhibit a close genetic distance. In contrast, Saran herring was found to be genetically very distant from the other three subspecies. This significant genetic divergence supports the assertion that the Sara subspecies is not only genetically distinct but may indeed have the status of a separate taxonomic species, *Alosa sarensis* (Mikhailovskaya, 1941).

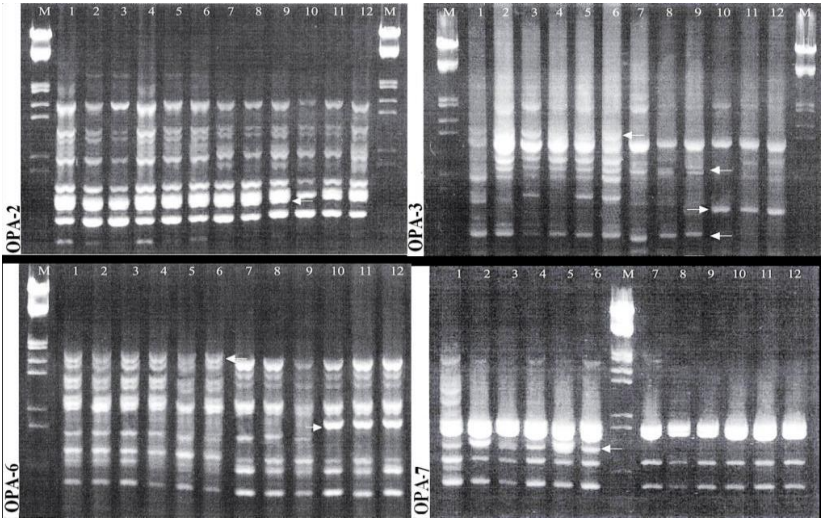


Figure 2. The RAPD amplification pattern with different primers was tested on 4 subspecies of Brashnikovi herring. The image shows 3 repeats for each subspecies: 1-3 - Agrakhan herring; 4-6 - Hasangulu herring; 7-9 - Dolgin herring; 10-12 - Sara herring. Arrows point to specific marker bands for a specific subspecies; M - 1

CHAPTER 6. VI CERTAIN CHARACTERISTICS OF HERRING DISTRIBUTION AND BEHAVIOUR IN THE CASPIAN SEA.

When we compared the horizontal distribution of herring with the plankton biomass at various stations in the Central and South Caspian during our research, a proportional relationship was observed between them. Our observations revealed that in the Kura Spit area of the South Caspian and the southeastern armpit region of the Kura, the herring catch during the winter season ranged from 5.9 to 10.2 kg, corresponding to a plankton biomass fluctuating between 10.0 and 22.2 mg/m³. During the same period, in the Guba and Siyazan regions of the Central Caspian, with plankton biomass varying from 16.7 to 49.6 mg/m³, the herring catch ranged from 3.0 to 12.1 kg. In the summer, the largest herring catches (4.7 kg or more in trawl fisheries) were recorded in areas where the plankton biomass exceeded 40.0 mg/m³.

A correlation was also identified between the vertical distribution of herring and plankton. In winter, particularly in January, the majority of herring (ranging from 3.5 to 12.7 kg) was concentrated at depths of 22-50 meters in the sea, where the plankton biomass was also high. It was observed that the vertical distribution of herring along the western coast of the Caspian Sea during the summer months is closely linked to the distribution of their food sources. Thus, in the western part of the Central and South Caspian, a strong correlation is observed between herring catches and zooplankton biomass during the summer (r=0,74;0,60).

In contrast, during the winter, this correlation weakens, with coefficients of 0.50 and 0.28. After spawning, herring engage in intensive feeding, forming large polulations in the summer and autumn based on the distribution of sprat and plankton in the Middle and South Caspian.

CHAPTER 7. FORECAST OF MIGRATION OF HERRING IN THE CASPIAN SEA. ICHTHYOPLANKTON IN THE PLANKTON COMMUNITY

7.1. On forecasting nesting migration of Caspian Sea herring

In addition to temperature, the prediction of herring migration timing involves considering various biological and environmental fac-

tors, such as temperature, salinity, pH, and food availability. Our research indicates that while temperature is a significant factor, the primary external environmental trigger for herring migration is the influence of sex hormones. These hormones play a crucial role in the development of reproductive products at specific maturity stages. For instance, in species such as the saposhnikovi shad, Northern Caspian shad, and even Caspian anadromous herring, mass migration occurs when the gonads reach maturity stages III-IV and IV (Maturity Stage - MS). This hormonal influence drives the onset of migration as the fish prepare for spawning. Dolgin and Sara herring initiate their migration at slightly earlier stages of gonadal maturity, typically stage III and even stage II-III. Our research revealed that in 2009 and 2015, gonad development in herring occurred earlier compared to 2008 and 2014, resulting in an earlier start to reproductive migration in the former years. However, not all herring reach biological readiness for migration simultaneously. In more favorable environmental conditions, gonad maturation occurs earlier, leading these individuals to begin migration sooner. Conversely, herring in less favorable conditions experience delayed gonad maturation and migration. This disparity in maturation timing causes a protracted initiation of reproduction, as more sexually mature herring migrate promptly while less mature individuals continue feeding in nutrient-rich areas until they are ready to migrate.Considering environmental factors, it is feasible to predict the timing of spring migration for herring 1-2 months in advance by comparing current-year data on gonad development with historical data from previous years. This approach, which integrates short-term forecasts of fish populations based on their biological condition, allows for a more accurate prediction of when herring will commence their spring migration.

7.2. Ichthyoplankton in the plankton community of the Central and Southern Caspian

Over the past two decades, the ichthyofauna of the Caspian Sea has been significantly affected by eutrophication, toxic pollution, and the introduction of the comb jelly *Mnemiopsis leidyi*. These adverse impacts have led to notable changes in the taxonomic structure of aquatic organisms, disruptions in the development of fish eggs and

larvae, and a sharp decline in both the overall population and the stocks of fish species in the region.

During comprehensive studies of the plankton community in the Azerbaijani sector of the Caspian Sea conducted in 2010-2011 and June-August 2014, 18 species of fish eggs and larvae belonging to seven families were identified. The research revealed that the areas with the highest concentration of ichthyoplankton were the Sara Peninsula, with 5.7 individuals per cubic meter, and the 10-meter depth of the Salyan Reef, with 3.8 individuals per cubic meter, both located in the western part of the South Caspian. In contrast, relatively lower concentrations of ichthyoplankton were observed in the western parts of the Middle and South Caspian, particularly in the Muktadir area, with 2.9 individuals per cubic meter, and the northeastern armpit area of the Kura, with 2.5 individuals per cubic meter, at depths ranging from 10 to 25 meters.

In July-August, the average density of ichthyoplankton was recorded at 3.38±0.53 individuals per cubic meter. The number of producers (0.97±0.25 individuals per cubic meter) was three times lower than the number of larvae, which was 3.38±0.53 individuals per cubic meter. In 2014, the dominant species identified were Sara herring, accounting for 37.9%, Caspian atherina at 21.4%, and golden mullet at 16.5%. Overall, the average number of fish eggs, represented by five species, was 1.03±0.07 units per cubic meter.

Notably, in 2010, the density of Saran herring larvae fluctuated between 0.22 and 2.04 individuals per cubic meter, averaging 0.84±0.39 individuals per cubic meter, while the density of Caspian sprat ranged from 0.20 to 1.53, averaging 0.64±0.30 individuals per cubic meter. In 2014, the density of Saran herring larvae varied between 0.31 and 3.20 individuals per cubic meter, with an average of 1.29±0.17 individuals per cubic meter, and the density of Caspian sprat fluctuated between 0.27 and 2.35 individuals per cubic meter, averaging 0.87±0.13 individuals per cubic meter.

It has been determined that the distribution of eggs and larvae of pelagic fish, as well as mesoplankton and meroplankton, is influenced by various factors including the water's temperature regime, salinity,

oxygen saturation, the availability of food resources, and the seasonal and long-term dynamics of the *Mnemiopsis leidyi* population.

CHAPTER 8. THE CURRENT STATE OF HERRING STOCKS IN THE CASPIAN SEA AND THEIR RESTORATION

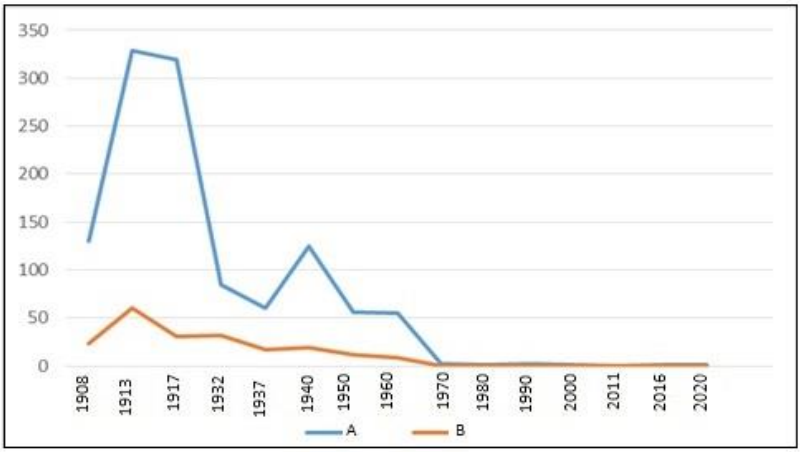
The Caspian Sea, known as one of the world's largest closed water bodies, is a crucial fishing area. Presently, out of the 18 species and subspecies of herring in the Caspian Sea, only four forms are considered of primary importance: the Caspian shad, Saposhnikovi shad, Dolgin herring, and Caspian anadromous herring.

Between 2002 and 2003, during collaborative trawling operations with Caspian states and in the Azerbaijani sector of the Caspian Sea from 2002 to 2020, it was determined that the total herring catch in the shelf zones of Azerbaijan, Iran, and Turkmenistan amounted to 40.6 thousand tons. The highest herring catch was reported in Azerbaijan's shelf zones, averaging 25.9 thousand tons, followed by Iran with an average of 14.6 thousand tons, and Turkmenistan with an average of 0.09 thousand tons. In our ichthyoplankton research conducted with the DJOM network on the "Alif Hajiyev" vessel along the western coast of the Middle and Southern Caspian in the summer, the distribution of herring larvae was as follows: 24.9% were Sara herring, 6.8% were Agrakhan herring, 4.4% were Caspian shad, and 3.3% were Dolgin herring.

The dynamics of herring fishing in the Caspian Sea and specifically in the Azerbaijani sector from 1908 to 2020 are illustrated in Qraphe 2. The graph reveals a significant decline in herring catch starting from 1960, both in the Caspian Sea as a whole and in the Azerbaijani sector. This decrease does not necessarily reflect a reduction in herring stocks but rather indicates a lower fishing intensity during these years.

Several measures are needed to restore the fish stocks of the Caspian Sea. For this purpose, it is advisable to implement the following measures:

1. Dams constructed on rivers flowing into the Caspian Sea, particularly the Volga, should be modified to ensure the free passage of transit herring to their spawning grounds and their successful spawning.



Qraph 2. The dynamics of herring catch in the Caspian Sea (in thousand tons). A - Herring caught throughout the Caspian Sea; B - Herring caught specifically in the Azerbaijani sector of the Caspian Sea.

2. The harvesting of herring in rivers where they enter for spawning and in nearby areas should be strictly prohibited. Enhanced monitoring of river mouths is required annually from May 1 to May 30 to enforce this regulation.

3. Continuous monitoring of the volume, structure, dynamics, and migration patterns of the spawning population should be conducted from mid-April until the end of the spawning migration of transit herring.

We anticipate that implementing these measures will lead to a significant increase in the stocks of key fish species in the Caspian Sea, including herring, in the near future.

RESULTS

1. Currently, the Central and Southern Caspian Seas host five species and eight subspecies of marine herring, all belonging to the order *Clupeiformes*, the family *Clupeidae*, and the genus *Alosa*. The endemic Caspian herrings include both saltwater and transient ecological groups. The saltwater species are represented by *Alosa saposchnikowii*, *A. caspia caspia*, *A. braschnikowi braschnikowi*, *A. b. agrachanica*, *A. sarensis*, *A. b. autumnalis*, *A. b. grimmi*, *A. b. kis-*

selewitschi, A. b. nirchi, A. b. orientalis, and *A. curensis*. The transient species include *A. kessleri* and *A. volgensis*. Most of these taxa are found in the Central and Southern Caspian [1, 2, 4, 13, 17, 18, 19, 20, 28, 39, 42].

2. Brashnikovi herring - *Alosa braschnikowi* (Borodin,1904) is exclusively distributed in the Caspian Sea and is noted for its extensive ecological plasticity and rapid morphological evolution. Within its subspecies, there is reproductive territorial isolation, and they differ in their morphosystemic status. Dolgin, Agrakhan, Big-eyed, Hasangulu, and other herring subspecies exhibit similar morphological traits, while Sara herring is significantly different from these subspecies based on several morphological characteristics ($P < 0.001$). Given these differences, it is deemed appropriate to classify Sara herring as a distinct species, *Alosa sarensis* (Mikhailovskaya, 1941) [8, 9, 10, 11, 36].

3. An analysis of the genetic distances between four subspecies of Brashnikovi herring (Dolgin, Agrakhan, Sara, and Hasangulu) considered a polytypic species in the Caspian Sea has revealed that Dolgin, Agrakhan, and Hasangulu herring are genetically closer to each other. In contrast, Sara herring shows a greater genetic distance from these three subspecies. This suggests that Sara herring is either significantly distinct from the other subspecies or potentially qualifies as an independent species, *Alosa sarensis* (Mikhailovskaya, 1941) [23, 36].

4. From 2002 to 2020, anthropogenic impacts have significantly altered herring migration patterns in the Caspian Sea. Previously, it was believed that the majority of herring migrated along the eastern coast of the Caspian Sea. However, recent observations reveal that most herring now migrate from their wintering grounds to the north, first along the southern and then the western coast of the Middle Caspian, with only a small portion migrating along the eastern coast. Consequently, in the Northern Caspian, the primary migration route has shifted to the western coast [6, 7, 26, 32, 33, 38, 41].

5. The horizontal and vertical distribution of herring at various stations is generally directly proportional to plankton biomass. In the summer, the correlation between herring catches and zooplankton bio-

mass is high in the western part of the Middle and South Caspian, with coefficients of 0.74 and 0.60. However, in winter, this correlation is lower, with coefficients of 0.50 and 0.28. The largest herring catches, exceeding 14.2 kg during trawling, are observed in areas with a plankton biomass greater than 50.0 mg/m³, at depths ranging from 25 to 50 meters, during both winter and summer [3, 5, 12, 16, 24, 31].

6. Herring reproduction is influenced by environmental conditions such as temperature, salinity, pH, and food availability. However, it is not these environmental factors but rather sex hormones that play a crucial role at specific stages of reproductive development. Understanding the impact of these hormones allows for more accurate and scientifically sound predictions regarding the timing of spring migration for industrial fishing. By studying the biological state of herring in conjunction with environmental conditions throughout their life cycle, more reliable forecasts can be made [44].

7. The spawning migration of herring populations primarily involves older individuals that participate in spawning multiple times. Those engaging in their second and third spawning events make up 31.0-59.7% of the population. Herring typically reach sexual maturity between the ages of 2 and 7 years, with the majority of spawning individuals being 3-4 years old (64.1%). Males generally mature at two years of age, while females reach maturity at three years [21, 24, 30, 32, 33, 40].

8. In the Central and Southern Caspian Sea, eggs and larvae of 18 fish species from 7 families were identified in the ichthyoplankton. Among these, herring species (Caspian shad, Sara, Dolgin, and Agrakhan herring) comprised 20.4% of the species composition. The highest concentrations of ichthyoplankton were found at the Sara Peninsula (12.2 individuals/m³) and at a depth of 10 meters in the Salyan roadstead (7.8 individuals/m³). Conversely, lower concentrations were observed in the Muktadir district at depths of 10-25 meters (4.1 individuals/m³). The average densities were 0.32±0.13 individuals/m³ for herring eggs and 1.83±0.14 individuals/m³ for larvae. The condition of ichthyoplankton, mesoplankton, and meroplankton is significantly influenced by climatic, hydrological, and anthropogenic factors, as well as

the seasonal and long-term dynamics of the invasive species *M. leidyi* [15, 29, 34, 35].

9. Herring feeds throughout the year, with the most intense feeding occurring during the spawning migration in March-April and the post-spawning migration in July-August. In the spring, the diet of the Northern Caspian shad primarily consists of Copepoda (37.6-40.4%), Mysidacea (30.0-34.2%), and Cumacea (13.0-20.9%). Meanwhile, the Brashnikovi herring's diet is dominated by sprat (43.0-48.4%), including North Caspian (Middle Caspian) goby (21.4-25.1%) and shrimp (14.4-16.4%). During the summer, the proportion of Copepoda, the main food component for Northern Caspian shad, increases to 82.5%, while the amount of sprat in the Brashnikovi herring's diet rises to 76.6% [14, 22, 27, 28, 33, 37, 43].

10. Our trawl-acoustic fishing surveys revealed that the total herring stock in the shelf zones of Azerbaijan, Iran, and Turkmenistan amounts to 40.6 thousand tons. The highest herring catch was recorded in the shelf zones of Azerbaijan, with an average of 25.9 thousand tons, followed by Iran with an average of 14.6 thousand tons, and Turkmenistan with an average of 0.09 thousand tons [7, 18, 25, 30, 33].

PRACTICAL RECOMMENDATIONS

Since the mid-20th century, herring stocks in the Caspian ecosystem, including Caspian anadromous herring and Volga herring, have been negatively impacted by a variety of natural and human-induced factors (such as periodic fluctuations in sea water levels, excessive regulation of rivers flowing into the Caspian Sea, pollution from industrial and household waste, illegal fishing, and the introduction of invasive species). Given these challenges, we believe it is crucial to implement the following measures to enhance the significance of fisheries in the Caspian region:

1. It is essential to ensure that transit herring can pass through the dams built on rivers flowing into the Caspian Sea, particularly on the Volga, to reach their spawning grounds. To facilitate this, fishing channels should be constructed near these dams, and these areas must be given special protection.

2. To enhance the effectiveness of fishing amidst the sharp decline in the catch of key species Acipenseridae and Salmonidae, it is crucial to make effective use of the existing herring stocks. One approach is to create or restore herring thickets along the Azerbaijani coast of the Caspian Sea. Additionally, during the spawning migration period, selective fishing using nets could be optimized by constructing single-layer polyamide-containing nets with a thickness of 40 to 45 mm.

3. To effectively organize fisheries in the Caspian Sea, experts from the surrounding countries - Azerbaijan, Russia, Iran, Kazakhstan, and Turkmenistannshould collaborate closely. This cooperation would involve conducting joint research on the Caspian Sea, analyzing its fish resources together, and preparing accurate fishing forecasts. Such a coordinated effort would enhance the sustainable management and utilization of the sea's fish stocks.

4. A unified system of regulation for fisheries should be established across the entire Caspian Sea.

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