Freshwater Tubenose Goby (*Proterorhinus semilunaris*)
Ecological Risk Screening Summary

U.S. Fish and Wildlife Service, December 2022
Revised, January 2023
Web Version, 12/17/2024

Organism Type: Fish
Overall Risk Assessment Category: High

Photo: Piet Spaans. Licensed under CC BY-SA 2.5. Available: https://commons.wikimedia.org/wiki/File:Proterorhinus_semilunaris,_the_Netherlands_-_20051030.jpg (December 2022).

1 Native Range and Status in the United States

Native Range

From Froese and Pauly (2022a):

"Euorpe [sic]: Black Sea basin; Maritza and Struma drainages in eastern Aegean basin."

Froese and Pauly (2022a) report this species as native in the following countries: Turkey, Bosnia and Herzegovina, Bulgaria, Croatia, Greece, Moldova, Romania, and Ukraine.

Status in the United States

According to Fuller et al. (2022a) nonindigenous occurrences of *Proterorhinus semilunaris* have been reported in the following States. Range of observation years, watersheds, and population status where reported (one or more watersheds) are provided in parentheses.

- Michigan (1990–2020; Cheboygan, Clinton, Detroit, Lake Erie, Lake Huron, Lake St. Clair, Lone Lake-Ocqueoc, Ottawa-Stony, Raisin, St. Clair; established)
- Minnesota (2001–2017; Lake Superior, St. Louis River; established)
- New York (2016–2021; Headwaters of the St. Lawrence River, Raisin River-St. Lawrence River; established)
- Ohio (2001–2019; Cedar-Portage, Lake Erie; established)
- Pennsylvania (2011–2015, Lake Erie; established)
- Wisconsin (2003–2016; Beartrap-Nemadji, St. Louis; established)

From Fuller et al. (2022b):

"This species is reproducing and overwintering in the St. Clair River, and in Lake St. Clair, Michigan (Jude 1993; Cavender, personal communication). However, it remains relatively rare in even these environments even 30 years after first introduced. This species is not spreading rapidly (Vanderploeg et al. 2002), but has undergone discontinuous expansion such that it is found in localized nearshore areas of 4 of the 5 Great Lakes (Vanderploeg et al 2002; Kocovsky et al. 2011; Grant et al. 2012; MISIN 2019; Bowen 2018)."

"Great Lakes Nonindigenous Occurrences: The species was introduced into the St. Clair River, Michigan. It was taken in several 1990 collection samples from the cove next to the Detroit Edison Company's Belle River Power Plant and near the intake structures (Jude et al. 1992; Jude 1993). Since then, additional specimens have been found in the area (Kingsville Marsh) and the species is believed to be overwintering and reproducing on the northwestern shore of Lake Erie. Tubenose gobies have been collected in the waters of western Lake Erie around Catawba, Kelly's, and the Bass Islands, Ohio (Kocovsky et al. 2011), and in eastern Lake Erie in a small embayment (Marina Lake) adjacent to Presque Isle Bay, Erie, Pennsylvania (Grant et al. 2012). In 2001, a specimen was found in Duluth Harbor of western Lake Superior on the Minnesota-Wisconsin border (Vanderploeg et al. 2002) and has subsequently spread along this shoreline. […] This species was first reported in Lake Huron's Georgian Bay in 2011 (MISIN 2019) and has also been reported in the St. Mary's River (Bowen 2018) and the mouth of the Cheboygan River (Pers. Comm. Bowen 2019)."

No records of *Proterorhinus semilunaris* in trade in the United States were found.

Regulations

State regulations were found for the family Gobiidae and under the scientific name *Proterorhinus semilunaris*. Additional regulations were found that used the scientific name *P. marmoratus. P. marmoratus* was the name in use for this species when it was first recorded within the United States (see Remarks, below, for more information). Due to the recent change in the valid name for this species, regulations on *P. marmoratus* were included in the following list. Please refer back to state agency regulatory documents for details on the regulations, including restrictions on activities involving this species. While effort was made to find all applicable regulations, this list may not be comprehensive. Notably, it does not include regulations that do not explicitly name this species or its genus or family, for example, when omitted from a list of authorized species with blanket regulation for all unnamed species.

All species in the family Gobiidae are regulated in Hawaii (HODA 2019).

Proterorohinus semilunaris is regulated in Missouri (MDC 2022), New Mexico (NMDGF 2010), New York (New York DEC 2022), North Carolina (North Carolina DEQ 2022), and North Dakota (NDGF 2019). Indiana regulates a species under the common name of 'tubenose goby' but the regulation does not provide a scientific name (Indiana DNR 2019).

P. marmoratus is regulated in Illinois (Illinois DNR 2015), Michigan (Michigan Compiled Laws 2022), Minnesota (Minnesota DNR 2022), Pennsylvania (PFBC 2022), Ohio (Ohio DNR 2022), Wisconsin (Wisconsin DNR 2022), and Virginia (Virginia DWR 2022).

Means of Introductions within the United States

From Fuller et al. (2022a):

"Introduced via ballast water."

Remarks

This ERSS was previously published in January 2021. Revisions were made to incorporate new information and conform to updated standards.

From Fuller et al. (2022a):

"All tubenose gobies were previously included in a single species, *P. marmoratus*. Recently, *P. marmoratus* was restricted to marine/brackish populations in the Black Sea, and several names were resurrected/created for freshwater populations of tubenose gobies in different regions: *P. nasalis* and *P. semipellucidus* for populations inhabiting the Caspian Sea and Volga River basins (Freyhof and Naseka 2007; Neilson and Stepien 2009); *P. tataricus* endemic to several rivers on the Crimean Peninsula, Ukraine (Freyhof and Naseka 2007); and *P. semilunaris* for tubenose gobies in rivers and estuaries in the Black, Azov, and Aegean Sea basins (Freyhof and Naseka 2007; Neilson and Stepien 2009)."

From Fuller et al. (2022b):

"In Canada, tubenose goby is listed as an invasive species under Canadian Federal Statutes and Regulations—Ontario Fishery Regulations SOR/2007-237, and is thus prohibited from being possessed, released, or used as bait without a license. In Quebec, aquarium fish keeping, production, keeping in captivity, breeding, stocking, transport, sale, or purchase of live tubenose goby is prohibited by Quebec Statutes and Regulations RRQ, c C-61.1, r 7."

2 Biology and Ecology

Taxonomic Hierarchy and Taxonomic Standing

According to Fricke et al. (2022), *Proterorhinus semilunaris* (Heckel 1839) is the current valid name for this species. It was originally described as *Gobius semilunaris* Heckel 1839.

From Bailly (2020):

“Animalia (Kingdom) > Chordata (Phylum) > Vertebrata (Subphylum) > Gnathostomata (Superclass) > […] Actinopterygii (Class) > Perciformes (Order) > Gobioidei (Suborder) > Gobiidae (Family) > Gobiinae (Subfamily) > *Proterorhinus* (Genus) > *Proterorhinus semilunaris* (Species)”

Size, Weight, and Age Range

From Fuller et al. (2022a):

“12.7 cm total length”

“This goby may live as long as five years (Jude 1993).”

From Eakins (2022):

“Adult Length (cm): 4.5-7.7 TL [total length]
Adult Weight (kg): 0.001-0.006
Age at Maturity (yrs): 1-2
Maximum Length (cm): 9.0 SL [standard length]
Maximum Weight (kg): no data
Lifespan (yrs): 3-4”

Environment

From Fuller et al. (2022a):

“Tubenose gobies generally inhabits shallow (less than 5 m depth), slow-moving, nearshore environments.”

From Froese and Pauly (2022a):

“Freshwater; brackish; benthopelagic.”

Climate

From Froese and Pauly (2022a):

“Temperate”

Distribution Outside the United States

Native

From Froese and Pauly (2022a):

“Euorpe [sic]: Black Sea basin; Maritza and Struma drainages in eastern Aegean basin.”

Froese and Pauly (2022a) report this species is native in the following countries: Turkey, Bosnia and Herzegovina, Bulgaria, Croatia, Greece, Moldova, Romania, and Ukraine.

Introduced

From Froese and Pauly (2022a):

"In Danube, present up to about Vienna [Austria], invasive since 1970s, now reaching upstream to southern Germany. […] Introduced to North America in 1991 […]."

Froese and Pauly (2020a) report this species as introduced in the following countries: Austria, Belarus, Germany, Hungary, and Netherlands.

From Eakins (2022):

"[In Canada] Thunder Bay Harbour (Lake Superior), Severn Sound (Georgian Bay), St. Clair River, Lake St. Clair, Thames River, Detroit River, western Lake Erie, eastern Lake Ontario, St. Lawrence River; […]"

From Manné and Poulet (2008):

"Western tubenose gobies were captured for the first time in France in the Rhine River in September 2007."

"It spread out its native range as far as the Netherlands in Europe in 2002 […]."

"In August 1997, *P. semilunaris* was observed in the Roth drainage (Germany), which receives water from the Rhine-Main-Danube canal (Von Landwust, 2006). It reached the River Main in 1999 (Reinartz et al., 2000; Schadt, 2000) and then it was reported in the Rhine River in 2000 between the Main confluence and Coblence before being captured in the Netherlands in 2002 (Kottelat and Freyhof, 2007). In 2005, it was found in the downstream part of the Moselle drainage, one of the main Rhine tributaries (Von Landwust, 2006)"

From Mombaerts et al. (2014):

"In 2010, the tubenose goby (*Proterorhinus semilunaris*) and round goby (*Neogobius melanostomus*) were observed in Belgium for the first time."

From Adámek et al. (2010):

"In the Danube River watershed, tubenose goby was registered for a long time as far west as Neusiedler Lake in Austria and in the Danube River tributaries – the Váh, Nitra and Morava rivers – on the Slovak territory."

"In the Morava River (the Danube tributary from the Czech territory), tubenose goby was first recorded by Koelbel (1874), near the mouth into the Danube. This site has been for a long time the only locality of tubenose goby occurrence in the Morava River. In the nineties, the tubenose

goby slowly commenced to spread upstream up to 41 r. km of the Morava River near the village of Gajary (Slovakia) (Spindler et al., 1992; Prášek and Jurajda, 2005)."

Means of Introduction Outside the United States

From Froese and Pauly (2022a):

"[…] through ballast of ships."

"It is invasive in Danube and Rhine where reportedly, the spreading was due to canalization of main river and reservoirs or slow-flowing waters created by hydroelectric plants [Kottelat and Freyhof 2007]."

From Manné and Poulet (2008):

"Its expansion in Western Europe has been facilitated by the digging of the 'Rhine-Main-Danube' canal in 1992 (Freyhof, 2003), but also by its use as live bait in the south-eastern Czech Republic (Prasek and Jurajda, 2005)."

From Kocovsky et al. (2011):

"Nighttime drift of larval and juvenile freshwater tubenose gobies has been demonstrated in the Danube River system in Austria (Zitek et al. 2004), which has facilitated their expansion beyond commercial shipping ports."

Short Description

From Fuller et al. (2022a):

"This species (along with the round goby *Neogobius melanostomus*) can be distinguished from all other fishes in the Great Lakes by the presence of fused pelvic fins. Tubenose goby can be distinguished from the round goby by its long anterior nostrils and lack of black spot on posterior base of dorsal fin (Miller 1986; Jude 1993)."

Biology

From Froese and Pauly (2020a):

"Inhabits a variety of slow-flowing or still waters from estuarine to small, slow flowing premontane streams; usually in dense vegetation or coarse rocks, and often very abundant in backwaters and lakes, breeds in reservoirs and channels. Preys on benthic invertebrates. Spawns for the first time at 1-2 years, usually for 1-2 seasons only, in April to August. Females may spawn more than once during the season and males guard the eggs that are deposited in cavities. Larvae and juveniles are benthic."

From Fuller et al. (2022a):

"The tubenose goby is a benthic omnivores [sic], consuming a wide variety of benthic invertebrates (chironomids, crustaceans, copepods, dipterans, ephemeropterans, ostracods, and trichopterans) and occasionaly [sic] larval fishes (French and Jude 2001; Adamek et al. 2007)."

"Tubenose gobies generally inhabits shallow (less than 5 m depth), slow-moving, nearshore environments. They prefer areas with abundant aquatic macrophytes, but can also be found in sandy areas (Jude and Deboe 1996). Eggs are typically attached to vegetation (Cavender, personal communication)."

From Kocovsky et al. (2011):

"Tubenose gobies, like round gobies *Neogobius melanostomus*, have early life stages that drift owing to vertical migration, which probably allowed them to spread from areas of colonization."

Human Uses

From Manné and Poulet (2008):

"[…] use as live bait in the south-eastern Czech Republic (Prasek and Jurajda, 2005)."

Diseases

No information was found associating *Proterorhinus semilunaris* with any diseases listed by the World Organisation of Animal Health (2022).

From Zhokhov et al. (2017):

"The metazoan parasites of the invasive goby species *Proterorhinus semilunaris* were studied in August 2015. In total, 101 specimens sampled at four sites of Rybinsk Reservoir [Russia] were analyzed. Six parasite species were found: Unionidae gen. sp., *Paracoenogonimus ovatus, Diplostomum* sp., *Ichthiocotylurus platycephalus, Posthodiplostomum cuticola*, and *Camallanus lacustris*. Trematode metacercariae were the dominant parasites in all the studied samples."

From Huyse et al. (2015):

"[*Gyrodactylus*] *proterorhini* was originally described from the tubenose goby *P. semilunaris* […]"

From Manné and Poulet (2008):

"Furthermore, *P. semilunaris* has been identified as a paratenic host [can be a host of immature stages of the parasite but is not necessary for parasite's life cycle] of *Anguillicola crassus*, an eel parasite with severe pathological effects with, nevertheless, a low prevalence (Koubková and Baruš, 2000)."

Threat to Humans

From Froese and Pauly (2022a):

"Harmless"

3 Impacts of Introductions

From Mikl et al. (2017):

"Gobies [*Proterorhinus semilunaris*] had a negative impact on invertebrates at both sites, with overall invertebrate density reduced by 15% (ca. 17.9 g m-2 per year) at Site 1 and 36% (ca. 23.6 g m-2 per year) at Site 2. Both species showed increased impact in summer and ingested larger invertebrates preferentially, resulting in an overall reduction in invertebrate body size. Tubenose gobies had a significant impact on Annelida, Gastropoda, Crustacea and Ephemeroptera nymphs, while tubenose and round goby together impacted Annelida, Bivalvia (Dreissena), Gastropoda, Crustacea, Ephemeroptera nymphs, Odonata nymphs and Chironomidae larvae. Our results confirm that round and tubenose gobies can have a significant negative impact on aquatic invertebrate density and community composition."

From Van Kessel et al. (2011):

"Various habitat choice experiments were conducted between two common native benthic fish species (*Cottus perifretum* and *Barbatula barbatula*) and four invasive non-native gobiid species (*Proterorhinus semilunaris, Neogobius melanostomus, N. kessleri* and *N. fluviatilis*). The first series of single specimen experiments determined the habitat choice of each individual fish species. In a second series of competition experiments, shifts in habitat choice in comparison with the previously observed habitat choice, were determined when a native benthic fish species co-occurred with non-native gobiid species. Native *C. perifretum* displayed a significant shift in habitat choice in co-occurrence with the gobiids *N. kessleri* or *P. semilunaris*. […] Our study therefore suggests that competition for shelter is likely to occur in rivers invaded by *N. kessleri* and *P. semilunaris* at sites where shelter is limiting […]"

The following quotations refer to *potential*, not documented impacts.

From Kocovsky et al. (2011):

"The diet of tubenose gobies was almost exclusively invertebrates, suggesting dietary overlap with other benthic fishes, such as darters (*Etheostoma* spp. and *Percina* sp.), madtoms (*Noturus* spp.), and sculpins (*Cottus* spp.)."

From Fuller et al. (2022b):

"Great Lakes Impacts: There is little to no evidence to support that *Proterorhinus semilunaris* has significant environmental impacts in the Great Lakes. Tubenose goby has generally not exhibited, nor is expected to have, severe ecological impacts in the ranges it inhabits (Jude et al. 1995, Vanderploeg et al. 2002). It remains rare in most locations where it is found in the Great

Lakes. Worldwide, it is reported as a dominant species only when other goby species are absent (Valova et al 2015)."

"Tubenose goby has been shown to have a significant overlap in diet preference with rainbow darter (*Etheostoma caeruleum*) and northern madtoms (*Noturus stigmosus*) and may compete with these native fish for food (French and Jude 2001). However, in aquarium experiments, tubenose gobies appear to be more cryptic than natives and not as aggressive at attacking food items (Jude et al 1992) Tubenose gobies may compete with Johnny darters (*Etheostoma nigrum*) for spawning sites (Kocovsky et al 2011) and refuge from predation (Jude and DeBoe 1996)."

"Unlike round goby, tubenose goby does not feed on zebra mussel (Vanderploeg et al. 2002). Tubenose gobies are occasionally reported as predators of larval round gobies (French and Jude 2001) but are unlikely to be a significant control on this other invasive goby population. Tubenose gobies may eventually become part of the forage base for predators, such as benthic-foraging yellow perch, white perch, smallmouth bass, burbot, white bass, and walleye, which all consume round gobies (Bunnell et al. 2005; Kocovsky et al. 2009, 2011). Tubenose goby is documented in several locations as a host for glochidia of unionid clams (Slapansky et al 2016, Zhokhov et al 2017), but it remains unknown whether it might serve as a host for rare/endangered native Great Lakes unionids."

The importation, possession, and/or trade of *Proterorhinus semilunaris* is regulated in the following States (see Section 1 for detailed information): Hawaii (HDOA 2019), Indiana (Indiana DNR 2022), Illinois (Illinois DNR 2015), Michigan (Michigan Compiled Laws 2022), Minnesota (Minnesota DNR 2022), Missouri (MDC 2022), North Carolina (North Carolina DEQ 2022), North Dakota (NDGFD 2019), New Mexico (NMDGF 2010), New York (New York DEC 2022), Ohio (Ohio DNR 2022), Pennsylvania (PFBC 2022), Virginia (Virginia DWR 2022), and Wisconsin (Wisconsin DNR 2022).

4 History of Invasiveness

The history of invasiveness for *Proterorhinus semilunaris* is classified as High. *P. semilunaris* has been introduced to several countries, including the United States, accidentally via ballast water and intentionally for use as a live baitfish. A peer-reviewed study demonstrated that *P. semilunaris* has an impact on benthic invertebrate communities in the areas it is introduced to, resulting in a reduction of those communities' densities.

5 Global Distribution

Figure 1. Reported global distribution of *Proterorhinus semilunaris*. Map from GBIF Secretariat (2022). Observations are reported from Eastern Europe, parts of Western Europe and the Great Lakes region of the United States and Canada. The point in Estonia was excluded from the climate matching analysis because occurrences of *Proterorhinus* sp. in the Gulf of Finland have been recently identified as *P. nasalis* (Truuverk et al. 2021).

6 Distribution Within the United States

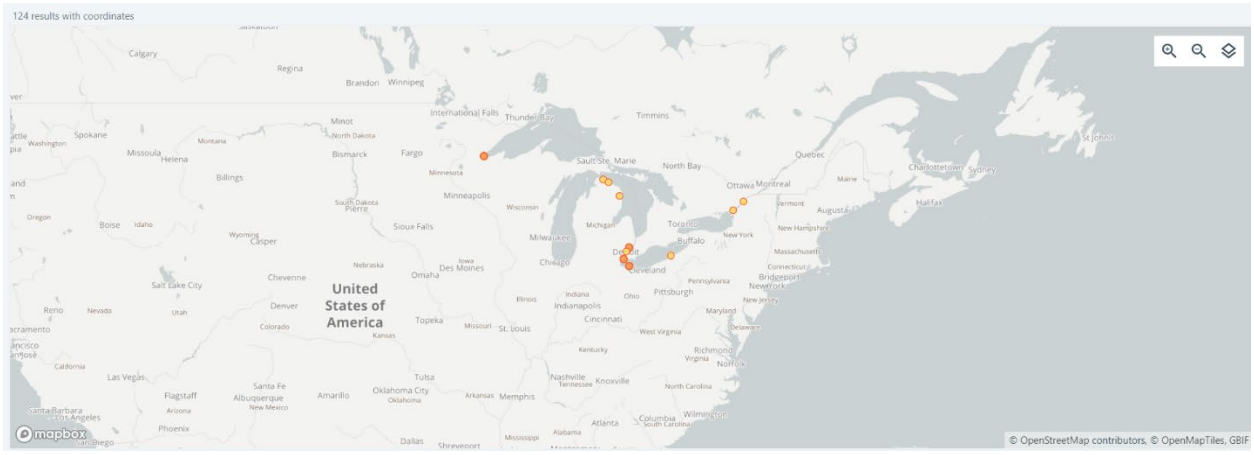

Figure 2. Reported distribution of *Proterorhinus semilunaris* in the United States. Map from GBIF-US (2022). Observations are reported from New York, Pennsylvania, Ohio, Michigan, Minnesota, and Wisconsin.

7 Climate Matching

Summary of Climate Matching Analysis

The climate match for *Proterorhinus semilunaris* was generally high throughout the contiguous United States with areas of medium match in western States and areas of low match in the Southeast and Pacific Northwest. Areas of high climate match were generally found around the Great Lakes, Northeast, and throughout the Midwest; while areas of low match were concentrated around the Gulf Coast, Cascade-Sierra Mountains, and coastal Pacific Northwest. The overall Climate 6 score (Sanders et al. 2023; 16 climate variables; Euclidean distance) for the contiguous United States was 0.839, indicating that Yes, there is establishment concern for this species. The Climate 6 score is calculated as: (count of target points with scores ≥ 6)/(count of all target points). Establishment concern is warranted for Climate 6 scores greater than or equal to 0.002 based on an analysis of the establishment success of 356 nonnative aquatic species introduced to the United States (USFWS 2024).

Projected climate matches in the contiguous United States under future climate scenarios are available for *Proterorhinus semilunaris* (see Appendix). These projected climate matches are provided as additional context for the reader; future climate scenarios are not factored into the Overall Risk Assessment Category.

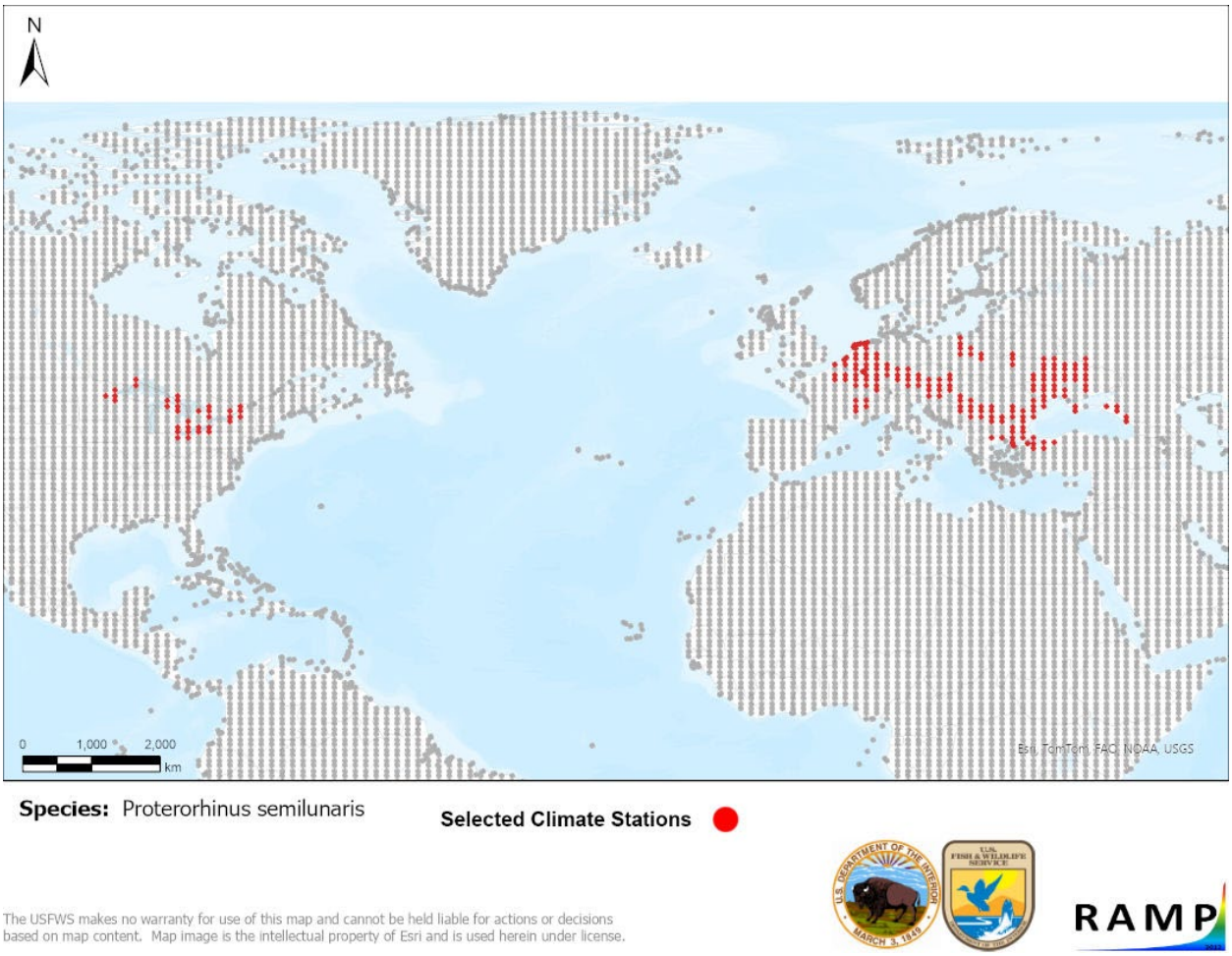

Figure 3. RAMP (Sanders et al. 2023) source map showing weather stations in North America and Europe selected as source locations (red; Canada, United States, Austria, Belarus, Belgium, Bosnia-Herzegovina, Bulgaria, Czechia, Croatia, France, Germany, Georgia, Greece, Hungary, Moldova, Netherlands, Poland, Romania, Russia, Serbia, Slovakia, Switzerland, Turkey, Ukraine) and non-source locations (gray) for *Proterorhinus semilunaris* climate matching. Source locations from GBIF Secretariat (2022). Selected source locations are within 100 km of one or more species occurrences, and do not necessarily represent the locations of occurrences themselves.

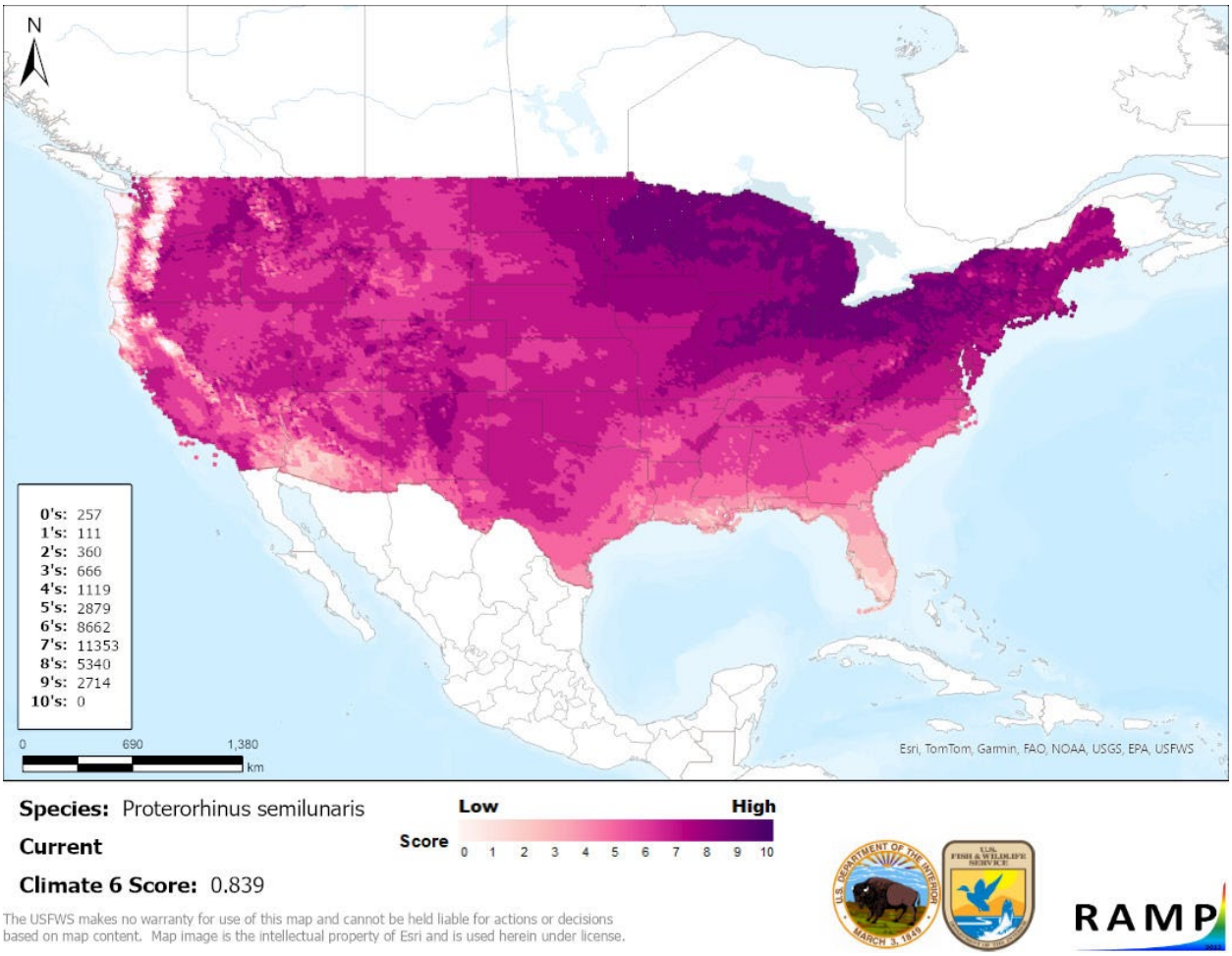

Figure 4. Map of RAMP (Sanders et al. 2023) climate matches for *Proterorhinus semilunaris* in the contiguous United States based on source locations reported by GBIF Secretariat (2022). Counts of climate match scores are tabulated on the left. 0/Pale Pink = Lowest match, 10/Dark Purple = Highest match.

8 Certainty of Assessment

The certainty for this assessment is High. There is quality information available about the biology, ecology, and distribution of *Proterorhinus semilunaris*. Records of introduction, vectors, and established populations were found in several countries outside of the native range for *P. semilunaris*. Impact information for *P. semilunaris* was available from peer-reviewed literature.

9 Risk Assessment

Summary of Risk to the Contiguous United States

Proterorhinus semilunaris, the Freshwater Tubenose Goby, is a freshwater fish native to Europe from the Black Sea basin and the Maritza and Struma drainages in the eastern Aegean basin. This species is a benthic omnivore that prefers slow moving water. *P. semilunaris* thrives in lake environments and it has been transported in the ballast water of ships to parts of Europe and to

several of the Great Lakes in North America. Additionally, use as a baitfish and dispersal through canal systems have led to further introductions and expansion of its introduced range. The history of invasiveness is classified as High. Introduction of *P. semilunaris* has resulted in decreased abundance of benthic invertebrate communities. The climate matching analysis for the contiguous United States indicates establishment concern for this species. High climate matches were primarily found in the Northeast, Midwest, and Great Lakes regions. Areas of low climate match were found around the Gulf Coast, Southwest, and Pacific Northwest. The certainty of this assessment is High due to the quantity and quality of information available. The overall risk assessment category is High.

Assessment Elements

- **History of Invasiveness (see section 4): High**
- **Establishment Concern (see section 7): Yes**
- **Certainty of Assessment (see section 8): High**
- **Remarks, Important additional information: None**
- **Overall Risk Assessment Category: High**

10 Literature Cited

Note: The following references were accessed for this ERSS. References cited within quoted text but not accessed are included below in section 11.

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Appendix

Summary of Future Climate Matching Analysis

Future climate projections represent two Shared Socioeconomic Pathways (SSP) developed by the Intergovernmental Panel on Climate Change (IPCC 2021): SSP5, in which emissions triple by the end of the century; and SSP3, in which emissions double by the end of the century. Future climate matches were based on source locations reported by GBIF Secretariat (2022).

Under the future climate scenarios (figure A1), on average, high climate match for *Proterorhinus semilunaris* was projected to occur in the Great Lakes region of the contiguous United States. There were also pockets of high match in the western mountains. Areas of low climate match were projected to occur in the Gulf Coast, Northern Pacific Coast, Cascade-Sierra Ranges, and Southern Florida regions. Areas of high and medium match decreased between SSP3 and SSP5 and from 2055 to 2085. The Climate 6 scores for the individual future scenario models (figure A2) ranged from a low of 0.209 (model: UKESM1-0-LL, SSP5, 2085) to a high of 0.749 (model: MPI-ESM1-2-HR, SSP5, 2055). All future scenario Climate 6 scores were above the Establishment Concern threshold, indicating that Yes, there is establishment concern for this species under future scenarios. The Climate 6 score for the current climate match (0.839, figure 4) falls above the range of scores for future projections. The time step and climate scenario with the most change relative to current conditions was SSP5, 2085, the most extreme climate change scenario. Under all time step and climate scenarios only minor or no increases in the climate match relative to the current match were observed. Under at least one time step and climate scenario, areas within the Appalachian Range, Colorado Plateau, Great Lakes, Gulf Coast, Mid-Atlantic, Northeast, Northern Plains, Southeast, Southern Atlantic Coast, Southern Plains, and Southwest saw a large decrease in the climate match relative to current conditions. Additionally, areas within the California, Great Basin, Northern Pacific Coast, Southern Florida, and Western Mountains saw a moderate decrease in the climate match relative to current conditions. Additional, very small areas of large or moderate change may be visible on the maps (figure A3). The degree of change increased from 2055 to 2085.

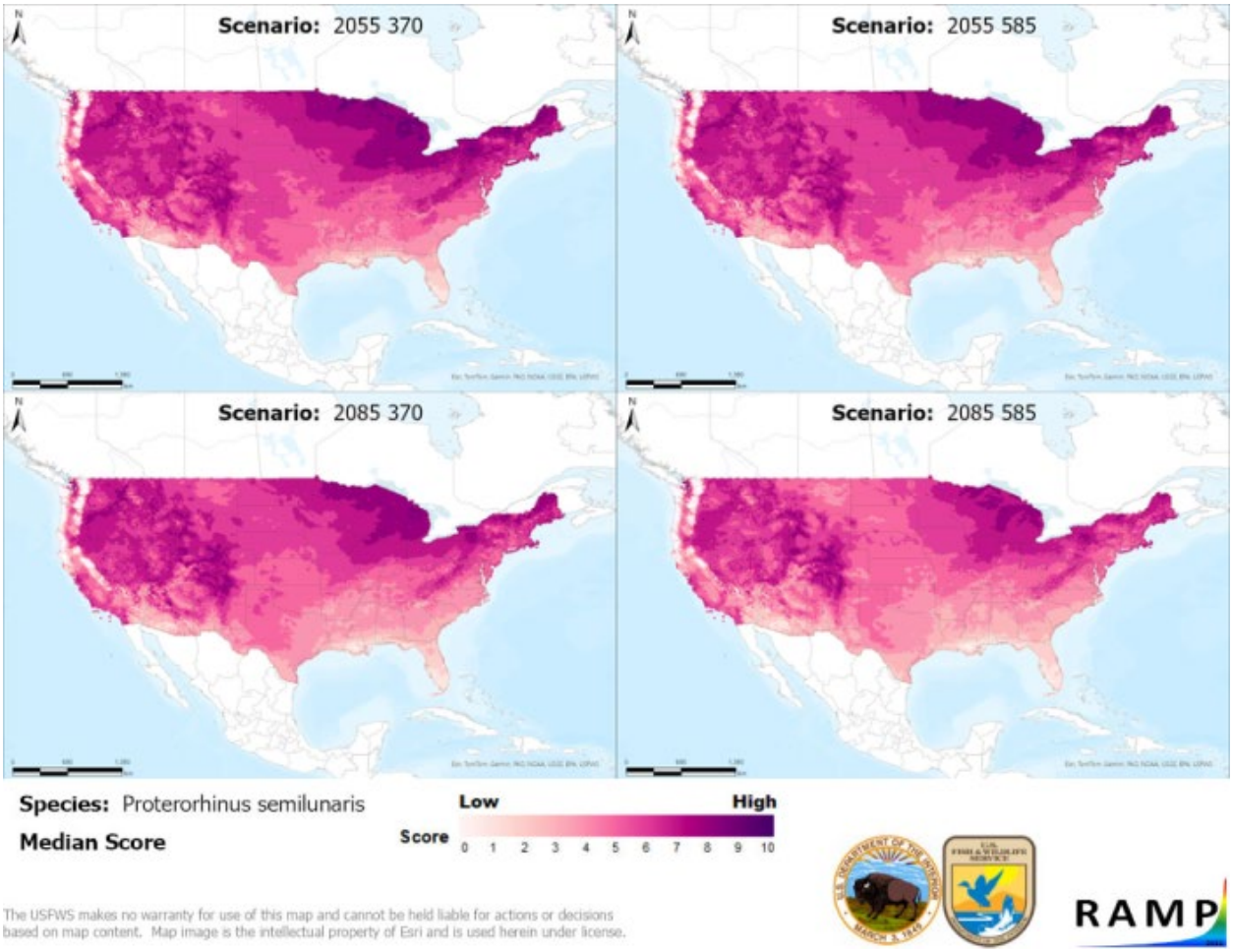

Figure A1. Maps of median RAMP (Sanders et al. 2023) climate matches projected under potential future climate conditions using five global climate models for *Proterorhinus semilunaris* in the contiguous United States. Climate matching is based on source locations reported by GBIF Secretariat (2022). Shared Socioeconomic Pathways (SSPs) used (from left to right): SSP3, SSP5 (IPCC 2021). Time steps: 2055 (top row) and 2085 (bottom row). Climate source data from CHELSA (Karger et al. 2017, 2018); global climate models used: GFDL-ESM4, UKESM1-0-LL, MPI-ESM1-2-HR, IPSL-CM6A-LR, and MRI-ESM2-0. 0/Pale Pink = Lowest match, 10/Dark Purple = Highest match.

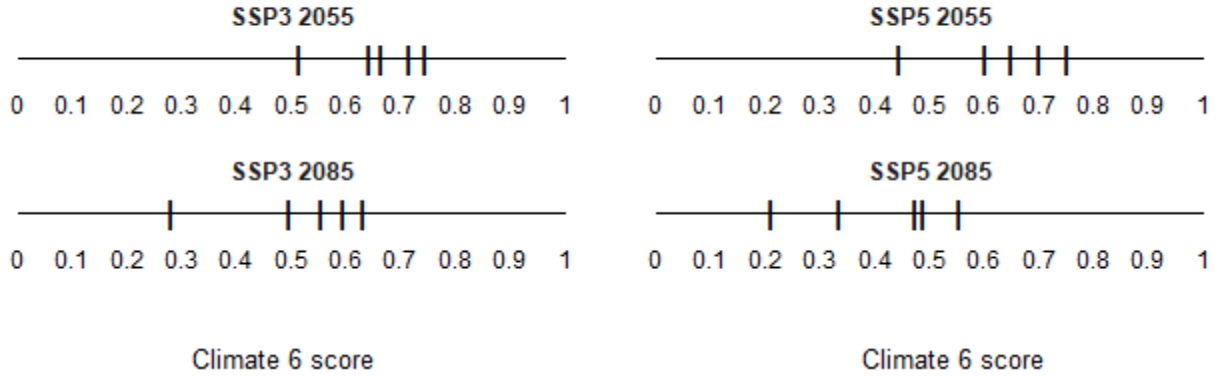

Figure A2. Comparison of projected future Climate 6 scores for *Proterorhinus semilunaris* in the contiguous United States for each of five global climate models under four combinations of Shared Socioeconomic Pathway (SSP) and time step. SSPs used (from left to right): SSP3, SSP5 (Karger et al. 2017, 2018; IPCC 2021). Time steps: 2055 (top row) and 2085 (bottom row). Climate source data from CHELSA (Karger et al. 2017, 2018); global climate models used: GFDL-ESM4, UKESM1-0-LL, MPI-ESM1-2-HR, IPSL-CM6A-LR, and MRI-ESM2-0.

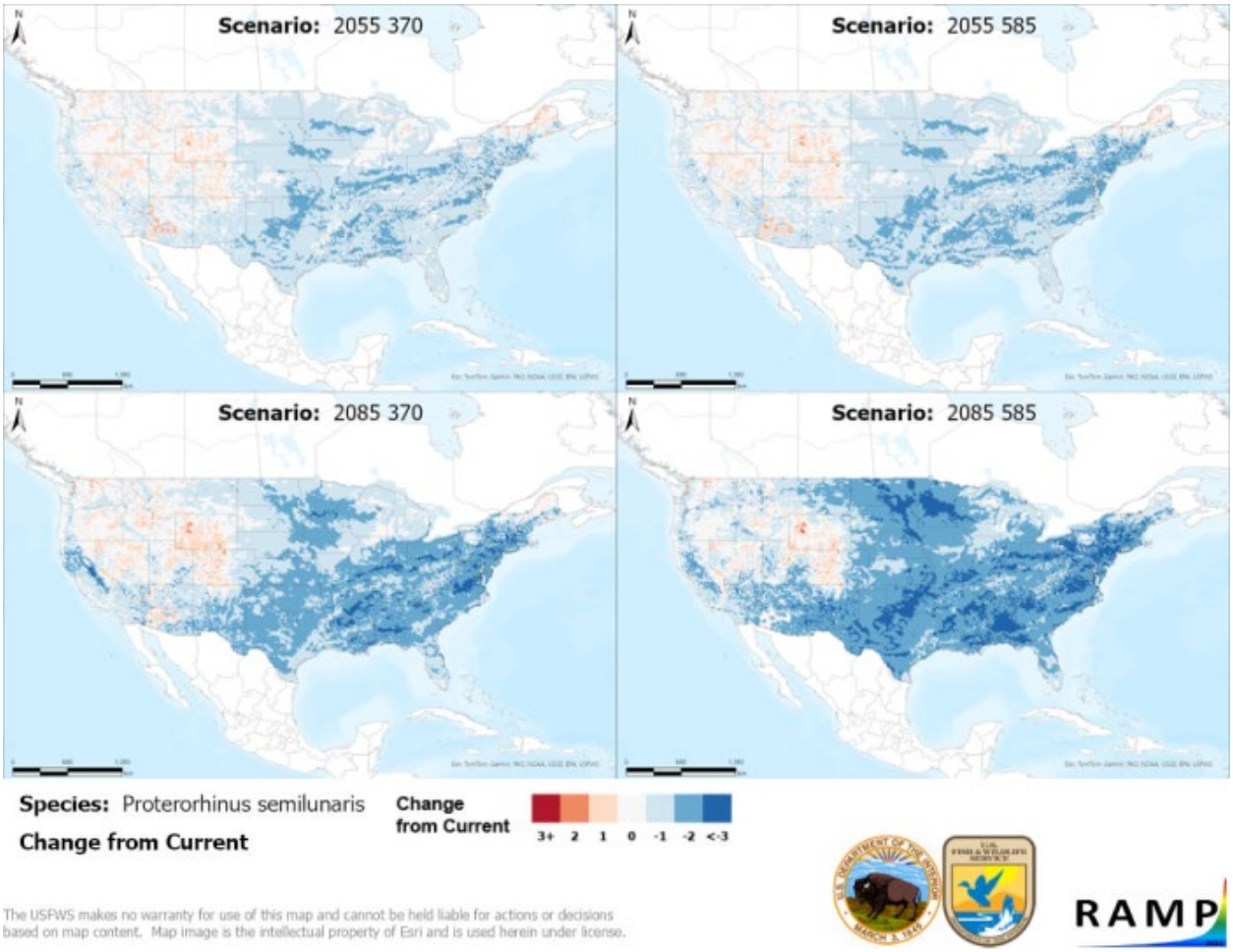

Figure A3. RAMP (Sanders et al. 2023) maps of the contiguous United States showing the difference between the current climate match target point score (figure 4) and the median target point score for future climate scenarios (figure A1) for *Proterorhinus semilunaris* based on source locations reported by GBIF Secretariat (2022). Shared Socioeconomic Pathways (SSPs) used (from left to right): SSP3, SSP5 (IPCC 2021). Time steps: 2055 (top row) and 2085 (bottom row). Climate source data from CHELSA (Karger et al. 2017, 2018); global models used: GFDL-ESM4, UKESM1-0-LL, MPI-ESM1-2-HR, IPSL-CM6A-LR, and MRI-ESM2-0. Shades of blue indicate a lower target point score under future scenarios than under current conditions. Shades of red indicate a higher target point score under future scenarios than under current conditions. Darker shades indicate greater change.

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