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Population characteristics of the non-indigenous round goby, *Neogobius melanostomus* (Actinopterygii: Perciformes: Gobiidae), in the eastern Gulf of Finland

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Abstract

The round goby, *Neogobius melanostomus* (Pallas, 1814), is a fish of Ponto-Caspian origin that has been invading the Baltic Sea since the 1990s. Currently, it is abundant and commercially important in some areas of the sea. This species was first reported in the eastern Gulf of Finland (GoF) in 2012. Its occurrence increased thereafter, however it has remained largely unstudied in this region. The aim of this study was to investigate the population characteristics of the round goby in the eastern GoF to better understand its expansion trend and whether it will become abundant enough to be exploited by the local fishery. Fish were caught using multi-mesh gillnets (12–60 mm mesh) and a beach seine (0.5–10 mm mesh). Occurrence, density, catch per unit effort, biomass per unit effort, relative number and biomass in catches, as well as age, size and sex ratio were studied. The species regularly occurred in samplings along the southern coastline of the GoF, as well as some central areas and along the northern coast. Within 2012–2019, its occurrence in catches increased, with the highest frequency in 2015–2019 in shallow waters (<1.5 m) of Koporye Bay (70%) and in the deeper waters of Narva Bay (74%). Similarly, the highest density in the shallow waters was also observed in Koporye Bay (10.0 ind. · 100 m^{-2}), and offshore in Narva Bay. Relative abundance and biomass usually did not exceed 23%, although it reached 93% in Narva Bay. The oldest specimen was five years old. Young-of-the-year (YOY) juveniles predominated in the shallow waters (85%), while three-year-olds prevailed in deeper waters (75%). Among the fish older than two years, females were more predominant (mean ratio 3 to 1), and males were larger than females. Specimens in all life stages were found in the eastern GoF, and their abundance increased annually, suggesting that the round goby has successfully colonized this region of the Baltic Sea. However, compared to other areas of the Baltic Sea inhabited by longer-established populations, its population size is still relatively low.

Keywords

abundance, distribution, invasive round goby, size

Introduction

The round goby, *Neogobius melanostomus* (Pallas, 1814), is considered to be one of the most invasive fish species in the Baltic Sea (Kornis et al. 2012). Expansion of this Ponto-Caspian fish began in the 1990s when it was transferred to the Baltic Sea via ballast waters (Sapota and Skóra 2005). The high adaptive ability and tolerance to different environmental conditions, along with its aggressive behavior and high reproductive potential, have resulted in the successful colonization of this species in new habitats (Charlebois et al. 1997). The first population of the round goby in the Baltic Sea was established along the coastline of Poland, where the species became abundant in the early 1990s (Sapota 2004). The fish then expanded its distribution both eastward and westward, where it was later caught along the coastlines of Lithuania, Latvia, and Germany (Kotta et al. 2016). Thus far, the round goby has been established in all the sub-basins of the Baltic Sea, including coastal waters of Denmark, Estonia, Finland, Russia, and Sweden (Puntila et al. 2018).

In some newly invaded areas, the round goby became so abundant that management actions were applied for its commercial fishing (Ojaveer et al. 2015). These actions resulted in sharp increases in Latvian catches, from less than 1 ton in 2011 to over 500 tons in 2016; this species accounted for approximately one-third of all catches (Puntila et al. 2018). The round goby was first found along the Estonian coastline in 2002 (Ojaveer 2006). By 2016, its catches exceeded 100 tons (Järv et al. 2018).

The increase in non-indigenous round goby populations can lead to competition with the local fauna of the Baltic Sea. Round gobies mainly feed on bivalve mollusks, although other benthic organisms can also be included in their diet (Smirnov 1986). Therefore, the round goby can compete for food with native benthivorous fish species (Karlson et al. 2007; Rakauskas et al. 2013; Ustups et al. 2016). In addition, the round goby can directly influence native fish populations by feeding on their eggs and/or juveniles, including commercial species (Wiegleb et al. 2018). Native piscivorous fish, in turn, can limit the abundance of the round goby through top-down control (Rakauskas et al. 2013). Therefore, studies on round goby populations in newly invaded areas are very important for understanding the dynamics of fish populations, including commercially important species.

In the Russian territorial waters of the eastern Gulf of Finland (GoF), the round goby was first observed in 2012 (Uspenskiy and Naseka 2014). Its abundance has since increased, and the species has become an unintentional by-catch. During the late 20th–early 21st centuries, local fisheries were mainly focused on herring, *Clupea harengus* Linnaeus, 1758; smelt, *Osmerus eperlanus* (Linnaeus, 1758); and sprat, *Sprattus sprattus* (Linnaeus, 1758), (see Lajus et al. 2015). The appearance of the round goby in the eastern GoF can essentially change the target species for fisheries, as observed in other parts of the Baltic Sea.

The aim of this study was to investigate the population characteristics of the non-indigenous round goby in the eastern GoF in order to better understand its expansion trend and whether it will become abundant enough to be exploited by the local fishery.

Materials and methods

Sampling sites. The fish community in the eastern GoF has been monitored annually since 1998 by the State Research Institute on Lake and River Fisheries (GosNIORKh, Saint-Petersburg), using multi-mesh gillnets. In total, 1627 samplings were carried out, mainly in Vyborg Bay and the adjacent waters (539 catches since 1998), Neva Bay (531 catches since 2002), and Luga Bay (245 catches since 2001) (Fig. 1). The Inner Estuary and Central Area were monitored less frequently (164 and 88 catches since 1998, respectively). In Koporye Bay, gillnet sampling was carried out only in 2014 and 2015. Gillnet sampling in Narva Bay began in 2016; to date, 57 catches have been conducted. An additional 179 beach seine samplings were organized between 2010 and 2019 at 48 coastal shallow sites of the eastern GoF (Fig. 1). All samplings were carried out during the ice-free season from April to November.

Fishing gears. Sampling gear included a hand-towed beach seine that reached a maximum depth of 1.2 m and gillnets that reached a sampling depth between 2.0 and 24.0 m. The length of the beach seine was 10 × 1.5 m; the mesh size was 10 mm in the wings and 0.5–4.0 mm in the cod end. On average, the mouth width of the beach seine while seining was 6.0 m. The trawling distance was 25–90 m according to the depth and bottom features of the sampling location. The demersal multi-mesh gillnet (48 × 1.8 m) included 8 monofilament net sections (6 m in length each) with mesh size 12, 15, 20, 25, 30, 35, 45, and 60 mm (Appelberg 2000). All fish specimens caught in the multi-mesh gillnet were combined into one sample.

Estimates of the abundance. Estimates of the abundance included: frequency of occurrence (V), density and biomass for beach seine catches, catch per unit effort (CPUE) and biomass per unit effort (BPUE) for the net catches, and relative abundance and biomass (RN and RB).

Frequency of occurrence (V) [%] in samples was estimated as:

$$V = 100 \cdot a \cdot A^{-1}$$

where, a represents the number of samplings where the species was caught, and A is the total number of the samplings. The species was classified as “accidental”, “rare”, “common”, and “constant” for V values < 15%, 15%–40%, 40%–70%, and > 70% respectively (Žiliukas et al. 2012).

Density (D) [ind. · 100 m^{-2}] and biomass (B) [g · 100 m^{-2}] for the beach seine were estimated as number (N_i) [ind.] and wet weight (W_i) [g] of individuals per 100 m^2 of the sampled area (S) [m^2] (Žiliukas et al. 2012):

$$D = 100 \cdot N_i \cdot S^{-1}$$

and

$$B = 100 \cdot W_i \cdot S^{-1}$$

where, S was calculated by multiplying the hauling distance and mouth width of a beach seine while seining; the distance was estimated by an optical laser distance meter (accuracy of 1 m).

CPUE [ind. · 12 h^{-1}] and BPUE [g · 12 h^{-1}] for the gillnets were estimated as number (N_i) [ind.] and wet weight (W_i) [g] of individuals caught by one net for 12 hours of fishing (Appelberg 2000):

$$\text{CPUE} = N_i \cdot 720 \cdot t_f^{-1}$$

and

$$\text{BPUE} = W_i \cdot 720 \cdot t_\text{f}^{-1}$$

where, 720 represents the number of minutes in 12 hours and t_f is the actual duration of fishing (in minutes).

Relative abundance (RN) [%] and biomass (RB) [%] in a sample were estimated as:

$$\text{RN} = 100 \cdot N_i \cdot N_\text{total}^{-1}$$

and

$$\text{RB} = 100 \cdot W_i \cdot W_\text{total}^{-1}$$

where, N_i and W_i are the number [ind.] and wet weight [g] in a sample, respectively, and N_total and W_total are the total number [ind.] and wet weight [g] of all fish in a sample, respectively. A species was classified as “dominant”, “abundant”, “moderate in number”, “few in number” and “scarce” for RN over 50%, 50%–10%, 10%–1%, 1%–0.1%, and less than 0.1%, respectively (Terešenko and Nadirov 1996).

Size, age, sex ratio. Fish which were examined to size, age and sex were collected at five sites in the shallow waters (<1.5 m depth) along the southern coastline (n = 109 ind.) and in two deeper (6–8 m depth) stations in Narva Bay (n = 1093 ind.) (Table 1).

Standard length (SL) and total (wet) weight (TW) were estimated with a ruler to the nearest mm and a laboratory scale (GP1200-G, Sartorius, Germany; accuracy of 0.01 g), respectively. TW of the goby specimens in the net samples was rounded to the nearest 0.1 due to the larger size. Age was estimated by examining otoliths cleared in glycerol (Kostûčenko 1961). Although sectioned and stained otoliths were recently recommended for age reading in the goby (Florin et al. 2018), earlier studies were mainly conducted using whole otoliths (Kostûčenko 1961; Sokołowska and Fey 2011; Azour et al. 2015; Bose et al. 2018). Hence, we also applied whole sagittal otoliths to obtain comparable data with previous studies. The age of goby specimens with visible growth zones of the current season was marked with “+” (Kostûčenko 1961). Sex was assigned according to the shape of the urogenital papilla (Kornis et al. 2012). Sex and age were both studied using an MBS–10 (LZOS, Russia) stereomicroscope.

Table 1. Number (N_i) of the round goby from the eastern Gulf of Finland analyzed in relation to length (L), mass (M), age (A), sex (S). Listed stations are depicted at Fig. 1.

Fishing gear	Depth [m]	Sampled stations	Date of catch	Studied population characteristics	N_i
Beach seine	0.0–1.2	1b, 2b, 3b, 4b, 5b	2012–2017	L, M, S, A	109
Gillnet	6.0–8.0	3n, 5n	06.2018	L, M	1093
		5n	06.2018	L, M, S, A	172

Statistical comparisons were conducted with the use of Statistica 12 and PAST Statistics software. The abundance of the round goby in different areas was compared using ANOVA. The abundance data were log-transformed to achieve normal distribution, which was checked with Shapiro–Wilk test. Males and females’ length were compared using t-test after checking for normality with the use of chi-square test. Non-normally distributed length data was compared by means of non-parametric Mann–Whitney U Test. Spearman’s rank correlation was used for the RN and RB relation analysis since normal distribution was not confirmed.

Results

Distribution. The round goby was first observed in the eastern GoF in 2012. Since then, its distribution area has increased (Table 2).

In shallow waters, gobies were caught at nine stations, i.e., 18.7% of all studied locations (stations 1b–9b, Fig. 1, Table 2). The first specimen was caught in Luga Bay (Fig. 1, station 1b). The easternmost finding was in 2015, collected by the St. Petersburg flood-prevention facility complex (SPb FPFC dam) (station 5b). In 2019, juveniles were first collected in the shallow waters along the northern coast (station 9b). No specimens were caught in the shallows of Vyborg and Neva Bay.

This species has occurred in gillnet catches since 2015, after its first finding in Luga Bay (stations 6n and 7n, Fig. 1, Table 2). In 2016, gobies were also caught in Narva Bay and close to Seskar Island (stations 2n and 12n). In 2017, it was first caught along the northern coast by cape Stirsudden (station 13n), and in Vyborg Bay in 2019 (station 15n). No specimens were caught by nets in Neva Bay.

Since 2012, the round goby has been regularly observed in catches along the southern coastline of the GoF, both in eastward and northward directions.

Frequency of occurrence (*V*) varied across the years, increasing from 2012 to 2019 (Table 2). The round goby was first caught in shallow waters with a beach seine in 2012, and three years later (2015) it was caught in deeper waters with gillnets. In beach seine catches between 2012 and 2019, V ranged from 2% to 50% (12% in total). Accordingly, the species was classified as “accidental” in 2012 and 2014, “rare” in 2015–2017, and “common” in 2019. In gillnets between 2012 and 2019, V ranged from 3% to 81% (26% in total) (Table 2). Accordingly, the species was “accidental” in 2015–2017, and “constant” in 2018–2019. This data includes the results for all sampled areas (including Neva Bay, where the species was not

Table 2. Number of beach seine and gillnet catches and frequency of the round goby occurrence in different parts of the eastern Gulf of Finland between 2012 and 2019 (see also Fig. 1).

Year	Areas of the eastern Gulf of Finland																						
	Luga Bay				Narva Bay				Koporye Bay				Inner Estuary*, Central and Island Area				Vyborg Bay, Berezovye Islands' Area				The entire eastern GoF		
	Beach seine																						
	A	*V*	N_i	Stns.	*A*	*V*	N_i	Stns.	*A*	*V*	N_i	Stns.	*A*	*V*	N_i	Stns.	*A*	*V*	N_i	Stns.	*A*	*V*	N_i
2012	1	100	1	1b	2	0	0						10	0	0		1	0	0		17	6	1
2013	2	0	0		4	0	0						12	0	0		5	0	0		35	0	0
2014	2	50	2	1b	2	0	0						29	0	0		3	0	0		52	2	2
2015	1	0	0						2	50	1	2b	5	20	3	5b					11	18	4
2016	1	100	1	1b					1	100	40	2b	11	18	31	4;5b	2	0	0		19	21	74
2017									5	60	16	2;3b	5	40	12	4;5b					13	38	28
2018																					0	0	0
2019	2	50	4	7b	1	100	8	6b	2	100	8	2;8b	4	50	3	5;9b	1	0	0		12	50	23
Total	**9**	**44**	**8**		**9**	**11**	**8**		**10**	**70**	**65**		**76**	**9**	**49**		**12**	**0**	**0**		**159**	**12**	**132**
	Multi-mesh gillnets																						
	A	*V*	N_i	Stns.	*A*	*V*	N_i	Stns.	*A*	*V*	N_i	Stns.	*A*	*V*	N_i	Stns.	*A*	*V*	N_i	Stns.	*A*	*V*	N_i
2012	34	0	0										9	0	0		3	0	0		82	0	0
2013	8	0	0										23	0	0		7	0	0		100	0	0
2014	8	0	0						1	0	0		22	0	0		2	0	0		76	0	0
2015	20	15	4	6;7n					2	0	0		24	0	0		6	0	0		87	3	4
2016					14	14	11	2n					20	15	10	12n					48	8	21
2017	3	67	3	7n	3	33	1	2n					24	4	1	13n	23	0	0		37	11	5
2018	21	76	35	6–10n	40	98	1395	1;3–5n					9	44	7	11n	5	0	0		75	81	1437
2019					101	74	714	1;3–5n					18	78	51	12–14n	6	17	1	15n	122	74	766
Total	**94**	**22**	**42**		**158**	**74**	**2121**		**3**	**0**	**0**		**149**	**15**	**59**		**52**	**2**	**1**		**627**	**26**	**2233**

Data is presented only for the areas where the species occurred in catches ever. Abbreviations: *A* – total number of catches; *V* – frequency of the round goby occurrence; N_i – number of the specimens caught; Stns. – stations where the species was caught (see also Fig. 1).
* For sampling with the beach seine only data for the Inner Estuary is presented.
** Mean *V* are estimated for each location from pool of all samplings.

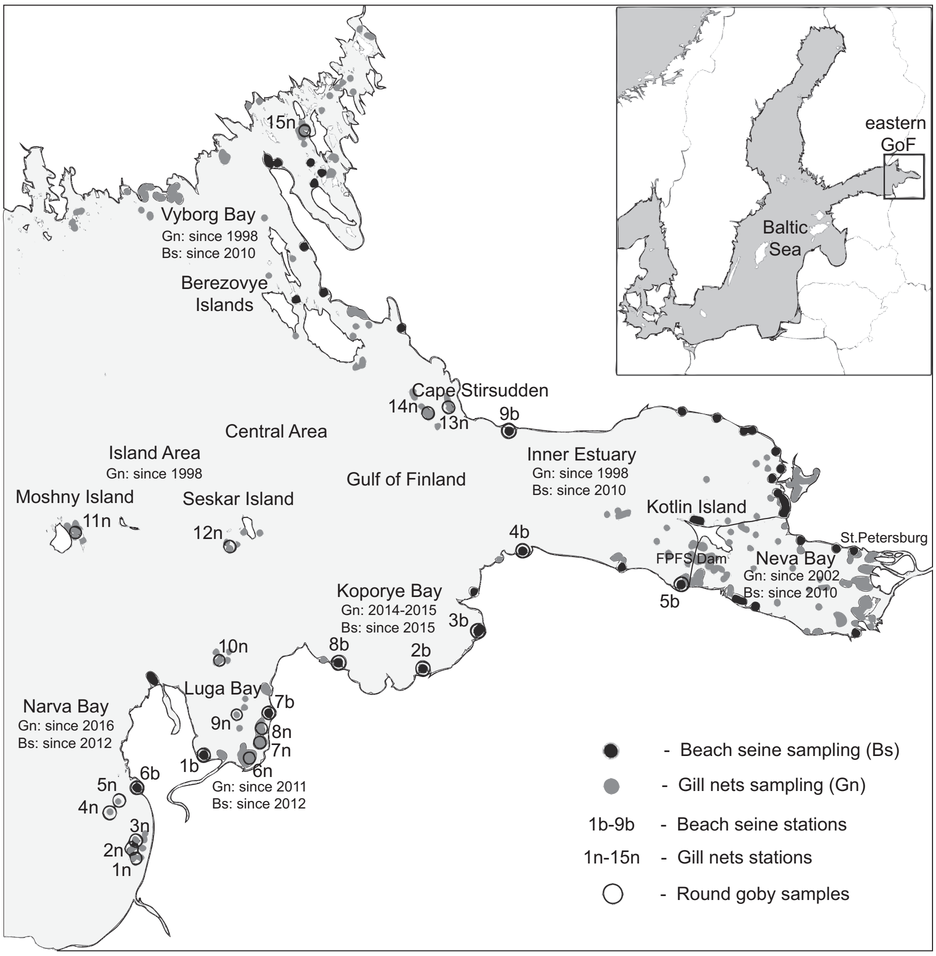

Figure 1. Stations in the eastern Gulf of Finland where round goby, *Neogobius melanostomus*, was sampled within 1998–2019 using multi-mesh gillnets (Gn, grey dots) and a beach seine (Bs, black dots) between 2010–2019. Stations, where the round goby was caught, are numbered and marked with circles: 1n–15n are the gillnet stations, 1b–9b are the beach seine stations. Years indicates sampling periods.

caught) for the period since it was first observed there. Due to the differences in numbers of catches and localities between years, *V* values are presented separately by the sampling area in Table 2.

V was highest between 2012 and 2019 in the shallow waters of Koporye Bay (70%); a relatively high occurrence was also observed in Luga Bay (44%). In the deeper waters, *V* was highest in Narva Bay (74%) (Table 2). In these areas, the species was classified as "constant" (Narva Bay) and "common" (Koporye and Luga Bays).

Density, biomass, and catch per unit effort. The density (*D*) of the round goby ranged from 0.1 to 10.0 ind. · 100 m^{-2} (mean ± SE = 1.9 ± 0.68) between 2012 and 2019, and biomass ranged from 0.1 to 9.4 g · 100 m^{-2} (mean ± SE = 1.7 ± 0.52). For 58% of the samples, density did not exceed 1 ind. · 100 m^{-2} (Table 3). In the shallow waters, the highest catches per 100 m^2 was observed in the Inner Estuary (max 10.0 ind. · 100 m^{-2}, mean ± SE = 2.0 ± 1.35) in Koporye Bay (max 9.5 ind. · 100 m^{-2}, mean ± SE = 2.6 ± 1.29).

The round goby was not found in gillnets before 2015, and was rare until 2018; CPUE and BPUE ranged from 0.3 to 4.8 ind. per 12 hours of fishing, and from 6.2 to 163.8 g per 12 hours of fishing, respectively (Table 4). It was first abundant in June 2018 in the catches of Narva Bay (means ± SE were 31.9 ± 5.71 for CPUE and 888.0±177.59 for BPUE, respectively). The highest catch throughout the monitoring period was 133.2 ind. · 12 h^{-1}, which was also in June 2018. CPUE was higher in Narva Bay (16.6 ± 2.58) (log-transformed data, ANOVA, $F = 45.9$, $P < 0.001$) than in other areas (1.9 ± 0.41), although the catches in Narva Bay varied between stations and seasons. In May–June 2018, catches per 12 h on stony bottom of the station 5n exceeded (log-transformed data, ANOVA, $F = 47.2$, $P < 0.001$) that at sandy bottom stations (87.6 ± 11.03 vs. 14.8 ± 1.91 ind. · 12 h^{-1}, respectively). In April–June 2019, the mean CPUE for Narva Bay was 18.2 ± 5.40 ind. · 12 h^{-1}, although station 5n was not sampled. Hence, mean CPUE was similar in spring and early summer in both 2018 and 2019 at the sandy bottom stations. Later in 2019, this value did not exceed 8.9 ± 1.42 ind. · 12 h^{-1}, although different grounds were observed.

Relative abundance (RN) and biomass (RB) in catches. The round goby was found to occur with 23 and 25 other fish species in the beach seine and gillnet catches, respectively. The most common species (arranged in ascending order of occurrence) were: gudgeon, *Gobio gobio* (Linnaeus, 1758); roach, *Rutilus rutilus* (Linnaeus, 1758); bleak, *Alburnus alburnus* (Linnaeus, 1758); common goby, *Pomatoschistus microps* (Krøyer, 1838); perch, *Perca fluviatilis* (Linnaeus, 1758); tubenose goby, *Proterorhius marmoratus* (Pallas, 1814); in the beach seine catches. In the gillnet catches, the most common species were perch, sprat, ruffe, *Gymnocephalus cernua* (Linnaeus, 1758), herring, and smelt.

In the beach seine catches within 2012–2019, RN and RB ranged from less than 0.1% to 11.1% (mean ± SE = 3.2 ± 0.70) and from 0.1% to 23.0% (mean ± SE = 5.1 ± 1.35), respectively (Fig. 2A). According to the mean RN

Table 3. Density (*D*) [ind. · 100 m^{-2}] and biomass (*B*) [g · 100 m^{-2}] of the round goby in catches of beach seine in the eastern Gulf of Finland.

Date	Narva Bay		Luga Bay		Koporye Bay		Inner Estuary	
	D	*B*	*D*	*B*	*D*	*B*	*D*	*B*
Jul 2012			0.1	0.4				
Jun 2014			0.4	1.0				
Aug 2015					0.3	1.7		
Sep 2015							0.3	0.1
Aug 2016			0.2	0.7	9.5	2.8	10.0	2.3
Sep 2016							0.3	4.9
Jul 2017					1.1	3.2		
Aug 2017					2.6 ± 2.16	5.1 ± 4.22	1.1 ± 0.74	1.5 ± 0.86
Aug 2019	2.7	0.2	1.1	0.1	1.0 ± 0.64	0.6 ± 0.39	0.7	0.1
Sep 2019							0.2	0.1

Mean values ± SE are given when two or more stations were sampled within one area (Fig. 1, Table 2).

Table 4. Catch per unit effort (CPUE) [ind. · 12 h^{-1}] and biomass per unit effort (BPUE) [g · 12 h^{-1}] of the round goby in catches of multi-mesh gillnets in the eastern Gulf of Finland. Mean values ± SE are given when two or more stations were sampled within one area (Fig. 1, Table 2).

Date	Narva Bay		Luga Bay		Seskar Island and Moshny Island*		Cape Stirsudden		Vyborg Bay	
	CPUE	BPUE	CPUE	BPUE	CPUE	BPUE	CPUE	BPUE	CPUE	BPUE
May 2015			1.0	56.0						
Jun 2015			1.0	23.0						
Aug 2015			2.0	103.0						
Aug 2016	4.8	163.8								
Sep 2016					1.4 ± 0.28	31.4 ± 8.22				
Jun 2017			1.5 ± 0.48	38.7 ± 18.72						
Sep 2017	0.3	6.2					0.5	8.8		
Jun 2018	31.9 ± 5.71	888.0 ± 177.59			2.4*	32.0*				
Oct 2018			1.8 ± 0.50	94.8 ± 24.91	1.3 ± 0.31	53.2 ± 13.52				
Nov 2018			1.0 ± 0.23	40.4 ± 14.22						
Apr–Jun 2019[1]	18.2 ± 5.40	490.4 ± 160.54								
Jul 2019	8.9 ± 1.42	233.5 ± 41.43			7.2 ± 4.44	222.6 ± 107.6	0.8 ± 0.04	49.1 ± 8.57		
Sep 2019					4.9 ± 2.68	243.3 ± 158.8	1.0 ± 0.20	41.0 ± 13.91		
Oct–Nov 2019	4.8 ± 1.28	229.3 ± 67.20							1.0	48.0

[1] Data obtained using gill nets of different mesh size (14, 18, and 20 mm) than in other lines, where multi-mesh gill nets of mesh size 12, 15, 20, 25, 30, 35, 45, and 60 mm were used. An asterisk * indicates a catches on Moshny Island, data without asterisks in such columns refers to Seskar Island.

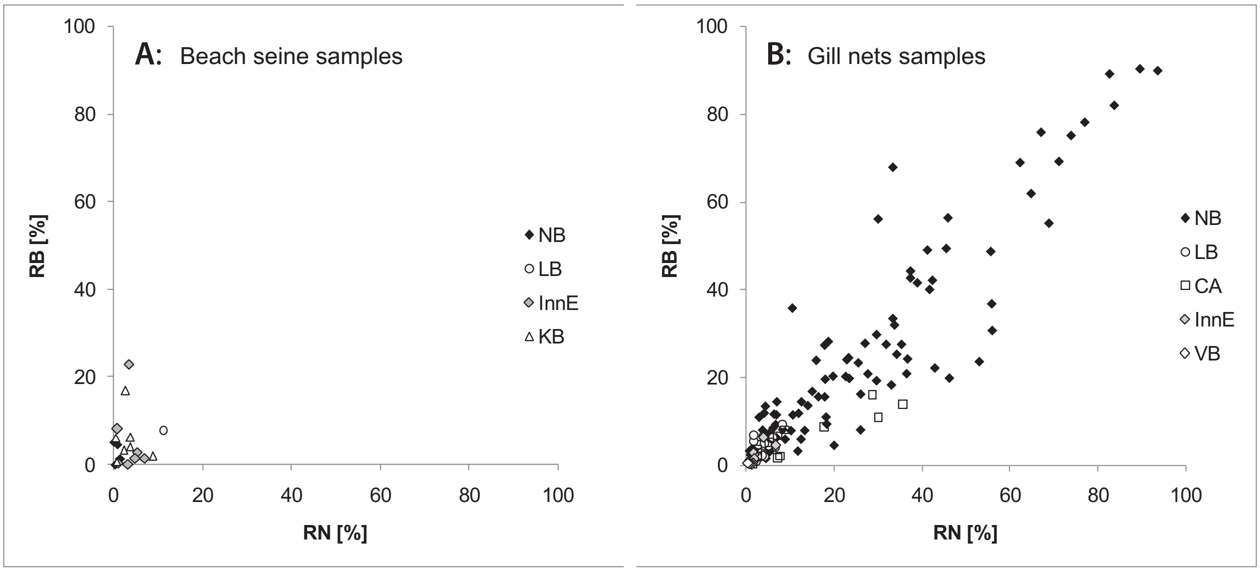

Figure 2. Relative abundance (RN) and relative biomass (RB) of the round goby, *Neogobius melanostomus*, in the eastern Gulf of Finland between 2012–2019. **A** Coastal beach seine catches. **B** Multi-mesh gillnet catches. Areas: LB = Luga Bay; NB = Narva Bay; KB = Koporye Bay; InnE = Inner Estuary; CA = Central and Island Area; VB = Vyborg Bay.

value, the species is considered as "moderate in number" in coastal stations.

Within 2015–2019, RN and RB in gillnet catches ranged from 0.3% to 93.4% (mean ± SE = 18.5 ± 1.76) and from 0.2% to 90.3% (mean ± SE = 17.5 ± 1.75), respectively (Fig. 2B). From 2015 to 2017 the RN and RB increased from 6.7 ± 1.81 and 3.5 ± 0.91 (mean ± SE), respectively. In 2018, these respective values increased to 23.4 ± 3.43 and 21.9 ± 3.31. In 2019, these values were 16.5 ± 2.02 and 16.2 ± 2.10, respectively. Accordingly, the species became "abundant" in gillnet catches in 2018.

The estimated RN was higher in Narva Bay (mean ± SE = 23.8 ± 2.25; log-transformed data, ANOVA, F = 16.1, $P < 0.001$) than in the other areas (Fig. 2B). In June of 2018 and 2019, the mean values (± standard error of the mean, SE) of RN in Narva Bay was 33.1 ± 4.33 and 11.0 ± 4.98, respectively, which is at least 3–4 times higher than in the later months.

In the gillnet catches, RN and RB were strongly correlated (Spearman's $R = 0.92$, $P < 0.001$), unlike the beach seine catches (Spearman's $R = 0.11$, $P = 0.66$). Therefore, in the shallow waters, round goby specimens never had high masses, even if they were numerous. However, it was more predominant in the deeper waters, in terms of both mass and numbers. Such correlation is explained by the differences in round goby size composition between shallow waters and offshore biotopes.

Size, age, and sex ratio. Juveniles of the age 0+ (85.3%), 1+ (13.8%), and 2+ (0.9%) were caught in the shallow waters of the southern coast (Table 5). Sex identification was possible only for fish with SL > 18 mm. The sex ratio was equal in age classes 0+ and 1+, while older specimens were sporadic in the shallow waters.

In late summer, young-of-the-year (YOY) gobies reached 42 mm (mean ± SE = 22.3 ± 0.48) SL and 1.69 g (mean ± SE = 0.27 ± 0.02) TW. The following July, length of yearlings (1+) ranged from 37 to 60 mm SL, and reached 72 mm SL in late August (Table 5). Males and females were not different in SL at age of 0+ and 1+ (t = 0.227, df = 55, $P = 0.821$, and U = 33.000, Z = – 0.241, $P = 0.810$, respectively).

In June 2018, round gobies caught by gillnets at depths of 6–8 m in Narva Bay ranged from 60 to 170 mm SL, and from 6.3 to 133.0 g TW (N_i = 1093, mean ± SE were 100.0 ± 0.11 and 30.4 ± 0.52, respectively). The age of the 172 specimens from this sample ranged from two to

Table 5. Age, length and mass of the round goby in the eastern Gulf of Finland.

Age*	Male					Female					Sex not determined				
	N_i	SL [mm]		TW [g]		N_i	SL [mm]		TW [g]		N_i	SL [mm]		TW [g]	
Beach-seine survey, N_i = 109. June–August 2012–2017															
0+	28	18–31	24.7 ± 0.61	0.12–0.63	0.34 ± 0.02	29	18–42	25.0 ± 0.78	0.12–1.69	0.36 ± 0.05	34	12–22	18.1 ± 0.42	0.04–0.25	0.13 ± 0.01
1+	9	36–72	55.5 ± 3.87	1.00–9.80	4.5 ± 1.02	8	41–71	54.8 ± 3.00	1.39–8.24	3.9 ± 0.71					
2+	1		81	14.80											
Gillnet survey, N_i = 172. June 2018															
2	4	77–90	81.0 ± 3.02	6.9–14.0	9.7 ± 1.51	10	68–77	71.2 ± 1.02	5.6–8.1	6.7 ± 0.29					
3	29	85–145	120.5 ± 3.00	10.9–73.5	43.5 ± 3.18	94	73–114	88.9 ± 0.80	6.6–27.9	13.6 ± 0.36					
4	7	106–155	132.6 ± 5.99	22.5–99.2	56.3 ± 9.20	22	106–145	124.8 ± 2.17	24.9–70.1	44.5 ± 2.50					
5	1		141	65.0		5	122–145	136.4 ± 4.91	43.0–91.6	65.4 ± 9.14					

Abbreviations: N_i – number of individuals. SL – standard length. TW – total weight. * The specimens marked + were collected during the period of active growth, which had the clearly visible zone of the current vegetation season in the otoliths (usually from the second half of June) (Kostûčenko 1961).

five years, with the age ratio 8.1%, 71.5%, 16.9%, and 3.5% for two-, three-, four-, and five-year-olds, respectively (Table 5). In the otoliths of gobies caught by nets in June, the growth zone of the current season has not formed, and the age ring of the last year had not yet been discerned. Therefore, the age of these specimens was marked without "+" (Table 5).

The sex ratio was female-biased, with the mean value of 3 females to 1 male, and this ratio increased with age. For example, the sex ratio was 2.5, 3.2, 3.1, and 5.0 females to 1 male at the age of two-, three-, four- and five-years-old (Table 5). Males were larger than females at the age of two ($U = 0.500$, $Z = –2.687$, $P = 0.007$) and three ($U = 221.000$, $Z = –6.801$, $P = 0.000$) years (Fig. 3, Table 5). In older fish, the differences were not significant, mainly due to the small number of individuals ($U = 47.000$, $Z = –1.503$, $P = 0.133$ for 4-years-olds and $U = 0.000$, $Z = 0.000$, $P = 1.000$ for 5-years-olds).

52.3% of all males (in the sample where age was estimated) had black spawning coloration.

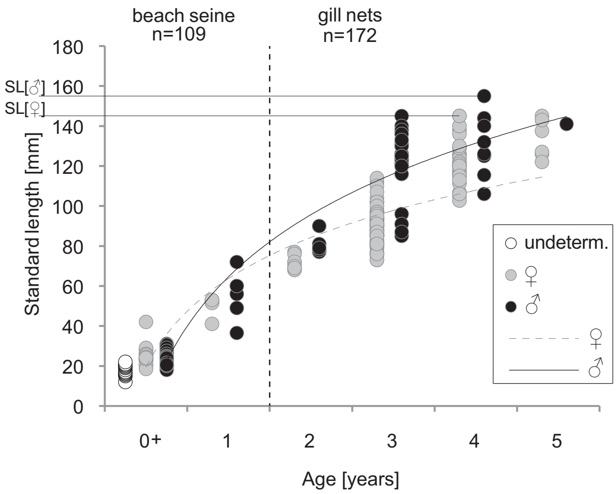

Figure 3. The size-at-age characteristics of round goby, *Neogobius melanostomus*. Fish caught by the beach seine and multi-mesh gillnets in the eastern Gulf of Finland between 2012 and 2018. Abbreviations: undeterm. = juveniles of undetermined sex; Sl [♂] = max SL of males; Sl [♀] = max SL of females. Curved lines are the log trends.

Discussion

Since the first reported occurrence of the round goby in the eastern Gulf of Finland (GoF) in 2012 (Uspenskiy and Naseka 2014), this non-indigenous species has increased its distribution range, abundance, and frequency of occurrence in catches in this area. Currently, it is caught mainly along the southern coastline, and to a lesser extent in the Island area and along the northern coast, but not within Neva Bay. Young-of-the-year (YOY) juveniles, yearlings, and adults up to five years old—including spawners—were caught, suggesting that the species has successfully colonized and is reproducing in these areas. In the following, we consider its population characteristics and the possible impacts on the ecosystem and fisheries.

Life span. The round goby is a fish with a short lifespan, with a predominance of younger age groups (Trifonov 1955). Although it can live up to 6 years, its average lifespan is 3–4 years (reviewed by Sokołowska and Fey 2011). This is consistent with the gobies sampled in the eastern GoF, where the maximum age was estimated to be 5 years old. YOY specimens were predominant in the shallow waters, while further from the coast in deeper habitats, 3-year-olds were the most abundantly sampled.

Sex ratio is almost equal in YOY specimens, but there was a female bias in fish older than two years. For gobies between the ages of 2 to 5 years old, the number of females increased from 2.5 to as many as 5 per male. A similar female-biased ratio was also observed in other areas and considered to be the result of males' mortality after the spawning season (Kostûčenko 1961; Charlebois et al. 1997). Nevertheless, male-biased populations have also been found (Corkum et al. 2004; Sokołowska and Fey 2011), which can be partly explained by fishing gear selectivity (Brandner et al. 2013b; Žák et al. 2018). In the presently reported study, both active and passive fishing gears were used, hence the female-biased ratio is more likely a feature of the studied population rather than the gear.

Growth. Male gobies were larger than females after the age of 2 years old, both in the eastern GoF and in other areas (MacInnis and Corkum 2000a; Kornis et al. 2012), including the Baltic Sea (Sokołowska and Fey 2011; Azour et al. 2015). This result is generally associated with the slower growth of females after maturation (Kostûčenko 1961).

In late summer, gobies of age 0+, 1+, and 2+ reached the standard length of 42, 72, and 81 mm, respectively. Overall, this corresponds well with the data of gobies in their native range. In the Sea of Azov, YOY also reach the length of 40–50 mm (SL), and rarely exceed 60 mm SL (Kostûčenko 1961). In the Bulgarian waters of the Black Sea, the mean length (SL) of the juveniles at this age were 65, 80, and 90 mm, respectively (Corkum et al. 2004). However, the round goby grows faster in other parts of the Baltic Sea. For example, in the waters of Sweden, gobies reached the mean total length of 100 and 130 mm at the ages of 1 and 2 years old, respectively (Florin et al. 2018). Along the Danish coastline, gobies of the age 0, 1, and 2 years reached 7, 15, and 19 cm (TL), respectively (Azour et al. 2015), i.e., these were apparently larger. In the presently reported study, the mean lengths (SL) of gobies at the age 2, 3, 4, and 5 years were 74, 96, 127, and 137 mm, respectively, which is lower than in other areas of the Baltic Sea and in the majority of the locations in their native range (see review Sokołowska and Fey 2011).

The higher growth rates have been previously attributed to newly established populations (Brandner et al. 2013a; Azour et al. 2015). Although the population in the eastern GoF can also be considered newly established, the growth rates reported here are apparently lower than in other newly established populations. The low salinity in the eastern GoF (0‰–5‰) may be a factor contributing to the slower growth rates. Indeed, round gobies in fresh and brackish Bulgarian waters and in the Laurentian Great Lakes were smaller than those in the Black Sea (MacInnis and Corkum 2000b; Corkum et al. 2004). However, the round goby was larger in brackish waters of the Gulf of Gdańsk (Baltic Sea) compared to those in marine waters of the Ponto-Caspian area (Sokołowska and Fey 2011). Moreover, the gobies reached a higher size-at-age in the Kuibyshev reservoir (Shemonaev and Kirilenko 2009) than in the eastern GoF. Apparently, other environmental factors are more important to growth. It is important to note that the population studied here is the northernmost of all populations mentioned above.

Spatial distribution and possible ways of the invasion. It is commonly assumed that the Ponto-Caspian round goby was translocated to the Baltic Sea via ballast waters, where it then spread further into the basin and established local populations (Sapota and Skóra 2005). Indeed, larvae and early juveniles migrate to the pelagic zone during the night and hence can be transferred with ballast waters and/or water currents (Hayden and Miner 2009). The round goby was first caught in Luga Bay of the eastern GoF in 2012 (Uspenskiy and Naseka 2014). Early life stages of the species could have been translocated there with ballast waters released in the nearly situated port Ust'-Luga and/or with currents from western areas. The prevailing circulation pattern in the GoF, which is eastward along the southern coast and westward along the northern coast (Zimin et al. 2011; Raateoja and Setälä 2016), can facilitate the spread of larval stages from western populations along the southern coastline.

In Muuga Bay (Estonia), the species was first observed in 2002 and has become abundant (Järv et al. 2011; Puntila et al. 2018). Notably, Muuga Bay is 230–250 km away from Luga Bay (along the coastline). Thus, the species may have naturally spread there during this period, given that the invasion front advances about 30 km per year (Azour et al. 2015). Three years after the first reported incidence in the GoF (2015), juveniles were caught by SPb FPFC roughly 110 km east of Luga Bay. The species was not previously found to the east of the dam (SPb FPFC), which can limit its easterly spread to Neva Bay. Along the northern coast of the eastern GoF, the species was caught occasionally in 2017–2019. The closest sample to the west was near the Kotka area (Finland) in 2010–2013 (Puntila et al. 2018), roughly 240 km away. Currently, the round goby is rarely found along the northern coastline, likely due to westward currents and/or lack of favorable conditions there.

The species occurrence was the highest along the southern coast of the GoF, where it is classified as "common" or "constant". Indeed, the conditions may be more appropriate there, as the coastal and seafloor topography is less fragmented and patchier than along the northern coast (Kotilainen et al. 2016). The location of the Leningrad nuclear power plant (NPP) on the southern coast and the associated release of heated water increase the water temperature in the adjacent areas (Dvornikov et al. 2017), which can facilitate the survival and self-spreading of the goby. For example, sampling from the Leningrad NPP outflow channels in 2017 and 2019 shows that the round goby CPUE (not less than 48 ind. · 100 m^{-2}) greatly exceeded that in the areas beyond the warm water (Uspenskiy unpublished data).

Wave exposure is also an important factor affecting the round goby distribution in the Baltic, as it is more likely to occur in areas with low exposure (Kotta et al. 2016). Relatively low wave exposure sites, classified as "sheltered", are situated in Vyborg, Neva, and Luga Bays; in contrast, the northern coast of the Inner Estuary and Narva Bay are "moderately exposed" (Wijkmark and Isæus 2010). In the first two areas (Vyborg and Neva Bays), the species is rare or has not been caught. However, the goby is common in Luga Bay and abundant in deeper waters, but scarce in shallow waters of Narva Bay. Thus, the species distribution in the eastern GoF does not seem to be markedly influenced by wave exposure.

In the eastern GoF, sandy and muddy bottom habitats were more prevalent in offshore areas, while the bottom diversity is rather high in coastal areas. Round gobies were caught with beach seine and nets on all types of bottom substrates, such as sandy, stony, and mixed bottom. In the Gulf of Gdańsk, the round goby prefers artificial biotopes and stony substrates, while the adjacent sandy areas were colonized to a lesser degree (Sapota and Skóra 2005). However, in the Sea of Azov, the round goby avoids stony substrates and vegetated biotopes (Smirnov 1986). Therefore, bottom substrate preference seems to be highly variable in different regions of the round goby distribution. The current study did not have enough data to analyze substrate preferences in the eastern GoF, hence we reserve this for future research.

Vertical distribution. YOY and 1+ gobies prevailed at depths less than 1.5 m, while three-year-olds predominated in catches at depths from 6 to 8 m. Beach seine sampling is not size-selective for gobies (Jůza et al. 2018), i.e., if adults inhabited the shallow waters, they would have been caught. Although gillnets may underestimate the number of smaller gobies (Jůza et al. 2018), we used gillnets with a 12 mm mesh size, which is small enough to capture juveniles over 60 mm SL but too large to collect smaller individuals. Thus, our result is more likely to be a consequence of the age group distribution than of the fishing gear selectivity. The observed pattern implies the migration of older gobies from shallow plains into deeper waters.

Abundance in the eastern GoF. The density of the round goby in shallow waters was higher along the southern coast, especially in Koporye Bay and the Inner Estuary. However, it never exceeded 10 ind. · 100 m^{-2}, which is essentially lower than in some other areas of the Baltic Sea. In the Estonian waters, goby abundance ranges from 1 to 9 ind. · m^{-2}, but has been estimated to increase to 20 ind. · m^{-2} (Puntila et al. 2018). Comparable densities are observed in some Danish areas with 2 ind. · m^{-2} (Azour et al. 2015). Relatively low catches in the eastern GoF suggest that the species has not reached its peak abundance yet.

CPUE for the gillnets was also the highest along the southern coast, in Narva Bay since 2018. Catches increased in June, and were higher at the stony biotopes (e.g., station 5n in Fig. 1), which are assumed to be spawning grounds since the male gobies there had spawning coloration. In the Gulf of Gdańsk, the latest gonad stages were observed in April and July, when spawning intensifies (Tomczak and Sapota 2006).

Relative abundance (RN) of the round goby was higher in offshore stations, where it markedly increased during 2018–2019 and hence became "abundant" in catches. In the shallow waters, the species may be considered as "moderate in number".

Potential impacts on the ecosystem. The growing role of this new species in the food webs of the eastern GoF can be seen by its increasing abundance and incorporation in the diets of the great cormorant, *Phalacrocorax carbo* (Busun and Uspenskiy unpublished data) and the grass snake, *Natrix natrix* (Bogdanov unpublished data). Similarly, the round goby is part of the great cormorant and grey heron, *Ardea cinerea*, diets in Curonian Lagoon (Rakauskas et al. 2013). In the Gulf of Gdańsk, it was estimated to contribute to up to 60% of the great cormorant diet (Bzoma 1998). Thus, cormorants can provide some top-down control of the invasive goby population. In addition, perch and pike-perch, *Sander lucioperca* (Linnaeus, 1758), feed on round gobies, and may also reduce its numbers (Oesterwind et al. 2017). In the Baltic Sea, the round goby occasionally occurred in the diet of pike, *Esox lucius* Linnaeus, 1758; shorthorn sculpin, *Myoxocephalus scorpius* (Linnaeus, 1758); turbot, *Scophthalmus maximus* (Linnaeus, 1758); European eel, *Anguilla anguilla* (Linnaeus, 1758); burbot, *Lota lota* (Linnaeus, 1758); cod, *Gadus morhua* Linnaeus, 1758 (see Wallin 2019). The grey seal, *Halichoerus grypus*, and the harbour seal, *Phoca vitulina*, also prey on the round goby in the Baltic Sea (Scharff-Olsen et al. 2018; Keszka et al. 2020).

The relative abundance of the round goby increased annually, which can also increase competition with other fish for benthos. Round goby juveniles feed on different benthic organisms, such as crustaceans, polychaetes, and chironomids, while adults become primarily molluscivorous and feed on any bivalves abundant in the region (Smirnov 1986; Skóra and Rzeźnik 2001). In the Baltic Sea, the round goby was found to feed mainly on zebra mussels, *Dreissena polymorpha*, and bay mussels, *Mytilus trossulus*; isopods, *Idotea balthica*, and chironomids are also abundant in stomachs (Skóra and Rzeźnik 2001; Rakauskas et al. 2013). In the Baltic Sea, food competition with native ruffe, flounder, *Platichthys flesus* (Linnaeus, 1758), and turbot was considered to be significant (Karlson et al. 2007; Rakauskas et al. 2013; Ustups et al. 2016), although the latter two are rare and of low commercial value in the eastern GoF. The ruffe is usually abundant in catches in coastal areas (Lajus et al. 2015), but has a low commercial value. Since the round goby diet may overlap with some demersal benthivorous fish species (Skóra and Rzeźnik 2001), diet competition can be expected with the roach, vimba bream, *Vimba vimba* (Linnaeus, 1758), and bream, *Abramis brama* (Linnaeus, 1758), which are important commercial species in the eastern GoF (Kuderskij 1999). The round goby is also known to feed on eggs of the herring and smelt (both are the main commercial species), potentially leading to a decrease in their populations (Wiegleb et al. 2018).

Conclusions

Since the first report of the round goby's occurrence in the eastern Gulf of Finland (GoF) in 2012, its abundance and distribution range have continued to increase. Currently, the species is common in some areas along the southern coastline. The finding of juveniles and pre-spawning adults suggests that this invasive species has successfully colonized this area, leading to our prediction of future expansion in this basin. However, its abundance in catches greatly fluctuates inter-annually, seasonally, and between the different areas of the GoF. Furthermore, the population size remains relatively low in most of the gulf area when compared to longer-established populations from other areas of the Baltic Sea. In the long term, the round goby can be considered a target species for commercial fisheries in the eastern GoF if the population size increases and the landings are profitable, as in the other Baltic regions. In the meantime, we recommend annual monitoring of the round goby population and its impact on the regional ecosystem and fisheries.

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