Round gobies are small, soft-bodied fish, characterized by a distinctive black spot on the first dorsal fin. © Maciej Bonk.

Invasive Alien Species native to parts of the EU: The round goby (*Neogobius melanostomus*)

Scientific name(s)	*Neogobius melanostomus* Pallas, 1814
Common names (in English)	Round goby
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Date of completion	21/10/2019
Citation	Verreycken, H. 2019. Invasive alien species native to parts of the EU: The round goby (*Neogobius melanostomus*). Technical note prepared by IUCN for the European Commission.

1.1. Native range within the EU

Neogobius melanostomus is widely distributed throughout the Ponto-Caspian basins, in freshwater, estuarine and coastal habitats. The global native range of the round goby consists of the littoral zone of the Black Sea, Sea of Azov, Sea of Marmara and the Caspian Sea, as well as the estuaries and downstream parts of the rivers Danube, Dniestr, Dniepr, Don and Ural (Kottelat and Freyhof, 2007). In the EU, it is native in Romania and Bulgaria where it inhabits tributaries of the Black Sea. In the Danube basin, the historical limit of its distribution was located in Vidin in Bulgaria (Manné *et al*., 2013).

1.2. Alien distribution within the EU

In the Danube basin, round goby moved upstream and was recorded for the first time in Serbia in 1997, in Vienna (Austria) in 2000, near Budapest (HU) in 2001, in Slovakia in 2003, in Germany in 2004 (Kottelat and Freyhof 2007) and in Croatia in 2011 (Manné *et al*., 2013). The round goby was found to be the most abundant species in offshore trawling catches in the Upper (Austria), Middle (Slovakia, Hungary, Croatia, Serbia) and Lower Danube (Bulgaria, Romania) (Szalóky *et al*., 2015). In France, the round goby is present and abundant only in the northeastern rivers (Meuse, Moselle and Rhine) (Manné *et al*., 2013). The round goby reached the Baltic Sea by the Gulf of Gdansk (Poland) in 1990 and the German part of this sea in 2002 (Kottelat and Freyhof, 2007). It was recorded in the Rhine delta (The Netherlands) for the first time in 2004, where it is now widespread and abundant. Later, it was reported in Germany between Düsseldorf and Cologne in 2008, and upstream of the confluence with the Neckar River in 2010 (Hartmann, 2010). Further west, it expanded into the basin of the Scheldt River and into the Albert Canal in Belgium in 2010 (Verreycken *et al*., 2011), and nowadays is abundant in most Belgian canals and the large rivers of the Meuse and Scheldt basins (Verreycken, unpublished data). It was recorded in Lithuania in 2002, but now occurs only in low numbers and is believed not to be invasive there (Rakauskas *et al*., 2018). The species is also widespread in Czechia (Šlapanskýa *et al*., 2017) and abundant in the Moselle in Luxembourg (Ries and Pfeiffenschneider, 2019). The most recent observations appeared in the northern regions (Northern Baltic Proper, the Gulf of Bothnia and the Gulf of Finland, i.e. Denmark, Finland, Estonia, Latvia, Lithuania) and on the eastern and western coasts of southern Sweden (Kotta *et al*., 2016). In 2012, it has been reported also in Italy, in the Po basin where the species spread (Busatto *et al*., 2016).

1.3. Status in EU Member States and the United Kingdom

AT	BE	BG	CY	CZ	DE	DK	EE	EL	ES	FI	FR	HR	HU
3	3	4		3	3	2	2			2	3	3	3
IE	**IT**	**LT**	**LU**	**LV**	**MT**	**NL**	**PL**	**PT**	**RO**	**SE**	**SL**	**SK**	**UK**
	2	2	2	2		3	3		4	2		3	

Presence codes: 1 – Native present; 2 – Alien; 3 – Alien invasive (i.e. evidence of impact); 4 – Both native and alien; 5 – Both native and alien invasive (evidence of impact); 6 – Cryptogenic.

Country names: AT – Austria; BE – Belgium; BG – Bulgaria; CY – Cyprus; CZ – Czechia; DE – Germany; DK – Denmark; EE – Estonia; EL – Greece; ES – Spain; FI – Finland; FR – France; HR – Croatia; HU – Hungary; IE – Ireland; IT – Italy; LT – Lithuania; LU – Luxembourg; LV – Latvia; MT – Malta; NL – Netherlands; PL – Poland; PT – Portugal; RO – Romania; SE – Sweden; SL – Slovenia; SK – Slovakia; UK – United Kingdom.

1.4. Areas within the EU where the subspecies is a potential threat, but not yet present

The round goby is not yet present in the British Isles (Ireland, Great Britain) and in most of the Mediterranean area (Spain, Portugal, Greece). It is unclear why these areas have not been invaded yet, as one of the main pathways of introduction over long distances is ballast water discharge. For the British Isles, an explanation may be that ballast water exchange is only permitted in UK ports if they have a ballast water reception facility. Otherwise, exchange must occur within designated ballast water exchange areas and there are none designated for the Irish Sea/Bristol Channel or the English Channel (Stacey Clarke, pers. comm.). Furthermore, there is no freshwater connection to mainland Europe, which makes secondary dispersal from infested areas impossible (Gordon Copp, pers. comm.). The round goby was not considered as a high risk species of becoming invasive in the UK, among 23 Ponto-Caspian species expected to be introduced in the UK from mainland Europe (Gallardo and Aldridge, 2015). Almeida *et al.* (2013) screened the round goby with the Fish Invasiveness Scoring Kit (FISK) and categorised it to be of high risk (second highest category) of becoming invasive in the Iberian peninsula.

2. Pathways of introduction

In both the USA and Europe, a combination of transfer by marine and inland shipping, and active swimming, has contributed to the rapid long-range dispersal of *Neogobius melanostomus* (Hensler and Jude 2007, Roche *et al.* 2013), with anthropogenically modified habitats, such as navigable rivers with rip-rap banks, typically facilitating successful establishment of new populations (Ray and Corkum, 2001; Janáč *et al.*, 2016).

N. melanostomus larvae are nocturnally pelagic, feeding on zooplankton at or near the water surface (0–9 m depth) (Hensler and Jude, 2007; Hayden and Miner, 2009). As such, nocturnal ballasting could easily result in the transport of thousands of juveniles at a time, and night-time foraging suggests that *N. melanostomus* would be able to survive in dark ballast tanks for extended periods (Hayden and Miner, 2009).

The opening of the Main-Danube-Rhine canal in 1992 created a corridor between the Rhine and the Danube drainages, linking the Black Sea basin with the North Sea basin (also called the Southern corridor)(Leuven *et al.*, 2009). This connection has made it possible for inland ships to travel from the Black Sea ports to the North Sea ports, but also for Ponto-Caspian species to actively swim from their native area to new areas. Evidence strongly suggests that, following its initial introduction, *N. melanostomus* has spread in Europe both through commercial shipping within invaded ecosystems and natural dispersal (Kornis *et al.*, 2012). The rapidity of downstream spread (>16 km/year) is most likely the result of goby early life stage drift (Janáč *et al.*, 2013).

The use of round goby as live bait to catch predatory fish species is also recognised as an important pathway for secondary introductions (Drake and Mandrak, 2014). Indeed, in Italy, the species has been first found in an area devoted to angling (Busatto *et al.*, 2016).

3. Significant impacts on biodiversity

In Europe, the round goby is considered one of the "100 worst" invasive species (Vilà *et al.*, 2009). Hirsch *et al*. (2016b) discovered round goby impacts to be profound, but surprisingly complex. Even if identical native species were affected, the impacts remained less comparable across ecosystems than expected.

A diet overlap, suggesting competition for food, between small flounders *Platichthys flesus* and round gobies was observed in the Gulf of Gdansk, Baltic Sea (Karlson *et al*., 2007). Round goby introduction appears to have also had a negative impact on native 0+ fish abundance and species richness in the Elbe River in Czechia (Janáč *et al*., 2019) and on species richness in the Meuse River in Flanders (Belgium) (Verreycken and Van Calster, in prep.). In the Meuse River in the Netherlands, in the years following the arrival of *N. melanostomus* in 2011, a rapid decline in native bullhead *Cottus perifretum* average density was observed (van Kessel *et al*., 2016). The native ruffe *Gymnocephalus cernua* almost completely disappeared in three artificial lakes of the Biesbosch area in the Netherlands, only two years after the invasion of round goby, due to a similar benthic lifestyle and high niche overlap (Jůza *et al*., 2018).

Mikl *et al*. (2017) revealed that gobies had a negative impact on invertebrates at two investigated sites in the Dyje River, with overall invertebrate density reduced by 15% at one site with only tubenose goby, and 36% at a site where both round and tubenose goby were present. In the Austrian Danube, characteristic fluvial fishes revealed negative associations (population losses) with invasive gobies, namely barbel *Barbus barbus* and Danube whitefin gudgeon *Romanogobio vladykovi* (Ramler and Keckels, 2019).

Ojaveer *et al.* (2015) summarise the following impacts of the round goby in the Baltic Sea: diet overlap with flounder *Platichthys flesus* and negative correlation between the abundances of both species, predation on eggs of commercially valuable fish, reduction of the density of benthic invertebrates (which are shared prey with numerous native species), bioaccumulation of contaminants such as mercury or polychlorinated biphenyls (PCBs) from polluted sediments (causing biomagnification of several toxic substances in the food chain), and functioning as a vector of botulism to avian predators.

Round gobies range in length from 4 to 10 inches, and in weight from 5 grams to 80 grams, increasing as they age. Male round gobies are larger than females. © Yuriy Kvach. CC BY-SA 4.0.

Round gobies are believed to detect prey only while stationary. © Maciej Bonk.

4.1. Measures to prevent introduction of the species

Measure 1: Ballast water management

Ballast water treatment and management, as mandated by the Ballast Water Management Convention (BWMC) (IMO, 2004), entered into force in September 2017, is essential for limiting the introduction and spread of the round goby (Ojaveer *et al.*, 2015). Vessels to which the BWMC applies will be expected to have ballast water systems fitted that enable on-board cleansing of water to meet the Ballast Water Exchange standard in regulation D2. At present, only newly built vessels are guaranteed to have such systems fitted, so most vessels will still be exchanging offshore (freshwater with sea water and vice versa) until the deadline to meet D2 standards (08/09/2024). A laboratory experiment found that all *N. melanostomus* died within 48 hours under 30 ppt salinity (Ellis and MacIsaac, 2009). This experiment suggests that current ballast water exchange regulations, during which ballast tanks are filled with ocean water for ca. 5 days, may prevent future *N. melanostomus* introduction events (Ellis and MacIsaac, 2009).

Unfortunately, inland ships and no-ballast-on-board (NOBOB) ships, to which the BWMC does not apply, will still be able to disperse the round goby across the EU.

Measure 2: Biosecurity measures, coupled with awareness campaigns

Recreational boats can serve as vectors for invasive fish, with fish eggs acting as propagules. Preventive approaches, coupled with awareness campaigns, such as the EU codes of conduct on anglers[1]/recreational boating[2] and invasive alien species (IAS) and the 'Check, Clean, Dry' campaign (Ireland[3] and UK[4]), targeting (recreational) boats and ships as vectors of IAS, can diminish and maybe prevent the introduction (of the eggs) of the round goby (Adrian-Kalchhauser *et al.*, 2017). It is plausible that goby eggs attached to boats, anchors or gear may be transported across watersheds. In experimental trials, Hirsch *et al.* (2016a) found that goby eggs show resistance to physical removal (90 mN attachment strength of individual eggs) and stay attached if exposed to rapid water flow (2.8 ms^{-1} for 1 h). Even when exposing the eggs to air, the hatching success remained high (>95%), even after eggs had been out of water for up to 24 h (Hirsch *et al.*, 2016a). As such, biosecurity measures can only be effective if applied rigorously.

1 https://easin.jrc.ec.europa.eu/easin/Document/EuropeanCodeofConduct/Recreational%20fishing%20and%20Invasive%20Alien%20Species.pdf
2 https://rm.coe.int/1680746815
3 http://www.biodiversityireland.ie/check-clean-dry/
4 http://www.nonnativespecies.org/checkcleandry/

4.2. Measures to prevent secondary spread of the species

Measure 1: Habitat rehabilitation

Altitude (often considered a surrogate of several habitat parameters) limits the current distribution of *N. melanostomus* both in Slovakia and other regions of Europe (Jakubčinová *et al*., 2018). Dispersal of the round goby is partly density driven, and intraspecific competition for food may cause continued dispersal of the species (Azour *et al*., 2015). Secondary spread can thus potentially be slowed down by diminishing the species density.

Round goby are found to be present most frequently at sites that have suffered from hydromorphological alterations, and waters with nature-friendly banks and substrate types are known to contain lower densities of round gobies than non-natural bank and substrate types. Therefore, habitat restoration, including banks, beds and flow regimes may limit the spread of round goby by reducing their densities.

For example, removing rip-rap from the banks, will result in lower densities of round goby, as they use large stones as shelter and spawning habitat (van Kessel *et al*., 2013). This measure can be applied to most non-navigable rivers.

Measure 2: Temporarily keep fish barriers

Until the mechanisms that result in the high invasion success of Ponto-Caspian species are well understood, isolated populations of endangered and/or protected species may only be preserved by implementing anthropogenic, and restoring, natural barriers to goby invasion (Rahel, 2013; van Kessel *et al*., 2016). To preserve environmentally valuable, uninvaded upstream parts of rivers, temporarily keeping fish barriers can help to prevent invasion by round goby and other invasive fish species.

A negative side effect is that other (native) fish species may be hindered in their migration by this measure. The measure can only be applied effectively to small, upstream parts of rivers.

Measure 3: Biosecurity measures (see Measure 2 of Section 4.1.)

Measure 4: Electrical barriers

Electrical barriers could be used to limit the movement of round goby into new waterways. A Smith-Root downstream-deterrence electric barrier with voltage gradients up to 5 V/cm was effective in preventing round goby movement in a Michigan stream, and could be implemented in artificial connections between watersheds (Savino *et al*., 2001). In the Chicago Sanitary and Ship canal, an electric barrier was constructed in part to prevent the spread of *N. melanostomus* into the Mississippi River catchment (Steingraeber and Thiel, 2000). While *N. melanostomus* crossed the barrier site prior to its activation, electric barriers effectively prevent passage by *N. melanostomus* and other fishes (Steingraeber and Thiel, 2000). As such, other (native) fish species may also be affected by this measure.

Measure 5: Prohibition of the use of round goby as live bait and its release into the wild

Live-bait anglers represent highly mobile vectors for the movement of the round goby, with frequent overland transport of fishes (Drake and Mandrak, 2014). The use of the gobies as bait fish, and the release of unwanted fish, are important vectors for the introduction of this species. This can be address by prohibiting the use of round goby as live bait, and releasing it into the wild, but these measures need to be effectively enforced. In addition, providing information for and creating awareness with sport fishermen, aquarium and pond holders should be intensified. Full cooperation of these stakeholder groups (e.g. anglers, see EU code of conduct in Measure 2 of Section 4.1.) is necessary for this measure to be effective.

4.3. Measures to rapidly eradicate the species at an early stage of invasion

Measure 1: Sustained trapping and removal of round goby adults and eggs

N'Guyen *et al*. (2018) removed 3,457 round goby adults with baited minnow traps (in 99 weeks between 2012 and 2016) and 336,170 round goby eggs with spawning traps (in 25 weeks in 2014) and using this data modelled a proportional removal. They showed that various combinations of removal proportions of eggs and adults are possible to cross an analytically derived, removal-induced extinction boundary (i.e. to reach eradication; defined as 10^{-6} individuals left per m^2). Their model showed that starting population control soon after detecting the species (early start) requires, in total, fewer years to achieve 'eradication', than controlling an established population (late start). To reach an eradication success rate of 95%, 13 years effort for early start vs. 18 years for late start are needed when removing eggs and adults; and when removing adults only, 20 vs. 29 years are needed respectively. Removing both eggs and adults results in a yearly effort of 5.01 hours/m^2, while removing adults only results in a yearly effort of 1.76 hours/m^2. Thus, removing adults only seems to be the most efficient option to eradicate populations. Furthermore, inflow of new propagules renders eradication efforts ineffective (N'Guyen *et al*., 2018).

It is important to stress that eradication using traps is currently only theoretical, and has not been proven in the field. In addition, because of the high effort needed, it is likely that eradication can only be achieved on a local scale, e.g. the upstream part of a river where inflow of new specimens can be prevented.

Although traps are not species specific, there are little negative impacts of this measure if the traps are checked regularly (e.g. twice a week), by-catch can be released again alive.

Measure 2: Use of piscicides

Toxicity tests of the currently USA-registered piscicides antimycin, rotenone, 3-trifluoromethyl-4-nitrophenol (TFM), and Bayluscide were conducted and indicated that round gobies are sensitive to all of those. However, the level of sensitivity of the round goby was similar to that of the native fish species tested. Piscicides, therefore, have limited potential to selectively remove round gobies. Nevertheless, the bottom-release formulations of some of these piscicides may have some application for the selective removal of round gobies (Schreier *et al*., 2008).

In 2005, rotenone was applied to a 5 km stretch of Pefferlaw Brook (Canada) to eradicate *N. melanostomus* (Borwick and Brownson, 2006; Dimond *et al*., 2010). Unfortunately, several *N. melanostomus* were captured a few months after treatment and, despite an intense seining effort to remove the remaining round gobies, individuals have since been captured in Lake Simcoe, a connected water body (Kornis *et al*., 2012). The use of piscicides can only be successful when active migration from neighbouring, inter-connected water catchments cannot occur (Verreycken, 2013). Though not for round goby, rotenone was successfully applied to eradicate the invasive smallmouth bass *Micropterus dolomieu* in a 4 km reach of the Rondegat river, South Africa (Weyl *et al*., 2013, 2014). The use of piscicides may have EU/national/local legal restrictions. Rotenone was withdrawn from use in the European Union in 2007 (Schapira, 2010), but derogations are probably possible in some Member States (e.g. Britton *et al*., 2010).

The potential to eradicate *N. melanostomus* populations depends on location and the opportunity for dispersal and establishment of populations. If broadly dispersed in large lakes or river systems, eradication is probably impossible. The use of piscicides is not species specific and kills much aquatic life, so it may be viewed as a controversial measure (Britton *et al*., 2010). As a result, its use in the USA has been challenged, halted, or discouraged by the American Fisheries Society.

The primary diet of round gobies includes mollusks, crustaceans, worms, fish eggs, zebra mussels, small fish, and insect larvae.

4.4. Measures to manage the species once it has become widely spread

Measure 1: Use of natural, complex three-dimensional structures in stream habitats

The round goby can reach high densities in habitats with hard substratum, such as groynes and dams made of basalt stones. However, Dorenbosch *et al.* (2017) demonstrated that natural, complex three-dimensional structures, such as (pieces of) large wood (e.g., trees that fall into the river), are a less attractive habitat for Ponto-Caspian gobies in Western European rivers. Application of large wood in regulated riverine habitats in the Lek River (The Netherlands) seems to facilitate native fishes, but not the invasive round goby. Large wood may be less suitable for this species because it contains fewer shelters. Densities of round goby were multifold lower in natural habitats than in habitats with rip-rap (Dorenbosch *et al.*, 2017). This measure can only be applied in non-navigable rivers.

Measure 2: Exploitation of round goby stocks and landing obligation

In large systems, commercial exploitation of *N. melanostomus* might reduce its local abundance (Kornis *et al.*, 2012). Round goby is commercially harvested in its native range, where the animals are canned for human consumption. In suitable areas with high density populations, angling may be encouraged as a management option for controlling population size and mitigating impacts locally. The potential of recreational fisheries to control population abundance should be explored. If experimental findings support its efficacy, regional management plans and policy documents should be revised to allow, and even promote, a recreational fishery for round gobies. These may include examples such as angling (Gutowsky *et al.*, 2011) in areas and at times where recreational fishing for other species might otherwise be restricted (e.g., nature reserves) (Ojaveer *et al.*, 2015). It is important to note that incentive mechanisms to control invasive alien species can have negative consequences such as the intentional spread of the species, and therefore careful consideration is needed before using such a measure, see Pasko and Goldberg (2014) for guidance. If round gobies are a bycatch of commercial fishery on other fish species, a requirement should be that the species is always landed. A landing obligation includes the requirement to develop discard plans, which contain detailed operational guidelines on the handling and storage of the fish both on-board and on land (Ojaveer *et al.*, 2015).

Measure 4: Acoustic and pheromone traps

A potential control mechanism exploits one aspect of the species' sensory ecology, its propensity to swim selectively toward sources of species-specific vocalisations. A trap was deployed containing a speaker broadcasting round goby reproductive calls (grunts) and catch efficacy was compared to silent traps and those broadcasting round goby aggression calls (drums). Traps playing the reproductive call caught more round gobies than traps playing either the silent or aggressive calls. Other species were captured at very low rates in the grunt traps. Acoustic traps may be viable for round goby control in vulnerable areas, as they do not seem to reduce native species numbers (Isabella-Valenzi and Higgs, 2016).

There is also a promise for the application of pheromone traps to control the round goby. Pheromones released by males attract females of round goby, so these could be used as a type of 'bait' to attract animals to traps. Once the chemical structure of odour attractants is identified and shown to lure conspecifics to traps, odorants or their blends can be used to control the aquatic pest (Corkum and Belanger, 2007). Pheromone traps have not been field tested for this species and would probably require great effort, but would be highly specific to *N. melanostomus* (Kornis *et al.*, 2012).

Measure 3: Sustained trapping (see Measure 1 of Section 4.3.)

Measure 5: Bio-control with predators

Bio-control with predators can help reduce the population density of round goby, but fundamental research efforts are required prior to suggesting the use of piscivorous fish (or birds) as bio-control agents (Ojaveer *et al.*, 2015). It is known that some predators have changed their dietary preferences to specialise feeding on round goby. Predators with heavy reliance on *N. melanostomus* in the Great Lakes include burbot *Lota lota*, double-crested cormorants *Nerodia sipedon*, watersnakes, yellow perch *Perca flavescens* and smallmouth bass *Micropterus dolomieu*. In the Baltic Sea, main predators include perch *Perca fluviatilis*, cod *Gadus morhua*, great cormorants *Phalacrocorax carbo* and grey herons *Ardea cinerea*. There is some evidence that high predation levels contribute to control *N. melanostomus* abundance (Kornis *et al.*, 2012). However, no specific bio-control actions for round goby have been described in the literature.

Measure 6: Habitat restoration (see Measure 1 of Section 4.2.)

Round goby eggs on rocks © Yuriy Kvach. CC BY-SA 3.0.

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