

# Assessment of Commercially Important Stocks of the Round Goby *Neogobius melanostomus* (Pallas, 1814) (Gobiidae) and its Relationship with the State of the Mediterranean Blue Mussel *Mytilus galloprovincialis* Lamarck, 1819 (Mytilidae) in the Gulf of Odessa, Ukraine

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**Abstract:** Using a mathematical model consisting of two modules, i.e. the Bayesian Schaefer Model and Length-based Bayesian Biomass, the state of the commercial stocks of the round goby *Neogobius melanostomus* in the Gulf of Odessa (Black Sea, Ukraine) is studied for the period 2009–2020. The results of the analysis are compared with the quantitative population parameters of the Mediterranean blue mussels *Mytilus galloprovincialis* around the coast of Odessa. The results show that (i) round goby stocks in the study area are now critically low and (ii) there was a noticeable decrease in mussel abundance and biomass in recent years off the coast of Odessa. These data suggest that when the biomass of mussels shorter than 20 mm decreases, the commercial stocks of round goby are reduced in the subsequent year.

**Key words:** stock assessment, fisheries, gobiids, Bivalvia, commercial species, fish diet

## Introduction

While fish stock assessments are generally considered an essential element of fisheries management, they often have a low priority in less-developed countries due to the high costs involved (COPE & PUNT 2009). Consequently, most stocks in such countries lack robust assessments, meaning that any subsequent practical advice will be biased and management measures potentially ineffective. In the

Black Sea, there is evidence that fish stocks have decreased gradually since the 1980s to the point that all stocks now are considered “unhealthy”, with confirmation of overfishing for most species (DEMIREL et al. 2020).

Ukraine is one of the top-ranked fishing countries in the Mediterranean Sea/Black Sea region (FAO 2018). Commercial fisheries in the Mediterranean are coordinated by the General Fisheries Commission for the Mediterranean (GFCM FAO). *This*

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commission is mostly concerned with turbot *Scophthalmus maeoticus* (Pallas, 1814), dogfish *Squalus acanthias* L., 1758, anchovy *Engraulis encrasicolus* (L., 1758), sprat *Sprattus sprattus* (L., 1758), horse mackerel *Trachurus mediterraneus* (Steindachner, 1868), red mullet (*Mullus barbatus* L., 1758) and whiting *Merlangius merlangus* (L., 1758) fisheries. In contrast, there has been little or no interest shown in the population status of gobies (Gobiidae) despite their local importance as a commercial fisheries species in the Black Sea, especially in Turkey and Bulgaria (GÜMÜŞ & KURT 2009, ZAREV et al. 2013, FAO 2020). In the recreational zone of the City of Odessa, e.g., anglers catch up to a tonne of gobies per day, even during the spawning period (KHUTORNOY 1998). While the commercial importance of gobies in the North-Western Black Sea (NWBS) varies significantly across years (BILKO 1971, APANASENKO 1973, STARUSHENKO & BUSHUYEV 2001), there are no published data on actual changes in gobiid populations in NWBS. Recently, there has been a significant decline in the numbers of gobies caught in the Sea of Azov (DEMCHENKO & TKACHENKO 2016, IZ-ERGIN et al. 2021), making this a highly topical subject for further study. One problem regarding such population studies, however, is that official statistics for commercial gobiid fisheries in Ukraine and other Black Sea countries do not separate gobiids by species, all being unified under the term “gobies”.

Throughout the 20<sup>th</sup> century, gobies have represented the dominant fish in the demersal fauna around the coast of Odessa (TKACHENKO & KHUTORNOY 2001, KHUTORNOY 2003, KOVTUN & TARASENKO 2005, VINOGRADOV & KHUTORNOY 2013, POPOV et al. 2016). This group includes the round goby *Neogobius melanostomus* (Pallas, 1814), mushroom goby *Ponticola eurycephalus* (Kessler, 1847), toad goby *Mesogobius batrachocephalus* (Pallas, 1814) and Pinchuk’s goby *Ponticola cephalargoides* (Pinchuk, 1976), representing the dominant fish in the demersal fauna around the coast of Odessa (TKACHENKO & KHUTORNOY 2001, KHUTORNOY 2003, KOVTUN & TARASENKO 2005, VINOGRADOV & KHUTORNOY 2013, POPOV et al. 2016). The round goby has consistently been recorded as the most numerous of the 17 gobiid species caught by net or angling in the Gulf of Odessa (CHERNIKOVA & ZAMOROV 2011, POPOV et al. 2016, ZAMOROV et al. 2010, 2015, 2019).

The round goby is a Ponto-Caspian species, with a natural range including coastal waters of the Black Sea, Sea of Azov, Marmara Sea and Caspian Sea as well as the lower reaches of inflowing rivers (SLASTENENKO 1955-1956, BOGUTSKAYA & NASEKA 2004, MOVCHAN 2011, BILECENOĞLU et al. 2014,

MANILO 2014). In recent decades, its range expanded to upper reaches of rivers in the Black Sea and Caspian Sea basins as well as to those in the North Sea and the Baltic Sea basins (SEMENCHENKO et al. 2009, BORCHERDING et al. 2011, HEMPEL & THIEL 2013, MANNÉ et al. 2013, VERREYCKEN 2013, ROCHE et al. 2015, KOTTA et al. 2016). This makes the round goby one of the most successful alien species in Europe (HIRSCH et al. 2016). Indeed, in some areas (but not all), the presence of round goby and other Ponto-Caspian gobies has been shown to have significant impacts (both positive and negative) on native fish assemblages (PIRIA et al. 2016).

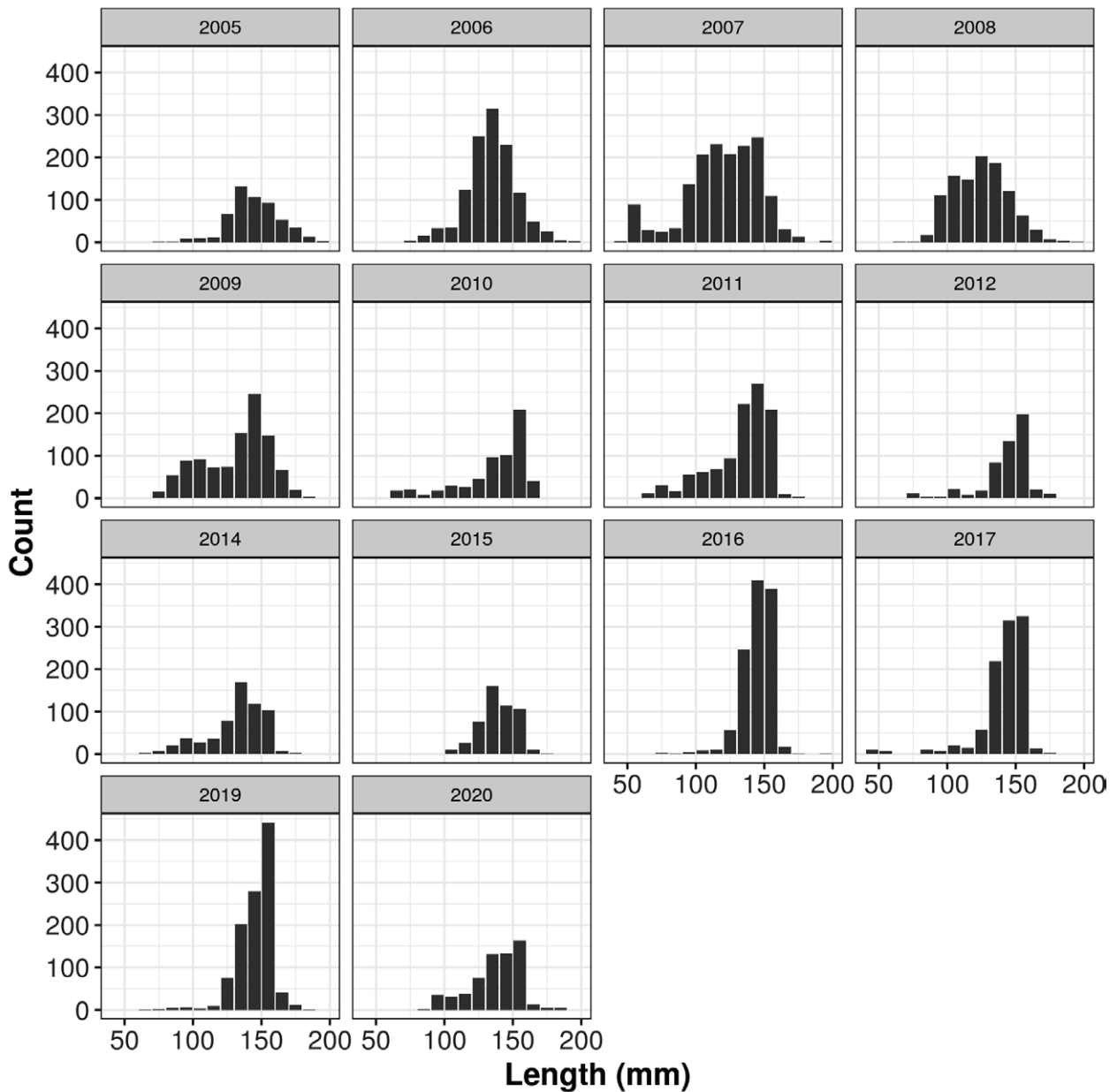
The Mediterranean blue mussel *Mytilus galloprovincialis* Lamarck, 1819 (herein referred to as mussels) is the main dietary item of round gobies in the Black Sea (KVACH & ZAMOROV 2001, ZAMOROV & CHERNIKOVA 2011, DEMCHENKO & TKACHENKO 2017). Its importance in the diet depends strongly on fish size, with gobies shorter than 150 mm in length feeding mainly on mussels shorter than 30 mm (ZAKUTSKIY & VINOGRADOV 1976, SCHWARTZBACH et al. 2020). While a recent study has shown a strong dependence between round goby range expansion in the Baltic Sea and declining mussel stocks (SKÓRA & RZEZNIK 2001), there have yet to be any studies examining the impact of the goby abundance on Mediterranean blue mussel stocks in its native geographical range.

In this study, we provide the first scientific estimate of round goby commercial stocks in the Gulf of Odessa and assess whether there is any relationship between goby abundance and the present state of the blue mussel population.

## Materials and Methods

To assess round goby population status, fish were caught with 50 m bottom gillnets (cell size 18–24 mm) around the Cape Small Fountain of the Gulf of Odessa (46.4415, 30.7783; depth 5–15 m, 200–500 m from the shore) from March to December in 2009–2020 (herein referred to as “scientific catch” or “gillnet catch”). Gillnets were checked every 24 hours and all fish caught were removed and subsequently frozen in a -20°C refrigerator. Prior to standard biological analysis, the fish were defrosted and each individual weighed to the nearest 0.1 g and measured for standard length (SL) to the nearest 1 mm. For the input data, see Fig. 1.

Data on commercial catches between 2009 and 2020, which also included data on fish length (SL), were provided by the Office of the State Agency for Fisheries in the Odessa Region. For both datasets,



**Fig. 1.** Length distribution of the round goby *Neogobius melanostomus* in scientific catches in the Gulf of Odessa.

length distributions charts were constructed using size groupings of 1 cm. Smaller specimens were only found sporadically in commercial gillnet catch areas; thus, only fish > 10 cm SL were used for further comparative analysis.

Two two-component mathematical models were used to assess round goby population status in the NWBS, Length-based Bayesian Biomass (LBB) and the Bayesian Schaefer Model (BSM) (FROESE et al. 2017, 2018a). LBB is a relatively new estimation method that can provide important parameters for fishery management such as the optimal length for first capture ( $L_{c\_opt}$ ) and the length at maximum possible yield per recruit ( $L_{opt}$ ), providing the

length-frequency distributions are representative of the fishery (FROESE et al. 2018a). In the resultant graph, the curvature on the right side is a function of total mortality ( $Z = M + F$ ) relative to the growth coefficient  $K$ , where  $M$  is the natural mortality and  $F$  is the fishing mortality (FROESE et al., 2018a). This curve is expressed by the equation:

$$N_L = N_{L_{start}} \left( \frac{L_{inf} - L}{L_{inf} - L_{start}} \right)^{Z/K}$$

where  $N_L$  is the number of survivors to length ( $L$ );  $N_{L_{start}}$  is the number at start length ( $L_{start}$ ) with

full selection (the length at which all individuals entering the gear are retained by it);  $Z/K$  is the ratio of total mortality rate  $Z$  to somatic growth rate  $K$ .

The lengths affected by partial selection are a function of the fishing gear (here assumed a trawl or another gear with a trawl-like selection curve):

$$S_L = \frac{1}{1 + e^{-\alpha(L-L_c)}}$$

where  $S_L$  is the fraction of individuals that are retained by the gear at length  $L$  and  $\alpha$  describes the steepness of the ogive.

The parameters of the selection ogive are estimated at the same time as  $L_{inf}$ ,  $L_c$ ,  $\alpha$ ,  $M/K$ , and  $F/K$  by fitting:

$$N_{L_i} = N_{L_{i-1}} S_{L_i} F \left( \frac{L_{inf} - L_i}{L_{inf} - L_{i-1}} \right)^{\frac{M}{K} + \frac{F}{K} S_{L_i}}$$

and

$$C_{L_i} = N_{L_i} \cdot S_{L_i} C_{L_i} = N_{L_i} \cdot S_{L_i}$$

where  $L_i$  is the number of individuals at length  $i$ ,  $L_{i-1}$  is the number at the previous length,  $C$  refers to the number of individuals vulnerable to the gear, and all other parameters are as described above (FROESE et al. 2018a).

Finally, the following equation describes the framework for approximating stock status from  $L_{inf}$ ,  $M/K$ ,  $F/K$  and  $L_c$ . First, given the estimates of  $L_{inf}$  and  $M/K$ ,  $L_{opt}$ , i.e. the size at which cohort biomass is at maximum, can be obtained as:

$$L_{opt} = L_{inf} \left( \frac{3}{3 + \frac{M}{K}} \right)$$

The given fishing pressure ( $F/M$ ) and the mean length at first capture that maximises catch and biomass ( $L_{c,opt}$ ) can be obtained from:

$$L_{c,opt} = \frac{L_{inf} (2 + 3 \frac{F}{M})}{(1 + \frac{F}{M})(3 + \frac{M}{K})}$$

Estimates of  $L_{c,opt}$  are used below to calculate a proxy for the relative biomass that can produce the Maximum Sustainable Yield (MSY; see below). Relative biomass ( $B/B_0$ ) was calculated as current

exploited biomass ( $B$ ) relative to unexploited biomass ( $B_0$ ). The LBB ( $B/B_0$ ) results were also used as priors for the BSM method, which requires independent estimates as inputs (SCHAEFER 1954, 1957).

$$B_{t+1} = B_t + r \left( 1 - \frac{B_t}{k} \right) B_t - C_t$$

where  $B_t$  is the biomass at year  $t$ ;  $r$  is the intrinsic rate of population increase;  $k$  is the carrying capacity (assumed equivalent to the unexploited population size);  $C_t$  is the catch in year  $t$ .

When the stock size is severely depleted, i.e. biomass falls below  $0.25 k$  (FROESE et al. 2017), a modified equation is used to calculate “depensation”, or reduced recruitment at low biomass levels (MYERS et al. 1995):

$$B_{t+1} = B_t + 4 \frac{B_t}{k} r \left( 1 - \frac{B_t}{k} \right) B_t - C_t \mid \frac{B_t}{k} < 0.25$$

The term  $4 B_t/k$  assumes a linear decline of recruitment below half of the biomass that can produce the MSY. MSY is calculated as the largest average catch or yield that can be taken continuously from a stock under existing environmental conditions, and fishing mortality ( $F_{MSY}$ ) as consistent with achieving MSY as:

$$F_{MSY} = r/2,$$

where  $r$  is the resilience rate estimated with the Markov Chain Monte Carlo (MCMC) method and the Schaefer function as likelihood (FROESE et al. 2017).

Other abbreviations used were as follows.  $B_{MSY}$  – the spawning stock biomass (SSB) that results from fishing at  $F_{MSY}$  for a long period.  $B_{pa}$  – a precautionary reference point for SSB.  $F$  – the instantaneous rate of fishing mortality expressed on an exponential scale, where  $F = 0.5$  means that  $1 - \text{EXP}(-0.5) = 39\%$  of fish are removed by the fishery each year.  $M$  – the instantaneous rate of natural mortality expressed on an exponential scale, where  $M = 0.5$  means that  $1 - \text{EXP}(-0.5) = 39\%$  of fish die by natural causes each year (COCHRANE 2002).

$L_{opt}$  was measured as the length, at which the biomass of an unexploited cohort would be at maximum, while  $L_{M=F}$  represents a proxy of  $L_{opt}$  on the condition that  $F = M$  (FROESE et al. 2018a).

For assessment of the status of marine biological resources where limited data on a species are available, BSM is an appropriate approach allowing estimations of MSY, exploitation level and

biomass, with corresponding confidence intervals from catches and resiliencies of the species being studied. The method is based on the Schaefer surplus production model and uses Bayesian MCMC (SCHAEFER 1954, GILKS 1996) to estimate growth and mortality parameters, relative exploitation level and stock size. The BSM approach combines well with LBB, which provides stock status priors. Priors for round goby resiliencies were taken from the recommendations of the FAO (see FROESE & PAULY 2021). This model has been widely tested and such an approach has already been applied for the assessment of many European fish stocks (FROESE et al. 2018b, LIANG et al. 2020, VARGHESE et al. 2020).

For the purposes of this study, scientific gillnet catch per fishing effort (g/gillnet per day) for data collected between 2005 and 2020 were used to tune the model, excluding data from 2013, during which fishing was carried out using 18 mm mesh gillnets, and 2018, when no scientific fishing took place.

Mohn's r-index was calculated for the average relative shift of retrospective estimates (MOHN 1999), with the upper permissible limit of the index for short-lived species (such as gobies) being taken as 0.30 (HURTADO-FERRO et al. 2015).

Between 2009 and 2019, analysis of mussel population structure in the Odessa region was carried out using quantitative samples obtained at sea with a Petersen grab, while standard hydrobiological indicators, such as average biomass and number of molluscs per 1 m<sup>2</sup> in the bottom community, were assessed using a standard 1 m<sup>2</sup> frame in the shallow coastal area. Average values were then obtained for annual mussel settlement characteristics from all mussel samples taken in the Odessa region over the analysis period. The size-age structure of mussels in each settlement was assessed using the length of the mollusc shell (in mm).

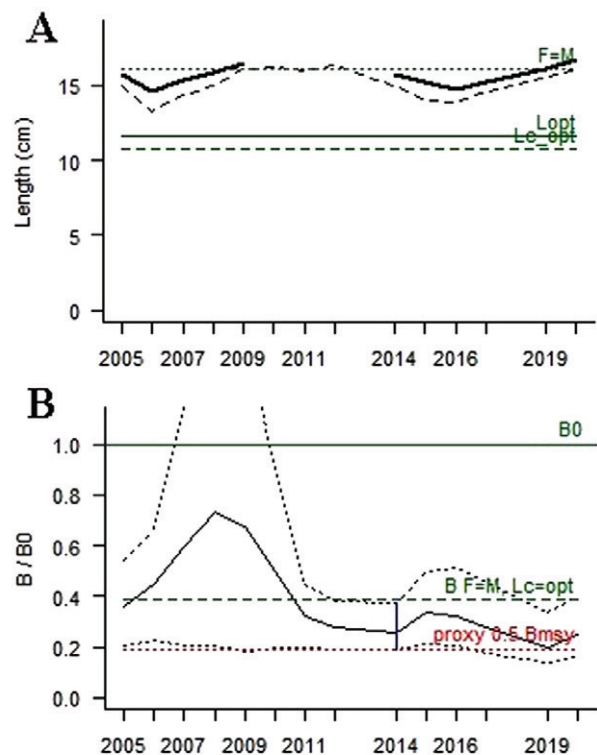
Statistical analysis of all data was undertaken using Statgraphics plus v.5.0. Multivariate analysis of variance (Multifactor ANOVA) was used to determine the influence of different factors on the dependent variable. Regression analysis was used to study the influence of mussel biomass (based on mussels < 20, the preferred size taken by round goby; see ZAKUTSKIY & VINOGRADOV 1976) on the biomass of round gobies in the Gulf of Odessa (see QUINN & KEOUGH 2002). In each case, mussel biomass values for the previous year were compared with the corresponding round goby catch per fishing effort in the following year.

## Results

LBB analysis indicated a round goby  $L_{c,opt}$  of 11.0 cm and  $L_{opt}$  of 12.0 cm, while  $L_{F=M}$  was equal to 16.0 cm (assuming that the instantaneous rate of fishing mortality (F) was equal to natural mortality (M)). Both the LBB and BSM models had similar curve forms and both showed a decreasing trend in biomass from  $B_{MSY}$  to  $B_{pa}$  over the same period. However, LBB overestimated fishing mortality rates compared with BSM, especially later in the study, possibly due to the different data sources used, i.e. LBB used length data from the scientific catch while BSM was based on commercial catch data.

Over the study period, the average size of captured round gobies was higher than the  $L_{c,opt}$ , though average SL in each catchment varied around the optimal  $L_{F=M}$  (Fig. 2a). Assessment of round goby stocks based on analysis of size series indicated a significant decrease in biomass over recent years, with biomass first decreasing to  $B_{MSY}$  then dropping close to critical levels (i.e.  $B_{pa} = 0.5 \times B_{MSY}$ ; Fig. 2b).

For a more defined assessment of round goby stocks, we used the scientific catch results from the



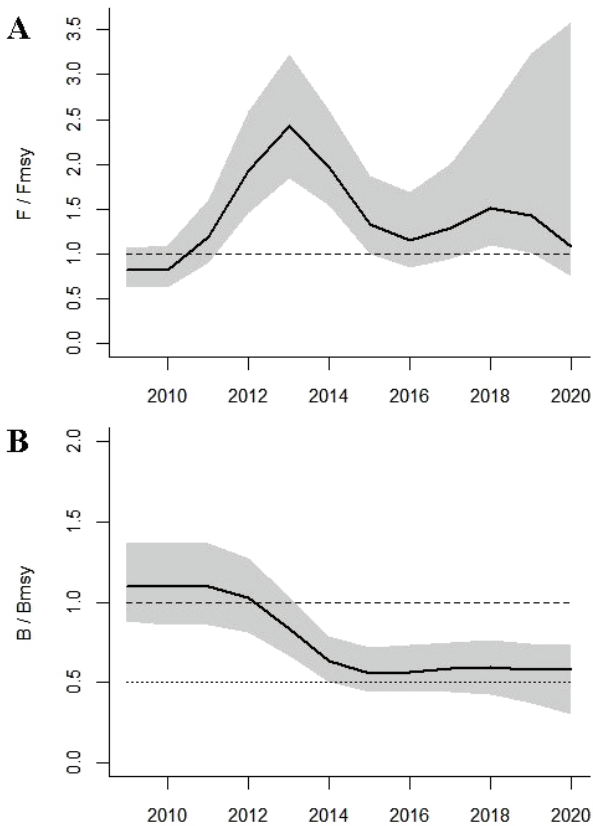
**Fig. 2.** Changes in the round goby length (A) and relative biomass (B) in the Gulf of Odessa between 2005 and 2020. F=M – the term under which length was determined (LF=M); B0 – maximum biomass parameter; BF=M, Lc=opt – biomass BMSY, occurred with term of F=M, Lc=opt; proxy 0.5 Bmsy: critical biomass.

commercial catch areas to adjust the model (Table 1). Using the BSM model, round goby biomass over the study period was lower than  $B_{MSY} = 60.0$  t, which corresponds to an MSY of 11.3 t per year and an  $F_{MSY}$  of 0.19. Over the same period that biomass de-

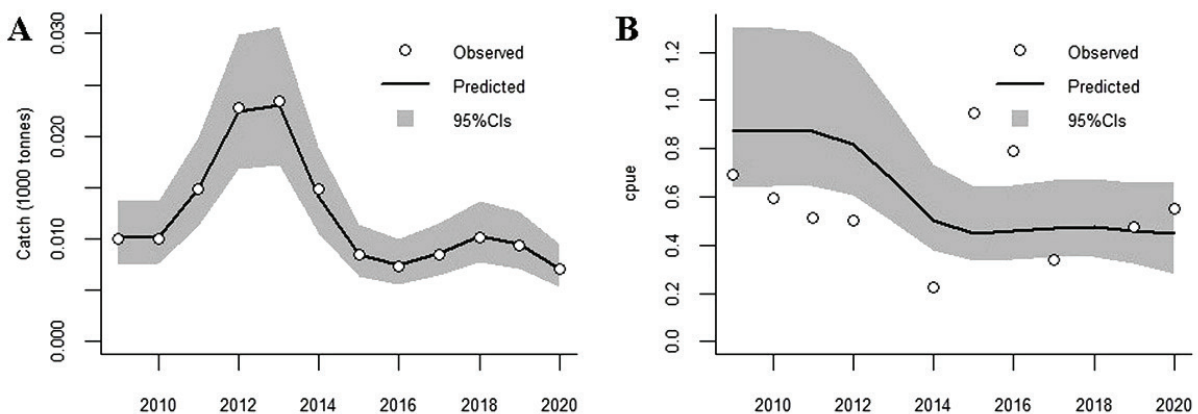
creased to critical levels ( $B_{pa} = 0.5 \times B_{MSY}$ ), fishing mortality increased slightly compared with the optimal  $F_{MSY}$ , with the result that biomass caught in 2020 was just 34.7 t (Fig. 3).

There was some discrepancy between fisheries and scientific catch area data, with maximum scientific catch values falling between 2015 and 2016 and maximum fishery values remaining relatively low over the same period, particularly when compared with the 2012 to 2013 season (Table 1). Fishery catch values were reconstructed well by the theoretical curve (Fig. 4A); however, the ancillary scientific data used for model tuning produced some inconsistencies (Fig. 4B), such that the theoretical curve had reduced accuracy. Nevertheless, a retrospective analysis of the final three-years data (Fig. 5) indicated that the model could be considered relatively stable for both fish mortality rates (F) and biomass (B), while Mohn's r-indices provided values of 0.03 for  $F/F_{MSY}$  (0.30 being the upper permissible limit for short-lived species) and 0.04 for  $B/B_{MSY}$ .

Mussel abundance and biomass in the bottom settlements displayed an uneven distribution, with mussel abundance varying from 70 to 13,300 ind.m<sup>-2</sup> per settlement (av. 1,750±339 ind.m<sup>-2</sup>). The minimum average mussel abundance in benthic settlements was 667 ind.m<sup>-2</sup>, registered in 2010, while the maximum was 4,400 ind.m<sup>-2</sup> in 2015 (Table 2). ANOVA indicated that the number of mussels in benthic settlements depended significantly on depth ( $p < 0.001$ ), with numbers changing significantly year-to-year ( $p < 0.01$ ). Mussel biomass differed significantly over the analysis period, ranging from 194.4 to 20,802 g.m<sup>-2</sup>, with an average of 4,641.81±757.09 g.m<sup>-2</sup>. Multifactorial analysis confirmed that mussel biomass was significantly related to year at the 95 % confidence level ( $p < 0.001$ ), and to covariates such



**Fig. 3.** Relative fishing mortality (A) and biomass (B) for the round goby in the Gulf of Odessa between 2009 and 2020.  $F/F_{MSY}$  – relationship between current fishing mortality and optimal fishing mortality;  $B/B_{MSY}$  – relationship between current biomass of commercial round goby stocks to optimal commercial biomass.



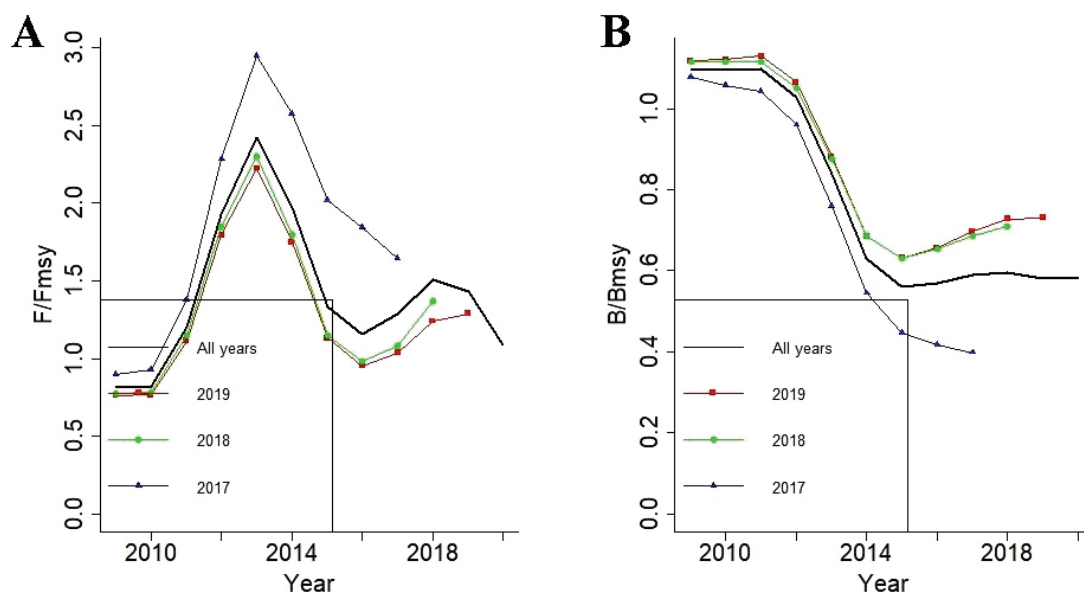
**Fig. 4.** Theoretical round goby catch curves with 95% confidence intervals (CI) for the Gulf of Odessa between 2009 and 2020. A – commercial catch areas (moving average for three years; t); B – scientific catch areas (g/gillnet); CPUE – relative catch per unit effort; each value divided by the maximum catch value achieved in 2015 (946 g).

**Table 1.** Fishery catch (t) and relative biomass index from gillnet surveys (g/gillnet) of round goby *Neogobius melanostomus* in the Gulf of Odessa between 2009 and 2020.

Catch area	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Fishery catch	12.6	6.3	6.2	29.6	41.7	1.0	6.8	9.0	2.7	17.7	8.6	4.1
Gillnet survey	694	593	513	504	-	224	946	792	340	-	474	551

**Table 2.** Population parameters for Mediterranean blue mussels *Mytilus galloprovincialis* in the Gulf of Odessa between 2009 and 2019.

Year	Abundance, ind. × m <sup>-2</sup>	Biomass, g × m <sup>-2</sup>	Average length, mm	Percentage with length ≤ 20 mm, %
2009	832±131	1777.0±334.6	25.64±1.59	36.9
2010	667±164	1686.9±453.6	26.19±1.01	31.4
2011	927±194	2967.4±690.9	29.49±1.80	25.4
2012	4394±1361	8202.5±2212.4	30.81±1.78	36.1
2013	1367±351	6999.1±2563.6	31.26±2.56	18.5
2014	4400	14134.5	33.93±1.35	15.6
2015	1207±600	3097.7±2021.4	28.88±1.77	22.7
2019	1967	19042.6	30.2±1.56	11.1

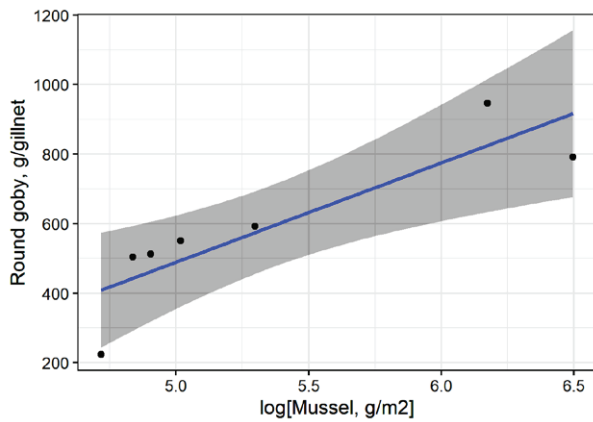

**Fig. 5.** Retrospective analysis of the relative round goby fishing mortality (A) and biomass (B).

as average mussel weight ( $p < 0.01$ ), percentage of mussels  $\leq 20$  mm in length ( $p < 0.05$ ) and average mussel length ( $p < 0.01$ ).

We found clear differences in the percentage of mussels with length  $\leq 20$  mm foraged (i.e. removed) from each settlement by year, with the lowest levels in 2011 (less than 1 %) and maximum levels in 2012 (72.9 %). There was a significant relationship between the percentage of mussels foraged and depth

( $p < 0.05$ ), while multifactorial analysis revealed a highly significant relationship between percentage of mussels foraged and year at the 95 % confidence level ( $p < 0.001$ ), and to covariates such as average mussel length ( $p < 0.001$ ) and weight ( $p < 0.01$ ).

Between 2009 and 2019, mussel settlements in the Gulf of Odessa showed relatively high population characteristic heterogeneity. However, round goby biomass showed a significant increase when



**Fig. 6.** Logarithmic regression (level-log) between round goby biomass in scientific catch areas (g/gillnet) and biomass of mussels  $\leq 20$  mm (g/m<sup>2</sup>) in the Gulf of Odessa between 2010 and 2020.

the biomass of mussels  $\leq 20$  mm was high in the previous year ( $p < 0.05$ ; Pearson correlation coefficient = 0.80). In order to provide a linear relationship, the data were log-transformed (FENG 2014) using the level-log, log-level and log-log natural logarithm functions (Fig. 6), the resulting Pearson correlation coefficients being 0.87, 0.70 and 0.78, respectively. The level-log regression with a slope of 285.75 and intersect of -939.54 provided the best fit (Fig. 6).

## Discussion

Our results confirm that there has been a decrease in the biomass of round goby caught by commercial fisheries in the Gulf of Odessa over recent years and that the demersal fish fauna in this region appears to be in a critical state. Overall, the reduction in anthropogenic pressure on the environment due to the 1990s economic crisis in Ukraine had a positive impact on the NWBS ecosystem, and on the Gulf of Odessa in particular (KHUTORNOY 1998, 2003, SNIGIROV et al. 2020), with self-restoration processes in the marine ecosystem resulted in an increase in both fish species diversity and abundance. In the late 1990s, 55 fish species were recorded off the coast of Odessa, compared with a total of 80 species registered up to 2020 (SNIGIROV et al. 2020). Further seven fish species were also registered in the coastal waters of the Gulf of Odessa at the beginning and middle of the 20th century. These are *Sardina pilchardus* (Walbaum, 1792), *Cyprinus carpio* (L., 1758), *Pelecus cultratus* (L., 1758), *Callionymus pusillus* (Delaroche, 1809), *Ponticola kessleri* (Günther, 1861), *Ponticola syrmian* (Nordmann, 1840), *Dactylopterus volitans* (L., 1758) and *Scomber scombrus* L., 1758 (KISILEVICH

1908, YATSENKOVSKIY 1909, ZAMBRIBORSHCH et al. 1995, CHERNIKOVA & ZAMOROV 2011, MOVCHAN 2011). These data bring the total number of fish species in the Gulf of Odessa in the observation period of this study to 87.

A similar trend in decreasing of the biomass and abundance is observed in Mediterranean blue mussels, a favoured prey of round gobies and many other demersal fishes, with average abundance decreased by 1.2 times and biomass by 2.4 times over the last two decades (VOROBYOVA et al. 2017). Two comparative studies of the main taxonomic groups of macrozoobenthos in the Gulf of Odessa, i.e. SINEGUB & RYBALKO (2001) in 1994–1999 and VOROBYOVA et al. (2017) in 2005–2015, showed a 1.8 times increase in biodiversity. In each case, the Mediterranean blue mussel formed the bulk of biomass. However, while mussels represented 96.0% of biomass in 1994–1999, this had dropped to 81.4% in 2005–2015. These data clearly suggest a connection between the reduction in mussel abundance over recent decades and the apparent reduction in round goby numbers.

The most likely factor affecting blue mussel populations (and thus round goby numbers) is the post-establishment spread of the veined rapa whelk *Rapana venosa* (Valenciennes, 1846), which is now widespread in the Black Sea. This polyphagous gastropod has a wide dietary spectrum, covering almost all common bivalve species in the Black Sea, along with some gastropods and crustaceans (GOVORIN & KURAKIN 2011). However, one of its preferred dietary items is the Mediterranean blue mussel (SINEGUB & RYBALKO 2001, GOVORIN & KURAKIN 2011). GOVORIN & KURAKIN (2011) found that rapa whelks near Snake Island (Ukraine) were reducing the local blue mussel population by 33 to 79 ind.  $\times$  day<sup>-1</sup> $\times$ m<sup>2</sup>. While the size of mussels taken will depend on the size of the whelk (STADNICHENKO & KURAKIN 2014), the mussel predated upon was 36.3 $\pm$ 1.5 mm medium length and 3.9 $\pm$ 0.2 g weight each day, meaning that individuals of 20–40 mm in length (which make up the bulk of the mussel population) receive the greatest predation pressure. Therefore, the rapa whelk poses a real threat to natural mussel populations, and consequently to round goby and other bottom-dwelling fish species foraging on the blue mussel such as the grey wrasse *Symphodus cinereus* (Bonnaterre, 1788) (DEMCHENKO & TKACHENKO 2017, KVACH & ZAMOROV 2001, SINEGUB & RYBALKO 2001, SNIGIROV et al. 2012, 2013, GOVORIN & KURAKIN 2011, VOROBYOVA et al. 2017, ZAMOROV & CHERNIKOVA 2011).

Clearly, the Mediterranean blue mussel as the main component of the Black Sea benthic community and an important dietary item for round goby

(KVACH & ZAMOROV 2001, VOROBYOVA et al. 2017) is heavily threatened by ongoing predation by the rapa whelk. Therefore, methods need to be developed (i) to protect existing mussel populations and (ii) to encourage and protect new populations replacing those predated. One method that has shown success in increasing the regional abundance and diversity of both demersal and pelagic fish in the Mediterranean is the construction of artificial reefs (BECKER et al. 2019, GROSSMAN et al. 1997, FOLPP et al. 2020). These structures are now commonly used to increase production of commercial species in areas where the lack of reef habitats limits populations (BOHNSACK et al. 1997). In some cases, such artificial reefs have been shown to develop fish and greater benthic communities than those on natural reefs (PONDELLA et al. 2002, PERKOL-FINKEL & BENAYAHU 2004). Previous studies in the Mediterranean region have also shown that the Mediterranean blue mussel rapidly becomes a dominant component of such artificial reef communities (NICOLETTI et al. 2007, RISSO-DE FAVERNEY et al. 2010). Therefore, such artificial reefs may represent an important approach to re-establishing round goby populations along the Ukrainian Black Sea coast.

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