Article

Spatial variation in the frequency of left-sided morph in European flounder *Platichthys flesus* (Linnaeus, 1758) from the marginal Arctic (the White Sea)

Peter N.Yershov 1\*, Gennadiy V.Fuks 2 and Vadim M.Khaitov 3, 4

|  |
| --- |
| **Citation:** Yershov P.N.; Fuks G.V.; Khaitov V.M. Title. *Diversity* **2022**, *14*, x. https://doi.org/10.3390/xxxxx  Academic Editor: Firstname Lastname  Received: date  Accepted: date  Published: date  **Publisher’s Note:** MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.    **Copyright:** © 2022 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/). |

1 Zoological Institute of the Russian Academy of Sciences, Universitetskaya nab. 1, 199034 Saint Petersburg, Russia; *e-mail: [peter.yershov@zin.ru](mailto:peter.yershov@zin.ru); [peteryershov@yandex.ru](mailto:peteryershov@yandex.ru)*

2 North branch of “VNIRO” (“Severnyy”), Uritskogo st. 17, 163002 Arkhangelsk, Russia; *[fuks@severniro.ru](mailto:fuks@severniro.ru)*

3 Department of Invertebrate Zoology, Saint-Petersburg State University, Universitetskaya nab. 7/9, 199034 Saint *Petersburg, Russia; e-mail: [polydora@rambler.ru](mailto:polydora@rambler.ru)*

4 Kandalaksha State Nature Reserve, Lineynaya 35, Kandalaksha, 184042 Murmansk Region, Russia

**\*** Correspondence: peter.yershov@zin.ru; peteryershov@yandex.ru

**Abstract:** The European flounder, *Platichthys flesus*, is a polymorphic flatfish exhibiting large population variation in proportion of left-sided and right-sided morphs across its range. Detailed studies of flounder populations within its geographic range can provide valuable information for analyzing spatial patterns of frequencies of the two morphs. We have examined the frequencies of left-sided individuals of flounder in the White Sea (Kandalaksha, Onega, Dvina, and Mezen bays), the region in the northeastern part of species’ range adjacent to the Arctic. The proportion of the two morphs in the populations of the White Sea flounders demonstrated high variability and specific regional characteristics. The highest frequency of left-sided individuals was observed in the northwestern (Kandalaksha Bay) and southwestern (Onega Bay) parts of the White Sea. Flounders living in the eastern part of the White Sea (Dvina and Mezen bays) showed much lower frequency of this trait. No consistent pattern of geographic variation in proportion of the morphs was observed across flounder’s geographic range. The lowest frequencies of left-sided individuals were recorded in the flounder populations living at the eastern and western margins of geographic range. Geographic variation in proportion of left-sided individuals in flounder populations is likely to be determined by a set of biotic and abiotic factors. Selective influence of the later acting through trophic relationships of this species with other hydrobionts can differ in different parts of flounder’s geographic range.

**Keywords:** asymmetry;geographical variation;morph proportions; Pleuronectidae; lateral polymorphism; White Sea

1. Introduction

The European flounder *Platichthys flesus* (Linnaeus, 1758) (Pleuronectidae) is a marine and brackish species distributed across a wide geographic area that ranges from the western part of the Mediterranean, through the Atlantic coast of Europe, around the British isles and Ireland, across the North, Baltic, Barents and White seas and eastward to the southwestern part of Novaya Zemlya archipelago and Kara Bay of the Kara Sea [**1**, **2**, **3**, **4**]. Individuals of this species can be either left-sided or right-sided depending on the side of the body on which the eyes lie at the early developmental stages following the metamorphosis. In the left-sided (reversed) flounders, both eyes are on the left side of the body, while in the right-sided individuals they lie on the right side. Both morphs are present in populations of this species in varying proportions (7, 9, 10, 12). Crossbreeding studies conducted on the starry flounder *P. stellatus* (Pallas, 1787)*,* a polymorphic congeneric species of *P. flesus*, have shown that body asymmetry direction is under moderate genetic control [**5**, **6**].

The studies of lateral polymorphism in the populations of the European flounder are still rather scarce and the majority of information on the frequency of morphs was obtained from the flounders caught in the Baltic Sea off the coasts of Sweden, Germany and Estonia (**7**, **8**, **9**, **10**]. Fornbacke *et al*. [**10**] have reported a clinal change in proportion of left-sided individuals in flounder catches along the coast of Sweden, but the results of other authors on Baltic and North Sea flounders have shown a very high variation in proportion of morphs in different populations (**7**, **9**, **11**, **12**, *etc.*). In the White Sea, the relative frequency of reversed individuals was measured for some most numerous flounder populations from Kandalaksha (Velikaya Salma Strait), Onega, Dvina and Mezen bays [**13**, **14**, **15**, **16**]. However, for the White Sea flounders our knowledge of regional variation in this trait remains incomplete because of the paucity of information on the flounder populations inhabiting the western part of the sea and because of the lack of statistical estimation of the observed variation in this trait among the samples studied by different authors. Besides that, the study of phenotypic diversity of flounder inhabiting the edge of north-eastern part of the range, on the boundary of Arctic, is of particular interest from the point of view of adaptive role of the lateral polymorphism of *P.flesus* in extreme habitats. No analysis has yet been conducted to date of the geographic patterns of variation in frequency of lateral morphs in *P.flesus* populations across the species range. Such data are necessary to study various mechanisms of maintaining lateral polymorphism in this species. Yershov et al. (2022) have shown that a significant effect on frequency of reversed individuals in flounder from the White Sea was determined by the location of the population (factor “Bay”), while other possible factors (length, age and sex) did not influence the ratio of morphs. Besides that, no statistically significant and consistent changes in interannual variation in proportion of left-sided individuals were found in flounder populations from the Onega, Dvina and Mezen bays (Fuks et al. 2021). All these findings allow us to conduct comparative studies of morph proportions in flounder populations on the base of recent and published data.

The primary goals of the present study were: 1) to analyse spatial variation in proportion of the two morphs in flounders from different bays of the White Sea; and 2) to evaluate large-scale geographic variation in proportion of left- and right-sided morphs in flounder populations across the geographic range of the species.

2. Materials and Methods

Specimens of *Platichthys flesus* for this study were collected in different bays of the White Sea during regular expeditions made by the Polar branch of the VNIRO and the Zoological Institute of the Russian Academy of Sciences (May-August 2014-2021). In Kandalaksha Bay, fish were caught in the Chupa Inlet, totaling 584 individuals (**Figure 1**). In Onega Bay, flounders were collected in two locations - at the head of the bay near Kiy island, situated in the mouth of Onega river (n=1186), and in the mouth of Nyukhcha river (n=1144). In Dvina and Mezen bays, fish were caught in the estuarine zones of Northern Dvina (n=2613) and Mezen rivers (n=905). For the generalized comparative analysis, the material collected during the present study was supplemented by data on previous catches made in 2001-2013 in Onega, Dvina and Mezen bays (collections of G.Fuks and other staff of the SevPINRO, Arkhangelsk; [**16**]). Flounders were collected in rivers and coastal waters at different depths using variable mesh gillnets (mesh size of 30-50 mm) and traps.

The number of left- and right-sided individuals was counted in all samples. . Comparison between proportions of morphs for flounders caught at different collection points was performed using χ2 test [**17**]. Bonferroni's correction was applied to adjust the significance level for multiple comparisons [**17**]. Because the males and females showed no difference in frequency of morphs [**16**, **18**], the comparison of samples was performed without differentiating for sex.

We conducted systematical search of published data for analysis of geographical variation in morph proportions in flounder *P.flesus*. In order to reveal the geographical range of the species, we used data from The Global Biodiversity Information Facility (GBIF.org (28 September 2022) GBIF Occurrence Download <https://doi.org/10.15468/dl.qe7bf3>). We obtained coordinates of 5992 unique points of flounder occurrence in European part of range. Using these data the geometric center of the range was calculated as a point with geographical coordinates equal to mean latitude and longitude. This point has the coordinates 54.29339N, 8.772293E. We estimated the distance from each point where frequency of left-sided morph was assessed to geometrical center of the flounder’s range. To analyse the pattern of geographic distribution we constructed two regression models in which the dependent variable was the proportion of left-sided morphs (the value was assumed to follow the beta distribution). The distance from the geometrical center of the European part of the species’ range was used as the first predictor in both models. Longitude was considered as the second predictor, additionally describing the geographic position. Latitude was not included in the models, because it demonstrated collinearity with the other predictors.

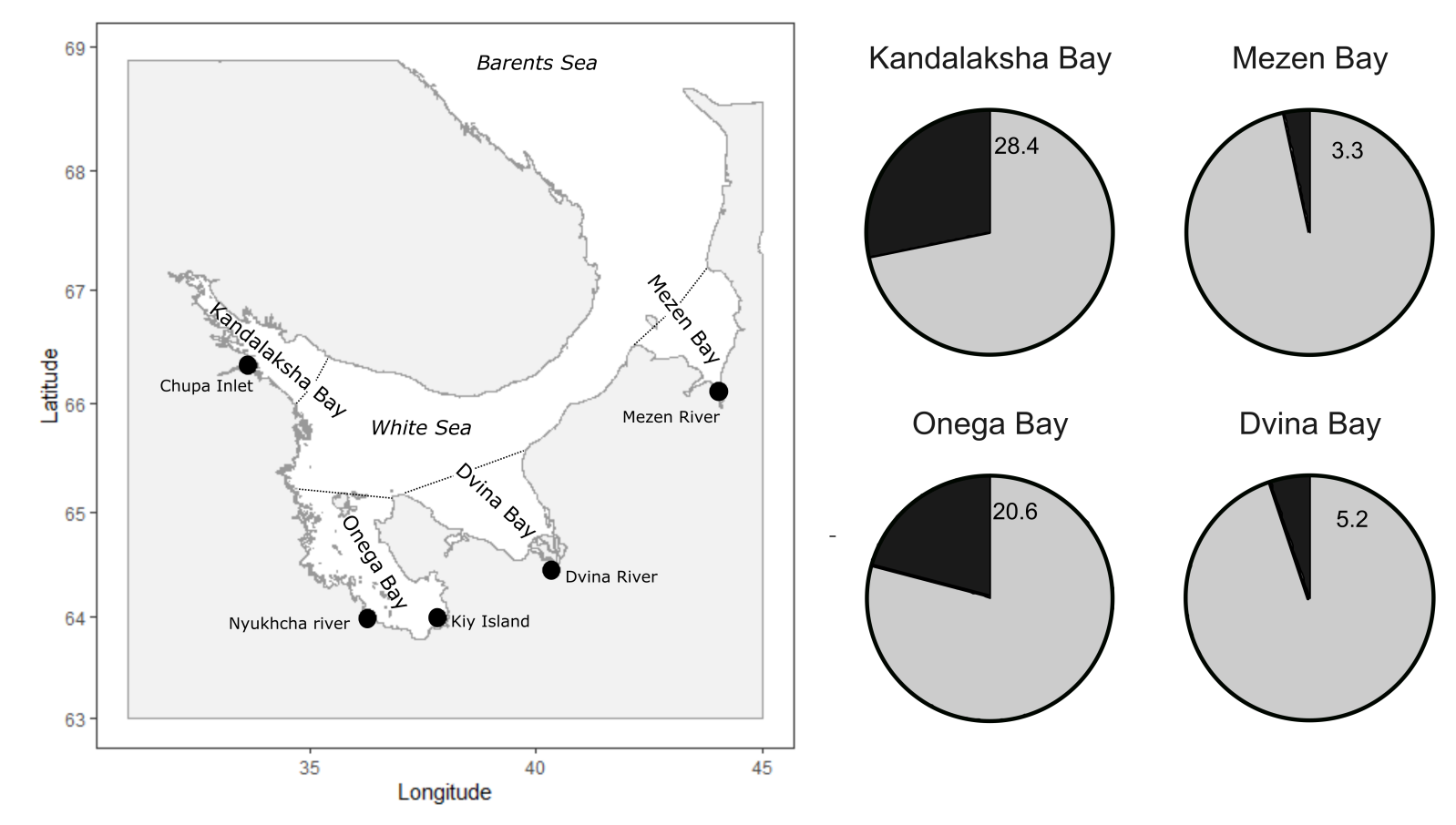
The first model was built for the material collected in European part of the flounder range (points 14 - 39, Table 1), and the second one for the group of points located in the Arctic region (points 1 - 13, Table 1). We did not combine both data sets (European and Arctic) into one model, as this would lead to the appearance of collinearity between the predictors.

Pairwise comparisons of the ratios of left- and right-sided morphs at different collection points were performed using the chi-square test. For multiple comparisons, a Bonferroni correction was introduced to correct the level of null hypothesis rejection.

Statistical processing was performed using the functions of the statistical programming language R (R Core Team, 2021). We used the “betareg” package (Cribari-Neto, Zeileis, 2010) to fit the regression model. To check collinearity of predictors in the models the variance inflation factor was estimated using functions from “car” package (Fox, Weisberg, 2019). No collinearity was detected in final versions of the models. Analsys of residuals did not reveal violations of linear models’ assumptions for both models.

3. Results

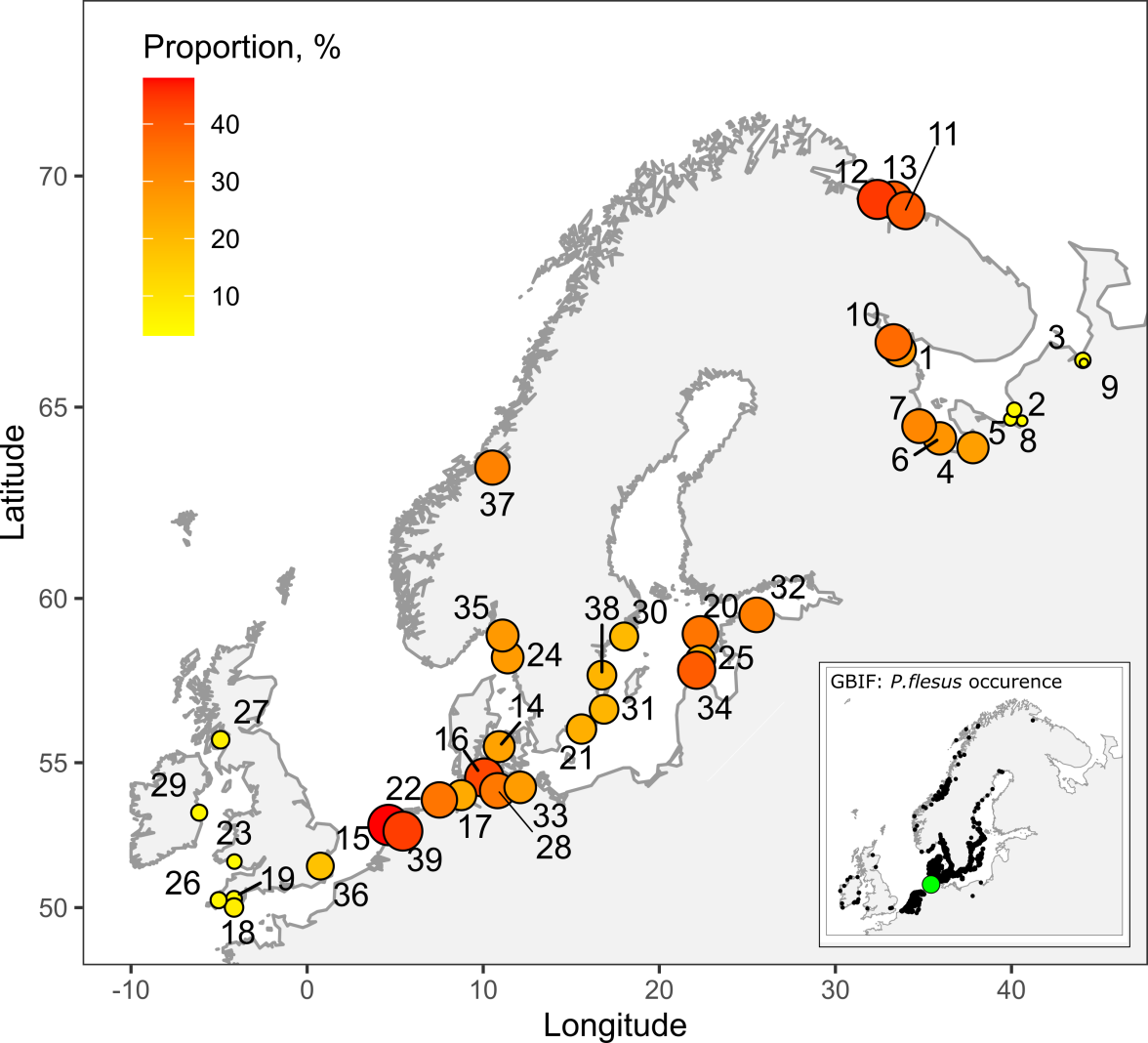
The proportion of left-sided individuals in flounder samples from different bays of the White Sea ranged from 3.3% to 28.4% (**Figure 1**). The highest frequencies of left-sided flounders were recorded in a population from Kandalaksha Bay (Chupa Inlet). The frequencies of reversed individuals in the samples taken from two different places in southern part of Onega Bay varied from 19.8% (Nyukhcha river area) to 20.9 % (Kiy island area) and had equal values (χ2, *р*>0.05). For further analysis, the data on flounder catches from these locations in Onega Bay were pooled into a single dataset. The comparison of populations from the northwestern (Chupa Inlet, Kandalaksha Bay) and southwestern (Nyukhcha river, Kiy island area; Onega Bay) parts of the White Sea revealed the difference in morph proportions between these two regions (28.4% and 20.6%, respectively; χ2=18.72, *р*<0.01). The frequencies of reversed individuals in the populations from the eastern part of the White Sea (Mezen and Dvina bays) were much lower and ranged from 3.3% to 5.2% (**Figure 1**). Differences between populations from these bays were statistically significant (χ2=11.89, *р*<0.01). Left-sided individuals were least frequent in the population from Mezen Bay.



**Figure 1.** Map showing the sampling areas in the White Sea. Frequency of left-sided *Platichthysflesus* (%, black sectors) morph from the four bays of the White Sea.



**Figure 2** shows the frequencies of reversed individuals in the populations of the European flounder from the White Sea and other parts of its geographic distribution. At first, consider the variability of this parameter in flounder from the White Sea. In Kandalaksha Bay, flounders from Chupa Inlet differed significantly from those of the Velikaya Salma Strait (χ2=12.18, *р*<0.01; **Table 1**, # 1, 2). Flounders from two close locations at the western coast of Onega Bay – Kuz Inlet and Kolezhma river (**Table 1**, # 32, 33) were similar in frequency of left-sided morph to one another and also to the flounders from Chupa Inlet (χ2, *р*>0.05). Besides, frequencies of left-sided individuals in samples from Kuz Inlet and Kolezhma river were significantly higher than in samples taken in the southern part of the same bay - Nyukhcha river and Kiy island area (χ2=22.02, *р*<0.01; **Table 1**, # 3). The gradual decline in the frequency of left-sided flounder was observed from the head of Kandalaksha Bay towards the head of Onega Bay (Table 2; #...). Proportion of non-typical morph in the populations from the eastern part of the White Sea (Dvina and Mezen bays) was 4-5 times lower as compared to the flounder from the head of Onega Bay. Our results on flounders from Dvina and Mezen bays were not significantly different from published data on frequency of reversed individuals in these populations (χ2, *р*>0.05; **Table 1**, # 4, 5, 24, 34, 35).



**Figure 2.** Geographical variation in the proportions of left-sided *Platichthys flesus* morph across its range (dotted line). The size of the circles corresponds to the proportion of left-sided individuals in a sample. Data sources are given in Table 2. The small map in the inset shows flounder occurrence according to GBIF/ The green dot marks the geometric center of the European part of the species’ range.**Table 1.** Proportions of left-sided *Platichthys flesus* morph in various populations based on thepublished and original data

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **No** | **Locality** | **Sample size** | **Left, %** | **Source of data** |
| 1 | Chupa Inlet, Kandalaksha Bay, White Sea, Russia | 584 | 28,4 | Present study |
| 2 | Velikaya Salma Strait, Kandalaksha Bay, White Sea, Russia | 957 | 37,1 | [**14**, **15**] |
| 3 | Nyukhcha river and Kiy island area, Onega Bay, White Sea, Russia | 4527 | 20,6 | Present study |
| 4 | Mezen river, Mezen Bay, White Sea, Russia | 2272 | 3,3 | Present study |
| 5 | Delta of the Northern Dvina river, Dvina Bay, White Sea, Russia | 5007 | 5,2 | Present study |
| 6 | Eckernforde Bay; Laboe (Kiel), Baltic Sea, Germany | 3331 | 42,7 | [**8**] |
| 7 | Neustadt Bay, Baltic Sea, Germany | 90 | 34,4 | [**7**] |
| 8 | Zuiderzee, North Sea, Netherlands | 50 | 44 | [**11**] |
| 9 | Den Helder, North Sea, Netherlands | 75 | 48 | [**11**] |
| 10 | Rostock, Baltic Sea, Germany | 15 | 26,7 | [**42**] |
| 11 | Loughor estuary, South Wales, UK | 64 | 4,7 | [**12**] |
| 12 | Sorve peninsula, Saaremaa, Baltic Sea, Estonia | 200 | 39,5 | [**9**] |
| 13 | Mandjala, Saaremaa, Baltic Sea, Estonia | 200 | 22,5 | [**9**] |
| 14 | Murman coast, Barents Sea, Russia | 475 | 44,5 | [**43**] |
| 15 | North Bull Island, Dublin Bay, Irish Sea | 590 | 5,6 | [**34**] |
| 16 | Murman coast, Barents Sea, Russia | no data | 39,6 | [**44**] |
| 17 | English Channel, Plymouth, UK | 1120 | 5,4 | [**7**] |
| 18 | Elbe river mouth, North Sea, Germany | 225 | 23,6 | [**7**] |
| 19 | Mevagissey harbour, UK | 192 | 5,7 | [**7**] |
| 20 | Langeoog, Wadden Sea, North Sea, Germany | 26 | 35 | [**45**] |
| 21 | Murman coast, Barents Sea, Russia | 25 | 40 | [**45**] |
| 22 | English Channel, Plymouth, UK | 40 | 7,5 | [**12**] |
| 23 | Thames estuary, London, UK | 50 | 18 | [**12**] |
| 24 | Mezen Bay, White Sea, Russia | 1367 | 3,1 | [**16**] |
| 25 | Danish Belt Sea | 49 | 25,4 | [**12**] |
| 26 | Stromstad, Skagerrak, Sweden | 455 | 27,5 | [**10**] |
| 27 | Lysekil, Skagerrak, Sweden | 653 | 27 | [**10**] |
| 28 | Karlskrona, Baltic Sea, Sweden | 631 | 22,4 | [**10**] |
| 29 | Oland, Baltic Sea, Sweden | 1673 | 21,1 | [**10**] |
| 30 | Vastervik, Baltic Sea, Sweden | 193 | 21,2 | **[10]** |
| 31 | Nynashamn, Baltic Sea, Sweden | 186 | 20,1 | [**10**] |
| 32 | Kuz Inlet, Onega Bay, White Sea, Russia | 187 | 31,3 | [**13**] |
| 33 | Kolezhma river, Onega Bay, White Sea, Russia | 358 | 28,5 | [**9**] |
| 34 | Delta of the Northern Dvina river, White Sea, Russia | 897 | 4 | [**15**] |
| 35 | Delta of the Northern Dvina river, White Sea, Russia | 2394 | 4,7 | [**16**] |
| 36 | Trondheimsfjord, Norway | 269 | 32,3 | [**46**] |
| 37 | Millport, Cumbrae, Scottish coast, UK | no data | 6,7 | [**47**] |
| 38 | Pudisoo, Baltic Sea, Estonia | 1271 | 33,1 | [**9**] |
| 39 | Hiiumaa, Baltic Sea, Estonia | 800 | 35 | [**9**] |

The analysis of the published data on frequency of reversed individuals from flounder’s geographic range has shown that all the studied populations were polymorphic and the frequency of left-sided individuals was not higher than 50% (**Table 1**). No apparent geographic trend was found for the changes in proportion of left-sided individuals in flounder populations (**Figure 2**). The highest frequency of left-sided individuals was found for the samples from the Murman coast of the Barents Sea (44.5%; **Table1**, # 14); coastal waters of Netherlands (48%; #....); the southwestern (42.7%; German coast, Kiel, Eckernforde; # 6) and eastern (39.5%; Estonian coast; # 12) parts of the Baltic Sea. In addition to the flounder populations from Dvina and Mezen bays of the White Sea, the lowest frequencies of this trait (4.7-7.5%) were also observed in some areas of the coastal waters of Great Britain and Ireland (**Table 1**; # 4, 5, 11, 15, 17, 19, 22, 37). It worth noting that these locations are situated in marginal (eastern and western) parts of the range of *P.flesus*. Parameters of the regression model describing the association of the frequency of left-sided morph in European populations with distance from geometric center of European part of the species’ range and with geographic longitude are shown in Table 2. For European populations of flounder (**Table 1**; . N 14-39), a statistically significant relationship was shown between the frequency of left-sided morph with both the distance and the longitude. The negative coefficient (**Table 2**) indicates a decrease in the frequency of reversed fish with increase of distance from the center of the species’ range. This decrease is well traceable when moving from the center of the European part of the range towards the British islands and Ireland. The positive coefficient for geographic longitude (Table 2) indicates an increase in the frequency of left-sided morph when moving from west to east. For Arctic flounder populations (Table 3, N 1-13), a statistically significant relationship of the dependent variable was shown only with geographic longitude. The negative coefficient (Table 3) indicates a decrease in the frequency of left-sided flounder in the direction from west to east.

Table 2. Parameters of beta-regression model describing the association of the frequency of left-sided morphs in European populations with distance from geometric center of European part of the species’ range and with geographic longitude.

| **Term** | **Parameter** | **SE** | **z-value** | **p.value** |
| --- | --- | --- | --- | --- |
| (Intercept) | -1.043 | 0.1957 | -5.33 | <0.0001 |
| Distance | -0.001 | 0.0003 | -3.86 | <0.0001 |
| Longitude | 0.049 | 0.0109 | 4.55 | <0.0001 |
| Precision coefficient (phi) | 25.049 | 6.8835 | 3.64 | <0.0001 |

Table 3. Parameters of beta-regression model describing the association of the frequency of left-sided morphs in Arctic populations with distance from geometric center of European part of the species’ range and with geographic longitude.

| **Term** | **Parameter** | **SE** | **z-value** | **p.value** |
| --- | --- | --- | --- | --- |
| (Intercept) | 9.166 | 1.7262 | 5.31 | <0.0001 |
| Distance | -0.00003 | 0.0009 | -0.03 | 0.975 |
| Longitude | -0.286 | 0.0348 | -8.22 | <0.0001 |
| Precision coefficient (phi) | 54.5867 | 21.4711 | 2.54 | 0.01101 |

4. Discussion

Previously it was shown that the morph proportions in flounder populations depended on sample location, but not on the size-age and sexual composition of samples (Yershov 2022). Obtained results demonstrated that the frequency of left-sided flounder differed significantly among four bays of the White Sea. In addition, the comparison between the results of the present study and previously published data (Shatunovsky, 1964; Dietrich, 2009; Nikolaev…, Mikelsaar …Semushin) has revealed differences in proportion of left-sided individuals in flounders living in various parts of Kandalaksha and Onega bays. This gives evidence that local populations of flounder exist in these two bays. To our opinion, the spatial isolation and morpho-ecological differentiation of flounders in Kandalaksha and Onega bays of the White Sea is determined to a significant extent by geomorphological and hydrological characteristics of these region (numerous inlets, rivers with estuarine zones, local cyclonic currents etc.) which provide variety of habitats for fish and restrict gene flow between populations around the coast.

Semushin *et al*. (2015) have reported that the proportion of left-sided individuals in the flounder populations inhabiting the White Sea region decreases from west to east. Additional data provided by the present study have shown that the left-sided individuals are most common in the northwestern part of the White Sea (Velikaya Salma, Kandalaksha Bay). In Chupa Inlet located more to the south along the Karelian coast of Kandalaksha Bay and in Onega Bay (western part, Kuz Inlet and the Kolezhma river) the proportion of left-sided fish in the populations is somewhat lower. Even lower occurrence of left-sided individuals was noted in the southern part of Onega Bay (Nyukhcha river and Kiy island area). A significant decrease in proportion of left-sided flounders is observed in Dvina Bay, and the lowest proportion of reversed individuals occurs in Mezen Bay. Given the quantitative characteristics of this trait, it can be concluded that the frequency of left-sided individuals is much higher in the flounder populations from Kandalaksha and Onega bays than in those from Dvina and Mezen bays. It is noteworthy that changes in frequency between these two groups of populations occur abruptly rather than in a gradual fashion. It should be also noted that along the coast of the White Sea between estuaries of the large rivers Northern Dvina, Onega and Mezen the flounder is not numerous and is encountered in small numbers mostly on shoals near estuaries of small rivers.

The total variability of left-sided morph proportion in flounder populations from marginal Arctic fluctuated from 3.3 % to 44.5% and was comparable with such variability in the European part of the range (/////////). The analysis of regression models, built for the north-eastern (Arctic) and European parts of flounder range, revealed the significant decrease of non-typical *P.flesus* proportion in populations, inhabiting marginal (western and eastern) locations of the range.

No consistent large-scale geographic trend has been observed for variation in this trait among the studied populations from the coastal waters of Europe (North and Baltic seas). However, Fornbacke *et al*. (2002) found another pattern of geographic variation in proportion of non-typical morph for the flounders living in Swedish coastal waters. The frequency of left-sided flounders in the six samples studied decreased gradually from the western coast of Sweden (27.5%), across its southeastern part (22.4%) and then in the northern direction (20.1%). The authors concluded that variation in this trait showed a biogeographic cline along the coast of Sweden. In our opinion, however, this statement calls for further research, because of the uneven sampling across the study area. For instance, this study lacks any data for the coastal waters of the vast part southern coast of Sweden. Numerous data on variation in frequency of reversed individuals in catches from the eastern part of the Baltic Sea (Estonian coast) has been provided by Mikelsaar (1958). The author has not revealed any consistent pattern of variation in this trait for flounder caught in different parts of the study area.

Possible causes producing interpopulation variation in proportion of morphs of the European flounder remain little explored. Fornbacke *et al.* (2002) have suggested that variation in frequency of left-sided individuals in the samples of flounders along the coast of Sweden is associated with interspecific interactions of young individuals of this species with those of the European plaice *Pleuronectes platessa* Linnaeus, 1758. These authors have argued that food competition of plaice fry on nursery grounds of the Skagerrak Strait is more intense with the right-sided individuals of flounder than with the left-sided individuals. This results in increased survival of the left-sided individuals on the west coast of Sweden, where the numbers of plaice fry in shallow water are high. The authors regarded a larger body size of left-sided fry compared to the right-sided individuals as indirect evidence of the advantage that the left-sided individuals have in using food resources. However, the results of the present study and previously published data suggest that variation in proportion of morphs in some other parts of flounder’s geographic range cannot be explained by the possible influence of competition with the European plaice. The average frequency of reversed individuals in flounders inhabiting the eastern part of the Baltic Sea (Estonian coast), where the plaice is rare (Mikelsaar, 1958; Ojaveer *et al*., 2003), is much higher than in flounders from the western coastline of Sweden, where the plaice is abundant in shallow water. In the White Sea, the highest frequency of left-sided flounders was recorded in Kandalaksha and Onega bays, where the plaices are only sporadically caught by fishing gears and their numbers are extremely low (Nikolaev, 1951; Mukhomedyarov, 1963; our observations). It is clear that increased survival of left-sided flounders in these parts of the geographic range is caused by some other factors. As regards the differences in size of fry between left- and right-sided individuals (Fornbacke *et al*., 2002), they can, in our opinion, be associated not only with differences in their growth rates as a result of the interspecific competition with plaice fry, but also with different hatching times due to a more extended spawning season in flounder. The spawning period of flounder normally lasts about 1 month and its duration varies in different parts of the Baltic Sea (Berg, 1949; Florin, 2005; Nissling, Dahlman, 2010; Ojaveer *et al.,* 2003).

In different parts of flounder’s geographic range, the interspecific competition resulting in preferential selection of morphs can also be associated with fish species other than plaice. In the shallow coastal waters of the White Sea, the flounder is known to cohabit with other benthophagous species: the Arctic flounder *Liopsetta glacialis* (Pallas, 1776) and the dab *Limanda limanda* (Linnaeus, 1758) (Altukhov *et al*., 1958; White Sea, 1995). Shatunovsky & Chestnova (1970) have shown that in the inlets of Kandalaksha Bay, where the Arctic flounder is relatively abundant, the young European flounder (*TL*<20 cm) compete with this species for food, and the food spectra of fishes of the two species can overlap by 60-70%. However, the information about possible differences in composition of food consumed by different morphs of the European flounder compared to the Arctic flounder is still lacking. Further studies of dietary habits and behavior in shared nursery areas are needed to evaluate the possible influence of competition with the plaice and other species of flatfish on survival of morphs of the European flounder during their first years (0+ and 1+) of life.

Another factor that is likely to influence spatial variation in flounder polymorphism is ecological selection between morphs in individual populations. Russo *et al*. (2012), for example, have revealed intrapopulation differences in food spectra between left- and right-sided individuals of flounders in Dublin Bay (Ireland). The morphs also showed some morphological differences in relative sizes of the premaxillare, the length of the tail peduncle and the position of eyes, i.e. the characters that play a role in targeting and capturing prey items. The authors have argued that the frequency of morphs can be dependent to a certain extent on characteristics of benthic food resources and the accessibility of certain food organisms, because the left- and right-sided individuals showed preference toward different dietary objects. It remains to be determined to what extent these differences in the composition of prey organisms are important for survival, growth, and fecundity of fish and whether there are ecological differences between two morphs in various regions of flounder geographic range. It should be noted that morphological differences in feeding habits, behavior and swimming have previously been found between the morphs of the starry flounder *P. stellatus* (Pallas, 1787), which suggested the existence of trophic specialization in the right- and left-sided individuals (Bengstrom, 2007; Bengstrom, Palmer, 2007; Bergstrom *et al.,* 2019).

Fornbacke *et al*. (2002) have noted that variation in proportion of left-sided adult flounders along the coast of Sweden correlates with the salinity gradient of the coastal waters. Over the last two decades, the basin of the Baltic Sea experienced major ecological changes due to eutrophication, intensive fishing, global climate change and other factors (Elmgren, 2001; Korpinen *et al.*, 2012; Olsson *et al.,* 2012). Negative trends in ecological health result in degradation of habitats of many fish species including the European flounder. In the early 2000s, a dramatic fall in numbers and biomass of the European flounder was observed in the northern part of the Baltic Sea (Jokinen et al., 2015). It is clear that in this situation the similarity in trends observed for changes in biological traits of fish and certain hydrological data do not necessarily imply any consistent relationship between these factors in the study area and the observed correlations should be treated with caution. Experimental studies are required to confirm the presumed relationship and determine the direction of natural selection. In our opinion, variations in water temperature and salinity can undoubtedly influence mortality of flounder in coastal waters, but the main influence of these factors is indirect, i.e. through qualitative changes in those environmental conditions that play a role in successful fish spawning, feeding and growth.

In conclusion, the analysis of lateral polymorphism across the geographic range of European flounder has demonstrated a high population variation in proportion of reversed individuals. *P.flesus* did not exhibit large-scale geographic trends in the proportions of left-sided morphs. Judging from the available information, however, the reversed individuals are least frequent in the populations living on the western (Great Britain, Ireland) and north-eastern, close to the Arctic region (Dvina and Mezen bays, White Sea, Russia) margins of species’ geographic range. It should be stressed that populations of *P. flesus* living in the White Sea and other parts of its geographic range are likely to be affected by factors of natural selection specific for each area that influence the proportion of left- and right-sided fish. Future studies should therefore be aimed at the analysis of adaptive strategy and ecological segregation of flounder morphs as a result of dynamic relationships with the environment and competitive biotic interactions with other fish species in different parts of flounder’s geographic range.

**Author Contributions:** All authors contributed towards conceptualization, methodology, analysis, investigation; P.Y. and G.F. have made substantial contributions to acquisition of data and conception; V.K. have been involved in analysis and interpretation of data; P.Y. wrote wrote the original draft of the work. All authors read, revised critically and

approved the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Data Availability Statement:** Data can be supplied by the corresponding author upon reasonable request.

**Acknowledgments:** We are grateful to the staff of the Coastal Research Laboratory of the Polar branch of FSBI “VNIRO” and White Sea Biological Station Kartesh of the Zoological Institute RAS for their help in collecting data during

expeditions. This work was carried out as part of the State Task of the Zoological Institute RAS (state registration

number no. 122031100283-9).

**Conflicts of Interest:** The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

1. Berg, L.S.*Freshwater fishes of the USSR and adjacent countries*; Nauka: Moscow-Leningrad, USSR, 1949.

[In Russian].

1. Andriashev, A.P.*Fishes of the northern seas of the USSR*; Izdatelstvo Akademii Nauk SSSR: Moscow-Leningrad, USSR, 1954. [In Russian].
2. Mecklenburg C.W.; Lynghammar, A.; Johannesen, E.; Byrkjedal, I.; Christiansen, J.S.; Dolgov, A.V.; Karamushko, O.V.; Mecklenburg, T.A.; Møller, P.R.; Steinke, D.; Wienerroither, R.M. *Marine fishes of the Arctic*

*Region*; Akureyri: Conservation of Arctic Flora and Fauna, Iceland, 2018.

1. Fuks, G.V.; Goncharov Yu.V.First capture of European flounder *Platichthys flesus* (Pleuronectidae) in the southwestern part of the Kara Sea. *Journal of Ichthyology* **2021,** *61*, 310-313. <https://doi.org/10.1134/S0032945221010070>

5. Policansky, D.The asymmetry of flounders. Scientific American **1982**,*246*, 116–122

<https://doi.org/10.1038/scientificamerican0582-116>

1. Boklage, C.E. On the inheritance of directional asymmetry (sidedness) in the starry flounder, *Platichthys*

*stellatus*: Additional analyses of Policansky’s data. *Behavioral and Brain Sciences* **1984**, *7*,725–730. <https://doi.org/10.1017/S0140525X00028326>

1. Duncker, G.Variation und Asymmetrie bei Pleuronectes flesus L. *Wissenschaftliche*

*Meereuntersuchungen* **1900**, *3*, 333-406.

1. Apstein, C.Junge Butt (Schollen, Pleuronectes platessa) in der Ostsee. *Wissenschaftliche*

*Meereuntersuchungen* **1905**,*8*,1-26.

1. Mikelsaar, N.Method of equalized scales. In *Hydrobiological investigations, Issue 1*; Izdatelstvo Akademii Nauk ESSR: Tartu, USSR, 1958; pp. 286-312. [In Russian].
2. Fornbacke, M.; Gombrii, M.; Lundberg, A.Sidedness frequencies in the flounder *Platichthys flesus*

(Pleuronectiformes) along a biogeographical cline. *Sarsia* **2002**, *87*, 392–395.

1. Redeke, H.C.Ueber den gegenwartigen Stand unserer Kenntnis von den Rassen der wichtigsten Nutzfische. Die Lokalformen der Pleuronektiden (Scholle und Flunder). *Rapports Proces-Verbaux des reunions Conseil*

*International pour l’exploration de la Mer* **1915**,*22*.

1. Galleguillos, R.A.; Ward, R.D.Genetic and morphological divergence between populations of the flatfish

*Platichthys flesus* (L.) (Pleuronectidae). *Biological Journal of the Linnean Society* **1982**, *17*, 395-408.

1. Nikolaev, A.P.Materials on the biology of European flounder of the Kuz Inlet of the White Sea. *Izvestiya*

*Karelо-Finskogo Filiala Akademii Nauk SSSR* **1949**, *4*,43-51. [In Russian].

1. Shatunovsky, M.I. Materials on systematics of European flounder *Pleuronectes flesus* L. from the White Sea. *Vestnik of the Moscow State University* **1964**, *1*, 32-38. [In Russian].
2. Dietrich, R.Populationsökologie der Plattfische (Familie Pleuronectidae) im Küsten- und Ästuarbereich des Weißen Meeres. Dissertation, University of Rostock, Germany, **2009**.
3. Semushin, A.V.; Fuks, G.V.; Shilova, N.A.Flatfishes of the White Sea: New data on the biology of the Arctic flounder *Liopsetta glacialis*, European flounder *Platichthys flesus*, and common dab *Limanda limanda*. *Journal of Ichthyology* **2015**, *55*, 527-539. <https://doi.org/10.1134/S0032945215030121>
4. Quinn, G.P.; Keough, M.J.*Experimental design and data analysis for biologists*; Cambridge university press: Сambridge, UK, 2002.
5. Yershov, P.N.; Fuks, G.V.; Khaitov, V.M.Frequencies of lateral morphs in different age classes of the flounder *Platichthys flesus* (Linnaeus, 1758) from the White Sea. *Proceedings of the Zoological Institute RAS* **2022**, *326*,*in press.*
6. Yershov, P.N.; Matvienko, А.А.Some features of biology and morphology of European flounder from the Chupa Inlet (Kandalaksha Bay, White Sea). In: *Biological Problems of the North.* The Materials of International Scientific Conference; Magadan, Russia, 2018; pp. 413-416 [In Russian].
7. Filatov, N.N.; Terzhevik, A.Yu. *The White Sea and their watershed under influences of climate and anthropogenic impact*; Karelian Research Center RAS: Petrozavodsk, Russia, 2007 [In Russian].
8. Altukhov, К. А. Reproduction of flatfishes of the family Pleuronectidae in the White Sea. *Journal of Ichthyology* **1980**, *20*, 285–296. [In Russian].
9. Parukhina, L.V.Ichthyoplankton of Onega Bay in 2002-2003 and 2006. In: *Problems of investigation, rational use and protection of the White Sea natural resources.* The Materials of the X International conference; Izdatelstvo SMGU: Arkhangelsk, Russia, 2007; pp. 190-195. [In Russian].
10. Parukhina, L.V.Eggs and larvae of fishes in the northern part of Onega Bay of the White Sea. In: *Problems of biodiversity maintenance in the water bodies*. The Materials of International scientific conference; AzNIIRKH:

Rostov-on-Don, Russia, 2015; pp.255-258. [In Russian].

1. Mishin, A.V.; Evseenko, S.A.; Bol’shakov, D.V.; Bol’shakova, Y.Y.Summer ichthyoplankton in Onega Bay of the White Sea: species composition and spatial distribution. *Journal of Ichthyology* **2018**, *58*,181-186.

<https://doi.org/10.1134/S003294521802008X>

1. Fuks, G.V.; Yershov, P.N.; Khaitov, V.M.Long-term dynamics of the proportion of left-sided individuals in the populations of the European flounder *Platichthys flesus* (Linnaeus, 1758) in the White Sea. *Proceedings of the*

*Zoological Institute RAS* **2021***, 325*,273-277. [https://doi.org/10.31610/trudyzin/2021.325.3.273](https://doi.org/10.31610/trudyzin/2021.325.3.273" \t "_blank)

1. Ojaveer, E.; Drevs, T. Flounder, *Platichthys flesus trachurus* (Duncker). In: *Fishes of Estonia*; Ojaveer, E., Pihu, E., Saat, T.E., Eds.; Estonian Academy Publishers: Tallinn, Estonia, 2003; pp. 362-370.
2. Nikolaev, A.P.Fish species of Pomor and Karelia Coasts of the White Sea. *Izvestiya Karelо-Finskogo Filiala*

*Akademii Na*uk SSSR **1951**, *3*, 93-99. [In Russian].

1. Mukhomediyarov, F.B.Biology and fishery of the noncommercial fishes in the coastal waters of the Karelia. In *Papers on the comprehensive studies of the White Sea*; Palenichko, Z.G., Ed.; Izdatelstvo Akademii Naus SSSR: Мoscow-Leningrad, USSR, 1963; pp. 131–143. [In Russian].
2. Florin, A.B.Flatfishes in the Baltic Sea – a review of biology and fishery with a focus on Swedish

conditions. *Finfo* **2005**,*14*, 1-56.

1. Nissling, A.; Dahlman, G.Fecundity of flounder, *Pleuronectes flesus*, in the Baltic Sea — Reproductive

strategies in two sympatric populations. *Journal of Sea Research* **2010**, *64*, 190–198. [https://doi.org/10.1016/j.seares.2010.02.001](https://doi.org/10.1016/j.seares.2010.02.001" \t "_blank" \o "Persistent link using digital object identifier)

1. Altukhov, К.А.; Мikhailovskaya А.А.; Mukhomediyarov, F.B.; Nadezhin, V.M.; Novikov, P.I.; Palenichko, Z.G. *Fishes of the White Sea*; Godarstvennoe izdatelstvo Karelskoy ASSR: Petrozavodsk, USSR, 1958.

[In Russian].

1. *White Sea. Biological resources and problems of their rational exploitations*; Scarlato, O.A., Ed.; Izdatelstvo ZIN RAS: Saint-Petersburg, Russia, 1995. [In Russian].
2. Shatunovsky, M.I.; Chestnova, L.G. Some biological characteristics of the flounder from the Kandalaksha Bay in the White Sea. *Reports of the White Sea biological station of the Moscow State University* **1970**, *3*, 166-188.

[In Russian].

1. Russo, T.; Pulcini, D.; Costantini, D.; Pedreschi, D.; Palamara, E.; Boglione, C.; Cataudella, S.; Scardi, M.;

Mariani, S. “Right” or “wrong”? Insights into the ecology of sidedness in European flounder, *Platichthys flesus*. *Journal of Morphology* **2012**, *273*, 337–346. <https://doi.org/10.1002/jmor.11027>

1. Bergstrom, C.A.Morphological evidence of correlational selection and ecological segregation between dextral and sinistral forms in a polymorphic flatfish, *Platichthys stellatus*. *Journal of Evolutionary Biology* **2007**, *20*,1104–1114. <https://doi.org/10.1111/j.1420-9101.2006.01290>
2. Bergstrom, C.A.; Palmer, A.R.Which way to turn? Effect of direction of body asymmetry on turning and prey strike orientation in starry flounder *Platichthys stellatus* (Pallas) (Pleuronectidae). *Journal of Fish Biology* **2007**, *71*,737–748. <https://doi.org/10.1111/j.1095-8649.2007.01531.x>
3. Bergstrom, C. A.; Alba, J.; Pacheco, J.; Fritz, T.; Tamone, S.L.Polymorphism and multiple correlated

characters: Do flatfish asymmetry morphs also differ in swimming performance and metabolic rate? *Ecology and Evolution* **2019**, *9*, 4772–4782. <https://doi.org/10.1002/ece3.5080>

1. Elmgren, R.Understanding human impact on the Baltic ecosystem: changing views in recent decades. *Ambio* **2001**,*30*, 222–231.
2. Korpinen, S.; Meski, L.; Andersen, J.H.; Laamanen, M.Human pressures and their potential impact on the Baltic Sea ecosystem.*Ecological Indicators* **2012**, *15*, 105–114.

<http://doi.org/10.1016/j.ecolind.2011.09.023>

1. Olsson, J.; Bergstrom, L.; Gardmark, A.Abiotic drivers of coastal fish community change during four decades in the Baltic Sea. *ICES Journal of Marine Science* **2012**, *69*, 961–970. <https://doi.org/10.1093/icesjms/fss072>
2. Jokinen, H.; Wennhage, H.; Lappalainen, A.; Ådjers, K.; Rask, M.; Norkko, A.Decline of flounder (*Platichthys flesus* (L.)) at the margin of the species' distribution range. *Journal of Sea Research* **2015,** *105*, 1-9. <http://dx.doi.org/10.1016/j.seares.2015.08.001>
3. Momigliano, P.; Denys, G.P.J.; Jokinen, H.; Merilä, J.*Platichthys solemdali* sp. nov. (Actinopterygii,

Pleuronectiformes): a new flounder species from the Baltic Sea. *Frontiers in Marine Science* **2018**, *5*, 1-21. <https://doi.org/10.3389/fmars.2018.00225>

1. Sych, N.S.*Pleuronectes flesus* of the Barents and White Seas. *Trudy Gosudarstvennogo Nauchno-Issledovatelskogo Instituta Rybnogo Khozyaistva* **1930**, *5*,89-116. [In Russian].
2. Suvorov, E.K.Biology of Murmansk *Pleuronectes flesus*. *Trudy Instituta Izuchenia Severa* **1927**, *38,* 56-63.

[In Russian].

1. Voronina, E.P.Morphology and systematics of river flounders of the genus Platichthys. *Journal of Ichthyology* **1999**, *39*, 588-599.
2. Nordgaard, O.Contributions to the life history of the fishes in Trondhjem fjord and environs. *Det Kongelige Norske Videnskabers Selskabs Skrifter* **1915**, *9*,1- 38.
3. Elmhirst, R.On some ambicoloured flatfish from the Clyde. *The Annals of Scottish Natural History* **1911**,*78*, 77-79.
4. Cribari-Neto, F.; Zeileis, A. Beta Regression in R. Journal of Statistical Software **2010**, 34(2), 1-24. doi: 10.18637/jss.v034.i02 (URL: <https://doi.org/10.18637/jss.v034.i02>).
5. R Core Team). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL <https://www.R-project.org/>.
6. Fox J., Weisberg S. (2019). An R Companion to Applied Regression, Third Edition. Thousand Oaks CA: Sage. URL: <https://socialsciences.mcmaster.ca/jfox/Books/Companion/>