Regional Studies in Marine Science
Volume 80, 30 December 2024, 103888

Determination of body length regression formulas for the golden grey mullet (*Chelon auratus*, Risso 1810) based on otoliths found in the feces of the Caspian Seal (*Pusa caspica* Gmelin, 1788)

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https://doi.org/10.1016/j.rsma.2024.103888

Abstract

The Caspian Seal (*Pusa caspica*), the sole marine mammal endemic to the Caspian Sea, is listed in the IUCN Red List as a species facing the threat of extinction, a status similarly recognized and/or assigned in all countries in the Caspian region. The study of seal nutrition using caprological methods is of great interest for understanding animal adaptation to deteriorating habitat conditions and assessing the adequacy of their food base in the sea. This method involves analyzing the contents of feces from ichthyophages to detect undigested fish otoliths. The results of studying the seal's diet during periods of haulout on breeding grounds showed that the frequency of occurrence of *Chelon auratus* otoliths ranged from 2% to 3–27.7% of all fish otoliths detected in feces. This study aims

to assess changes in *Chelon auratus* otoliths as they pass through seals' gastrointestinal tracts and estimate formulas for recovering the linear dimensions of fish consumed by these seals. The research indicates that otolith growth slows with fish growth but does not cease entirely. Allometry is evident in the different ratios of otolith length and width to fish length in various size groups and the change in otolith shape as fish grow. To recover the body length of fish consumed by seals based on otoliths found in their feces, applying inverse calculation formulas obtained when studying the relationship between otolith growth and fish body growth using collection material obtained directly from fish is possible. Further research should focus on refining the recovery formula for the length of large fish by dividing the length into several segments, each described by separate formulas describing the relationship between fish body length and otolith length and width growth.

Introduction

The Caspian seal (*Pusa caspica*) is the only mammal endemic to the Caspian Sea. It is listed on the IUCN Red List as an endangered species (Goodman and Dmitrieva, 2016). It is included in the List of Rare and Endangered Species of Kazakhstan. The species has a similar status in other Caspian countries (Rustamov et al., 2021; Eybatov and Hajiyev, 2022).

Firstly, overfishing has had a negative impact on the seal population, as well as several other factors: marine pollution, accumulation of toxins in the animals' bodies leading to decreased immunity and increased infertility in females, development of epidemics, increased navigation in areas where island and ice haulouts form, and bycatch in fishing nets (Baimukanov, 2019).

The reduction of river inflows, the drop in the Caspian Sea level, and intensive fishing have led to a decline in fish stocks that seals feed on (Rumyantsev et al., 1975). Introducing the invasive comb jelly species (*Mnemiopsis leidyi*) into the sea also negatively affected the seals' food base (Zaitsev et al., 2003). It has been noted that due to the decline in the number of sprat (*Clupeonella*), seals have primarily started feeding on goby fish (*Gobiidae*), which increases the risk of toxic substance accumulation in their bodies (Zakharova, 2003).

Currently, the ecological situation in the Caspian Sea is unstable and alarming due to the continuing increase in anthropogenic impact, sea regression, and reduction of ice cover in the Northern Caspian (Bukharitsin, 2006, Chen et al., 2017), which collectively create unfavorable living conditions for seals (Baimukanov, 2022).

Since feeding is one of the essential life functions of an organism, studying the dietary spectrum of seals and conducting a comparative analysis with retrospective data (Badamshin, 1948, Badamshin, 1966, Badamshin, 1971, Vorozhtsov et al., 1972, Rumyantsev et al., 1975, Krylov, 1984, Oleynikov, 2015) is of great interest for understanding the adaptation of animals to deteriorating living conditions and assessing the adequacy of their food base in the sea.

Previous studies on the diet of Caspian seals were based on the slaughter of animals, which is currently unacceptable due to the species' "Red List" status. However, there are coprological methods based on the analysis of fecal contents of ichthyophagous animals to detect indigestible fish otoliths (Härkönen, 1986, Pierce et al., 1991; Svetocheva and Eriksen, 2013). It is known that otoliths are represented by three pairs - asteriscus, lapillus, and sagitta. In most fish, the sagitta is the largest otolith, so it is most often used to identify the species of consumed fish (Härkönen, 1986, Popper et al., 2005, Tuset et al., 2006, Svetocheva et al., 2007, Bani et al., 2013).

It is important to note that no specific otolith identification guide exists for Caspian Sea fish. Given that fish otoliths exhibit species and population-specific characteristics (Khrustalyova & Pavlov, 2000; Svetocheva and Stasenkova, 2006; Svetochova and Eriksen, 2013; Pavlov, 2016; Pavlov and Shirokova, 2020), it is crucial first to create a catalog of otoliths extracted from known fish species inhabiting the Caspian Sea and described using standardized methodologies. This work has begun, and methodologies for the collection, processing, and species identification of otoliths from several fish species that are prey for Caspian seals during haulout periods in the Kazakh part of the sea from 2015 to 2023 have been developed (Baimukanov et al., 2022a). However, during this work, it also became necessary to study the changes that otoliths undergo as they pass through the animal's gastrointestinal tract.

The haulout sites of the Caspian Seal are currently primarily located in the Kazakh sea

sector along the northeastern coast. Until 2018, seals also hauled out at the only haulout site in the Middle Caspian, in the Kendirli Bay (Baimukanov et al., 2020, Baimukanov et al., 2022b). Studies on the feeding habits of seals during haulout periods showed that the frequency of occurrence of golden grey mullet (*Chelon auratus*) otoliths ranges from 2 % to 3–27.7 % of all fish otoliths found in feces.

Mullet was introduced to the Caspian Sea from the Black Sea between 1930 and 1934, successfully naturalized, and began to be commercially exploited from 1940 onwards (Tereshchenko, 1950, Holcík, 1991). The golden grey mullet utilizes the entire Caspian Sea for feeding grounds and is found year-round in the southern part of the sea. In March, it migrates from the south to the north, with a return migration to the south in autumn (Mirzoyan et al., 2018). In the Kazakh sea sector, commercial stocks of golden grey mullet are actively exploited, mainly in areas adjacent to the Tupkaragan Peninsula.

This work aims to initiate a series of articles dedicated to studying the diet of the Caspian seal at the present stage and the role of various fish species in this marine mammal's diet.

This study aims to evaluate the changes in golden grey mullet otoliths as they pass through the seal's gastrointestinal tract and to determine the formulas for restoring the linear dimensions of fish consumed by seals of this species.

The objectives of the study are:

1. To study the variability of otoliths extracted from fish with known linear parameters and to determine the dependence of otolith growth on fish growth.
2. To study the changes in otoliths as they pass through the gastrointestinal tract of the Caspian seal.
3. To determine formulas for restoring the body length of fish consumed by seals based on otoliths found in their feces.

Section snippets

Materials and methods

A bioanalysis of 63 mullet specimens caught at the Kendirli, Prorva, Zuyd-Westovye Shalygi, and Novye Durneva Islands sites in the Caspian Sea (Fig. 1) was conducted to describe the morphological diversity and size variability of fish otoliths.

Fish species identification was performed using the "Guide to Fish and Invertebrates of the Caspian Sea" (Bohutska et al., 2013) and other sources (Fishbase, Thomson, 1986). Measurements of 10 fish parameters were conducted according to standard methods (…

Results

The sample of fish from which otoliths were extracted was divided into two cohorts based on fish length: small (34.1–61.4/44.81 mm) and large (178–415/344.8 mm). All small fish were juveniles less than one-year-old, while the large fish were mature individuals aged 4–12.

Otoliths extracted from the fish collection were accordingly divided into small and large. Notably, otoliths from fecal samples also fell into these two cohorts (Table 2), with the difference between mean values being highly …

Discussion

The work has made it possible to determine the linear dimensions of consumed mullets by seals, one of the Caspian Sea's most important commercial fish species (Ivanov et al., 2023). For this purpose, the largest otoliths (sagittae), located in special capsules in the fish's inner ear, were used. Sagittae is used for species identification of food items of pinnipeds (Rae, 1972, Härkönen, 1986), and there are many studies on the otolith morphology for various fish species, including fish of the …

Conclusion

The studies indicate that the continuous growth of *Chelon auratus* otoliths is associated with the growth of fish bodies. However, as fish grow, the growth rate of otoliths slows down but does not cease within the range of the considered fish lengths. Allometry is manifested in the different ratios of otolith length and width to fish length in various size groups of fish and in the change of otolith shape as the fish grow.

We recommended using regression formulas to estimate the body length of …

Ethical Approval

The study did not involve human or animal subjects. …

Funding

This research has been funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. AP14871482). …

CRediT authorship contribution statement

Anuar Shagilbayev: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Akzhan Iskakov:** Writing – review & editing, Methodology, Investigation, Formal analysis. **Mirgaly Baimukanov:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation. …

Declaration of Generative AI and AI-assisted technologies in the writing process

While preparing this work, the authors used Grammarly to improve language translation, overall clarity, and readability. After using this tool/service, the authors reviewed and

edited the content as needed and took full responsibility for the publication's content. ...

Declaration of Competing Interest

The authors declare that they have no known competing financial or ethical interests or personal relationships that could have appeared to influence the work reported in this paper. ...

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