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Rapid Communication

The western tubenose goby (*Proterorhinus semilunaris* Heckel, 1837) is expanding its range into the St. Lawrence River: first record in Quebec

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Abstract

The invasive western tubenose goby (*Proterorhinus semilunaris*) was introduced in the Great Lakes in the 1990s. Since then, its range slowly expanded downstream into Ontario's portion of the St. Lawrence River. This rapid communication reports on the first occurrence of a western tubenose goby found in Lake St. Francis (St. Lawrence River, Quebec) in August 2022. The specimen, the study area and the sampling methodology are described while hypotheses about its presence and expansion are explored.

Key words: aquatic invasive species, range expansion, secondary spread, Lake St. Francis

Introduction

Western tubenose goby, *Proterorhinus semilunaris* (Heckel, 1837), is a known freshwater invasive species in eastern North America and Europe. This small benthic Ponto-Caspian fish, originating from the lower Danube River basin (downstream of Vienna) (Stepien and Tumeo 2006; Kvach et al. 2021), is present in freshwaters of lakes from the Black Sea basin, lower Dnipro River, north to the Aegean Sea and Sea of Marmara (Kvach et al. 2021). In Europe, it is a prolific species in freshwaters, being one of the most widespread invasive fish (Grabowska et al. 2021). Western tubenose goby has invaded the upper Danube and some of its tributaries, in Austria and Germany, as well as other river systems such as the Rhine, Meuse and Vistula (Borcherding et al. 2011; Cammaerts et al. 2012; Roche et al. 2013; Cerwenka et al. 2018; Kvach et al. 2021). Ballast water transported and discharged by ships is believed to be the main vector of long-distance dispersal (Ahnelt et al. 1998; Wiesner 2005; Roche et al. 2013). Tubenose

goby has recently expanded its range to higher latitudes, showing its ability to colonise small river systems under colder conditions than expected for the species (Švolíková et al. 2021).

In North America, western tubenose goby, together with round goby (*Neogobius melanostomus* (Pallas, 1814)), were introduced into the St. Clair River (Michigan) during the 1990s, probably through the discharge of ballast water of ships coming from Europe (Jude et al. 1992). Jude et al. (1992) then projected the potential expansion of these species through the Laurentian Great Lakes. Initially, tubenose gobies spread within short distances from the first occurrence. A decade after its introduction, western tubenose goby distribution was limited to the Hudson-Erie corridor and Lake Superior (Vanderploeg et al. 2002; Kocovsky et al. 2011). Between 2011 and 2016, a slow and steady eastern expansion was observed. Western tubenose goby has since expanded its distribution to Eastern Lake Erie, Lake Ontario and the Upper St. Lawrence River (Grant et al. 2012; Goretzke et al. 2019).

The western tubenose goby invasion has been qualified as discrete and without much detrimental impacts to the environment, mainly due to its generally low abundance (Borcherding et al. 2011; Švolíková et al. 2021). However, it may have greater impacts in habitats where its abundance is known to be higher, such as in submerged macrophyte beds (Cammaerts et al. 2012). Other consequences of its presence may include fish larvae predation (Gebauer et al. 2019), competition due to diet or habitat overlap with native benthic fishes (Jude et al. 1995; Jude and DeBoe 1996; French and Jude 2001; Kocovsky et al. 2011), potential overlap with endangered or vulnerable species (French and Jude 2001; MFFP 2021), competition for spawning sites (Balon 1975; Jude et al. 1995) and food web alterations (French and Jude 2001). They can also promote the spread of trematode parasites (Ondračková et al. 2019), although parasite load is known to be lower in invaded ranges (enemy release hypothesis) (Kvach and Stepien 2008). Overall, western tubenose gobies are known to have a high biological plasticity due to its life-history traits, including opportunistic feeding (Ondračková et al. 2019; Tarkan et al. 2019) and variability in habitat use (lakes, estuaries, rivers, streams, canals, etc.) (Kottelat and Freyhof 2007; Ondračková et al. 2019; Top et al. 2018).

In the last few years, western tubenose goby has been found to expand its range downstream of the Laurentian Great Lakes into the St. Lawrence River (Goretzke et al. 2019) but limited to Ontario waters. Although the observation described in the present communication was made within the same watercourse, it is important to report this first occurrence of western tubenose goby within Quebec waters, mainly for the management and risk assessment of its future expansion. The aim of this rapid communication is thus to inform on the presence of this species in the province of Quebec (Canada) and to provide context on the first steps of the secondary invasion process.

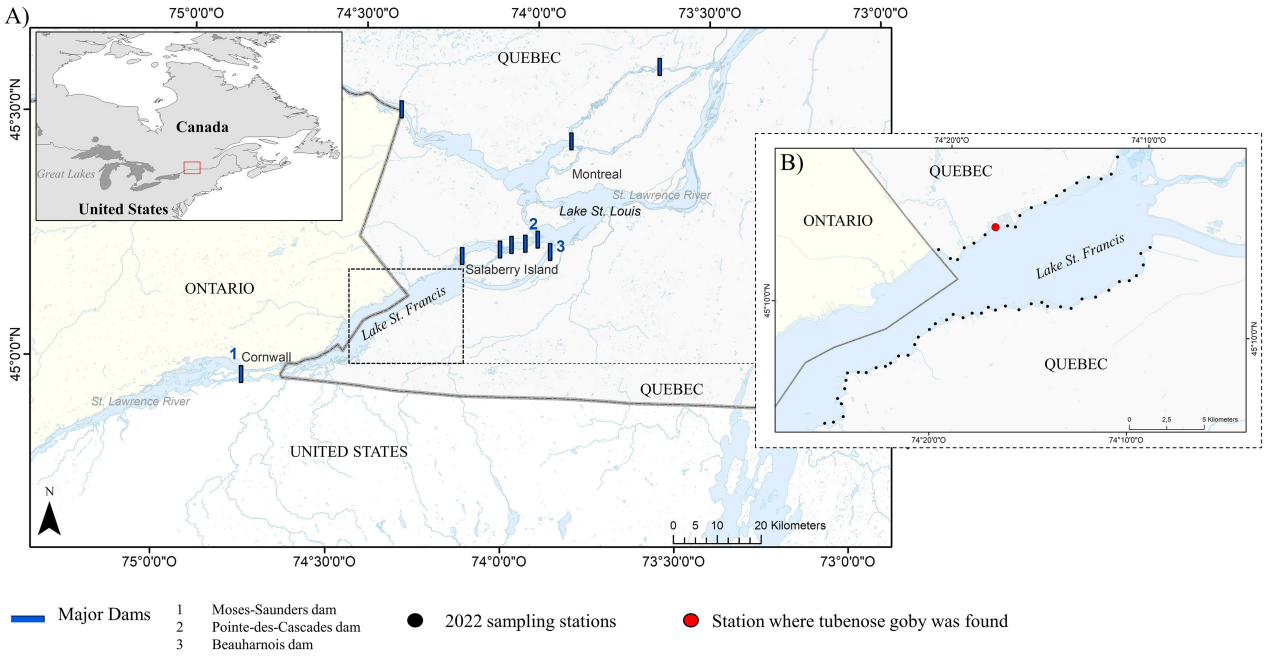

Figure 1. Study area: A) location of main dams, and B) sampling stations (seine) visited in 2022, including where the first western tubenose goby was found in Quebec (red point). For details see Supplementary material Table S1.

Materials and methods

Study area

Lake St. Francis is an enlargement of the St. Lawrence River, nearly 8 km wide by 50 km long, which extends from Cornwall, Ontario, to the western tip of Salaberry Island, Quebec (Figure 1A; Morin and Leclerc 1998). Lake St. Francis is thus a shared jurisdiction between the two provinces. The Quebec portion of Lake St. Francis represents 69% of the total area of 272 km^2 (La Violette et al. 2003). Its maximum depth is 26 m and its average depth is 5.7 m (Morin 2001). The water level of Lake St. Francis is artificially stabilized by control structures at the outlets of the lake which limit variations to less than 15 cm annually (Morin 2001). Upstream of Lake St. Francis, the water level is controlled by the Moses-Saunders dam and, to a lesser extent, by the Beauharnois and Pointe-des-Cascades dams, which are located downstream (Figure 1A). The Soulanges canal is an old shipping canal that connects Lake St. Francis and Lake St. Louis on the North shore of Lake St. Francis, downstream of the Pointe-des-Cascades dam (due to scale constraints, see major dam number 2 in Figure 1 to see the geographic location of the canal). This 23-km-long canal, which includes five locks in total, is another hydrologic connection that could act as a corridor for downstream dispersal. No sampling effort was deployed in this region, but additional potential for dispersal remains plausible. Because Lake St. Francis is located between two major dams, its fish communities are considered isolated from the rest of the St. Lawrence River system.

Figure 2. Picture of the western tubenose goby found in St. Francis Lake (St. Lawrence River), Quebec, Canada. Conservation: 10% formalin. Photo credit: Virginie Boivin.

Sampling method

Since 1995, the Government of Quebec conducts annually, at the end of the summer/early autumn, a standardised fish survey in different sections of the Quebec portion of the St. Lawrence River (a fish monitoring network called *Réseau de Suivi Ichtyologique* (RSI); Deschamps et al. 2022). In this monitoring program, fish communities are sampled along the shoreline approximately every one km using gillnets in lentic and lotic habitats (depth between 1.5 and 14 m), while beach seine is used in lentic nearshore littoral habitats (depth < 1.5 m). The seine net is 12.5 × 4 meters, with a stretched mesh measuring 3 mm (Deschamps et al. 2022). The RSI was previously used to detect and assess the impacts of aquatic invasive species, notably the round goby (Morissette et al. 2018). Between August 22nd and 25th, Lake St. Francis was surveyed by the RSI monitoring network using 61 seine and 62 gillnet stations (Figure 1B). A total of 31 fish species were sampled with the seine and 24 with the gillnets.

Results and discussion

In 2022, other aquatic invasive species were caught by the RSI, notably the round goby, which was present in both types of sampling gears (gillnet and seine) and the common carp (present in gillnets) (Table S1). A western tubenose goby was caught during the RSI seine sampling, representing the first occurrence point in the province of Quebec (Lake St. Francis; latitude: 45.22142; longitude: −74.29092) on August 25th, 2022 (Figures 1 and 2). This new occurrence is 11 km away from the closest report within Ontario waters (M. Windle, River Institute, *pers. comm*). The specimen was first preserved in formalin (10%), and subsequently measured (53 mm total maximum length) and weighed (1.88 g). The sex of the specimen was not determined. The western tubenose goby was caught at a station where depth ranged from 0.75 to 1.10 m. The water temperature was 25.7 °C, with a specific conductivity of 323 µS/cm and a turbidity of 0.74 NTU. The substrate was dominated by sand, with a moderate abundance of macrophytes

(*Vallisneria americana* was the dominant species). Other fish species caught in the same seine haul included, in order of importance: *Lepomis macrochirus* Rafinesque, 1819 (bluegill), *Labidesthes sicculus* (Cope, 1865) (brook silverside), *Neogobius melanostomus* (round goby), *Lepomis gibbosus* (Linnaeus, 1758) (pumpkinseed), *Perca flavescens* (Mitchill, 1814) (yellow perch), *Ambloplites rupestris* (Rafinesque, 1817) (rock bass), *Micropterus salmoides* (Lacepède, 1802) (largemouth bass), *Fundulus diaphanus* (Lesueur, 1817) (banded killifish), and *Semotilus corporalis* (Mitchill, 1817) (fallfish) (Table S1).

This first mention of western tubenose goby in Quebec waters is most likely the result of a downstream expansion through the St. Lawrence River system coming from Ontario. Goretzke et al. (2019) has shown that tubenose gobies are dispersing outside the Great Lakes. In 2022, over 300 individuals from 20 sites were found in the Upper St. Lawrence River, all representing eastward expansion within the St. Lawrence River (M. Windle, River Institute, *pers. comm.*). Other dispersion vectors, however, could have contributed to the expansion.

Although passive downstream dispersal by water currents is a known dispersal mechanism for tubenose gobies (Zitek et al. 2004), downstream dispersion of adults in the St. Lawrence River may be possible but seriously impeded by the presence of the Moses-Saunders Power dam (Figure 1A) that could potentially act as a downstream barrier, specially for benthic fish known to have low mobility. Migration of tubenose and round gobies despite the presence of dams have been reported in the past (e.g., Moselle River in Germany, Rhine River in France, Border Meuse area in The Netherlands and Belgium, Dyje River in Czech Republic, historic Rideau Canal in Canada) (Von Landwüst 2006; Manné and Poulet 2008; Cammaerts et al. 2012; Janáč et al. 2013a; Bergman et al. 2022), with high juvenile survival (only 3% mortality) following turbine passage (Janáč et al. 2013a). Juvenile drift in currents may act as an important vector of passive downstream dispersal, as observed in other gobiid fish species, including western tubenose goby (Janáč et al. 2013b). Vertical migration is an important factor in drift of early life stages of tubenose goby (Kocovsky et al. 2011). Larvae are known to perform nighttime vertical migrations, facilitating passive and unassisted dispersion (Zitek et al. 2004). Moreover, early life stages drift is commonly known for the dispersion of non-native invertebrates and plant species (Dawson and Holland 1999; Stoeckel et al. 2004; Jacquemyn et al. 2010; Van Riel et al. 2011), and other gobiid fish species (such as round goby and bighead goby *Ponticola kessleri* Günther, 1861), which together with western tubenose goby, have been found to disperse downstream after being introduced by anthropogenic means (e.g., ballast water discharge) (Borcherding et al. 2011; Janáč et al. 2012).

Even if downstream expansion is the most probable hypothesis of this first mention of western tubenose goby in Quebec, other potential explanations

cannot be ruled out. Even though live baitfish is banned in Quebec since 2017 (Paradis and Brisson-Bonenfant 2017), and that the use of gobies as baitfish is prohibited by law in Ontario (MNRF 2023), there is still a potential for illegal introductions and intentional release that cannot be excluded. As suggested by Kocovsky et al. (2011), bait bucket introduction may be one of the hypotheses of its expansion through the Great Lakes.

Lastly, the maritime traffic along the St. Lawrence Seaway is also a potential explanation, acting as an introduction pathway. The St. Lawrence Seaway is a very important shipping route, summing 3700 km in length. It connects the Great Lakes to the Atlantic Ocean through the St. Lawrence River and Gulf of St. Lawrence, with more than a hundred ports, 15 of which are major ports while the remaining are regional ports (GLSLS 2023). Lakers, the group of shipping vessels only transiting in the Great Lakes, are one of the main users of the Seaway and are responsible for 95% of the ballast water that is discharged between the Great Lakes and the St. Lawrence River (Rup et al. 2010). Lakers could easily act as facilitators and a significant vector of aquatic invasive species at any one port in the system (Niimi 2004; Ricciardi 2006; Rup et al. 2010). This pathway poses an important risk since trip duration is shorter than international transits, which could lead to considerably higher survival rates (Lavoie et al. 1999). Moreover, smaller boats could also act as vectors at a smaller scale. In fact, it was recently shown that round goby, which is closely related to western tubenose goby, can use and feed on vertical walls and boat hulls (Bussmann and Burkhardt-Holm 2020). In their study, Bussmann and Burkhardt-Holm (2020) showed round gobies in direct contact with boats, which could eventually be used as hiding or potential suitable structures for laying eggs. Although this behaviour has not been observed for western tubenose goby, it could be expected as both species share high ecological, morphological, and phylogenetic similarities (Neilson and Stepien 2009). In addition, tubenose goby has been observed hiding in crevices and submerged objects such as shipping material (Grabowska et al. 2021).

Although several potential vectors and dispersion pathways could explain the presence of the tubenose goby in Lake St. Francis, it is important to highlight that plasticity of life-history traits provide tubenose goby a high adaptive capacity when facing conditions following introductions (Top et al. 2018). Some of these traits depend on the invasion stage, such as the ones related to fecundity that may be favoured during early stages of the invasion (Grabowska et al. 2021) or flexibility in their diet and habitat type that could facilitate secondary invasions (Ondračková et al. 2019).

Tubenose goby in Europe has been found to colonise small water bodies at high latitudes (in colder rivers than expected for the species), illustrating its tolerance to and optimal metabolism at lower temperatures compared

to round goby (O'Neil 2013; Švolíková et al. 2021). This characteristic may help tubenose spread, survive, and reproduce in inland waters in Quebec. This colonization potential in inland waters may be enhanced by the absence of round goby, one of their main competitors (contrary to the St. Lawrence River). Round goby outcompetes tubenose goby (Baer et al. 2017; Cartwright et al. 2019), but in the absence of its competitor, tubenose goby can become abundant and dominant (Valová et al. 2015). Moreover, in their native ranges, they occupy different habitats. Tubenose goby has been generally associated with more lentic environments with submerged vegetation, while round goby has been generally found in rivers (Lelek 1980; Miller 1984). Vegetation may act as expansion corridors and a dispersal pathway into inland waters and slow-moving shallow areas (Kocovsky et al. 2011).

It is a matter of time until it can be seen if Quebec has a self-sustaining population of tubenose gobies, as more individuals may be found through future sampling efforts. It will also be important to examine whether the western tubenose goby shows a similar dispersion pattern and population dynamic in the St. Lawrence River compared to what was observed for the round goby in Quebec. The latter species was first detected in the St. Lawrence River in 1997 near Quebec City and in the year 2000 in Lake St. Francis (Vachon et al. 2014; Morissette et al. 2018). The species was still in low abundance in 2004 but the population has increased considerably since 2009 (Bernatchez et al. 2022).

For the time being, this is the first mention of western tubenose goby in Quebec waters. This is a new aquatic invasive species with the potential to further expand downstream through the St. Lawrence River and with risks of colonizing more lentic water bodies.

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Authors' contribution

Research conceptualization: JG, YP; sample design and methodology: NV, YP, VB; investigation and data collection: VB; data analysis and interpretation: JG, YP, NV, OM, VB, AD; funding provision: YP, NV; roles/writing – original draft; writing – review and editing: JG wrote the original draft, with help from YP. All authors reviewed and edited the manuscript.

Ethics and permits

The data used in this study come from fish sampling conducted by the Ministère de l'Environnement, de la Lutte contre les changements climatiques, de la Faune et des Parcs. No approval of research ethics committees was required. However, the authors confirm that fish handling was done according to the usual ethical standards.

References

Ahnelt H, Banarescu P, Spolwind R, Harka A, Waidbacher H (1998) Occurrence and distribution of three gobiid species (Pisces, Gobiidae) in the middle and upper Danube region-examples of different dispersal patterns? *Biologia-Bratislava* 53: 665–678

Baer J, Hartmann F, Brinker A (2017) Invasion strategy and abiotic activity triggers for nonnative gobiids of the River Rhine. *PLoS ONE* 12: e0183769, https://doi.org/10.1371/journal.pone.0183769

Balon EK (1975) Reproductive guilds of fishes: a proposal and definition. *Journal of the Fisheries Research Board of Canada* 32: 821–864, https://doi.org/10.1139/f75-110

Bergman JN, Raby GD, Neigel KL, Rennie CD, Balshine S, Bennett JR, Fisk AT, Cooke SJ (2022) Tracking the early stages of an invasion with biotelemetry: behaviour of round goby (*Neogobius melanostomus*) in Canada's historic Rideau Canal. *Biological Invasions* 24; 1149–1173, https://doi.org/10.1007/s10530-021-02705-2

Bernatchez S, Paradis Y, Vachon N, Hatin D, Côté C, Brodeur P, Kameni DW (2022) Rapport d'opération du Réseau de suivi ichtyologique (RSI): Secteur du lac Saint-François. Ministère des Forêts, de la Faune et des Parcs, 11 pp

Borcherding J, Staas S, Krüger S, Ondračková M, Šlapanský L, Jurajda P (2011) Non-native Gobiid species in the lower River Rhine (Germany): recent range extensions and densities. *Journal of Applied Ichthyology* 27: 153–155, https://doi.org/10.1111/j.1439-0426.2010.01662.x

Bussmann K, Burkhardt-Holm P (2020) Round gobies in the third dimension-use of vertical walls as habitat enables vector contact in a bottom-dwelling invasive fish. *Aquatic Invasions* 15: 683–699, https://doi.org/10.3391/ai.2020.15.4.09

Cammaerts R, Spikmans F, van Kessel N, Verreycken H, Chérot F, Demol T, Richez S (2012) Colonization of the Border Meuse area (The Netherlands and Belgium) by the non-native western tubenose goby *Proterorhinus semilunaris* (Heckel, 1837) (Teleostei, Gobiidae). *Aquatic Invasions* 7: 251–258, https://doi.org/10.3391/ai.2012.7.2.011

Cartwright A, Gebauer R, Vanina T, Stejskal V, Drozd B (2019) Shelter competition between mature non-indigenous western tubenose goby (*Proterorhinus semilunaris*) and immature invasive round goby (*Neogobius melanostomus*) for plants and rocks. *Biological Invasions* 21: 2723–2734, https://doi.org/10.1007/s10530-019-02006-9

Cerwenka A, Brandner J, Schliewen U, Geist J (2018) Population trends of invasive alien gobies in the upper Danube River: 10 years after first detection of the globally invasive round goby (*Neogobius melanostomus*). *Aquatic Invasions* 13: 525–535, https://doi.org/10.3391/ai.2018.13.4.10

Dawson FH, Holland D (1999) The distribution in bankside habitats of three alien invasive plants in the UK in relation to the development of control strategies. In: Caffrey J, Barrett PRF, Ferreira MT, Moreira IS, Murphy KJ, Wade PM (eds), Biology, Ecology and Management of Aquatic Plants. Springer, Dordrecht, pp 193–201, https://doi.org/10.1007/978-94-017-0922-4_27

Deschamps D, Brodeur P, Côté C, Vachon N (2022) Protocole d'échantillonnage du Réseau de suivi ichtyologique du fleuve Saint-Laurent: Lac Saint-François 2022. Ministère des Forêts, de la Faune et des Parcs, 54 pp + 44 annexes

French JRP III, Jude DJ (2001) Diet and diet overlap of nonindigenous gobies and small benthic native fishes coinhabiting the St. Clair River, MI. *Journal of Great Lakes Research* 27: 300–311, https://doi.org/10.1016/S0380-1330(01)70645-4

Grabowska J, Tarkan AS, Błońska D, Karakuş NT, Janic B, Przybylski M (2021) Prolific pioneers and reserved settlers. Changes in the life-history of the western tubenose goby (*Proterorhinus semilunaris*) at different invasion stages. *Science of the Total Environment* 750: 142316, https://doi.org/10.1016/j.scitotenv.2020.142316

Gebauer R, Veselý L, Vanina T, Buřič M, Kouba A, Drozd B (2019) Prediction of ecological impact of two alien gobiids in habitat structures of differing complexity. *Canadian Journal of Fisheries and Aquatic Sciences* 76: 1954–1961, https://doi.org/10.1139/cjfas-2018-0346

Goretzke JA, Windle MJ, Farrell JM (2019) Range expansion of the western tubenose goby (*Proterorhinus semilunaris* Heckel, 1837) in eastern Lake Ontario and the upper St. Lawrence River. *BioInvasions Records* 8: 684–698, https://doi.org/10.3391/bir.2019.8.3.26

Grant KA, Shadle MJ, Andraso G (2012) First report of tubenose goby (*Proterorhinus semilunaris*) in the eastern basin of Lake Erie. *Journal of Great Lakes Research* 38: 821–824, https://doi.org/10.1016/j.jglr.2012.09.019

Janáč M, Valová Z, Jurajda P (2012) Range expansion and habitat preferences of non-native 0+ tubenose goby (*Proterorhinus semilunaris*) in two lowland rivers in the Danube basin. *Fundamental and Applied Limnology* 181: 73–85, https://doi.org/10.1127/1863-9135/2012/0321

Janáč M, Jurajda P, Kružíková L, Roche K, Prášek V (2013a) Reservoir to river passage of age-0+ year fishes, indication of a dispersion pathway for a non-native species. *Journal of Fish Biology* 82: 994–1010, https://doi.org/10.1111/eff.12037

Janáč M, Šlapanský L, Valová Z, Jurajda P (2013b) Downstream drift of round goby (*Neogobius melanostomus*) and tubenose goby (*Proterorhinus semilunaris*) in their non-native area. *Ecology of Freshwater Fish* 22: 430–438, https://doi.org/10.1111/jfb.12037

Jacquemyn H, Van Looy K, Breyne P, Honnay O (2010) The Meuse river as a corridor for range expansion of the exotic plant species *Sisymbrium austriacum*: evidence for long-distance seed dispersal. *Biological Invasions* 12: 553–561, https://doi.org/10.1007/s10530-009-9461-0

Jude DJ, DeBoe SF (1996) Possible impact of gobies and other introduced species on habitat restoration efforts. *Canadian Journal of Fisheries and Aquatic Sciences* 53: 136–141, https://doi.org/10.1139/f96-001

Jude DJ, Reider RH, Smith GR (1992) Establishment of Gobiidae in the Great Lakes basin. *Canadian Journal of Fisheries and Aquatic Sciences* 49: 416–421, https://doi.org/10.1139/f92-047

Jude DJ, Janssen J, Crawford G (1995) Ecology, distribution, and impact of the newly introduced round tubenose gobies on the biota of the St. Clair and Detroit rivers. In: Munawar M, Edsall T, Leach J (eds), The Lake Huron Ecosystem: Ecology, Fisheries, and Management. Academic Publishing, Amsterdam, 497 pp, https://doi.org/10.14321/j.ctt1pwtcm0.25

Kocovsky PM, Tallman, JA, Jude DJ, Murphy DM, Brown JE, Stepien CA (2011) Expansion of tubenose gobies *Proterorhinus semilunaris* into western Lake Erie and potential effects on native species. *Biological Invasions* 13: 2775–2784, https://doi.org/10.1007/s10530-011-9962-5

Kottelat M, Freyhof J (2007) Handbook of European freshwater fishes. Publications Kottelat, Berlin, Germany, xiii, 646 pp

Kvach Y, Stepien CA (2008) Metazoan parasites of introduced round and tubenose gobies in the Great Lakes: support for the "enemy release hypothesis". *Journal of Great Lakes Research* 34: 23–35, https://doi.org/10.3394/0380-1330(2008)34[23:MPOIRA]2.0.CO;2

Kvach Y, Zamarov V, Pupins M (2021) Review of invasive Ponto-Caspian gobiids: current range and history of expansion. Daugavpils University Academic Press "Saule", 92 pp

La Violette N, Fournier D, Dumont P, Mailhot Y (2003) Caratérisation des communautés de poissons et développement d'un indice d'intégrité biotique pour le fleuve Saint-Laurent, 1995-1997. Société de la faune et des parcs du Québec, Direction de la recherche sur la faune, Ville de Québec, 237 pp

Lavoie DM, Smith LD, Ruiz GM (1999) The potential for intracoastal transfer of nonindigenous species in the ballast water of ships. *Estuarine Coastal Shelf Science* 48: 551–564, https://doi.org/10.1006/ecss.1999.0467

Lelek A (1980) Threatened freshwater fishes of Europe. In: European Committee for the Conservation of Nature and Natural Resources-Council of Europe (eds), The freshwater fishes of Europe. Vol. 9. AULA-Verlag, Wiesbaden, Germany, pp 1–343

Manné S, Poulet N (2008) First record of the western tubenose goby *Proterorhinus semilunaris* (Heckel, 1837) in France. *Knowledge and Management of Aquatic Ecosystems* 389: 931–938, https://doi.org/10.1051/kmae:2008009

Miller PJ (1984) Tokology of gobies. In: Wootton RJ (ed), Fish reproduction. Academic Press Ltd., London, pp 119–153

Morin J (2001) Modélisation des facteurs abiotiques de l'écosystème fluvial du lac Saint François, fleuve Saint-Laurent. PhD thesis, Université du Québec, Institut national de la recherche scientifique INRS-Eau, Québec

Morin J, Leclerc M (1998) From pristine to present state: hydrology evolution of Lake Saint-François, St. Lawrence River. *Canadian Journal of Civil Engineering* 25: 864–879, https://doi.org/10.1139/l98-019

Morissette O, Paradis Y, Pouliot R, Lecomte F (2018) Spatio-temporal changes in littoral fish community structure along the St. Lawrence River (Québec, Canada) following round goby (*Neogobius melanostomus*) invasion. *Aquatic Invasions* 13: 501–512, https://doi.org/10.3391/ai.2018.13.4.08

Neilson ME, Stepien CA (2009) Evolution and phylogeography of the tubenose goby genus *Proterorhinus* (Gobiidae: Teleostei): evidence for new cryptic species. *Biological Journal of the Linnean Society* 96: 664–684, https://doi.org/10.1111/j.1095-8312.2008.01135.x

Niimi AJ (2004) Role of container vessels in the introduction of exotic species. *Marine Pollution Bulletin* 49: 778–782, https://doi.org/10.1016/j.marpolbul.2004.06.006

O'Neil JA (2013) Determination of standard and field metabolic rates in two Great Lakes invading fish species: round goby (*Neogobius melanostomus*) and tubenose goby (*Proterorhinus semilunaris*). Electronic Theses and Dissertations, 4989, https://scholar.uwindsor.ca/etd/4989

Ondračková M, Všetičková L, Adámek Z, Kopeček L, Jurajda P (2019) Ecological plasticity of tubenose goby, a small invader in South Moravian waters. *Hydrobiologia* 829: 217–235, https://doi.org/10.1007/s10750-018-3833-3

Paradis Y, Brisson-Bonenfant C (2017) Résultats du sondage sur l'utilisation des poissons appâts par les pêcheurs sportifs au Québec et sur leurs préoccupations concernant les espèces aquatiques envahissantes. Ministère des Forêts, de la Faune et des Parcs du Québec, 22 pp + 6 annexes

Ricciardi A (2006) Patterns of invasion in the Laurentian Great Lakes in relation to changes in vector activity. *Diversity and Distributions* 12: 425–433, https://doi.org/10.1111/j.1366-9516.2006.00262.x

Roche KF, Janač M, Jurajda P (2013) A review of Gobiid expansion along the Danube-Rhine corridor - geopolitical change as a driver for invasion. *Knowledge and Management of Aquatic Ecosystems* 411: 01, https://doi.org/10.1051/kmae/2013066

Rup MP, Bailey SA, Wiley CJ, Minton MS, Whitman Miller A, Ruiz GM, MacIsaac HJ (2010) Domestic ballast operations on the Great Lakes: Potential importance of Lakers as a vector for introduction and spread of nonindigenous species. *Canadian Journal of Fisheries and Aquatic Sciences* 67: 256–268, https://doi.org/10.1139/F09-180

Stepien CA, Tumeo MA (2006) Invasion genetics of Ponto-Caspian gobies in the Great Lakes: a 'cryptic' species, absence of founder effects, and comparative risk analysis. *Biological Invasions* 8: 61–78, https://doi.org/10.1007/s10530-005-0237-x

Stoeckel JA, Rehmann CR, Schneider DW, Padilla DK (2004) Retention and supply of zebra mussel larvae in a large river system: importance of an upstream lake. *Freshwater Biology* 49: 919–930, https://doi.org/10.1111/j.1365-2427.2004.01237.x

Švolíková KS, Števove B, Križek P, Mosna P, Fedorčák J, Kováč V (2021) Tubenose goby - a discreet invader from the past goes higher. *Journal of Vertebrate Biology* 70: 21042-1, https://doi.org/10.25225/jvb.21042

Tarkan AS, Tepeköy EG, Karakuş U, Top N, Vilizzi L (2019) Plasticity in the feeding ecology of native Ponto-Caspian gobies suggests establishment success in their nonnative range. *International Review of Hydrobiology* 104: 57–67, https://doi.org/10.1002/iroh.201801974

Top N, Karakuş U, Tepeköy EG, Britton JR, Tarkan AS (2018) Plasticity in habitat use of two native Ponto-Caspian gobies, *Proterorhinus semilunaris* and *Neogobius fluviatilis*: implications for invasive populations. *Knowledge and Management of Aquatic Ecosystems* 420: 40, https://doi.org/10.1051/kmae/2019031

Vachon N, Dumont P, Brodeur P, Côté C, Mailhot Y, Mingelbier M, Paradis Y (2014) Réseau de suivi ichtyologique dans le lac Saint-François de 1996 à 2009. Ministère des Forêts, de la Faune et des Parcs, 16 pp

Valová Z, Konečná M, Janáč M, Jurajda P (2015) Population and reproductive characteristics of a non-native western tubenose goby (*Proterorhinus semilunaris*) population unaffected by gobiid competitors. *Aquatic Invasions* 10: 57–68, https://doi.org/10.3391/ai.2015.10.1.06

Van Riel MV, Der Velde GV, De Vaate AB (2011) Dispersal of invasive species by drifting. *Current Zoology* 57: 818–827, https://doi.org/10.1093/czoolo/57.6.818

Vanderploeg HA, Nalepa TF, Jude DJ, Mills EL, Holeck KT, Leibig JR, Grigorovich IA, Ojaveer H (2002) Dispersal and emerging ecological impacts of Ponto-Caspian species in the Laurentian Great Lakes. *Canadian Journal of Fisheries and Aquatic Sciences* 59: 1209–1228, https://doi.org/10.1139/f02-087

Von Landwüst C (2006) Expansion of *Proterorhinus marmoratus* (Teleostei, Gobiidae) into the River Moselle (Germany). *Folia Zoologica-Praha* 55(1): 107

Wiesner C (2005) New records of non-indigenous gobies (*Neogobius* spp.) in the Austrian Danube. *Journal of Applied Ichthyology* 21: 324–327, https://doi.org/10.1111/j.1439-0426.2005.00681.x

Zitek A, Schmutz S, Ploner A (2004) Fish drift in a Danube sidearm-system: II. Seasonal and diurnal patterns. *Journal of Fish Biology* 65: 1339–1357, https://doi.org/10.1111/j.0022-1112.2004.00534.x

Web sites and online databases

GLSLS (2023) Great Lakes St. Lawrence Seaway. http://greatlakes-seaway.com/en/ (accessed 11 January 2023)

MFFP (2021) Ministère des Forêts, de la Faune et des Parcs. Liste des espèces fauniques menacées ou vulnérables au Québec. https://www3.mffp.gouv.qc.ca/faune/especes/menacees/fiche.asp?noEsp=17

MNRF (2023) Ministry of Natural Resources and Forestry of Ontario. Recreational fishing regulations summary. https://www.ontario.ca/files/2023-01/mnrf-fwsb-fishing-regulations-summary-en-2023-01-04.pdf

Supplementary material

The following supplementary material is available for this article:

Table S1. Sampling stations during survey (name of area and period/year).

This material is available as part of online article from:
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