GENETİCS OF CASPİAN SEA FİSH SPECİES

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Abstract: The Caspian Sea, the world's largest enclosed body of water, hosts a diverse and unique fish fauna, particularly the economically valuable sturgeons (e.g., *Huso huso*, *Acipenser gueldenstaedtii*), adapted to its unique brackish environment. Understanding the genetic composition of these fish is vital for studying their evolutionary adaptations and population dynamics.Genetic studies reveal features such as polyploidy in sturgeons, which contributes to high genetic variability, and osmoregulation genes which enable adaptation to fluctuating salinity. However, overfishing, pollution, and climate change are causing genetic erosion and population decline in these species.This research aims to assess the genetic diversity of key Caspian Sea fish species and to propose effective conservation and management strategies based on genetic findings. Utilizing molecular markers like mtDNA researchers can identify genetic bottlenecks and ensure the sustainability of the Caspian Sea's unique ichthyofauna.
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Introduction:

The Caspian Sea, the largest inland body of water on Earth, is a distinct and ecologically important ecosystem that supports a diverse range of fish species. Its semi-isolated nature and fluctuating salinity levels have facilitated the development of unique genetic adaptations in the fish populations. Understanding these genetic traits is essential for studying species diversity, the evolutionary processes, and the ecological stability of the region. Furthermore, many fish species in the Caspian Sea are of significant economic and cultural value, with sturgeons, renowned for their caviar production, being a prime example. Unfortunately, human activities such as overfishing, pollution, and habitat destruction pose serious threats to these species, underscoring the importance of genetic research for conservation efforts. By examining the genetic makeup of Caspian Sea fish, researchers can better understand their adaptability, population trends, and devise strategies for their sustainable management [12].

Spanning around 390,000 km² with a water volume of 78,700 km³ and a coastline of 7,000 km, the Caspian Sea plays a vital role in regional biodiversity, ecology, and fisheries [12]. Unlike typical seas, the Caspian Sea is a remnant of the ancient Paratethys Ocean, which became increasingly isolated due to tectonic activities. It is divided into three main areas:

The Northern Caspian, which is shallow and rich in nutrients; the Middle Caspian, which has

1. Caspian Sea Fish and Their Names:

The Caspian Sea, the largest enclosed inland body of water on the planet, is home to a wide range of fish species that have evolved in response to its unique and brackish waters. Its semi-isolated environment has fostered the adaptation of various fish species to the specific ecological conditions found in the region.

moderate depths; and the Southern Caspian, which reaches depths exceeding 1,025 meters [4].

The Caspian Sea is home to a wide variety of fish species, many of which are either endemic or of considerable commercial value. With more than 155 fish species recorded, it serves as a crucial hub for both freshwater and marine-origin species [4]. Notably, sturgeons (Acipenseridae) are among the most important, as they have been heavily exploited for caviar production. Other significant species include herrings, gobies, and cyprinids, all of which play vital ecological and economic roles [1]. Despite the Caspian's rich biodiversity, its fish populations are under intense pressure from overfishing, habitat degradation, and pollution, highlighting the urgent need for conservation efforts.

According to a review of existing literature, the current ichthyofauna of Azerbaijan consists of 113 species and subspecies of cyclostomes and fish, distributed across 13 orders, 18 families, and 56 genera. Among the most commercially valuable fish species are the Russian and Kura sturgeons, as well as various other sturgeon species, asp, Caspian roach, common carp, shemaya, Caspian shad, and others, whose life cycles are intricately tied to freshwater ecosystems. These fish predominantly reside in and grow within the Caspian Sea, but they migrate to riverine habitats for spawning [11].

Some of the most notable fish species from the Caspian Sea include:

Beluga Sturgeon (Huso huso) – One of the largest freshwater fish in the world, renowned for its high-quality caviar production.

Russian Sturgeon (Acipenser gueldenstaedtii) – Another significant sturgeon species, highly prized for its roe.

Persian Sturgeon (Acipenser persicus) – Endemic to the Caspian Sea, playing a crucial role in the caviar industry.

Caspian Roach (Rutilus caspicus) – A common species found in both the freshwater and brackish areas of the sea.

Caspian Salmon (Salmo trutta caspius) – A subspecies of trout native to the Caspian region.

Caspian Kutum (Rutilus kutum) – A commercially valuable fish in local markets.

Northern Pike (Esox lucius) – A carnivorous fish found in the Caspian region.

Zander (Sander lucioperca) – A predatory fish widely distributed throughout the Caspian basin.

These species have evolved unique genetic traits that allow them to thrive in the Caspian Sea's variable salinity and temperature conditions [1], [12].

2. Structure of Caspian Sea Fish:

The structure of fish in the Caspian Sea varies according to their ecological roles and evolutionary adaptations. These fish can be classified based on their skeletal structure, body shape, and specific environmental adaptations.

Skeletal Structure: The majority of Caspian Sea fish possess either cartilaginous (e.g., sturgeons) or bony (e.g., roach, kutum) skeletal systems. Sturgeons, being ancient species, have partially cartilaginous skeletons, which provide flexibility that is beneficial in deep water environments [7].

Body Shape and Adaptations: For instance, the beluga sturgeon has a long, streamlined body that facilitates efficient navigation in deep waters. On the other hand, smaller species like the Caspian roach have a more compact body structure, suited to living in shallow, brackish waters [7].

Fins and Movement: Species like the Caspian salmon, which are fast swimmers, possess streamlined bodies and strong caudal fins that assist in long-distance migrations. In contrast, bottom-dwelling species like sturgeons have ventral mouths and barbels, specialized for detecting food along the sea floor [4].

Respiration and Circulatory System: Caspian Sea fish rely on their gills to extract oxygen from the water. Some species, such as sturgeons, have adapted to low-oxygen environments by developing efficient gill structures and unique hemoglobin variations, which enhance their ability to absorb oxygen.

The Caspian Sea is home to a diverse range of fish, each of which exhibits unique anatomical and morphological features. Below is a summary of some notable species and their

specific structural adaptations [10].

1. Sturgeons (Family: Acipenseridae):

Russian Sturgeon (*Acipenser gueldenstaedtii*): Characterized by a cartilaginous endoskeleton and a series of bony scutes along the body, sturgeons have a heterocercal tail and an elongated snout equipped with barbels for detecting prey on the substrate [10].

Persian Sturgeon (*Acipenser persicus*): Similar in morphology to the Russian sturgeon, this species exhibits slight variations in scute patterns and snout length.

2. Caspian Shad (*Alosa caspia*):

This clupeid fish possesses a deep, laterally compressed body with long, thin gill rakers that are notably longer than the gill filaments. The species typically displays a black spot posterior to the gill opening, with occasional additional spots along the flank [6].

3.Caspian Salmon (*Salmo ciscaucasicus*):

Endemic to the Caspian Sea, the Caspian salmon can reach lengths up to 130 cm. It exhibits a streamlined body adapted for both lacustrine and anadromous lifestyles, with morphological forms varying between migratory and resident populations [14].

4. Gobies (Family: Gobiidae):

Round Goby (*Neogobius melanostomus*): This species exhibits alternative reproductive tactics, with males displaying a prominent mesorchial gland—a pheromone-releasing connective tissue structure attached to the testes, influencing reproductive behavior [9].

5. Caspian Lamprey (*Caspiomyzon wagneri*):

An endangered species, the Caspian lamprey exhibits at least two morphological forms with significant morphometric differentiation across rivers in the southern Caspian Sea basin. These variations are crucial for conservation strategies [5].

3. Genes Located in These Fish:

The genetic composition of Caspian Sea fish species has been extensively researched to understand their evolutionary adaptations, physiological functions, and conservation status. Sturgeons and other endemic fish species exhibit complex genetic structures that contribute to their unique biological characteristics.

Polyploidy in Sturgeons: Sturgeon species are known to exhibit polyploidy, a condition in which they have multiple sets of chromosomes. For example, the Beluga sturgeon (*Huso huso*) possesses between 270 and 290 chromosomes. This genetic trait contributes to their high genetic variability and adaptability to a wide range of environmental conditions. It is hypothesized that polyploidy enhances physiological resilience, growth potential, and reproductive flexibility.

Osmoregulation and Salinity Adaptation: Caspian Sea fish species carry genetic markers that regulate ion transport, a key process for osmoregulation in environments with varying salinity levels. Specific genes, such as those encoding Na+/K+-ATPase, aquaporins, and solute carrier proteins, play crucial roles in maintaining ionic balance, especially for anadromous species like the Caspian salmon (*Salmo trutta caspius*), which migrate between freshwater and marine environments.

Growth and Developmental Genes: The regulation of somatic growth in Caspian Sea fish is influenced by important hormonal genes, including those for growth hormone (GH) and insulin-like growth factor (IGF). These genes regulate metabolic processes, skeletal development, and reproductive maturity, particularly in commercially significant species like the Persian sturgeon (*Acipenser persicus*).

Reproductive and Caviar-Related Genetic Markers: The reproductive physiology of sturgeon species is controlled by the expression of zona pellucida (ZP) genes, which are essential for ovarian follicle development and egg formation. These genetic factors are crucial for caviar production, making them a primary focus in both aquaculture and genetic conservation efforts.

Disease Resistance and Immunogenetics: The immune response in Caspian Sea fish is largely mediated by genes within the major histocompatibility complex

(MHC), which encode proteins responsible for antigen presentation and immune recognition. Variability in MHC alleles has been linked to pathogen resistance, a critical factor for population sustainability and the viability of aquaculture.

Mitochondrial DNA and Conservation Genetics: Mitochondrial DNA (mtDNA) and microsatellite markers are widely used in genetic studies to assess the population structure, phylogenetic relationships, and genetic diversity of Caspian fish species. These molecular markers are vital for identifying genetic bottlenecks, hybridization events, and evolutionary paths, providing valuable insights for developing effective conservation strategies.

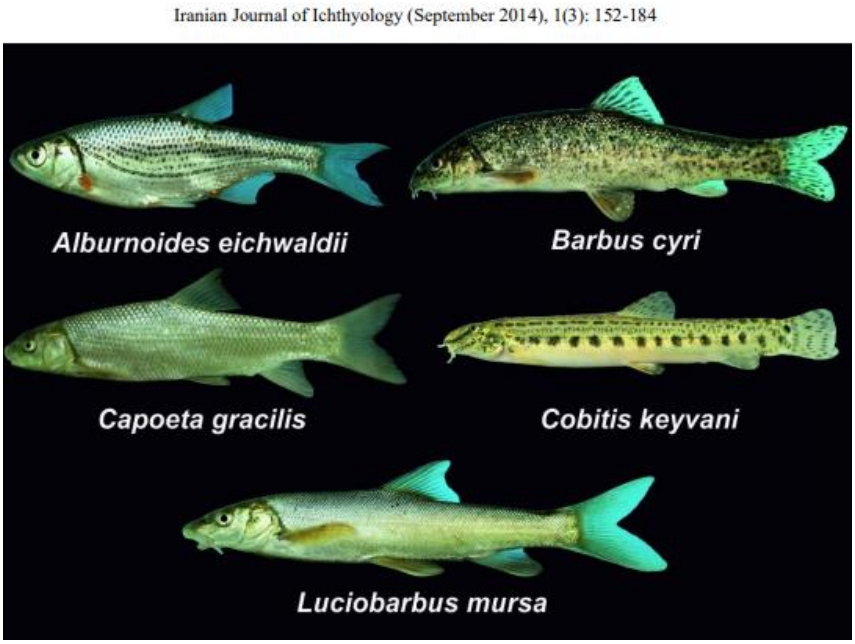
Biodiversity in fish species

Genetic research in marine biology is essential for understanding population dynamics, species adaptation, and developing effective conservation strategies. Modern genetic studies provide valuable insights into species differentiation, evolutionary history, and genetic diversity, which are crucial for managing fisheries and protecting endangered species. By analyzing DNA sequences, scientists can trace gene flow, detect hybridization, and evaluate the genetic health of populations.

Mitochondrial gene analysis involves studying the DNA in mitochondria, which is maternally inherited and used in genetic research due to its small size and high mutation rate. Mitochondrial DNA, particularly genes like 12S and 16S rRNA, is valuable for determining species' genetic relationships, evolutionary history, and species identification. These genes evolve faster than nuclear DNA, making them effective for differentiating closely related species and analyzing phylogenetic patterns. Mitochondrial DNA 16S rRNA gene analysis is a direct approach for differentiating marine animals, plants, and bacteria. mtDNA 12S and 16S rRNA genes have been widely used as molecular markers for categorizing mammals, birds, shrimp, and other species These genes show high variability compared to other markers, as the region is highly conserved Greig et al. (2005) used mtDNA 12S and 16S rRNA markers in North Atlantic Ocean sharks and found less sequence variability within species compared to between species, suggesting these markers are suitable for species identification. Due to the conserved nature of mitochondrial ribosomal genes, they are significant as genetic markers for closely related species. Therefore, the genetic relationships of selected marine fish species were studied and characterized using partial sequences of mtDNA 12S and 16S rRNA genes [8].

In the Caspian Sea**,** genetic research holds particular significance due to the sea's semi-enclosed and isolated nature, which limits genetic exchange with other marine systems. The use of molecular markers, mitochondrial DNA (mtDNA) analysis, and next-generation sequencing (NGS) has enabled researchers to study fish populations with greater accuracy, uncovering genetic bottlenecks caused by overfishing and habitat fragmentation (Esmaeili et al., 2014). Moreover, genetic research helps distinguish endemic species from invasive ones, providing critical information for fisheries management and conservation policy development [2].

The fish fauna of the Southern Caspian Sea Basin (SCSB) has been studied for over 200 years, yet new species continue to be discovered and renamed. This updated checklist, based on historical records and recent collections, lists 119 species across 63 genera, 18 families, and 16 orders. Of these, 19 species are exotic, belonging to seven families. The number of species surpasses previous checklists from 1988 (74 species, 42 genera) and 2010 (116 species, 61 genera). Fish taxa were categorized into four main groups, based on origin, ecoregion, and ecological factors such as saltwater tolerance and lifestyle. Two new species have been described since 2010, and some species' taxonomic statuses have been revised, with subspecies elevated to full species status. The region's high ichthyodiversity results from its ancient Paratethys origin, the closing of the Tethys Sea, glacial refugia, historical connections to fresh and marine waters, diverse species sources, varying latitudinal extent, and a mix of habitats, including fresh and brackish environments [3].



The Caspian Sea harbors one of the most genetically diverse fish populations globally. This diversity is attributed to its complex geological history, fluctuations in salinity, and varied ecological niches [12]. Major species, such as sturgeons (*Acipenser gueldenstaedtii*, *Acipenser stellatus*), herrings (Clupeidae), gobies (Gobiidae), and cyprinids (Cyprinidae), display distinct genetic lineages, reflecting their adaptation to diverse environmental conditions [1].

Historical events**,** such as glaciations, sea level changes, and tectonic shifts, have had a profound impact on the genetic diversity of Caspian fish species. These events have led to periods of isolation and reconnection of fish populations, resulting in the development of unique genetic adaptations [4]. Furthermore, the introduction of exotic species has influenced the genetic makeup, occasionally leading to hybridization and competition with native species.

Despite this genetic richness, many fish populations in the Caspian Sea have suffered significant genetic erosion due to human activities. Habitat fragmentation, overfishing, and pollution have led to a reduction in genetic variability, making species more susceptible to diseases and environmental changes [12]. Understanding these genetic patterns is critical for developing effective conservation and restoration programs.

The genetic diversity of Caspian fish species is under significant threat from anthropogenic factors. Overfishing, particularly of sturgeons for caviar, has sharply reduced wild populations, raising concerns about genetic bottlenecks and inbreeding [4]. Many species are now classified as endangered or critically endangered, with some populations nearing extinction.

Another major threat is pollution**,** primarily from oil extraction, industrial waste, and agricultural runoff. The Caspian Sea, surrounded by oil-rich nations, has been subjected to hydrocarbon pollution, which has been linked to genetic mutations and reproductive failures in fish populations [1]. Additionally, plastic pollution and heavy metal contamination contribute to genetic damage and reduced survival rates.

Climate change is further reshaping the genetic landscape of Caspian fish populations. Increasing temperatures, fluctuating water levels, and changes in salinity affect reproduction and migration patterns of fish species [12]. These environmental stressors, combined with habitat

destruction, are accelerating the loss of genetic diversity, emphasizing the urgency of conservation efforts.

Despite significant progress in genetic research, many knowledge gaps remain concerning the genetic structure and adaptive mechanisms of Caspian fish species. While some studies have focused on phylogenetic relationships and population genetics, there is limited research on how genetic diversity impacts species resilience to environmental changes [4].

Furthermore, most genetic studies have focused on commercially valuable species like sturgeons, leaving many smaller, ecologically important fish species understudied [1]. Further research is required to understand the effects of invasive species on native fish genetics and how conservation strategies can be optimized using genomic data.

The primary objective of this study is to assess the genetic diversity of key fish species in the Caspian Sea, identify genetic markers of conservation concern, and propose management strategies based on genetic findings. By filling these research gaps, this study aims to contribute to sustainable fisheries, biodiversity conservation, and ecosystem resilience in the Caspian region [4].

Conclusion:

The genetic study of Caspian Sea fish species provides significant insights into their adaptation, evolution, and conservation. Understanding their genetic structure helps in the management of fish populations, particularly for commercially valuable species like sturgeons, which are threatened by overfishing and habitat degradation. Genetic research continues to play a crucial role in ensuring the sustainability of these unique aquatic species in the Caspian ecosystem [13].

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