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Distribution and population characteristics of the invasive tubenose goby *Proterorhinus marmoratus* (Pallas, 1814) in the eastern Gulf of Finland

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ABSTRACT

The article examines the characteristics of the invasive tubenose goby population that has become established in the eastern Gulf of Finland in the last 15 years. The species inhabits the most part of the studied area, and mainly occurs in waters with salinity equal to or lower than 3‰. Abundance of the tubenose goby is positively correlated with the density of filamentous algae, but not with other estimated parameters (substrates, macrophytes, water characteristics). The tubenose goby in the Gulf of Finland reached 62 mm Sl and age 1+. Age composition changed from mature female predominance to the male predominance during the season. Numerous juveniles and spawning adults were observed. The tubenose goby demonstrates successful naturalization in the new conditions and was numerically dominant in the coastal fish assemblage in summer.

Key words: Gulf of Finland, population structure, tubenose goby

Распространение и популяционные характеристики инвазионного бычка-цуцика *Proterorhinus marmoratus* (Pallas, 1814) в восточной части Финского залива

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РЕЗЮМЕ

В статье рассматриваются характеристики инвазионной популяции бычка-цуцика, образовавшейся в восточной части Финского залива за последние 15 лет. Область распространения вида-вселенца охватывает значительную часть исследуемой акватории, вид встречается преимущественно при солености воды до 3‰. Отмечена положительная корреляция между численностью бычка-цуцика и обилием нитчатых водорослей, но не с типом донного субстрата, высшей водной растительностью и гидрологическими характеристиками. Бычок-цуцик в Финском заливе достигал длины 62 мм (Sl) и возраста двухлетки (1+). Соотношение полов менялось в течение сезона с преобладания половозрелых самок до преобладания самцов. Были обнаружены многочисленные сеголетки и нерестовые особи. Для бычка-цуцика подтвердилась успешная натурализация в новых условиях обитания. Отмечено, что вид в летнее время доминировал по численности в рыбном сообществе на мелководных микробиотопах.

Ключевые слова: Финский залив, структура популяции, бычок-цуцик

INTRODUCTION

From the beginning of the 20th century the ecosystem of the eastern Gulf of Finland has been exposed to substantial stress due to invasions of new species (Orlova et al. 2008). Significant changes in the fish fauna have been observed, which warrants a revision of the established fish species lists for the Neva Bay and the eastern Gulf of Finland (Ruzhin 1987; Kuderskiy 1999; Kuderskiy et al. 2007, 2008). Annual coastal fish monitoring (Uspenskiy and Naseka 2014; Uspenskiy, unpublished data) in 2010–2017 made it possible to collect the data on non-native fish species in the eastern Gulf of Finland.

The tubenose goby identified as *Proterorhinus marmoratus* (Pallas, 1814) was first recorded in the Neva estuary in 2006, also several specimens were caught along the northern coast of the Neva Bay (near Olgino and Lachta) in 2007 (Antsulevich 2007). Following the first observation, the researchers proposed a hypothesis of the species introduction into the Neva Bay through the Volga-Baltic Waterway also known as the "Northern invasion corridor" (Antsulevich 2007; Panov et al. 2007). Early juveniles of the tubenose goby may have been transferred in the ballast water of vessels. The goby larvae can rise to mid-water at night, which allows them to be drawn with water into ballast tanks (Vašek et al. 2011; Janác et al. 2013). This is the way, which was proposed earlier for the invasion of the Ponto-Caspian gobies to the North American Great Lakes (Jude at al. 1992; Hayden and Miner 2009). The self-colonization by tubenose goby of the Volga-Baltic Waterway basin above the Rybinsk Reservoir has not been confirmed (Slynko and Tereschenko 2014). Therefore, the transfer of *P. marmoratus* into the Neva River Estuary by vessels seems to be the most probable hypothesis.

The tubenose goby has not been caught presently in other areas of the Baltic Sea. Among the rivers of the Baltic basin, it has occurred in the Vistula and its tributary Western Bug on the Polish territory (Grabowska et al. 2008; Semenchenko et al. 2011). New populations of the tubenose goby have been recorded in Central Europe, namely in the Rhine-Main-Danube canal water system (Von Landwüst 2006; Manné and Poulet 2008; Manné et al. 2013), in the rivers and reservoirs of the Danube basin (Prášek and Jurajda 2005; Harka and Biro 2007; Vašek et al. 2011; Valova et al. 2015; Lojkásek and Lusk 2018), the Dnieper River basin (Pinchuk et al. 1985; Rizevsky et al. 2007; Semenchenko et al. 2011; Didenko 2013), the Don and Volga rivers basin (Boldyrev 2002; Naseka et al. 2005; Slynko 2008), and also in North American Great Lakes (Jude et al. 1992; Kocovsky et al. 2011). All those invasive populations have been found much further to the south than the Gulf of Finland.

Tubenose gobies spread faster than other invasive Ponto-Caspian gobies (Semenchenko et al. 2011) and have good potential to colonize new habitats (Valova et al. 2015). Some invasive populations of the species have reached high abundance (Slynko 2008; Valova et al. 2015) and have been rapidly integrated in the trophic chains (Všetičková et al. 2018). In an ecosystem, *P. marmoratus* generally compete with other invasive gobies and other native species sharing the same ecological niche (Van Kessel et al. 2011; Vašek et al. 2014; Valova et al. 2015; Janác et al. 2016).

The earlier paper on the coastal fish community of the eastern Gulf of Finland (Uspenskiy and Naseka 2014) reported some data on the sites from which the tubenose goby was recorded and its abundance after a few years of the first record. However, many questions about the population structure could not be answered due to the scarcity of the material. The aim of the present study is to investigate the distribution and population features of the invasive tubenose goby in the eastern Gulf of Finland.

MATERIAL AND METHODS

The samples were collected in the Russian part of the Gulf of Finland from 2010 to 2017. Totally 47 coastal stations (166 samples from a depth of 0–1.5 m) were examined in the Neva, Luga and Kopor Bays and in the Vyborg Bay and Gulf of Narva (Fig. 1). The beach-seine of 10 m long, 1.5 m high and with a 3 m cod end was used for sampling. The mesh size was 10 mm in wings, and 4 mm in the cod end, where additional sieve plug with a 0.5 mm mesh was installed. Hauling distance varied from 25 to 90 m depending on the bottom structure and depth; it was measured using a monocular laser distance meter with an accuracy of 1 m. The annual and seasonal sampling replications were made at the stations 10–28, 30–37, 41, 43 and 47. The samples were collected from May to November.

All specimens were fixed with 4% formaldehyde and analyzed in a lab. Standard length (Sl; rounded

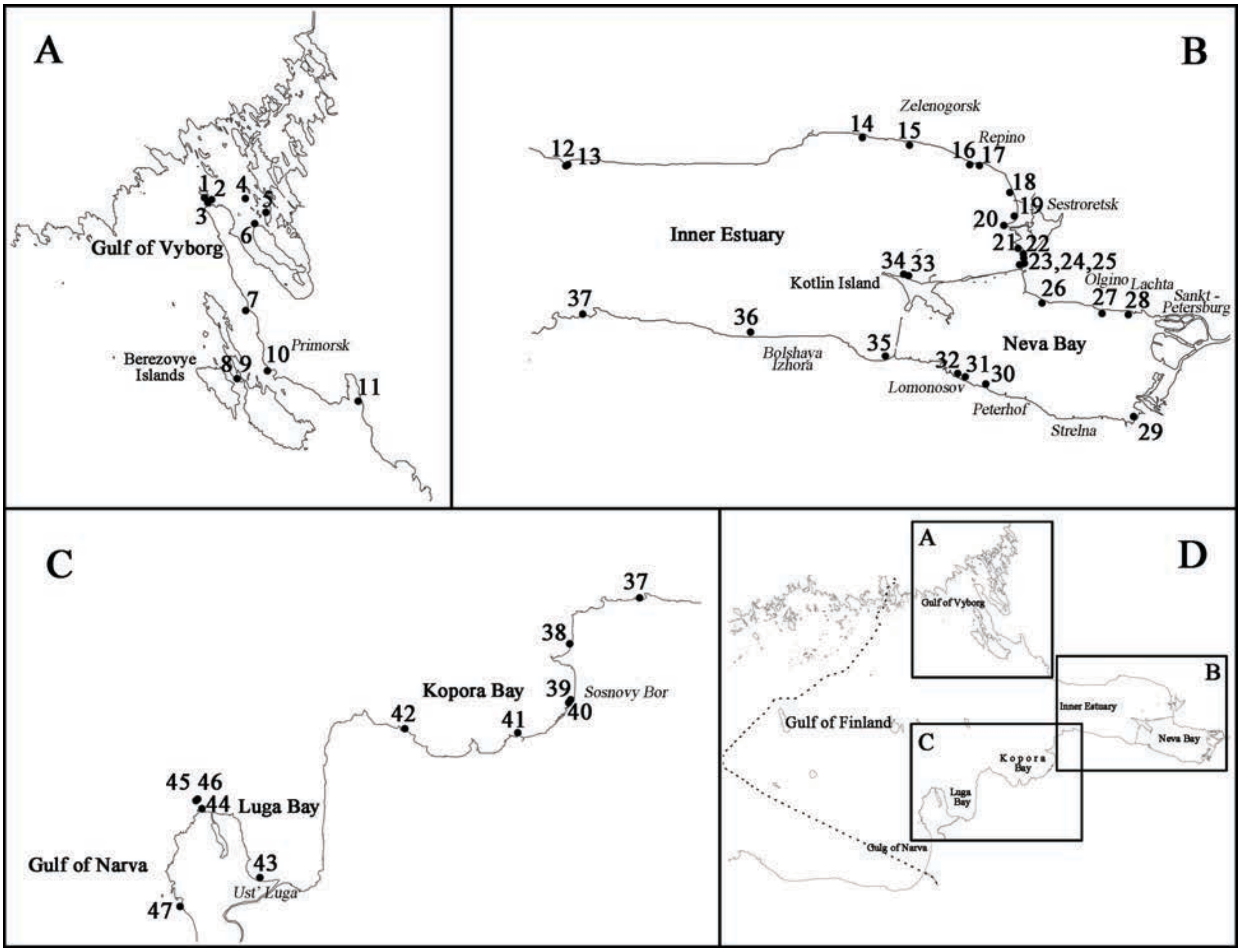

Fig. 1. Stations (black dots) for the coastal fish assemblage study in the eastern Gulf of Finland in 2010–2017.

down to the nearest millimeter) and total weight (Tw; with an accuracy of 0.01 g for specimens Sl ≥ 18 mm and 0.001 g for the smaller ones) of all the specimens in the samples 2011–2017 were measured. All individuals were separated into size groups at intervals of 5 mm for the age and sex structure examination. Sex of all the gobies larger than 16–19 mm was identified according to the urogenital papilla shape, the smaller ones not being differentiated (Kazanova 1951). The gobies whose gonads were either absent or unobservable were regarded as juveniles and those with clearly distinguishable gonads as adults. Whether the females took part in spawning was determined on the basis of the gonad maturation stages IV and V (Koutrakis and Tsikliras 2009) and, in the case of adult males, on the basis of the dark spawning coloration. Age was evaluated for the specimens in the samples 2012–2017. Sagittal otoliths of gobies of Sl 20–63 mm have been extracted before the fixation of samples. The otoliths were cleared with glycerol. Age, sex and gonads maturation were analysed using a stereomicroscope "MBS-10". In the May and June samples, the age of all specimens was estimated. All gobies shorter than 20 mm collected in July and all specimens shorter than 30 mm (after selective age examination) collected in August–September were considered as young-of-the-year. Therefore, in the July and October samples age examination was made for all specimens exceeding 20 mm in length. In the August and September in abundant samples, all specimens, which exceeded 30 mm in length were examined. Samples which had been composed by 42 and 35 individuals of 20–29 mm length were examined in August and September respectively.

For each sample, the density of the tubenose goby was assessed as the number of individuals per 100 m^2, using the formula: D (density) = $N_i / j*L*h$; where N_i is the number of goby specimens; L is the distance of hauling, m; j is the number of sampling replications; h is the beach-seine mouth width while hauling, m. Catching efficiency coefficient was excluded due to the difficulty of its estimation in highly variable coastal habitats and sampling conditions (Rudenko 1969). It has to be mentioned that the collected data were generally intended to be used for comparison of the gobies' habitat preferences rather than to estimate the total population size. Therefore, "density" may be read here as "catch per unit effort" expressed as the effort of beach seine sampling of 100 m^2 of shallows (Žiliukas et al. 2012).

Frequency of occurrence (as percentage) was estimated based on the number of samples where the species was found: $V = a/A*100\%$; where a is the number of samples where the species occurs; A is the total number of samples. A species is considered as the "core of ichtyocoenosis" (or "constant") if V exceeds 50%; "secondary" if it is on a range from 25 to 50%, "rare" if it ranges from 7 to 25% and "occasional" if V is lower than 7% (Ioganzen and Fajzova 1978).

Relative abundance of the tubenose goby in catches (RN, %) was estimated as $RN = N_i/N_{total}*100\%$, where N_i is the number of the tubenose goby specimens in a sample and N_{total} is the total number of fishes in a sample. A species is considered as "super-dominant" when RN is over 50% and "abundant" when RN is over 10% but under 50%. It is "average in number" when RN ranges from 1 to 10%, "few in number" when RN is 0.1–1% and "scarce" when RN is lower than 0.1% (Tereshchenko and Nadirov 1996).

The characteristics of biotopes were measured at the time of sampling. Water temperature and salinity were measured with a *Hanna HI98130 Combo* multimeter. Other parameters were estimated by means of ranging (indexes). Bottom substrate: 1 – sand of different grain-size; 2 – stones prevail; 3 – mixed sand and stone substrate. Silt: 0 – absent; 1 – present but not abundant; 2 – abundant. Macrophytes and filamentous algae were estimated separately. Aquatic vegetation (macrophytes): 0 – absent; 1 – submerged vegetation present; 2 – reeds. Filamentous algae: 0 – absent; 1 – present but not abundant; 2 – abundant growth or mats.

Statistical analysis was conducted in Statistica 10 Portable and PAST Statistics. The association between the densities of the tubenose goby and microhabitat characteristics and water conditions such as surface water temperature, salinity, bottom substrate and vegetation was studied by means of correlation analysis. All samples collected in the summer period (15 of June – 15 of September) 2011–2017, during which the tubenose gobies were presented, were examined. *Spearman Rank correlation* was used, because the normal distribution of samples (densities grouped by indexes of ranged parameters, temperature and salinity) was not confirmed. Differences in the tubenose goby densities between the samples grouped by ranks of each parameter were analyzed using *Kruskal-Wallis test*. The following analysis by means of *Mann-Whitney pairwise test* was conducted to find out which groups of samples were significantly different. The differences found were estimated using Bonferroni corrected p'-values. The same tests (*Spearman Rank correlation, Kruskal-Wallis*) were used for the weight and length samples analysis, because the normal distribution of samples (Sl and Tw) was not confirmed.

The estimation of weight–length relationship was calculated by the adjustment of an exponential curve: $W = aL^b$; where W is the total weight (g), L – the standard length (mm), a – intercept (initial growth coefficient or condition factor) and b – slope (growth coefficient) (Santos et al. 2002).The parameters a and b were estimated by linear regression analysis on ln-transformed data, and the association degree between variables (W and L) was calculated by the determination coefficient (r^2) and its statistical significance level in Excel 2007.

RESULTS

Distribution and frequency of occurrence

During 2010–2017 the tubenose goby expanded westward from the mouth of the Neva River along the northern and southern coasts of the Gulf of Finland (Fig. 2). The species did not occur in catches in 2010. The first time it became numerous in samples in 2011. The western-most point of recording on the northern coast was close to Severny Berezovy Island (st. 8) and on the southern coast near Cape Navolok in the Kopor Bay (st. 41). The highest salinity at the sites of occurrence was 2.9–3.1‰. In the Luga Bay, Gulf of Narva, as well as in the central part of the Vyborg Bay, the tubenose goby was not caught during the study.

Regardless of quite a wide range of distribution, the occurrence of the tubenose goby in the eastern

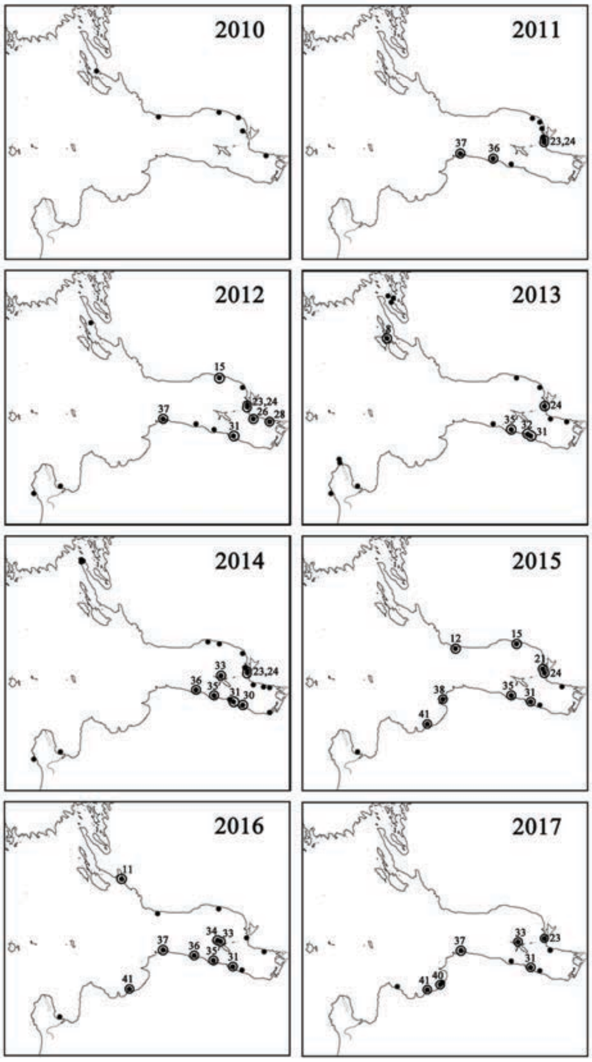

Fig. 2. Stations of the tubenose goby occurrence (marked with circles and numbers) in the eastern Gulf of Finland in 2010–2017. Other sampled stations marked with black dots.

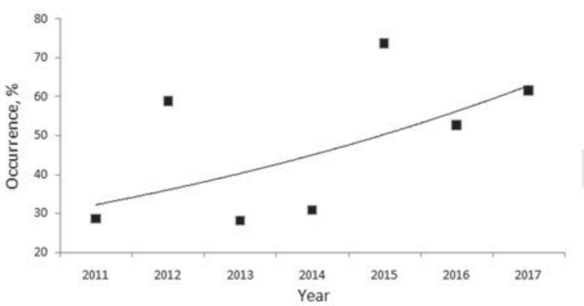

Fig. 3. Tubenose goby frequency of occurrence (*V*, %) in the eastern Gulf of Finland in 2011–2017. Curved line shows the exponential trend.

Gulf of Finland was various. During 2011–2017 the tubenose goby was recorded at 10 (st. 8, 11, 12, 15, 21, 23–26, 28) of the 28 stations on the northern coast, at 9 (st. 30–32, 35–38, 40, 41) of the 18 stations on the southern coast, and at two stations near the Kotlin Island (st. 33–34) (Table 1). The total number of samples containing tubenose gobies amounted to 65. During the study, 2697 specimens were caught (Table 2), most of them were sampled in 2014–2016.

The tubenose goby frequency of occurrence was varying during the study. It was identified as a "secondary species" in 2011, 2013 and 2014, and as a "core of the ichtyocoenosis" species in 2012, 2015–2017. The total value of V in 2011–2017 was equal to 38.9%. The increase in the occurrence was observed after 2011 (Fig. 3). The tubenose goby frequency of occurrence was higher at the stations of the southern coast and Kotlin Island (st. 30–47) – 51.2%, along the northern coast (st. 1–29) the species was present in 30.4% of samples.

Abundance and its seasonal changes

The tubenose goby reached the highest density in the well-vegetated biotopes of the south coast from the Neva Bay to the Kopor Bay (st. 30, 32, 35–37, 41) including Kotlin Island (st. 33) (Fig. 4). The average density during the survey in this coastal area (st. 30–41) was 14.2 ± 4.8 ind./100 m^2 (mean ± SE), the maximum densities amounting to 84–161 ind./100 m^2. Bottom substrate at the stations in the discussed area (Table 1) was generally formed by sand or mixed sand and pebble with some boulders (82% of stations). Stony substrate was observed only at two stations in the area (st. 37 and 40).

In the shallow part of the northern coast, tubenose goby mainly occurred at two stations (st. 23, 24; 62.5% of samples in the area) on the vegetated biotopes in the Alexandrovskaya Bay. Westward (st. 8, 11, 12, 15, 21), as well as in the Neva Bay (st. 26, 28), occurrence was less frequent. The tubenose goby densities were occasionally as high as 25–29 ind./100 m^2 (st. 12, 15) (Fig. 4), the average density at the stations of the north coast was 3.1 ± 1.5 ind./100 m^2 (mean ± SE). Extensive thickets of reed were observed only locally (st. 8 and 23). Sandy bottom was observed only at st. 23 (Table 1).

The highest tubenose goby densities were observed at coastal stations in 2011 and 2014–2016 (the average densities ± SE: 13.4 ± 9.0; 7.4 ± 4.2; 11.8 ± 5.5; 29.5 ±

Table 1. Stations of the tubenose goby occurrence and their characteristics (substrate, silt, vegetation, temperature and salinity during the sampling). Ranks of environmental parameters are presented in Material and methods. Percentage refers to temporal variability of each ranged parameter observed at the same station during the study, but not the spatial composition of the substrates.

St. No.	Bottom substrate	Silt	Aquatic vegetation	Filamentous algae	Water temperature, °C (range)	Salinity, ‰ (range)
Severny Berezovy Island						
8	3	0	2	2	21.4	2.76
Northern coast						
11	2	0	0	1; 2 (50; 50%)	16.7	2.90
12	2	0	0	1	20.7	0.82
15	2; 3 (50; 50%)	0; 1 (50; 50%)	0; 1 (50; 50%)	0; 2 (50; 50%)	20.6–22.3	0.45–0.56
21	2	1	0	1	22.0	0.14
23	1	0; 1; 2 (25; 50; 25%)	1; 2 (25; 75%)	0; 1 (75; 25%)	12.0–23.1	0.09–1.34
24	3	0; 1 (40; 60%)	0; 1 (20; 80%)	0; 1 (10; 90%)	13.5–22.5	0.07–0.32
25	3	0	0	0	14.5	0.20
26	3	0	1	1	21.2	0.11
28	3	0	1	1	22.1	0.12
Kotlin Island						
33	1; 3 (75; 25%)	0; 1 (25; 75%)	2	1; 2 (75; 25%)	12.9–22.8	0.19–0.63
34	1	0	1	1	19.5	0.41
Southern coast						
30	1	2	2	0; 2 (50; 50%)	14.5–19.0	0.08–0.09
31	1	1; 2 (50; 50%)	2	0; 1 (90; 10%)	7.8–22.0	0.08–0.36
32	3	0	2	1	21.1–22.0	0.08–0.12
35	1	0; 1; 2 (25; 50; 25%)	0; 2 (25; 75%)	0; 1 (63; 37%)	15.8–20.5	0.11–1.5
36	1; 3 (75; 25%)	0; 1 (75; 25%)	2	0; 1 (50; 50%)	15.5–20.2	0.43–2.6
37	2; 3 (75; 25%)	1; 2 (75; 25%)	1; 2 (25; 75%)	0; 2 (25; 75%)	17.0–21.6	0.97–3.1
38	1	0	0	1	20.0	2.24
40	2	0	2	2	28.8	2.50
41	3	0; 1 (50; 50%)	1; 2 (50; 50%)	0; 2 (25; 75%)	16.0–21.0	1.30–2.70

17.0 ind./100 m^2 respectively). In 2012, 2013 and 2017 the average density values (mean ± SE) were 0.6 ± 0.2; 3.2 ± 2.8 and 4.8 ± 1.4 ind./100 m^2 respectively.

The tubenose goby relative abundance in catches (*RN*) varied from 0.03 to 84.9%. The species were identified as “super-dominant” in 12.3% of samples, “abundant” in 23.1% samples, “average in numbers” in 38.5% samples, “rare” in 24.6% samples, and “scarce” in 1.5% samples. The total value of *RN* in the surveyed area was estimated as 3.4%. Therefore the species was primarily “average in numbers”. Regionally the values varied from less than 0.1% to 11.9%, and the highest value was calculated for the samples from the Kopor Bay. The abundance in catches was positively correlated with the tubenose goby density ($R = 0.75$; $p < 0.05$), so *RN* values were generally determined by the quantity of gobies and not by the total size of fish samples.

Seasonal variability of the tubenose goby quantity was characterised by late summer peaks in July–September caused by the massive appearance of goby juveniles. 98.8% of the tubenose goby specimens were caught in that period (*RN* was 18.8 ± 3.6%). Summer peaks of relative abundance were more visible on the southern coast (23.1 ± 4.7%; mean ± SE). Only 1.2% of the goby specimens were caught in other months, mainly in May. In spring and autumn the species was generally “average in numbers”: 8.1 ± 4.4%.

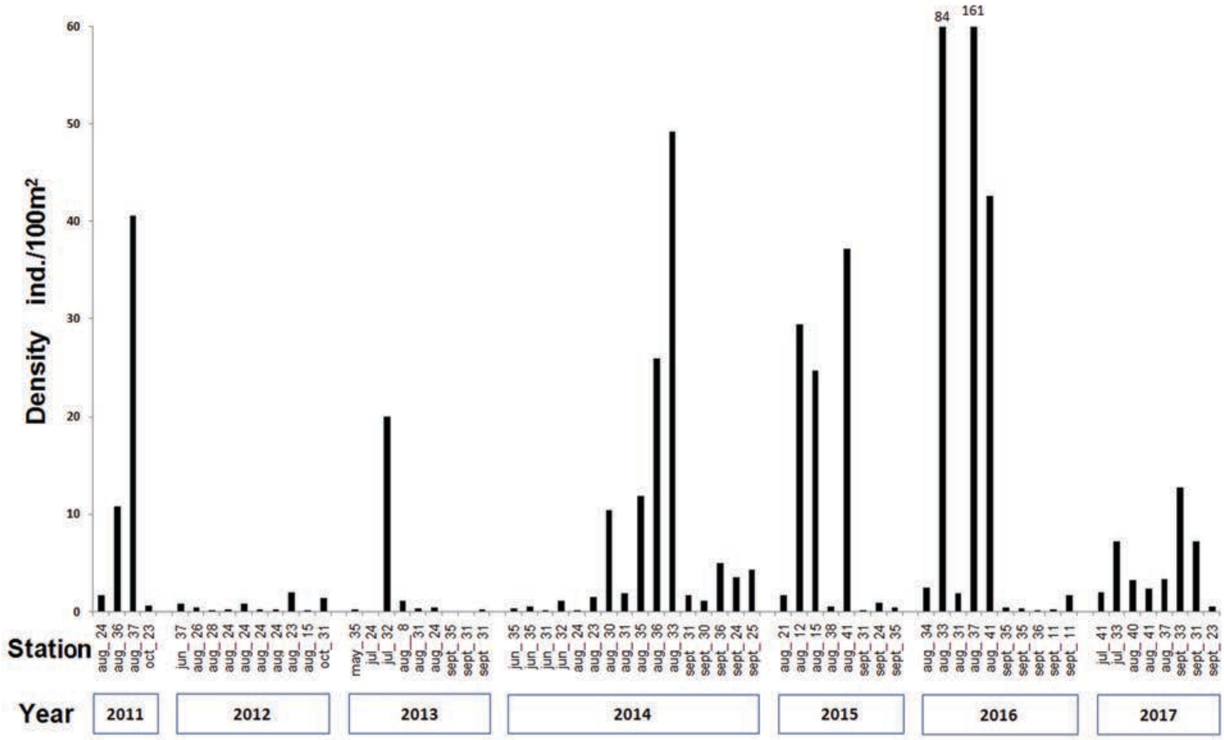

Fig. 4. Tubenose goby densities at 21 coastal stations in the eastern Gulf of Finland. Stations labels: month of sampling_station number as in Fig. 1.

In early summer, before the start of the spawning period in mid-June, the tubenose goby distribution was highly erratic. The species occurred in three samples during this time; the highest density was 0.8 ind./100 m^2. From the middle of June to the beginning of September, the tubenose goby was caught in 54 samples, the highest density estimated as 161 ind./100 m^2, the average density was 11.7 ± 3.7 ind./100 m^2 (mean ± SE). In early October the species was sporadically registered at shallow sites (in 8 samples totally; highest density was 5 ind./100 m^2; the average density was 4.3 ± 1.6 ind./100 m^2). The data on the tubenose goby wintering in the eastern Gulf of Finland cannot be shown since the species did not occur in samples in November 2013 and 2014.

Table 2. Number of stations of the tubenose goby occurrence and sizes of samples in 2010–2017.

Year	Number of stations goby occurrence/ total	Samples goby presence/ total	Total number of goby specimens
2010	0/7	0/7	0
2011	4/11	4/13	246
2012	7/13	10/17	67
2013	5/19	9/35	131
2014	8/22	16/52	567
2015	8/11	8/11	498
2016	8/14	10/19	994
2017	7/12	8/13	194

The impacts of environmental factors on distribution

From the middle of June to the beginning of September 2011–2017, in the period of spawning and mass hatching, the tubenose goby density at shallow sites was positively correlated (*Spearman's* R = 0.44; $p < 0.001$) with the abundance of filamentous algae along the coastline. Based on the filamentous algae abundance the stations were divided into three groups (0; 1; 2), in which the tubenose goby densities also varied

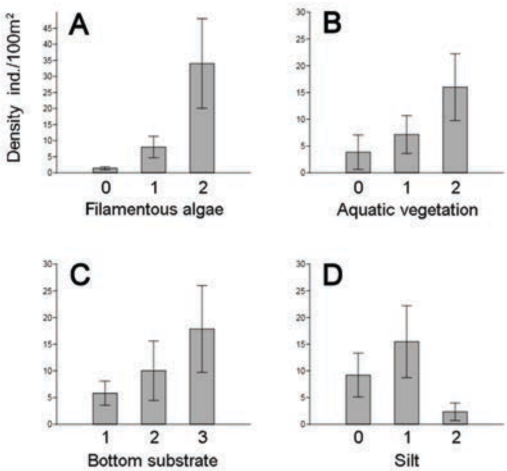

Fig. 5. Average tubenose goby densities (ind./100 m^2) in samples from stations with different (A) filamentous algae abundance (0 – absent; 1 – present but not abundant; 2 – abundant growths or mates), (B) aquatic vegetation (0 – absent; 1 – submerged vegetation; 2 – reeds), (C) bottom substrate (1 – sand of different grain size; 2 – stones prevail; 3 – mixed sand and stone substrate), (D) silt abundance (0 – absent; 1 – present but not abundant; 2 – abundant).

(*Kruskal-Wallis* H = 13.01; p = 0.001). Densities of goby were higher (Fig. 5A) at the stations with abundant filamentous algae (mean density of gobies ± SE: 34.0 ± 13.9 ind./100 m^2) than at those where filamentous algae were not abundant (8.0 ± 3.3 ind./100 m^2) (*Mann-Whitney* U_{2-1} = 17; p'_{2-1} = 0.009), or absent (1.7 ± 0.5 ind./100m^2) (*Mann-Whitney* U_{2-0} = 56; p'_{2-0} = 0.001). The differences between the latter two groups (0 and 1) were not significant (*Mann-Whitney* U_{0-1} = 183; $p'_{0-1} > 0.05$). In the coastal microhabitats with mass development of filamentous algae, the tubenose goby was numerically dominant with densities up to 161 ind./100m^2. At the stations without filamentous algae the tubenose goby densities were low even if macrophytes were abundant.

The densities of the tubenose goby had been positively but weak correlated (*Spearman's* R = 0.34; p = 0.01) with different types of aquatic vegetation (macrophytes) in the summer period of 2011–2017. Three groups of samples varying in abundance and type of aquatic vegetation (0; 1; 2) showed different tubenose goby densities (*Kruskal-Wallis* H = 6.2; p = 0.04). Differences between the densities on the stations with thickets and those without any vegetation were only when applying the Bonferroni uncorrected p value (*Mann-Whitney* U_{2-0} = 69; p_{2-0} = 0.036), after the correction no significant differences were observed (p'_{2-0} = 0.1). The differences between the other groups were not significant in any case (*Mann-Whitney* U_{2-1} = 154; p'_{2-1} = 0. 19; *Mann-Whitney* U_{0-1} = 58; p'_{0-1} = 1). Density of the tubenose goby was highest at the stations with abundant growths of aquatic vegetation (15.9 ± 6.2 ind./100 m^2; mean ± SE), lower at the stations with submerged vegetation (7.1 ± 3.5 ind./100 m^2), and the lowest at the sites without macrophytes (3.8 ± 3.2 ind./100 m^2) (Fig. 5B).

Also in the shallow habitats lacking any aquatic vegetation or filamentous algae the tubenose goby density decreased sharply (0.2 ± 0.09 ind./100 m^2; mean ± SE): the species occurred only at two stations not far from the vegetated biotopes.

No correlations between the tubenose goby densities (summer period of 2011–2017) and bottom substrate types (*Spearman's* R = 0.02; NS), abundance of silt (*Spearman's* R = 0.08; NS), salinity (*Spearman's* R = 0.39; NS) and surface water temperature (*Spearman's* R = 0.04; NS) were found. On the other hand average densities were higher (Figs. 5C–D) at the stations with mixed sand and stone substrates and at those where silt was present but not abundant. The differences between densities grouped by types of bottom substrate (*Kruskal-Wallis* H = 0.26; p = 0.87) and abundance of silt (*Kruskal-Wallis* H = 4.04; p = 0.13) were not significant.

Size-weight and age structure

The samples included juvenile and adult tubenose gobies of SL from 5 to 63 mm. Males reached 63 mm in length and females were not longer than 54 mm. The females with mature gonads were over 33 mm long, the males in spawning coloration were larger than 37 mm. There were two age groups in the samples: young-of-the-year (0+) and one-year old (1 and 1+) gobies. In August–September the highest abundance of different age and size groups of the tubenose goby was recorded in the shallows. In this period 0+ males were larger in length and weight (25.1 ± 0.1 mm; 0.36 ± 0.01 g; mean ± SE; for Sl *Kruskal-Wallis* H = 43.3; $p < 0.001$; and for Tw *Kruskal-Wallis* H = 45.8; $p < 0.001$) than females (22.8 ± 0.2 mm; 0.26 ± 0.01 g; mean ± SE). The average length and weight of 0+ gobies of unclear sex in the same period were 14.1 ± 0.2 mm and 0.061 ± 0.003 g (mean ± SE) respectively. The average length of 1+ gobies in the

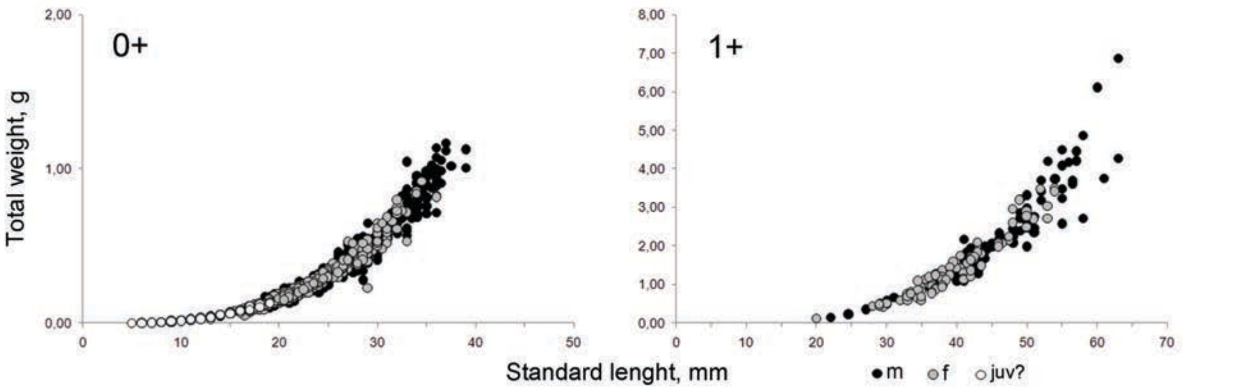

Fig. 6. Standard length and weight of the tubenose goby in August (summarized data for 2011–2017). Legend: m (black dots) – males; f (grey dots) – females; juv? (white dots) – juveniles of unclear sex.

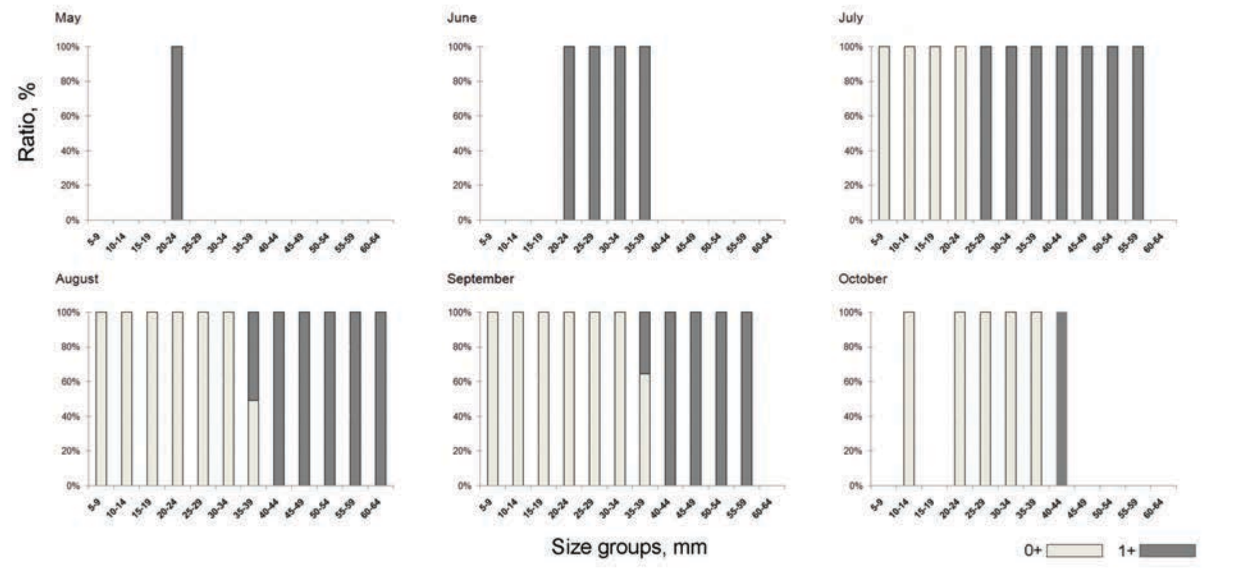

Fig. 7. Age and length composition of the tubenose goby population in May–October of 2012–2017 (summarized data) in the eastern Gulf of Finland. Legend: light-grey – young-of-the-year (0+); dark-grey – one-year old (1+).

summer period was 43.9 ± 0.7 mm and 40.1 ± 0.7 mm (mean ± SE), and the weight was 2.03 ± 0.11 g and 1.47 ± 0.08 g (mean ± SE) for males and females respectively. Adult 1+ males and females were significantly different in Sl (*Kruskal-Wallis* $H = 10.4$; $p = 0.001$) and Tw (*Kruskal-Wallis* $H = 9.4$; $p = 0.002$). The weight of the individuals increased in relation to body length (for juvenile gobies *Spearman's* $R = 0.99$; $p < 0.001$; for mature 1+ females *Spearman's* $R = 0.94$; $p < 0.001$; for mature 1+ males *Spearman's* $R = 0.92$; $p < 0.001$) (Fig. 6). The parameters of the tubenose goby weight–length relationship calculated as $W = aL^b$ are given in Table 3.

The spawning of the tubenose goby starts in June and continues until the end of summer. All mature specimens whose gonades and coloration indicated their participation in spawning were aged 1+. Gobies of age 1+ (Sl 20–39 mm) were quantitatively predominant in shallows until the end of June (Fig. 7). Young-of-the-year juveniles appeared in shallows in early July, and the larval gobies were sampled until

Table 3. *Weight – length* relationship parameters of the tubenose goby sampled in 2010–2017. *N* – sample size; L – standard length (*Sl*, mm); W – total weight (*Tw*, g); *a* – intercept; *b* – slope, r^2 – determination coefficient; SE – standard error. Juveniles included males, females and specimens of unclear sex.

Sample	N	L mean ± SE	W mean ± SE	*a*	*b*	r^2	SE of *b*
Juveniles 0+ and 1+	1239	22.3 ± 0.2	0.27 ± 0.01	0.000012	3.147909	0.98 (p < 0.01)	0.012011
Adult males 1+	101	45.8 ± 0.7	2.25 ± 0.11	0.000018	3.042059	0.95 (p < 0.01)	0.098223
Adult females 1+	79	40.9 ± 0.6	1.54 ± 0.08	0.000009	3.213270	0.95(p < 0.01)	0.120000

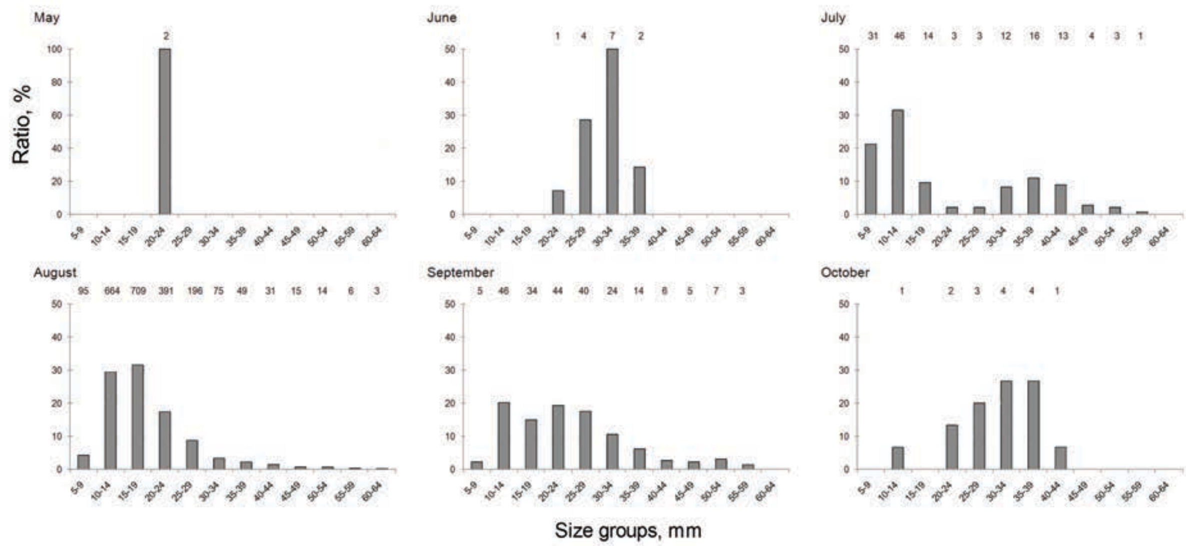

Fig. 8. Quantity distribution of different size groups in the tubenose goby samples in May–October of 2011–2017 (summarized data) in the eastern Gulf of Finland. Numbers above the columns show the quantity of specimens in the size group.

the end of September (Fig. 8). The young-of-the-year individuals of 10–29 mm composed the main part of the tubenose goby population in August and early September. The maximum lengths of the 0+ gobies were 35–37 mm from August to October. All 0+ gobies were immature. The majority of 1+ females at the end of August had visible signs of atrophy. Post-spawn 1+ males (characterised by dark coloration and drained gonads) were eliminated from the population later than females and occurred in shallows until the end of October.

Sex composition

During the mass spawning period (July) females were predominant (62–88% of the total number) in the most abundant size groups (30–44 mm). Females' ratio among the specimens with clearly identified sex was 58.3% in June and 67.3% in July. The sex composition of the tubenose goby population was the most representative at the end of the warm season (August – the first half of September) due to the highest density of the gobies in the shallows after the mass hatching of goby larvae. In August–September a similar ratio of males and females was observed in the size groups of the smallest juveniles with determinable sex (15–19 mm and 20–24 mm) (Fig. 9). Males prevailed among the specimens over 25 mm, composing 88–93% in the size group 35–39 mm in August and September. A certain increase in the number of females in the size groups 45–49 mm and 50–54 mm at the end of summer was caused by the lack of large

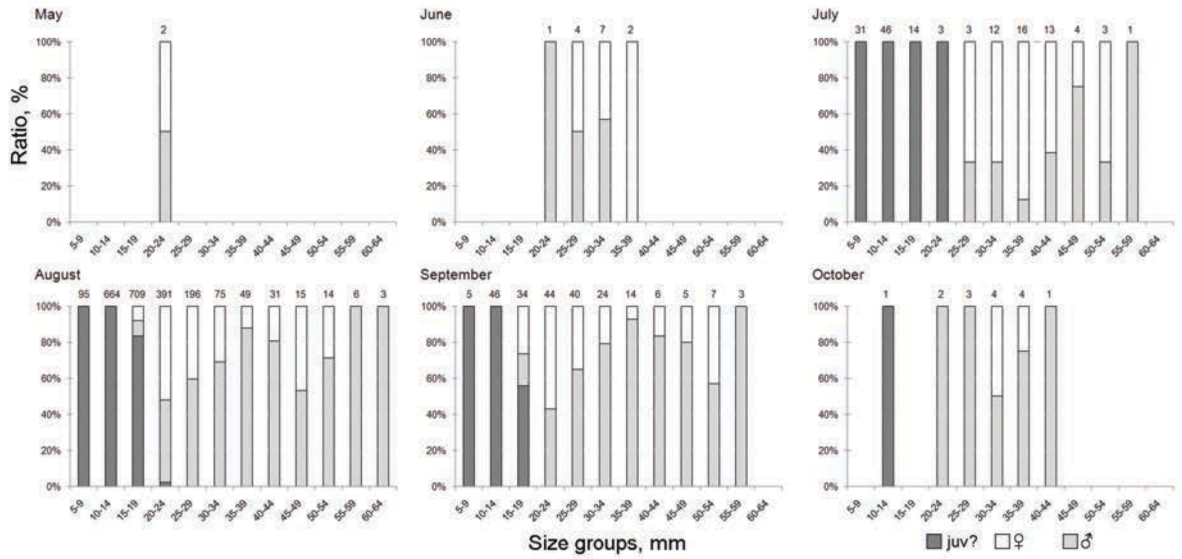

Fig. 9. Sex composition of the tubenose goby population in May–October of 2011–2017 (summarized data) in the eastern Gulf of Finland. Legend: white – females (♀); light-grey – males (♂); dark-grey – juveniles of unclear sex (juv?). Numbers above the columns show the quantity of specimens in the size group.

gobies of both sexes in the samples. This fact determined a corresponding increase in the influence of each specimen on the ratio. Females' ratio among the specimens with clearly identified sex was 43.8% in August and 37.4% in September. The lowest ratio of females (15.4%) was recorded in October.

DISCUSSION

The results of the study show that the tubenose goby population has been self-reproductive since 2011. Thus, it may be considered that in the study area the population has successfully naturalized within a decade. The high abundance of juveniles and adult gobies of different sizes demonstrates that the species has found favourable conditions for spawning and feeding in the shallows.

The routes of the tubenose goby invasion into the Gulf of Finland are still not clear, because of the difficulties with *Proterorhinus* species identification. The tubenose goby was first reported in the Neva Bay by Antsulevich (2007) who identified it as *P. marmoratus*; for this reason we use this specific name in the present study. However, a recent genetic examination showed that *P. marmoratus* is associated with marine and brackish waters of the north-eastern part of the Black Sea and unrelated to the other tubenose goby populations of the Ponto-Caspian basin (Neilson and Stepien 2009; Sorokin et al. 2011; Slynko et al. 2013). The present observation of the tubenose goby in the waters with low salinity may suggest a relationship of the studied population with some freshwater or euryhaline populations. In any case, a direct genetic examination of the tubenose goby from the eastern Gulf of Finland is required.

The tubenose goby is widely distributed in the eastern Gulf of Finland. During the study the tubenose goby distribution was restricted to the Severny Berezovy Island on the northern coast and the Cape Navolok in the Kopor Bay on the southern coast. Further westward expansion may occur in favorable environmental conditions. The tubenose goby occurred with relatively high frequency, it was "constant" or "secondary" species in different years of the study. The species occurred most frequently along the southern coast of the gulf. The tubenose goby was the "super-dominant" and "abundant" species in 35% of the samples, and "average in numbers" in 38%. Abundance in catches and densities reached their peaks at the end of summer along the southern coast of the gulf (highest *RN* was 84.9% and density was 161 ind./100m^2). In other regions, the tubenose goby was also found in high numbers locally. In the Rybinsk Reservoir the abundance was up to 40% and the highest density was 2000 ind./100m^2 near Yurshinsky Island (Slynko 2008). The highest density in the Dneprodzerzhinsk Reservoir on the Dnieper River was 504 ind./100 m^2 (Didenko 2013). Such a notably high range of densities in comparison with the Gulf of Finland may potentially be explained by differences in sampling methods and hauling distances. In the river Duje in the Danube basin the tubenose goby abundance was 51.3–78.3% of catches (Valova et al. 2015). Also in the Danube basin, the species was abundant in the ichthyoplankton but never dominant (Vašek et al. 2011; Janác et al. 2013). In the other water bodies, the non-native tubenose goby's frequency of occurrence and abundance have been commonly defined as not high (Boldyrev 2002; Semenov 2011; Semenchenko et al. 2011; Janác et al. 2012; Valova et al. 2015). Therefore, the tubenose goby population in the eastern Gulf of Finland may be identified as one of the abundant populations.

The tubenose goby in the investigated area was characterized by significant interannual fluctuations of population number. In the first place, it might be caused by annual changes of environmental conditions and hydrological regime of the Gulf of Finland which affect the coastal shallow-water ecosystem. During the study period, an increase in the tubenose goby population largely driven by the appearance of the young-of-the-year age group was observed in different areas reaching the highest values in 2014 and 2015. In these years, the growth and accumulation of filamentous algae (*Cladophora glomerata, Ulva* spp.) in the shallows were especially high (Gubelit et al. 2017). A notable dependence on filamentous algae is typical for the tubenose goby both in the native area (Kazancheev 1981; Smirnov 1986) and outside (Galanin 2012). In the eastern Gulf of Finland, the tubenose goby quantity was positively correlated with the abundance of filamentous algae in the shallows. It should be noted that the correlation was estimated as low ($0.3 < R < 0.5$). In this case, it should be noted that we used the expert estimation of ranged criteria, whereas quantitative estimation of the filamentous algae biomass would be more suitable. In any case in the coastal biotopes where filamentous algae were abundant, much higher number of the tubenose goby has been observed in the samples irrespectively of other aquatic vegetation and the bottom substrate type. Masses of filamentous algae may play a role of refuge for gobies, which hide in rocky or rip-rap bottom substrate in other areas (Janác et al. 2012). Filamentous algae, which are common in the coastal areas of the Gulf of Finland, may serve as a factor determining successful reproduction and population size of the tubenose goby. This point undoubtedly requires further research.

The currents prevailing in the Gulf of Finland (Eremina 1999) may promote westward distribution of the tubenose goby due to the possibilities of larval drifting observed in different areas (Vašek et al. 2011; Janác et al. 2013). The tubenose goby larvae may also drift within the floating fragments of filamentous algae (Galanin 2012). This was confirmed by findings of the tubenose goby larvae in the ichthyoplankton of the Neva Bay in 2015 (Susloparova et al. 2015). The absence of tubenose gobies in the coastal samples from the most saline western area gives a reason to examine the possible limitation effect of salinity on different tubenose goby life stages as it has been done already with tubenose gobies from the Rybinsk Reservoir (Martemyanov and Borysovskaya 2012). At the same time, no correlation was found in the eastern Gulf of Finland between the number of tubenose gobies and water salinity (0.05–3.10‰). This may suggests that the tubenose goby distribution in low salinity largely depends on other habitat characteristics. At the same time we can suggest the future expansion of the tubenose goby into the oligohaline waters of the Gulf of Finland.

In the eastern Gulf of Finland, tubenose gobies have been caught in microhabitats with sandy, stony or mixed bottom substrates, both with thickets of aquatic vegetation and away from them. High heterogeneity of the coastal biotopes in the investigated area, salinity and water level fluctuations and different rates of wave effect (Rumiantsev and Drabkova 1999; Gogoberidze et al. 2013) make it significantly difficult to estimate the key factors for coastal fish distribution. At the same time, for other regions researchers revealed a positive correlation between the tubenose goby densities and stony substrates but not with silt and sand (Jude and De-Boe 1996; Prášek and Jurajda 2005; Von Landwüst 2006; Slynko 2008; Kocovsky et al. 2011; Janác et al. 2012). However, the tubenose goby microhabitat preferences vary in different water bodies, for instance, the species prefers silty and sandy bottoms in small streams of Turkey (Gaygusuz et al. 2010) and in the Dneprodzerzhinsk Reservoir (Didenko 2013). In the latter a positive correlation between the tubenose goby number and the abundance of macrophytes was also observed. Therefore, the results of the current and earlier studies demonstrate that the tubenose goby is highly tolerant to different habitat conditions and such a factor as a type of bottom substrate is not limiting for its expansion.

Seasonal fluctuations in species abundance in the shallows was caused by an increase in number of young-of-the-year juveniles in the end of summer and its several-fold decrease in the cold season. Such seasonal dynamics has often been observed in the native and invasive tubenose goby populations and for other Gobiidae species in different regions (Erös et al. 2005; Kocovsky et al. 2011; Valova et al. 2015; etc.). The decrease in number of gobies at shallows during autumn and winter has been explained by different authors as a result of growing predation, migration to the deepwater, and high mortality due to the lack of feeding resources (Hurst 2007; Všetičková et al. 2014; Valova et al. 2015). At the same time, in the Volgograd Reservoir, the tubenose goby juveniles wintered in the coastal silt (Boldyrev 2002). Our research did not include winter sampling due to ice and storm conditions in the Gulf of Finland. During the sampling in October and November 2011–2014, the species was highly sporadic or totally absent in shallows. Hypothetically, it was caused by changes in the juveniles' spatial distribution and post-spawning mortality. According to Boldyrev (2002), the post-spawn mortality of all 1+ gobies in the Volgograd Reservoir occurred in the end of August.

The absence of two-year-old (2 and 2+) and older gobies in the samples demonstrates that the life cycle of most tubenose goby individuals was short and ended in the year after hatching. The same one-year life cycle has been earlier demonstrated for the invasive goby population in the Volgograd Reservoir (Boldyrev 2002). Spawning and elimination at the age of one year (1+) were similarly described as typical for the vast majority of tubenose gobies in the Dyje River at the Danube basin (Valova et al. 2015). Probably, the duration of the life cycle varies among different native and invasive populations. The age of two years (2+) was found to be maximal for tubenose gobies in the Rybinsk (Slynko 2008; Kiyashko et al. 2010) and the Kuibyshev (Semenov 2011) Reservoirs of the Upper Volga River, and in the Dyje River at the Danube basin (Valova et al. 2015). The maximum age of the species in the native populations was usually 2–3 years (Kazancheev 1981; Smirnov 1986; Ragimov 1991) reaching 4 years in some rivers (Dolgiy 1993; Harka and Farkas 2006). Early maturation and short (usually annual) life cycle may be a trait of the tubenose goby's life strategy that was adopted by recent invasive populations and allows fast habitat colonization (Valova et al. 2015).

The maximum length (Sl 63 mm) of the tubenose gobies in the samples from the eastern Gulf of Finland was shorter than in the other invasive freshwater populations. In the Dyje River, it was estimated as 75.4–84.5 mm (Valova et al. 2015), in the Rybinsk Reservoir 70.0–112.0 mm (Slynko 2008). In both areas the age of largest individuals was estimated as two (2+) years. At the same time, the maximum length of the gobies from the investigated area was equal to that of one-year (1+) individuals identified by the aforementioned authors. The maximum length of one-year (1+) tubenose gobies in the Volgograd Reservoir was estimated by Boldyrev (2002) as 51 mm for females and 60 mm for males, also the maximum lengths of the young-of-the-year was 44–50 mm (females and males respectively), which indicates less growth in the second year of life. The size and age population structure of the tubenose goby in the Volgograd Reservoir is most similar to that in the eastern Gulf of Finland. Therefore, the absence of larger individuals may be explained by the short life cycle of the tubenose goby in the studied population. The estimation of the weight-length relationship of the tubenose goby from the studied area revealed that adult 1+ females and juveniles (irrespectively of the age) both showed positive allometries ($b > 3$), and the adult 1+ males showed primarily isometric growth ($b = 3$).

The females were generally more abundant than the males during the spawning period in both native and invasive populations (Smirnov 1986; Boldyrev 2002, Valova et al. 2015), although the opposite may occur in some areas (Semenov 2011). Similarly, in the studied population, females prevailed in a ratio of 2.7:1.0 (females: males) during the spawning. It is remarkable that the sex ratio was close to 1.0:1.0 in the smallest juveniles after mass hatching. The males became predominant among the young-of-the-year individuals larger than 25 mm, and consequently there were 10 times more males in the size group 35–39 mm at the end of summer. Therefore, during the spawning period the sex structure of the tubenose goby population changed from female to male predominance due to rapid elimination of post-spawning females and higher ratio of males among juveniles. During the winter season females seem to show better survival ability, which causes the evident increase in the female-to-male ratio at the start of the spawning.

A short life cycle and longtime partial spawning of the tubenose goby provide a high rate of habitat colonization and population growth, which in favorable environmental conditions allow the species to become numerically dominant in the fish community and increase its impact on the coastal ecosystem. Valova et al. (2015) suggested that the high growth rate of the tubenose goby population was possible in case of low competition with other invasive Gobiidae species which are generally larger and more fecund. The recent research in the Danube basin has shown that the direct impact of the tubenose goby on other fish species through eggs and larvae predation was extremely low (Vašek et al. 2014; Všeticková et al. 2014). At the same time, the competition of the tubenose gobies with small-sized fish species for feeding resources, spawning grounds and shelters is possible to a varying degree (Van Kessel et al. 2011; Všeticková et al. 2014). The tubenose goby is a feeding object of the river perch (*Perca fluviatilis* L.) in the water bodies of the Danube basin (Všetičková et al. 2018) and in the eastern Gulf of Finland (Uspenskiy, unpublished data). In the studied area some reliably identified tubenose goby specimens have been occasionally found in stomachs of perches caught by the beach-seine in the biotopes with growths of submerged vegetation in August. This may indicate that the perch plays a role in limiting the tubenose goby quantity in the recipient ecosystem. Change in the feeding specialization of the large perch from cyprinid juveniles to the tubenose goby led to an evident decrease in the latter's quantity in the reservoir on the Dyje River (Všetičková et al. 2018).

According to Valova et al. (2015), the predominance of tubenose goby in the fish community may be caused not by low competition with native fish species but by primary colonization of vacant microhabitats, such as "rip-rap" river beds of the channelized hydrologic system in the Danube basin. In the eastern Gulf of Finland, the predominance of tubenose goby in the coastal fish community was observed in the shallows with the growths of filamentous algae. Therefore, we may conclude that this seasonal microhabitat is settled by tubenose gobies most intensively. Preliminary data (Uspenskiy, unpublished) suggest that tubenose goby may compete there with early juveniles of cyprinids and three-spined stickleback (*Gasterosteus aculeatus* L.). The detailed investigation of the relationship between the tubenose goby and the native fish species of the eastern Gulf of Finland is the aim of our further research.

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