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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

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ABSTRACT

Interannual variation in proportion of left-sided individuals has been studied in the populations of the European flounder from Onega (2002–2019), Mezen (2010–2016), and Dvina (2005–2019) bays of the White Sea. It was found that the flounder populations show no statistically significant and consistent changes in this character. The frequency of left-sided individuals in the local populations and the character of interpopulation differences in different years of the observation period remain relatively constant. The comparison of the results of this study with those of earlier studies reveals a similarity in proportions of left-sided fish over the past 40–60 years in flounder populations of the Kandalaksha Bay and Onega Bay. These results highlight the importance of the proportion of left-sided morphs for the analysis of population differentiation of the European flounder in the White Sea.

Key words: flounder, left-sided morph, long-term population dynamics, White Sea

Многолетняя динамика доли левосторонних особей в популяциях речной камбалы *Platichthys flesus* (Linnaeus, 1758) Белого моря

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РЕЗЮМЕ

Исследована межгодовая изменчивость доли левосторонних рыб в популяциях речной камбалы из Онежского (2002–2019 гг.), Мезенского (2010–2016 гг.) и Двинского (2005–2019 гг.) заливов Белого моря. Показано, что статистически достоверные закономерные изменения признака в популяциях отсутствуют. Частота встречаемости левосторонних особей в локальных популяциях и характер межпопуляционных отличий в разные годы наблюдений остаются относительно постоянными. Сравнение полученных результатов с данными более ранних исследований показало сходство частот встречаемости левосторонних рыб в изученных популяциях речной камбалы из Кандалакшского и Онежского заливов за прошедшие 40–60 лет. Полученные результаты свидетельствуют о важности такого морфологического признака, как пропорции левосторонних морф, для анализа популяционной дифференциации речной камбалы в Белом море.

Ключевые слова: речная камбала, левосторонняя морфа, многолетняя популяционная динамика, Белое море

INTRODUCTION

The European flounder *Platichthys flesus* (Linnaeus, 1758) is a common species of the fish fauna of the White Sea (Altukhov et al. 1958). In the White Sea, this species inhabits shallow shelf waters forming local populations and ecological groupings in different bays (Shatunovsky 1964; Sherstkov 2005; Semushin et al. 2015; Yershov et al. 2019a). Flounder populations living in different bays of the sea differ in growth rates, sexual maturation age, age structure, certain morphological characters, parasite fauna, etc. (Shatunovsky 1964; Shatunovsky and Chestnova 1970; Dietrich 2009; Semushin et al. 2015; Yershov et al. 2019a, 2019b). Literature data indicate that flounders from different bays of the White Sea also show population differences in the proportion of left-sided individuals (Dietrich 2009; Semushin et al. 2015). At the same time, the problem of long-term variation in this character in the local populations of *P. flesus* and the possible influence of this variation on the extent of the observed interpopulation differences remains unresolved. However, the significance of this character for the analysis of the population structure of the European flounder in this geographic region can be better understood if we have a more robust knowledge of the long-term dynamics of this character in individual populations. The aim of this study was to examine interannual and multiyear variation in proportion of left-sided individuals in the flounder populations of Onega, Dvina and Mezen bays of the White Sea.

MATERIALS AND METHODS

Specimens of flounders for the analysis of interannual variation in morph proportions were caught in Onega (2002–2019, n=4716; Nyukhcha River and the head of the bay), Dvina (2005–2019, n=4717; mouth of the Severnaya Dvina) and Mezen (2010–2016, n=2267; mouth of the Mezen River) bays of the White Sea during the regular expeditions made by the Polar Branch of the Russian Federal Research Institute Of Fisheries and Oceanography (VNIRO) (collected by G.V. Fuks and other employees). Since the samples from two localities from the Onega Bay showed no statistically significant differences in the size-age composition and morph proportions, they were pooled together into a single dataset. In all bays, flounders were caught in coastal waters using variable mesh gillnets (mesh size of 30–50 mm) and traps. The number of left- and right-sided individuals was counted in each sample. The sex of flounders was determined visually after their dissection. Since the males and females of the White Sea flounders have previously been shown to have no differences in proportion of the reversed individuals (Semushin et al. 2015), all comparisons between samples were performed on the mixed material. The analysis of multiyear variation in morph proportions for the populations of the White Sea flounders was conducted using both published data (Nikolaev 1949; Mikelsaar 1958; Shatunovsky 1964; Dietrich 2009) and our own observations for Onega Bay. Samples collected in 2006 and 2010 in Onega Bay were excluded from the comparative analysis because of their small size ($n < 44$ specimens).

To test the presence of directional long-term trends in proportion of left-sided individuals, a logistic regression model was constructed; in this model, the probability that an individual belongs to the left-sided morph was considered as dependent variable. The year the fish were caught (continuous variable)

and the bay of the sea (categorical predictor with three levels) were used as predictors for the model. The interaction between predictors was excluded from the model as statistically insignificant following the model selection protocol by Zuur et al. (2009). The model was checked for overdispersion and for the presence of non-linear patterns in the residuals. Calculations were made using functions of the R statistical language (R Core Team 2020).

RESULTS AND DISCUSSION

Interannual dynamics of the frequency of left-sided individuals in Onega, Dvina, and Mezen bays is shown in Fig. 1. This index ranged from 0.13 to 0.26 in Onega Bay (0.21 ± 0.031, multiyear mean value ± standard deviation), from 0.02 to 0.07 in Dvina Bay (0.05 ± 0.013) and from 0.01 to 0.07 in Mezen Bay (0.04 ± 0.018). It can be seen that the regression lines describing the dynamics of this character in the three study bays are oriented almost parallel to the OX axis. The slope coefficient describing the relationship between the frequency of left-sided individuals and the year the fish were caught was not statistically different from zero (p=0.567, Table 1), which indicates that there were no one-directional long-term trends in variation of this character during the study period. In our opinion, insignificant interannual changes in the frequency of left-sided individuals relative to its multiyear average observed for each of the populations studied was associated primarily with variation in sample sizes.

The study of multiyear variation has demonstrated that the proportion of left-sided individuals in the local populations and the character of interpopulation differences remain relatively stable in different years (Fig. 1). For instance, the proportions of reversed flounders in the area of the Velikaya Salma Strait (Kandalaksha Bay) were similar ($\chi 2$=0.44, p>0.05; our calculations) in the samples collected more than 40 years apart (Shatunovsky 1964; Dietrich 2009). Left-sided flounders are now encountered in Onega Bay just as often as over half a century ago (Nikolaev 1949; Mikelsaar 1958; our observations). Somewhat higher values of the character that have been previously published for Onega Bay can be associated with differences in sample composition and size and with different collection methods. It should, however, be noted that these values do not exceed the limits of the interannual variation in proportion of left-sided individuals observed in our material. It is also noteworthy that interpopulation differences in proportion of reversed individuals for flounders caught in Dvina and Mezen bays, on the one side, and for those caught in the Kandalaksha Bay and Onega Bay, on the other hand, have remained almost unchanged throughout a long period of time.

Table 1. Parameters of the model describing long-term changes in proportion of left-sided fish in different population of the White Sea flounders

Model term	Parameter	SE	Z-statistic	p-value
(Intercept)	4.0157	12.1950	0.3293	0.7419
Year	−0.0035	0.0061	−0.5725	0.5670
Bay_{Mezen}	−0.4078	0.1354	−3.0108	0.0026
Bay_{Onega}	1.6371	0.0775	21.1227	0.0000

Interannual variation in morph proportions in the populations of *P. flesus* from different parts of its distribution range has never been studied before. Some data can be found in a study by Mikelsaar (1958) on the European flounders living in the Baltic Sea off the Estonian coast. The results of his study have shown, in particular, that the proportions of left-sided individuals in the near-shore catches from the area of the Pudisoo River in 1942–1946 were similar and varied over a narrow range of 32.2% to 35.5%. It should be noted that a closely related species living in the northern Pacific, the starry flounder *P. stellatus* (Pallas, 1787), also exhibits no interannual variation in proportion of reversed individuals (Forrester 1969; Bergstrom 2007).

Our results showing only insignificant interannual and multiyear variation in morph proportions for the flounders from different bays of the White Sea suggest that the proportion of left-sided individuals is a population characteristic, which, together with other characters, reflects the distinctiveness and the extent of divergence of the local populations in the White Sea. Interpopulation diversity of the European flounder in proportion of phenotypic morphs is, in turn, indicative of the specific nature of local factors and mechanisms that maintain a certain level of this diversity in different bays of the White Sea.

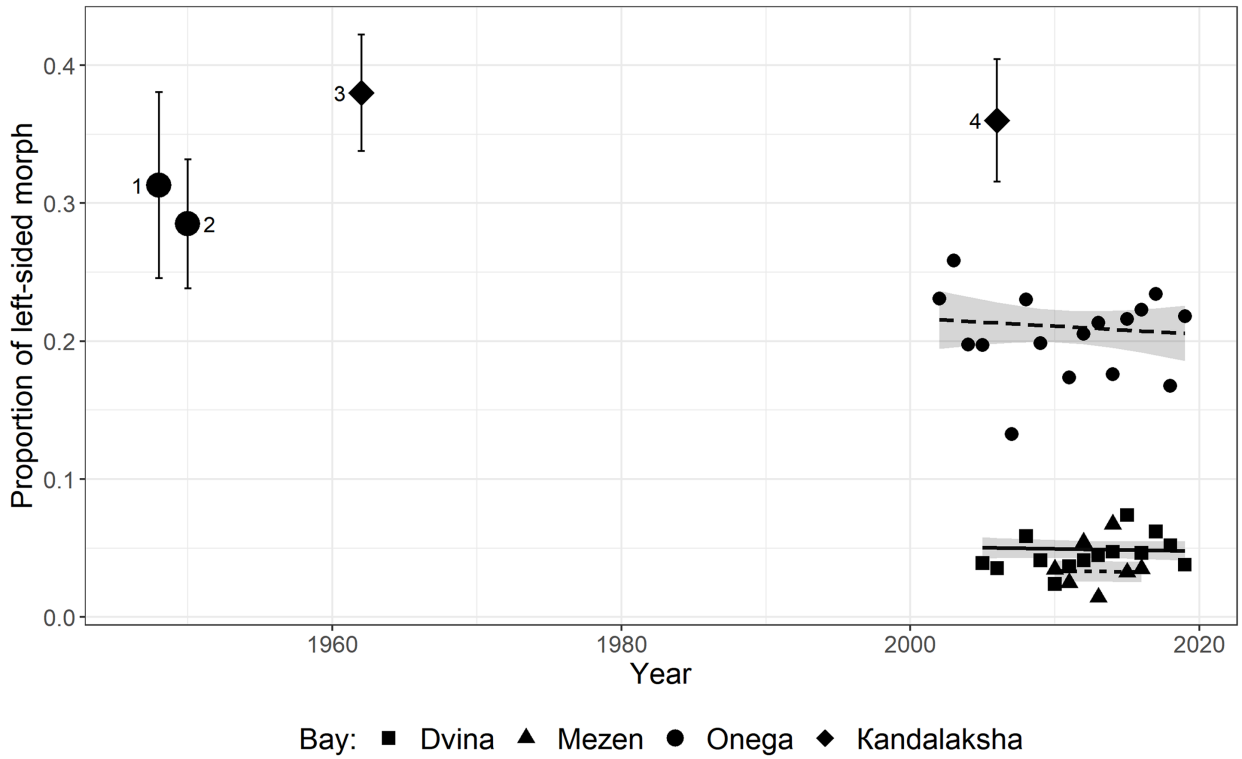

Fig. 1. Long-term variation in proportion of left-sided individuals in the populations of the European flounder from different bays of the White Sea. Different symbols indicate different populations. The gray areas around the regression lines represent 95%-confidence intervals. The error bars show confidence intervals for the proportion of left-sided flounders (derived from the literature data).

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