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2020 UPDATE TO "AN IMPACT ASSESSMENT OF GREAT LAKES AQUATIC NONINDIGENOUS SPECIES"

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1.0 SUMMARY

This report includes all major updates to the earlier Risk Assessments on nonindigenous species conducted by the GLANSIS project during the 2020 calendar year. All new assessments were conducted following the same methods outlined in the original technical memorandum, [NOAA Technical Memorandum GLERL-161] "An impact assessment of Great Lakes aquatic nonindigenous species" (Sturtevant et al., 2014). All re-assessments are based on new literature surveys using the original as a baseline and conducted to the same methods. All assessments were reviewed by members of the GLANSIS Team (according to expertise) and by select external reviewers. Results of each risk assessment are incorporated into the species profiles found on the GLANSIS website (https://www.glerl.noaa.gov/glansis/).

To be included in the GLANSIS nonindigenous list, the species in question must meet a particular set of criteria:

1. records of the species appeared suddenly and had not been recorded in the basin previously;
2. it subsequently spreads within the basin;
3. its distribution in the basin is restricted compared with native species;
4. its global distribution is anomalously disjunct (meaning it contains widely scattered and isolated populations);
5. its global distribution is associated with human vectors of dispersal;
6. the basin is isolated from regions possessing the most genetically and morphologically similar species.

Additionally, to be listed on the nonindigenous list rather than the GLANSIS watchlist, a species must have a reproducing population within the basin that is capable of overwintering, as inferred from multiple discoveries of adult and juvenile life stages over at least two consecutive years. Further, impact assessments are only listed in this Technical Memorandum 161 series for species on the nonindigenous list, and not for those with a range expander or cryptogenic status. Range expander species are those that are considered nonindigenous to only a portion of the Great Lakes basin according to the above nonindigenous criterion, but are also native or cryptogenic to some portion of the basin. Cryptogenic species are those that cannot be verified as native or introduced in any of the Great Lakes' basins.

A total of 10 species were assessed or reassessed in 2020, which includes: one species now excluded due to a status change (nonindigenous to cryptogenic); six species that underwent changes detailed in this document; and three species with impacts assessed for the first time (two of which are new to the GLANSIS nonindigenous list). See Table 1 for an overview of the new species and changes to the impact assessments and Table 2 for the new or revised quantitative and qualitative impact scores by species. The centric diatom *Actinocyclus normanii f. subsalsa* was listed in NOAA TM-161 as a nonindigenous species in the Great Lakes, but its status has since been reclassified as cryptogenic. Sediment cores were

collected between 2010 and 2014 as part of the U.S. Environmental Protection Agency Cooperative Agreement GL-00E23101-2 (awardee Euan D. Reavie). Paleolimnological records of *A. normanii f. subsalsa* were identified in the eastern basin of Lake Erie between 1893 and 1897 and in eastern Lake Ontario between 1709 and 1720, decades before the recorded specimens in the cores dated by Stoermer et al. (1985). *Actinocyclus normanii f. subsalsa* is retained in the GLANSIS system, but is designated as cryptogenic and will no longer be included in updates to this tech memo series unless additional evidence comes to light confirming it as nonindigenous.

The ecology section of the profile was created or revised for three species: alewife (*Alosa pseudoharengus),* rainbow smelt *(Osmerus mordax),* and sea lamprey (*Petromyzon marinus).* For alewife, additional literature reduced the number of unknown impact scores to zero, and the beneficial impact of this species increased by six. The socioeconomic-impact score for rainbow smelt changed from unknown to low. The beneficial impact of sea lamprey increased by one point due to its value as a model organism in medical research (Xu et al., 2016*)*.

The following three species (rudd *Scardinius erythrophthalmus*, round goby *Neogobius melanostomus, and* tubenose goby *Proterorhinus semilunaris*) had changes to one or more impact categories. Rudd was changed by one level for both socioeconomic and beneficial impacts to low and moderate impacts respectively. The beneficial impact score for round goby was upgraded from low to moderate due to the positive impact that round goby had on Lake Erie water snakes and sturgeon (King et al., 2006; Jacobs et al., 2017*)*. Lastly*,* new information in the last five years has changed the environmental impact score for tubenose goby from unknown to low – the confidence has risen in this species as it did not have any impacts to the questions in this category.

Scud (*Echinogammarus ischnus),* prior to this year, did not have an organism impact assessment completed. Therefore, the impact assessment in TM-161d is the first iteration for this species.

Two new species were added to the nonindigenous list, Japanese stiltgrass (*Microstegium vimineum*) and the gill maggot (*Salmincola californiensis).* Japanese stiltgrass is a high impact plant species that is widely spread in the inland basins of the Great Lakes. It was first reported below the high-water line of Lake Erie in 1991 on Presque Isle. It was only recently re-discovered in 2020 within a few hundred meters of the original sighting on Presque Isle, prompting its entry into the nonindigenous list. *Salmincola californiensis* has been steadily spreading eastward from its native range in the Pacific Northwest, where it parasitizes *Oncorhynchus* spp*.* Anecdotal reports from anglers *of S. californiensis* parasitizing rainbow trout in Lake Erie beginning in the 1980's (Jason Detar, personal communication, December 18, 2020). It was later discovered in an eastern Lake Ontario tributary in 2014 by anglers and fisheries managers in the Salmon River, qualifying it to join the nonindigenous list (Figura, 2014). *Salmincola californiensis* was likely introduced to the Great Lakes region as a hitchhiker with infected hatchery fish transported from the west coast and stocked in the lakes and their tributaries (Mullin and Reyda, 2020).

An updated version of Table 1 from Sturtevant et al. (2014) is presented in Table 3 below. General changes to the table include a net overall loss of three species from the nonindigenous list as a result of two additions and five reclassifications/removals. One crustacean species (*Salmincola californiensis*) and one plant species (*Microstegium vimineum*) were added, while one algae species (*Actinocyclus normanii f. subsalsa*) was reclassified as cryptogenic, one plant species (*Phalaris arundinacae*) and two fish species (*Esox niger* and *Noturus insignis*) were reclassified as range expanders, and one plant species hybrid (*Mentha x graclilis*) was removed as a standalone species and combined under *Mentha spicata*.

In addition, all of the summary statements in the original Sturtevant et al. (2014) remain relevant and represent the current situation, and they are as follows:

1. Additional research is still needed to understand the environmental impacts of nonindigenous species. The state of knowledge is inadequate to assess the environmental impact for nearly half (now 44% instead of 48%) of the established species.
2. At least 35% (previously 32%) of the nonindigenous species found in the Great Lakes have significant (moderate to high) environmental impact. If the 81 species for which the state of scientific knowledge is insufficient to complete the assessment of environmental impact follow the trends of the assessed species this number will be closer to 50%. References in the literature (e.g., Williamson and Fitter 1996) and popular media of approximately 10% of non-native species becoming invasive is a severe underestimate for the Great Lakes.
3. We estimate 17% (previously 14 to 16%) of the nonindigenous species found in the Great Lakes have moderate to high socioeconomic impact.

Table 1. New species and major changes to the assessments, etc. originally published in Sturtevant et al. (2014).

Species	Addenda	Author, date added
Alosa pseudoharengus	Added ecology section to profile. Environmental and beneficial impact quantitative scores changed, but no change in qualitative statements.	Bartos, 2020
Echinogammarus ischnus	New impact assessment for an existing nonindigenous species.	Bartos, 2020
Microstegium vimineum	New nonindigenous species. New impact assessment.	Bartos, 2020
Neogobius melanostomus	Beneficial impact increased from low to moderate.	Sturtevant, 2020
Osmerus mordax	Revised ecology section, socio-economic impact changed from unknown to low.	Bartos, 2020
Petromyzon marinus	Added ecology section to profile, beneficial score increased by one, but no change in qualitative statements	Lower, 2020
Proterorhinus semilunaris	Environmental impact changed from unknown to low.	Sturtevant, 2020
Salmincola californiensis	New nonindigenous species. New impact assessment.	Bartos, 2020
Scardinius erythrophthalmus	Socio-economic and beneficial impact changed to low and moderate respectively.	Bartos, 2020

Table 2. Changes and additions to Tables 2-11 in Sturtevant et al. (2014). An asterisk indicates species with new impact assessments. For each impact category (i.e., environmental, socio-economic, beneficial), the number of species whose impact was assessed as high (H), moderate (M), low (L), or unknown (U) is given. Note: "Arthropods" refers to non-crustacean arthropods. Relative to Sturtevant et al. (2014), "+" indicates an increase in the number of species in the category, while "–" indicates a decrease.

Scientific Name	Common Name	Family	Environmental Impact		Socio-Economic Impact		Beneficial Impact	
			Score	# Unknown	Score	# Unknown	Score	# Unknown
Alosa pseudoharengus	Alewife	Clupeidae	18	0 (–2)	14	0	13 (+6)	0 (–1)
			High		High		High	
Echinogammarus ischnus *	Scud	Gammaridae	2	1	0	0	1	0
			Moderate		Low		Low	
Microstegium vimineum *	Japanese stiltgrass	Poaceae	19	1	7	0	1	0
			High		High		Low	
Neogobius melanostomus	Round goby	Gobiidae	14 (+1)	0 (–2)	8 (–5)	0	2 (+1)	0
			High		High		Moderate	
Osmerus mordax	Rainbow smelt	Osmeridae	13 (+1)	0 (–2)	1 (+1)	1 (–3)	14	0
			High		Low		High	
Petromyzon marinus	Sea lamprey	Petromyzontidae	12	0	18	1	1 (+1)	0
			High		High		Low	
Proterorhinus semilunaris	Tubenose goby	Gobiidae	1 (+1)	0 (–3)	0	0 (–1)	0	0
			Low		Low		Low	
Salmincola californiensis *	A gill maggot	Lernaepodidae	6	1	2	0	0	0
			High		Moderate		Low	
Scardinius erythrophthalmus	Rudd	Cyprinidae	5 (+2)	1 (–1)	1 (+1)	1 (–1)	2 (+1)	1 (–1)
			Moderate		Low		Moderate	

Table 3. Summary of revised impact assessment results by taxonomic group. Impact assessment scoring is identical to Table 2 above.

	Environmental				Socio-Economic				Beneficial			
Taxon	**H**	**M**	**L**	**U**	**H**	**M**	**L**	**U**	**H**	**M**	**L**	**U**
Fishes (n=26) (–2)	10 (+2)	5	1 (+1)	10 (–4)	3	2 (+1)	19	2 (–2)	8	4 (+2)	11 (–1)	3 (–2)
Annelids (n=6)	0	0	0	6	0	0	6	0	0	0	5	1
Arthropods (n=2)	0	0	0	2	0	0	2	0	0	1	1	0
Bryozoans (n=1)	0	0	0	1	0	0	0	1	0	0	1	0
Coelenterates (n=2)	0	0	0	2	0	0	1	1	0	0	2	0
Crustaceans (n=25) (+1)	4 (+2)	3 (+1)	1 (+1)	17 (–3)	0	2 (+1)	21	2	0	1	21 (+1)	3
Mollusks (n=18)	3	2	1	12	2	2	11	3	0	0	16	2
Plants (n=54) (–1)	7 (+1)	20	3	25 (–3)	6 (+2)	9	37 (–4)	3	3 (–1)	15	31 (–2)	5
Algae (n=26) (–1)	0	2 (–2)	20	3	0 (–1)	3	22 (–1)	0	0	1	25 (–1)	0
Amoebae (n=3)	0	0	0	3	0	0	3	0	0	0	3	0
Parasites and Diseases (n=20)	7	1	12	0	2	0	18	0	0	0	20	0
Total (n=183) (–3)	**31 (+5)**	**33 (–1)**	**38 (+2)**	**81 (–10)**	**13 (+1)**	**18 (+2)**	**140 (–5)**	**12 (–2)**	**11 (–1)**	**22(+2)**	**136 (–3)**	**14 (–2)**

2.0 RISK ASSESSMENTS

Scientific Name: *Alosa pseudoharengus*

Common Name: Alewife

Organism Impact Assessment

IMPACT RESULTS

Environmental: High
Socio-Economic: High
Beneficial: High

Comments: No change in qualitative statements. Beneficial impact score was increased by six, and two unknowns were removed from environmental impact.

ENVIRONMENTAL IMPACT

Does the species pose some hazard or threat to the health of native species (e.g., it magnifies toxin levels, is poisonous, a virus, bacteria, parasite, or a vector of one)?

Yes, and it has resulted in the reduction or extinction of one or more native species populations, affects multiple species, or is a reportable disease	6√
Yes, but negative consequences have been small (e.g., limited number of infected individuals, limited pathogen transmissibility, mild effects on populations and ecosystems) AND/OR It has significantly affected similar species in past invasions outside of the Great Lakes	1
Not significantly	0
Unknown	U

- *Alewife has been shown to cause thiamine deficiency and, consequently, early mortality syndrome (EMS) in populations of alewife predators. EMS and its adverse effects on recruitment and fish populations is well-documented for coho salmon (*Oncorhynchus kisutch*) (Fitzsimons et al. 1999), lake trout (Fitzsimons et al. 1999), and Atlantic salmon (Ketola et al. 2000; Madenjian et al. 2008b) (in which it is also referred to as Cayuga syndrome (Fitzsimons et al. 1999)), among other fishes.*

Does it out-compete native species for available resources (e.g., habitat, food, nutrients, light)?

Yes, and it has resulted in significant adverse effects (e.g., critical reduction, extinction, behavioral changes) on one or more native species populations	6√
Yes, and it has caused some noticeable stress to or decline of at least one native species population	1
Not significantly	0
Unknown	U

- *Disappearance of native planktivorous salmonids, such as lake whitefish (*Coregonus clupeaformis*), in the Great Lakes has been attributed in part to the introduction of alewife because of reduced zooplankton populations (Crowder and Binkowski 1983; Todd 1986; Page and Laird 1993).*
- *Crowder (1984) speculated that a cisco native to Lake Michigan, the bloater (*C. hoyi*) evolved fewer and shorter gill rakers, and shifted to benthic habitat and diet as a result of competition with alewife.*

Does it alter predator-prey relationships?

Yes, and it has resulted in significant adverse effects (e.g., added pressure to threatened/endangered species, significant reduction or extinction of any native species populations, creation of a dead end or any other significant alteration in the food web)	6√
Yes, and it has resulted in some noticeable stress to or decline of at least one native species population AND/OR Yes, and it has resulted in some alteration of the food web structure or processes, the effects of which have not been widespread or severe	1
Not significantly	0
Unknown	U

- *Alewife likely has an even larger effect on native fish populations through predation of larvae than competition for food resources (Eck and Wells 1987; Madenjian et al. 2008b). Using time-series data for various fish populations along with change point regression analysis, scientists concluded that predation of larvae by alewife likely contributed to the decline of yellow perch (*Perca flavescens*), deepwater sculpin (*Myoxocephalus thompsonii*), burbot (*Lota lota*), Atlantic salmon (*Salmo salar*), lake trout (*Salvelinus namaycush*), and emerald shiner (*Notropis atherinoides*) (Madenjian et al. 2008b).*
- *Alewife and rainbow smelt predation in Lake Champlain may prevent* Mysis diluviana *(formerly* Mysis relicta*) from recovering from pre-1995 (zebra mussel invasion) densities (Ball et al. 2015). In inland lakes, young-of-year largemouth bass grow slower and have lower trophic position due to the strong effects alewife has on the zooplankton community (Boel et al. 2018).*

Has it affected any native populations genetically (e.g., through hybridization, selective pressure, introgression)?

Yes, and it has caused a loss or alteration of genes which may be irreversible or has led to the decline or extinction of one or more native species	6
Yes, some damage to markets or sectors has been observed, but negative consequences have been small AND/OR It has a history of harming markets or economic sectors in past invasions outside of the Great Lakes	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to affect native populations genetically in this review.*

Does it negatively affect water quality (e.g., increased turbidity or clarity, altered nutrient, oxygen, or other chemical levels/cycles)?

Yes, it has caused widespread, frequent, or otherwise expensive inhibition of recreation and tourism	6
Yes, but negative consequences have been small	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to affect water quality in this review.*

Does it alter the physical ecosystem in some way (e.g., facilitated erosion/siltation, altered hydrology, altered macrophyte/phytoplankton communities, changes to substrate (physical or chemical))?

Yes, and it has had a widespread, long term, or severe negative effect on the physical ecosystem AND/OR Yes, and it has resulted in significant negative consequences for at least one native species	6
Yes, it has affected the physical ecosystem to some extent, but the alterations and resulting adverse effects have been mild AND/OR It has significantly altered physical ecosystems in past invasions outside of the Great Lakes	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to alter the physical ecosystem in this review.*

Environmental Impact Total	18
Total Unknowns (U)	0

SOCIO-ECONOMIC IMPACT

Does the species pose some hazard or threat to human health (e.g., it magnifies toxin levels, is poisonous, a virus, bacteria, parasite, or a vector of one)

Yes, significant effects on human health have already been observed	6
Yes, but negative consequences have not been widespread, long lasting, or severe AND/OR It has significantly affected human health in past invasions outside of the Great Lakes	1
Not significantly	0√
Unknown	U

- *This species has not been reported to pose a hazard to human health in this review.*

Does it cause damage to infrastructure (such as water intakes, pipes, or any other industrial or recreational infrastructure)?

Yes, it is known to cause significant damage	6
Yes, but the costs have been small and are largely reparable or preventable AND/OR It has a history of causing significant infrastructural damage in past invasions outside of the Great Lakes	1
Not significantly	0√
Unknown	U

- *This species has not been reported to damage infrastructure in this review.*

Does it negatively affect water quality?

Yes, it has significantly affected water quality, and is costly or difficult to reverse	6
Yes, but the effects are negligible and/or easily reversed AND/OR It has a history of significantly affecting water quality in past invasions outside of the Great Lakes	1√
Not significantly	0
Unknown	U

- *During the 1950s and 60s, dead alewives contributed to oxygen depletion and hypoxia (Madenijan et al. 2008b).*

Does it harm any markets or economic sectors (e.g., commercial fisheries, aquaculture, agriculture)?

Yes, it has caused significant damage to one or more markets or economic sectors	6
Yes, some damage to markets or sectors has been observed, but negative consequences have been small AND/OR It has a history of harming markets or economic sectors in past invasions outside of the Great Lakes	1√
Not significantly	0
Unknown	U

- *Through predation of yellow perch and EMS effects on lake trout, alewife has negatively affected commercial fisheries in the lower 4 Great Lakes (Mills et al. 2005; Madenijan et al. 2008b).*

Does it inhibit recreational activities and/or associated tourism (e.g., through frequent water closures, equipment damage, decline of recreational species)?

Yes, it has caused widespread, frequent, or otherwise expensive inhibition of recreation and tourism	6√
Yes, but negative consequences have been small	1
Not significantly	0
Unknown	U

- *Periodic large-scale die-offs littered the beaches of the Great Lakes with rotting fish in the 1960s. Such die-offs caused large-scale beach closures (Brown 1968; Becker 1983).*

Does it diminish the perceived aesthetic or natural value of the areas it inhabits?

Yes, the species has received significant attention from the media/public, significantly diminished the natural or cultural character of the area, or significantly reduced the area's value for future generations	6 √
Yes, but negative consequences have been small	1
Not significantly	0
Unknown	U

- *Alewife mortality events that littered the beaches of the Great Lakes with rotting fish happened with such frequency that they became known as "the annual spring and summer die-off" (Brown 1968).*

Socio-Economic Impact Total	14
Total Unknowns (U)	0

BENEFICAL IMPACT

Does it act as a biological control agent for aquatic weeds or other harmful nonindigenous organisms?

Yes, it has succeeded significantly as a control agent	6
Yes, it has had some success as a control agent, but may be inconsistent or lack a desired level of effectiveness	1√
Not significantly	0
Unknown	U

- *In the Great Lakes, alewife consume the invasive cladocerans* Bythotrephes *and* Cercopagis *(Keilty 1990; Mills et al. 1992; Bushnoe et al. 2003), with the highest consumption rates nearshore (Keeler et al. 2015). Alewife also heavily prey upon the invasive bloody red shrimp (*Hemimysis anomala*) (Boscarino et al. 2020).*

Is it commercially valuable (e.g., for fisheries, aquaculture, agriculture, bait, ornamental trade)?

Yes, it is economically important to at least one of these industries	6√
Yes, but its economic contribution is small	1
Not significantly	0
Unknown	U

- *Alewife is extremely important as prey for the salmon and trout fisheries in the Great Lakes (Dettmers et al. 2012).*
- *Chinook (*Oncorhynchus tshawytscha*), coho (*Oncorhynchus kisutch*), and Atlantic salmon (*Salmo salar*) all rely on alewife as forage in Lake Ontario (Mumby et al. 2018). In late summer 2016, alewife dominated lake trout (*Salvelinus namaycush*) diets in northeastern Lake Michigan (Luo et al. 2019).*

Is it recreationally valuable (e.g., for sport or leisurely fishing, as a pet, or for any other personal activity)?

Yes, it is commonly employed recreationally and has some perceived value for local communities and/or tourism	6
Yes, it is sometimes employed recreationally, but adds little value to local communities or tourism	1
Not significantly	0√
Unknown	U

- *This species has not been reported to be recreationally valuable in this review.*

Does the species have some medicinal or research value (outside of research geared towards its control)?

Yes, it has significant medicinal or research value	6
It is potentially important to medicine or research and is currently being or scheduled to be studied	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to have medicinal or research value in this review.*

Does the species remove toxins or pollutants from the water or otherwise increase water quality?

Yes, it has caused widespread, frequent, or otherwise expensive inhibition of recreation and tourism	6
Yes, but negative consequences have been small	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to improve water quality in this review.*

Does the species have a positive ecological impact outside of biological control (e.g., increases the growth or reproduction rates of other species, fills an important gap in the food web, supports the survival of a species which is threatened, endangered species, or commercially valuable)?

Yes, it significantly contributes to the ecosystem in one or more of these ways	6√
Yes, it provides some positive contribution to the ecosystem, but is not vital	1
Not significantly	0
Unknown	U

- *Non-native salmonids in the Great Lakes support a multimillion dollar sport fishing economy and have caused alewife populations to decline to the extent that salmonid stocking has been reduced to bolster alewife abundance and sustain the sport fisheries (McCrimmon 2002; Horns 2010; Murry et al. 2010).*

Beneficial Impact Total	13
Total Unknowns (U)	0

Scientific Name: *Echinogammarus ischnus*

Common Name: A scud

Organism Impact Assessment

IMPACT RESULTS

Environmental: Moderate
Socio-Economic: Low
Beneficial: Low

Comments: New impact assessment for an existing established species.

ENVIRONMENTAL IMPACT

Does the species pose some hazard or threat to the health of native species (e.g., it magnifies toxin levels, is poisonous, a virus, bacteria, parasite, or a vector of one)?

Yes, and it has resulted in the reduction or extinction of one or more native species populations, affects multiple species, or is a reportable disease	6
Yes, but negative consequences have been small (e.g., limited number of infected individuals, limited pathogen transmissibility, mild effects on populations and ecosystems) AND/OR It has significantly affected similar species in past invasions outside of the Great Lakes	1
Not significantly	0√
Unknown	U

- Echinogammarus ischnu*s has been found to host a parasitic water mold (oomycete) in the St. Lawrence River. This oomycete also parasitizes the Great Lakes native amphipod* Gammarus fasciatus*, but the effects are less severe, potentially preventing* E. ischnus *from becoming dominant (Kestrup et al. 2011b).*

Does it out-compete native species for available resources (e.g., habitat, food, nutrients, light)?

Yes, and it has resulted in significant adverse effects (e.g., critical reduction, extinction, behavioral changes) on one or more native species populations	6
Yes, and it has caused some noticeable stress to or decline of at least one native species population	1 √
Not significantly	0
Unknown	U

- *Following its initial establishment,* E. ischnus *became one of the most abundant non-dreissenid benthic invertebrates in the Lake Ontario, Lake Michigan, and Lake Erie watersheds, where it locally displaced the native amphipod* Gammarus fasciatus *from many sites (Dermott et al. 1998; Stewart et al. 1998a,b; Nalepa et al. 2001; Ratti and Barton 2003; van Overdijk et al. 2003; Haynes et al. 2005; Limén et al. 2005). It has been hypothesized that such displacement is partially due to competition for resources (Witt et al. 1997; González and Burkart 2004; Limén et al. 2005; Palmer and Ricciardi 2005; Kestrup and Ricciardi 2009b).*
- *A mechanism for competitive exclusion of* G. fasciatus *by* E. ischnus *is less clear and may be influenced by total or relative amphipod densities (van Overdijk et al. 2003; Kestrup and Ricciardi 2009a) or by differences in the physical environment (Palmer and Ricciardi 2004).*

- *For instance, the initial replacement of* G. fasciatus *by* E. ischnus *occurred in primarily rocky and dreissenid-covered habitats, while* G. fasciatus *populations continued to persist on algal and macrophyte covered substrates (Dermott et al. 1998; Duggan and Francoeur 2007). These two amphipod species may also differ in their responses to abiotic factors such as current velocity or pH, which could affect their relative fitness in different environments (Palmer and Ricciardi 2004).* Echinogammarus ischnus *typically numerically dominates high flow sites, and its abundance in the St. Lawrence River has been more positively correlated with current velocity than with any other physical attribute (Palmer and Ricciardi 2004). Kang et al. (2007) also encountered* E. ischnu*s more frequently at high energy coastal sites throughout the Great Lakes.*
- *It has been suggested that* E. ischnus *has potentially benefited from a co-evolved relationship with 262 dreissenid mussels (Ricciardi and MacIsaac 2000). Available nutrition from mussel bio deposits, in combination with the structural complexity of* Dreissena *mussel substrate, may have given* E. ischnus *a competitive advantage, stimulating its population expansion in the lower Great Lakes (van Overdijk et al. 2003). However, at some sites, native amphipods have been found to consume more* Dreissena *pseudofeces than* E. ischnus *(González and Burkhart 2004). Furthermore, carbon isotopic composition data indicated that the diets of* E. ischnus *and native Great Lakes amphipod* G. fasciatus *differ, suggesting that competition for food is an unlikely mechanism of the species replacement (Limén et al. 2005).*

Does it alter predator-prey relationships?

Yes, and it has resulted in significant adverse effects (e.g., added pressure to threatened/endangered species, significant reduction or extinction of any native species populations, creation of a dead end or any other significant alteration in the food web)	6
Yes, and it has resulted in some noticeable stress to or decline of at least one native species population AND/OR Yes, and it has resulted in some alteration of the food web structure or processes, the effects of which have not been widespread or severe	1√
Not significantly	0
Unknown	U

- *Following its initial establishment,* E. ischnus *became one of the most abundant non-dreissenid benthic invertebrates in the Lake Ontario, Lake Michigan, and Lake Erie watersheds, where it locally displaced the native amphipod* Gammarus fasciatus *from many sites (Dermott et al. 1998; Stewart et al. 1998a,b; Nalepa et al. 2001; Ratti and Barton 2003; van Overdijk et al. 2003; Haynes et al. 2005; Limén et al. 2005). It has been hypothesized that such displacement is partially due to intraguild predation (Witt et al. 1997; González and Burkhart 2004; Limén et al. 2005; Palmer and Ricciardi 2005; Kestrup and Ricciardi 2009b).*
- *Studies in the St. Lawrence River have shown that* E. ischnu*s and* G. fasciatus *are mutual (intraguild) predators.* Echinogammarus ischnus *is generally the superior predator of adult gammarids in waters of higher conductivity (Kestrup and Ricciardi 2009b), but this advantage is offset by* G. fasciatus *preying more efficiently on* E. ischnu*s juveniles (Kestrup et al. 2011a).*
- *Research in central Europe also reports the invasive* E. ischnus *to be a stronger predator over native gammarids in cases of intraguild predation, suggesting that predation is a probable mechanism of species replacement (Kinzler and Maier 2006).*
  It is possible that E. ischnus *evades predators more easily than* G. fasciatus*, particularly on dreissenid covered substrate (González and Burkhart 2004). In laboratory feeding trials,* G. fasciatu*s was more heavily consumed by yellow perch (*Perca flavescen*s*) *and northern madtom (*Neogobius melanostomus*) on dreissenid-covered substrate than* E. ischnu*s, while* E. ischnus *was consumed more heavily on macrophyte beds (González and Burkhart 2004). In contrast, other studies have found no difference between the two species in their vulnerability to predation on dreissenid-covered substrate (Palmer and Ricciardi 2005; Kestrup and Ricciardi 2009a).*

Has it affected any native populations genetically (e.g., through hybridization, selective pressure, introgression)?

Yes, and it has caused a loss or alteration of genes which may be irreversible or has led to the decline or extinction of one or more native species	6
Yes, some damage to markets or sectors has been observed, but negative consequences have been small AND/OR It has a history of harming markets or economic sectors in past invasions outside of the Great Lakes	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to affect native populations genetically in this review.*

Does it negatively affect water quality (e.g., increased turbidity or clarity, altered nutrient, oxygen, or other chemical levels/cycles)?

Yes, it has caused widespread, frequent, or otherwise expensive inhibition of recreation and tourism	6
Yes, but negative consequences have been small	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to affect water quality in this review*

Does it alter the physical ecosystem in some way (e.g., facilitated erosion/siltation, altered hydrology, altered macrophyte/phytoplankton communities, changes to substrate (physical or chemical))?

Yes, and it has had a widespread, long term, or severe negative effect on the physical ecosystem AND/OR Yes, and it has resulted in significant negative consequences for at least one native species	6
Yes, it has affected the physical ecosystem to some extent, but the alterations and resulting adverse effects have been mild AND/OR It has significantly altered physical ecosystems in past invasions outside of the Great Lakes	1
Not significantly	0
Unknown	U √

- *Unknown.*

Environmental Impact Total	2
Total Unknowns (U)	1

SOCIO-ECONOMIC IMPACT

Does the species pose some hazard or threat to human health (e.g., it magnifies toxin levels, is poisonous, a virus, bacteria, parasite, or a vector of one)

Yes, significant effects on human health have already been observed	6
Yes, but negative consequences have not been widespread, long lasting, or severe AND/OR	1

It has significantly affected human health in past invasions outside of the Great Lakes	
Not significantly	0√
Unknown	U

- *This species has not been reported to pose a hazard to human health in this review.*

Does it cause damage to infrastructure (such as water intakes, pipes, or any other industrial or recreational infrastructure)?

Yes, it is known to cause significant damage	6
Yes, but the costs have been small and are largely reparable or preventable AND/OR It has a history of causing significant infrastructural damage in past invasions outside of the Great Lakes	1
Not significantly	0√
Unknown	U

- *This species has not been reported to damage infrastructure in this review.*

Does it negatively affect water quality?

Yes, it has significantly affected water quality, and is costly or difficult to reverse	6
Yes, but the effects are negligible and/or easily reversed AND/OR It has a history of significantly affecting water quality in past invasions outside of the Great Lakes	1
Not significantly	0√
Unknown	U

- *This species has not been reported to negatively impact water quality in this review.*

Does it harm any markets or economic sectors (e.g., commercial fisheries, aquaculture, agriculture)?

Yes, it has caused significant damage to one or more markets or economic sectors	6
Yes, some damage to markets or sectors has been observed, but negative consequences have been small AND/OR It has a history of harming markets or economic sectors in past invasions outside of the Great Lakes	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to harm any markets or economic sectors in this review.*

Does it inhibit recreational activities and/or associated tourism (e.g., through frequent water closures, equipment damage, decline of recreational species)?

Yes, it has caused widespread, frequent, or otherwise expensive inhibition of recreation and tourism	6
Yes, but negative consequences have been small	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to inhibit recreation or tourism in this review.*

Does it diminish the perceived aesthetic or natural value of the areas it inhabits?

Yes, the species has received significant attention from the media/public, significantly diminished the natural or cultural character of the area, or significantly reduced the area's value for future generations	6
Yes, but negative consequences have been small	1
Not significantly	0√
Unknown	U

- *This species has not been reported to diminish aesthetic or natural value in this review.*

Socio-Economic Impact Total	0
Total Unknowns (U)	0

BENEFICAL IMPACT

Does it act as a biological control agent for aquatic weeds or other harmful nonindigenous organisms?

Yes, it has succeeded significantly as a control agent	6
Yes, it has had some success as a control agent, but may be inconsistent or lack a desired level of effectiveness	1
Not significantly	0√
Unknown	U

- *This species has not been reported to act as a biological control agent in this review.*

Is it commercially valuable (e.g., for fisheries, aquaculture, agriculture, bait, ornamental trade)?

Yes, it is economically important to at least one of these industries	6
Yes, but its economic contribution is small	1
Not significantly	0√
Unknown	U

- *This species has not been reported to be commercially valuable in this review.*

Is it recreationally valuable (e.g., for sport or leisurely fishing, as a pet, or for any other personal activity)?

Yes, it is commonly employed recreationally and has some perceived value for local communities and/or tourism	6
Yes, it is sometimes employed recreationally, but adds little value to local communities or tourism	1
Not significantly	0√
Unknown	U

- *This species has not been reported to be recreationally valuable in this review.*

Does the species have some medicinal or research value (outside of research geared towards its control)?

Yes, it has significant medicinal or research value	6
It is potentially important to medicine or research and is currently being or scheduled to be studied	1

Not significantly	0 √
Unknown	U

- *This species has not been reported to have medicinal or research value in this review.*

Does the species remove toxins or pollutants from the water or otherwise increase water quality?

Yes, it has caused widespread, frequent, or otherwise expensive inhibition of recreation and tourism	6
Yes, but negative consequences have been small	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to improve water quality in this review.*

Does the species have a positive ecological impact outside of biological control (e.g., increases the growth or reproduction rates of other species, fills an important gap in the food web, supports the survival of a species which is threatened, endangered species, or commercially valuable)?

Yes, it significantly contributes to the ecosystem in one or more of these ways	6
Yes, it provides some positive contribution to the ecosystem, but is not vital	1 √
Not significantly	0
Unknown	U

- *Benthic invertebrates including* Echinogammarus ischnus *are a major part of the native yellow perch (*Perca flavescens*) and lake sturgeon (*Acipenser fulvescens*) diets (Gonzalez and Burkart 2004; Bruestle et al. 2019).*

Beneficial Impact Total	1
Total Unknowns (U)	0

Scientific Name: *Microstegium vimineum*

Common Name: Japanese stiltgrass

Organism Impact Assessment

IMPACT RESULTS

Environmental: High
Socio-Economic: High
Beneficial: Low

Comments: New established species.

ENVIRONMENTAL IMPACT

Does the species pose some hazard or threat to the health of native species (e.g., it magnifies toxin levels, is poisonous, a virus, bacteria, parasite, or a vector of one)?

Yes, and it has resulted in the reduction or extinction of one or more native species populations, affects multiple species, or is a reportable disease	6 √
Yes, but negative consequences have been small (e.g., limited number of infected individuals, limited pathogen transmissibility, mild effects on populations and ecosystems) AND/OR It has significantly affected similar species in past invasions outside of the Great Lakes	1
Not significantly	0
Unknown	U

- *It can be a reservoir for pathogens such as* Bipolaris *sp. (Leaf Blight disease), and promotes their emergence and amplification which results in spillover to native species (Flory et al. 2011; Kleczeweski et al. 2012; Stricker et al. 2016).*

Does it out-compete native species for available resources (e.g., habitat, food, nutrients, light)?

Yes, and it has resulted in significant adverse effects (e.g., critical reduction, extinction, behavioral changes) on one or more native species populations	6 √
Yes, and it has caused some noticeable stress to or decline of at least one native species population	1
Not significantly	0
Unknown	U

- Microstegium vimineum *can quickly outcompete and replace existing vegetation. Its fast growth and adaptations to low light allowed it to reduce tree and other native plants regeneration through shading of the sub-canopy (Leict 2005; Flory 2010).*
- *It alters local soil chemistry and microbial activity to increase NO_3^- pools (by reducing NH4) which promotes its growth over native species even further (Strickland et al. 2010; Strickland et al. 2011; Craig and Fraterrigo 2017; Craig et al. 2019).*

Does it alter predator-prey relationships?

Yes, and it has resulted in significant adverse effects	6

(e.g., added pressure to threatened/endangered species, significant reduction or extinction of any native species populations, creation of a dead end or any other significant alteration in the food web)	
Yes, and it has resulted in some noticeable stress to or decline of at least one native species population AND/OR Yes, and it has resulted in some alteration of the food web structure or processes, the effects of which have not been widespread or severe	1 √
Not significantly	0
Unknown	U

- *Invasion of the forest floor by* M. vimineum *and the subsequent reduction in herbaceous plant cover can reduce arthropod abundance and richness across multiple trophic levels (Marshall and Buckley 2009; Simao et al. 2010). These altered trophic interactions between native insect species reduced the abundance of* Anaxyrus [Bufo] americanus *(American toad) in invaded forests (DeVore and Maerz 2014).*
- M. vimineum *facilitated declines in sub-canopy habitat in New Jersey deciduous forests may have resulted in the decline in abundance of some guilds of birds between 1980 to 2005 (Baiser et al. 2008). Rapid increases to soil pH and phosphorus availability following* M. vimineum *invasion may reduce microarthropod community diversity and favor mite abundance in leaf litter (McGrath and Binkley 2009).*

Has it affected any native populations genetically (e.g., through hybridization, selective pressure, introgression)?

Yes, and it has caused a loss or alteration of genes which may be irreversible or has led to the decline or extinction of one or more native species	6
Yes, some damage to markets or sectors has been observed, but negative consequences have been small AND/OR It has a history of harming markets or economic sectors in past invasions outside of the Great Lakes	1
Not significantly	0
Unknown	U √

- *Insufficient information was uncovered in this review to determine if this species can affect native populations genetically.*

Does it negatively affect water quality (e.g., increased turbidity or clarity, altered nutrient, oxygen, or other chemical levels/cycles)?

Yes, it has caused widespread, frequent, or otherwise expensive inhibition of recreation and tourism	6
Yes, but negative consequences have been small	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to affect water quality in this review.*

Does it alter the physical ecosystem in some way (e.g., facilitated erosion/siltation, altered hydrology, altered macrophyte/phytoplankton communities, changes to substrate (physical or chemical))?

Yes, and it has had a widespread, long term, or severe negative effect on the physical ecosystem AND/OR Yes, and it has resulted in significant negative consequences for at least one native species	6√

Yes, it has affected the physical ecosystem to some extent, but the alterations and resulting adverse effects have been mild AND/OR It has significantly altered physical ecosystems in past invasions outside of the Great Lakes	1
Not significantly	0
Unknown	U

- M. vimineum’s *high biomass production leads to large amounts of leaf litter, which is a physical barrier to tree seedling establishment (Flory and Clay 2010).*
- *Alterations to local soil chemistry by* M. vimineum *invasion have been shown to favor its growth and spread over native species.* M. vimineums’s *high nitrogen demand promotes the activity of nitrifying cycling bacteria and archaea, leading to increased nitrification rates and transformation of ammonia to nitrate (Lee et al. 2012; Rodrigues et al. 2015; Shannon-Firestone et al. 2015; Rippel et al. 2020). A larger nitrate pool benefited* M. vimineum *growth and spread, resulting in increased soil pH that further increased nitrification rates (Kourtev et al. 1998, 2002; Ehrenfeld et al. 2001).*
- *Carbon-cycling is also impacted by* M. vimineum *invasion. It’s rapid growth and effect on soil microbes accelerated carbon-cycling, resulting in a net loss of soil carbon which may have implications on long term soil fertility (Strickland et al. 2010; Strickland et al. 2011; Craig and Fraterrigo 2017; Craig et al. 2019).*

Environmental Impact Total	19
Total Unknowns (U)	1

SOCIO-ECONOMIC IMPACT

Does the species pose some hazard or threat to human health (e.g., it magnifies toxin levels, is poisonous, a virus, bacteria, parasite, or a vector of one)

Yes, significant effects on human health have already been observed	6
Yes, but negative consequences have not been widespread, long lasting, or severe AND/OR It has significantly affected human health in past invasions outside of the Great Lakes	1
Not significantly	0√
Unknown	U

- *This species has not been reported to pose a hazard to human health in this review.*

Does it cause damage to infrastructure (such as water intakes, pipes, or any other industrial or recreational infrastructure)?

Yes, it is known to cause significant damage	6
Yes, but the costs have been small and are largely reparable or preventable AND/OR It has a history of causing significant infrastructural damage in past invasions outside of the Great Lakes	1
Not significantly	0√
Unknown	U

- *This species has not been reported to damage infrastructure in this review.*

Does it negatively affect water quality?

Yes, it has significantly affected water quality, and is costly or difficult to reverse	6
Yes, but the effects are negligible and/or easily reversed	1

AND/OR It has a history of significantly affecting water quality in past invasions outside of the Great Lakes	
Not significantly	0√
Unknown	U

- *This species has not been reported to negatively impact water quality in this review.*

Does it harm any markets or economic sectors (e.g., commercial fisheries, aquaculture, agriculture)?

Yes, it has caused significant damage to one or more markets or economic sectors	6
Yes, some damage to markets or sectors has been observed, but negative consequences have been small AND/OR It has a history of harming markets or economic sectors in past invasions outside of the Great Lakes	1 √
Not significantly	0
Unknown	U

- *Its fast growth and adaptations to low light allowed it to reduce tree and other native plants regeneration through shading of the sub-canopy which could negatively impact the timber industry (Leict 2005; Flory 2010).*

Does it inhibit recreational activities and/or associated tourism (e.g., through frequent water closures, equipment damage, decline of recreational species)?

Yes, it has caused widespread, frequent, or otherwise expensive inhibition of recreation and tourism	6
Yes, but negative consequences have been small	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to inhibit recreation or tourism in this review.*

Does it diminish the perceived aesthetic or natural value of the areas it inhabits?

Yes, the species has received significant attention from the media/public, significantly diminished the natural or cultural character of the area, or significantly reduced the area's value for future generations	6√
Yes, but negative consequences have been small	1
Not significantly	0
Unknown	U

- *Historical ecosystems may be lost through a loss of species diversity (Leict 2005; Flory 2010). Continuous removal and prevention (labor, chemicals, and time) may be costly (Flory 2017).*
- *It can infest lawns and gardens and become a visual and physical nuisance and its control is advocated for by various extension offices and landscape companies (Hubbard 2018; GreenTurf 2019; NYIS 2019).*

Socio-Economic Impact Total	7
Total Unknowns (U)	0

BENEFICAL IMPACT

Does it act as a biological control agent for aquatic weeds or other harmful nonindigenous organisms?

Yes, it has succeeded significantly as a control agent	6
Yes, it has had some success as a control agent, but may be inconsistent or lack a desired level of effectiveness	1
Not significantly	0√
Unknown	U

- *This species has not been reported to act as a biological control agent in this review.*

Is it commercially valuable (e.g., for fisheries, aquaculture, agriculture, bait, ornamental trade)?

Yes, it is economically important to at least one of these industries	6
Yes, but its economic contribution is small	1
Not significantly	0√
Unknown	U

- *This species has not been reported to be commercially valuable in this review.*

Is it recreationally valuable (e.g., for sport or leisurely fishing, as a pet, or for any other personal activity)?

Yes, it is commonly employed recreationally and has some perceived value for local communities and/or tourism	6
Yes, it is sometimes employed recreationally, but adds little value to local communities or tourism	1
Not significantly	0√
Unknown	U

- *This species has not been reported to be recreationally valuable in this review.*

Does the species have some medicinal or research value (outside of research geared towards its control)?

Yes, it has significant medicinal or research value	6
It is potentially important to medicine or research and is currently being or scheduled to be studied	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to have medicinal or research value in this review.*

Does the species remove toxins or pollutants from the water or otherwise increase water quality?

Yes, it has caused widespread, frequent, or otherwise expensive inhibition of recreation and tourism	6
Yes, but negative consequences have been small	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to improve water quality in this review.*

Does the species have a positive ecological impact outside of biological control (e.g., increases the growth or reproduction rates of other species, fills an important gap in the food web, supports the survival of a species which is threatened, endangered species, or commercially valuable)?

Yes, it significantly contributes to the ecosystem in one or more of these ways	6
Yes, it provides some positive contribution to the ecosystem, but is not vital	1 √
Not significantly	0
Unknown	U

- *Due to its fast growth and high biomass in shaded habitat,* M. vimineum *invasions have been shown to promote insect abundance and diversity despite a reduction in native plant species (Metcalf and Emery 2015).*

Beneficial Impact Total	1
Total Unknowns (U)	0

Scientific Name: *Neogobius melanostomus*

Common Name: Round goby

Organism Impact Assessment

IMPACT RESULTS

Environmental: High
Socio-Economic: High
Beneficial: Moderate

Comments: Beneficial impact category increased from low to moderate.

ENVIRONMENTAL IMPACT

Does the species pose some hazard or threat to the health of native species (e.g., it magnifies toxin levels, is poisonous, a virus, bacteria, parasite, or a vector of one)?

Yes, and it has resulted in the reduction or extinction of one or more native species populations, affects multiple species, or is a reportable disease	6
Yes, but negative consequences have been small (e.g., limited number of infected individuals, limited pathogen transmissibility, mild effects on populations and ecosystems) AND/OR It has significantly affected similar species in past invasions outside of the Great Lakes	1√
Not significantly	0
Unknown	U

- *Round goby, via predation on zebra and quagga mussels, likely has the ability to facilitate the bioaccumulation of contaminants up the food chain to benthic-oriented piscivores and ducks that feed on round goby, although experimental results with various contaminants vary (Jude et al. 1995; Morrison et al. 2000; Brey 2006; Hogan et al. 2007; Ng et al. 2008; Almqvist et al. 2010; Macksasitorn et al. 2015; Sun et al. 2016).*
- *Despite a decline in sediment mercury concentrations in Lake Erie, smallmouth bass continued to accumulate mercury at historical rates, possibly because of their high consumption rate of the benthivorous round goby. As smallmouth bass continue to consume round gobies and their growth rates continue to increase, their mercury concentrations also may continue to increase, potentially increasing mercury contamination to humans consuming this important sport fish (Hogan et al. 2007).*
- *In contrast, round gobies may have lower lead concentrations than traditional prey due to their consumption of zebra mussels which efficiently excrete metals; therefore round gobies in smallmouth bass diets may contribute to further diminution and lower concentrations of lead in smallmouth bass (Hogan et al. 2007).*
- Neogobius melanostomus *introductions may also be a vector for the spread of avian botulism (Corkum et al. 2004). The change in behavior of infected* N. melanostomus *may make them preferred prey items to piscivorous birds (Yule et al. 2006; Kornis et al. 2012). In Lake Erie, botulism infected birds had been feeding more on round goby compared to uninfected birds (Corkum et al. 2004). They also affected and killed lake sturgeon near Sleeping Bear Dunes (Jude 2021, personal communication) and other large predators as well.*
- *Study found larval helminths of* Acanthocephalus dims, Diplostomum *sp., and* Eustrongylides *sp. in round gobies in southern Lake Michigan indicating they have the potential to harbor native parasites (Camp et al 1999), in Lake Erie round goby was found to be a newly described host for the trematode* Neoehasmus umbellus *as well as for other metazoan parasites (Kvach and Stepien 2008).*

- *The acanthocephalan* Pomphorhynchus tereticollis *was found in high numbers in round goby of the Elbe River (Kvach et al. 2017); in the Saratov River parasites include* Nicolla skrjabini*,* Phyllodistomum folium*,* Holostephanous cobitidis*,* Diplostomum *spp.,* Tylodelphys clavata*,* Paracoenogonimus ovatus*,* Apatemon gracilis*,* Apharhyngostrigea cornu *(Mineeva 2019); in the River Rhine round goby was parasitized by 8 species (Ondrackova et al. 2015); in the Dnieper River and Black Sea by* Loma acerinae *(Ovcharenko et al. 2017); in the Dnieper Estuary to the Vistula River delta by* Gyrodactylus proterorhini *(Kvach et al. 2014).*
- *Infection of cyprinids with* B. polymorphus *increased after introduction of round goby to the River Morova (Ondrackova et al. 2015).*

Does it out-compete native species for available resources (e.g., habitat, food, nutrients, light)?

Yes, and it has resulted in significant adverse effects (e.g., critical reduction, extinction, behavioral changes) on one or more native species populations	6 √
Yes, and it has caused some noticeable stress to or decline of at least one native species population	1
Not significantly	0
Unknown	U

- *Several native Great Lakes fish species populations have declined in areas where the round goby has become abundant (Crossman et al. 1992).*
- *Competition from the introduced round goby, coupled with the impacts of zebra mussel establishment, appear to have extirpated the greenside, johnny, fantail and rainbow darter in regions of southern Michigan (Jude et al. 2018. The round goby is also credited for several regional extirpations of the mottled sculpin (*Cottus bairdii*) and the johnny darter (*Etheostoma nigrum*) (Jude et al. 2018).*
- *Mottled sculpin and johnny darter have been regionally extirpated since the introduction of round goby. Reduction of mottled sculpin and johnny darter catches to near zero in 2000, 2001, and 2002 concomitant with round goby expansion cannot be viewed as coincidental. Although the mottled sculpin and johnny darter populations between 1984 and 1999 were present in low amounts, they were consistent in occurrence until the goby introduction (Lauer et al. 2004) The mean reactive distance for mottled sculpins was 3.7 (SD =1.27) mm, whilst the mean reactive distance for round gobies was 5.2 mm (SD= 1.74) indicating a higher sensitivity for Daphnia (Jude et al. 1995).*
- *It competes with rainbow darter (*Etheostoma caeruleum*), logperch (*Percina caprodes*), and the endangered northern madtom (*Noturus stigmosus*) for small macroinvertebrates (French and Jude 2001). Round gobies may compete with and have the potential to affect other benthic fishes throughout the Great Lakes including darters (*Etheostoma *spp.,* Percina *spp.), sculpins (slimy sculpin* Cottus cognatus*, deepwater sculpin* Myoxocephalus thompsoni*), and madtoms (*Noturus *spp.) (MacInnis and Corkum 2000). Several native benthic-feeding fish such asp, perch (*Perca *spp.), sculpin (*Cottus *spp.), and darter (*Etheostoma *spp.) have shown a decline in numbers since the invasion of the round goby due to prey resource competition. (Thompson and Simon 2014).*
- *In a study of fish from Duluth-Superior Harbor, round gobies gained significantly more weight than the native fishes during all trials. Slimy sculpins were able to maintain their weight in the presence of the round goby; however, spoonhead sculpins and logperch lost a significant amount of weight during the trials (Bergstrom and Mensinger 2009).*
- *Two species found to have significant diet overlap with round gobies in 1994, northern madtom and rainbow darter, showed a significant decline in relative abundance or CPUE between 1994 and 2011 in the St. Clair River (Burkett and Jude 2015).*
- *Significant diet overlap was observed between small round gobies and rainbow darters (Schoener index = 0.83) on 27 June, and small round gobies and small logperch (Schoener index = 0.83) on 27 June. Diet overlap between large round gobies and logperch was moderate in late June. Both sizes of round gobies showed significant diet overlap with small northern madtoms for* Hexagenia *in September (Schoener's Index = 0.67 for small gobies, 0.70 for large ones). However, the significant diet overlap between northern madtoms and round gobies may not portend real competition for food resources. Northern madtom foraging behavior might cause nymphs to emerge from sediments and drift in currents. Waiting on the bottom, round gobies probably captured drifting ephemeropterans (French and Jude 2001).*

- *Round goby predation on* Mysis relicta *(observed) may result in competition with the three most common offshore fishes of Lake Ontario - alewife, rainbow smelt and slimy sculpin - as well as juvenile lake trout which all rely on* Mysis *(Walsh et al. 2007).*
- *In Lake Erie, significant dietary overlap between juvenile yellow perch and round goby was observed, however, juvenile yellow perch prefer macrophyte habitats while gobies prefer dreissenid beds which may limit competition (Duncan et al. 2011).*
- *1994 collections suggest that logperch numbers have declined in the Algonac, MI area. Authors documented the movement of round gobies onto sandy beach areas at night, where they could depress prey items logperch rely upon for food (Jude et al. 1995).*
- *Mottled sculpin (*Cottus bairdii*) has been particularly affected since the establishment of* N. melanostomus *(Marsden and Jude 1995). This is almost certainly due to competition from large round goby (greater than 100 mm) for spawning sites, from medium round goby (60-100 mm) for space, and from small round goby (less than 60 mm) for food (Janssen and Jude 2001).*
- *Three corroborating pieces of evidence suggest that round gobies are decimating populations of mottled sculpins in the St. Clair River. ... 2nd site: The most-often impinged fish here was logperch (19% of the catch), followed second by mottled sculpin (Jude et al. 1995).*
- *Round goby have a well-developed lateral line system, almost unique among Great Lakes fishes. This is thought to allow these fish to feed in the dark and thereby out-compete resident native fish for food (Jude 1993).*
- *Jude et al. (1995) found that mottled sculpins in the St. Clair River were apparently decimated by round gobies in shallow water, while mottled sculpins apparently found a refugium in deeper waters (7 m) that exposed them to stronger currents (French and Jude 2001). Round gobies may have forced mottled sculpins deeper, exposing eggs and YOY to predation by native fishes and round gobies, which may be an important factor in the decline of mottled sculpin populations in the St. Clair River (Baltz and Moyle 1993; French and Jude 2001).*
- *Now that round gobies have been found in the upper Great Lakes and have been reported in 15 m deep water in Lake Michigan, there is the potential for impact on deepwater sculpin populations in areas where distributions overlap (Jude et al. 1995). Round gobies have recently been found in deep water (> 30 m) in Lake Michigan (Jude, unpublished data) and Lake Huron (G. Curtis, personal communication, USGS, Great Lakes Science Center, Ann Arbor, MI), setting up the potential to negatively impact populations of deepwater (see Vass et al. 1975), spoonhead (*Cottus ricei*), and slimy (*C. cognatus*) sculpins in the oligotrophic upper Great Lakes (French and Jude 2001). Round gobies have been found with deepwater sculpins in 60 0feet of water (March 14, 2021, Grand Traverse Bay off Mission Peninsula (Jude 2021, personal communication)).*
- *Round goby consume the eggs of deepwater and slimy sculpin (determined by DNA – Jude 2021 personal communication re work by J. Mychek-Longer).*
- *Consumption of fish suggests that round gobies might have a detrimental impact on native species through competition for food and predation on eggs and young fish. Since the round goby may grow to sizes of 215–250 mm, which is a much larger adult size than the darters (*Etheostoma *spp.), sculpins (*Cottus *spp.), and logperch, with which they currently share habitat in the St. Clair River, round gobies may consume the YOY and yearlings of these species (Jude et al. 1992).*
- *Their aggressive nature probably allows round goby to occupy optimal sites among rocks and to defend spawning sites, thus preventing native species access to prime areas (Jude 1993). Shelters inhabited by round goby are similar to those of logperch, and in experiments, round goby was a more aggressive and successful competitor for this limited space, regardless of which species had prior residence of the habitat (Balshine et al. 2005). Laboratory experiments have shown that the more aggressive* N. melanostomus *will evict* C. bairdii *from rock shelters that are being used for spawning or daytime predator evasion (Jude et al 1995; Janssen and Jude, Dubs and Corkum 1996).*
- *Round goby outcompetes tubenose goby for both space and prey.* N. melanostomus *was able to displace the resident fish. The higher aggression of* N. melanostomus *in shelter competition could account for greater invasive success and the reduction of* P. semilunaris *observed in the wild (Cartwright et al. 2019). A model based on work in the Netherlands shows niche (functional feeding trial) overlap between round goby and tubenose goby (Nagelkerke et al. 2018).*
- *In Great Lakes tributaries, sites where round gobies were numerically dominant had 2.9 fewer native species on average when compared with other sites in the same rivers (Kornis et al. 2013). In Elk Creek,*

PA, round gobies comprised 17.1% of the total number of fish where they were present (Phillips et al. 2003).

- *Round goby's reproductive pattern confers an ecological advantage on this species. Round gobies spawn over a long period of time so it can take advantage of optimal temperature and food conditions. It is a repeat spawner, spawning every 20 days or so, and males of this species protect their nests (under rocks, logs, cans) vigorously (Jude 1993).*
- *Impacts seen in the GL may not be reflected in tributaries. Kornis et al. (2013) found no changes in abundance of johnny darter, logperch or blackside darter (despite diet overlap) following round goby invasion and increase in abundance because they preferred separate stream habitats. They also found round gobies, mottled sculpin, and yellow perch share habitat preferences in the Great Lakes but not in tributaries. In tributaries, species negatively associated with round gobies are unlikely to co-occur due to preference for habitat characteristics sub-optimal for round goby, including tolerance of low oxygen conditions (central mudminnow), watersheds with higher slope and faster flow (rainbow trout, brook stickleback), and cooler temperature (mottled sculpin) (Kornis et al. 2013).*

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Does it alter predator-prey relationships?

Yes, and it has resulted in significant adverse effects (e.g., added pressure to threatened/endangered species, significant reduction or extinction of any native species populations, creation of a dead end or any other significant alteration in the food web)	6 √
Yes, and it has resulted in some noticeable stress to or decline of at least one native species population AND/OR Yes, and it has resulted in some alteration of the food web structure or processes, the effects of which have not been widespread or severe	1
Not significantly	0
Unknown	U

- *Round goby diet*
  - *Wide range of foods but prefer to consume zebra mussels (*Dreissena polymorpha*) (Ghedotti et al. 1995).*
  - *Gastropods (as well as chironomid larvae, caddisfly larvae, and ostracods) were consistently among the most preferred prey items consumed by gobies, whereas dreissenids (as well as leeches and freshwater mites) were consistently avoided (Kipp et al. 2012).*
  - *(Ephemeroptera, Plecoptera, Trichoptera), taxa richness, Shannon diversity, and EPT/chironomid ratios were lower in streams with gobies compared to streams lacking gobies. Ephemeroptera, Plecoptera, Trichoptera ratios were lower in streams with round gobies and the percent Chironomidae was higher. These results suggest that streams invaded by round gobies have experienced a reduction in mayfly/stonefly/caddisfly abundance with a resultant dominance by midges (Krakowiak and Pennuto 2008).*
  - *Preliminary gut analysis of a recent Great Lakes invader, the round goby,* Neogobius melanostomus *(7.0–8.4 cm), collected from the Detroit River, showed that they ate zebra mussels (58%), snails (6%), and other invertebrates (36%), including aquatic insects (*Hexagenia*), soft-shelled crayfish, and zooplankton (Ray and Corkum 1997).*
  - *Round gobies can severely depress benthic organisms by predation on non-dreissenid invertebrates, which in turn affect benthic plants they prey upon, and the mussels they directly prey on. When round goby were present in southwestern Lake Michigan, the total benthic invertebrate biomass was reduced (Kuhns and Berg 1999).*
  - *There were significantly fewer zebra mussels, quagga mussels, isopods, amphipods, and snails from the rocks incubated at the round goby abundant site compared to those returned to the round goby free site. Thus, the results of the survey and rock-transfer experiment suggest that round gobies are influencing the benthic macroinvertebrate abundance through predation (Lederer et al. 2006).*

- *Round gobies preyed on zebra mussels, leaving only large size classes in exposed places (Djuricich and Janssen 2001).*
- *Diets of small round gobies changed throughout the sampling season, and were mainly composed of dipterans and mollusks (36% and 32% of mean total stomach volume, respectively) (French and Jude 2001).*
- *In late June, dipterans consumed by small round gobies were so numerous (40 ± 24 SD; range = 0 to 101) that they dominated diets (French and Jude 2001).*
- *In LeBoeuf and French creeks, Pennsylvania, native juvenile Unionid mussels comprised a significant portion of round goby diets (Bradshaw-Wilson 2019). In addition to potential predation on unionids, gobies may further impact mussels by altering populations of host fishes that the mussels need to complete their lifecycle, during which they are required to attach to host fish as glochidia and grow (Bradshaw-Wilson et al. 2019).*

- *Round goby diet piscivory*
  - *The numbers of native fish species have declined in areas where the round goby has become abundant (Crossman et al. 1992). In laboratory experiments, this species has been found to prey on darters and other small fish, as well as lake trout (*Salvelinus namaycush*) eggs and fry.*
  - *Round gobies may also feed on eggs of native fish species as recorded here and may reduce lake trout survival by feeding on eggs (Chotkowski and Marsden 1999) or larvae on spawning reefs where these two species co-occur (French and Jude 2001).*
  - *Considering large amount of fish larvae consumed by both fishes (round and tubenose gobies) confirmed in our study, pelagic lifestyle of juveniles (Hensler and Jude 2007) and their preference for soft-bodied prey (Ray and Corku, 1997), the influence on fish populations by direct predation can be tremendous (Gebauer et al. 2017).*
  - *Round goby are a Type 2 functional response predator (based on* Cyprinus carpio *larvae feeding experiments) and consequently, may have a destabilizing effect on population dynamics of cyprinids through high prey exploitation at low prey densities (Gebauer et al. 2018).*
  - *Great Lakes round goby prey on larval tubenose goby (Ricciardi 2001).*
  - *Results confirm that* Neogobius melanostomus *and* Proterorhinus semilunaris *can have a detrimental impact on fish larva populations (Gebauer et al. 2019).*
  - *They are very aggressive, pugnacious fish which feed voraciously with the potential to eat the young and smaller juveniles of benthic (deep water) fish with which they share the river: sculpins, darters, logperch (Jude 1993).*
  - *This lateral line and the fact they grow larger than all native benthic fish species give the gobies ab ability to consume competing fish's young and even small adults, such as darters (Jude 1993)*
  - *When cohabitating the same aquaria in our laboratory, round gobies ate smaller tubenose gobies and rainbow darters (Jude et al. 1995).*
  - *Similar to findings at the Toledo Zoo (J. Hemdal, personal communication, Toledo, Ohio). There 100-mm round gobies killed and ate 17 of 20 rainbow and greenside darters* Etheostoma blennioides *(30-60 mm) (Jude et al. 1995).*
  - *Further information on the piscivorous nature of round gobies includes: (1) small dead rainbow smelt* Osmerus mordax *were regularly eaten by round gobies in aquaria, (2) fisherman report catching round gobies with minnows, (3) round gobies eat fish in their native habitat (Jude et al. 1995).*
  - *Round gobies were found to consume the eggs of smallmouth bass (*Micropterus dolomieu*), pumpkinseed (*Lepomis gibbosus*), and rock bass (*Ambloplites rupestris*) at varying intensities, dependent on the depths at which nests were found (LeBlanc et al. 2019).*
  - *In addition, one large (139 mm) round goby ate a 41-mm trout-perch (*Percopsis omiscomaycus*), the only evidence of predation on an adult native fish (French and Jude 2001).*
  - *Weimer and Sowinski (1999) found white perch (*Morone americana*) larvae in stomachs of four round gobies trawled from the bottom of dredged harbors (depths = 8 to 10 m) in Lake Erie during summer 1998 (French and Jude 2001).*
  - *In laboratory experiments, gobies will eat darters and other small fish. Of perhaps more concern is their predation on the eggs and fry of lake trout, which has been observed in laboratory experiments (Marsden and Jude 1995).*
  - *Results demonstrate that round gobies will readily consume lake trout eggs and fry in the laboratory. Round gobies are capable of penetrating interstitial spaces to obtain prey, and*

perform similarly to mottled sculpin when foraging over laboratory substrata (Chotkowski and Marsden 1999).

- *Predation on round goby*
  - *Stomach contents showed round goby to be the second most abundant diet item in lake trout, and comprised of almost 20% (by number) of their diet. Round goby range expansion to deep water and prominence in the diet of lake trout signal significant change in the eastern Lake Ontario food web (Dietrich et al. 2006). Hensler and Jude reported a switch from native sculpins to more round gobies in burbot in many of the Great Lakes.*
  - *Round goby energy density in Muskegon Lake was not markedly different from that of native benthic fishes (Ruetz et al. 2009).*
  - *Round gobies invaded Lake Michigan ~1994, but did not make up a substantial portion of the lake trout diet until 2005, following crash of the alewife population. In 2005 in SE Lake Michigan, round goby composed 49% of the relative importance to the lake trout diet. The switch from alewife to round goby does not appear to have caused an energy deficit to lake trout (Brey 2006).*
  - *The round goby has contributed substantially to smallmouth bass diets. First noted in smallmouth bass diets from the central basin of Lake Erie in 1996, round gobies occurred in stomachs of 100% of the smallmouth bass sampled in 2003 (Hogan et al. 2007).*
  - *Round goby remains were found in all piscivorous predator species examined. The study provides evidence that the round goby was an important component in the Bay of Quinte ecosystem in 2005, with a mean biomass of 5.0 tonnes/km2 for the upper bay and 11.2 tonnes/ km2 for the lower bay (Taraborelli et al. 2010).*
  - *Round goby YOY migrated from nearshore to the slope in autumn and became easy prey of mottled sculpins and northern madtoms at the slope and bottom of the channel (French and Jude 2001).*
  - *Results indicated that the adult burbot population in eastern Lake Erie annually consumed 1,361 metric tons of round goby; feeding on round goby at an annual rate equal to 61% of the estimated round goby standing stock. We concluded that the burbot population had high potential to exert predatory control on round goby in offshore waters of eastern Lake Erie (Madenjian et al. 2011).*
- *Despite a lack of difference in functional response types among habitats, authors found differences in model parameters*. Neogobius melanostomus *attack rate values significantly differed among habitats, with the highest value for sandy substrate with significantly lower values on gravel. Higher attack rate implies high efficiency at even low prey densities. They also found* Neogobius melanostomus *to show significantly different handling time among habitat structures, with highest handling time on sand, with a clear preference for hard substrates (lower handling time on gravel). They observed significant differences among habitat conditions, with highest weight specific maximum feeding rate on gravel substrate, followed by gravel with artificial plant and sand. This reflects habitat preference and induced stress in non-sheltered habitats. Round goby forage efficiently in structured habitats that might otherwise serve as prey refugia (Gebauer et al. 2019).*

Has it affected any native populations genetically (e.g., through hybridization, selective pressure, introgression)?

Yes, and it has caused a loss or alteration of genes which may be irreversible or has led to the decline or extinction of one or more native species	6
Yes, some damage to markets or sectors has been observed, but negative consequences have been small AND/OR It has a history of harming markets or economic sectors in past invasions outside of the Great Lakes	1
Not significantly	0 √
Unknown	U

- *No congeneric species are native to the Great Lakes.*
- *Round goby can hybridize with congenerics (monkey goby) (Lindner et al. 2013).*

Does it negatively affect water quality (e.g., increased turbidity or clarity, altered nutrient, oxygen, or other chemical levels/cycles)?

Yes, it has caused widespread, frequent, or otherwise expensive inhibition of recreation and tourism	6
Yes, but negative consequences have been small	1
Not significantly	0 √
Unknown	U

- *We find no evidence suggesting that round goby directly impact water quality – It can be hypothesized that they alter water quality indirectly through consumption of zebra and quagga mussels (which do impact water quality) (Jude 2021, personal communication).*

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Does it alter the physical ecosystem in some way (e.g., facilitated erosion/siltation, altered hydrology, altered macrophyte/phytoplankton communities, changes to substrate (physical or chemical))?

Yes, and it has had a widespread, long term, or severe negative effect on the physical ecosystem AND/OR Yes, and it has resulted in significant negative consequences for at least one native species	6
Yes, it has affected the physical ecosystem to some extent, but the alterations and resulting adverse effects have been mild AND/OR It has significantly altered physical ecosystems in past invasions outside of the Great Lakes	1 √
Not significantly	0
Unknown	U

- *Round goby had a direct effect on grazer and shredder abundance which led to a significant increase in periphyton chlorophyll A, a significant reduction in leaf breakdown rate, an increase in leaf biomass remaining, but no change in periphyton ash-free dry mass (Pennuto et al. 2018).*

Environmental Impact Total	14
Total Unknowns (U)	0

SOCIO-ECONOMIC IMPACT

Does the species pose some hazard or threat to human health (e.g., it magnifies toxin levels, is poisonous, a virus, bacteria, parasite, or a vector of one)

Yes, significant effects on human health have already been observed	6
Yes, but negative consequences have not been widespread, long lasting, or severe AND/OR It has significantly affected human health in past invasions outside of the Great Lakes	1 √
Not significantly	0
Unknown	U

- *Round goby, via predation on zebra mussel, likely has the ability to facilitate the bioaccumulation of contaminants up the food chain to benthic-oriented piscivores that feed on round goby, although experimental results with various contaminants vary (Morrison et al. 2000; Hogan et al. 2007; Ng et al. 2008).*
- *Round goby has been implicated as a link in magnifying botulinum toxin (Jude 2021, personal communication) though human cases have not been documented.*

Does it cause damage to infrastructure (such as water intakes, pipes, or any other industrial or recreational infrastructure)?

Yes, it is known to cause significant damage	6
Yes, but the costs have been small and are largely reparable or preventable AND/OR It has a history of causing significant infrastructural damage in past invasions outside of the Great Lakes	1
Not significantly	0√
Unknown	U

- *This species has not been reported to damage infrastructure in this review.*

Does it negatively affect water quality?

Yes, it has significantly affected water quality, and is costly or difficult to reverse	6
Yes, but the effects are negligible and/or easily reversed AND/OR It has a history of significantly affecting water quality in past invasions outside of the Great Lakes	1
Not significantly	0√
Unknown	U

- *This species has not been reported to negatively impact water quality in this review.*

Does it harm any markets or economic sectors (e.g., commercial fisheries, aquaculture, agriculture)?

Yes, it has caused significant damage to one or more markets or economic sectors	6
Yes, some damage to markets or sectors has been observed, but negative consequences have been small AND/OR It has a history of harming markets or economic sectors in past invasions outside of the Great Lakes	1
Not significantly	0 √
Unknown	U

- *We find no direct evidence of this species directly harming any economic sector.*
- *There is limited anecdotal evidence (mostly from recreation) that gobies compete with more desirable species (like yellow perch) for bait (Jude 2021, personal communication).*

Does it inhibit recreational activities and/or associated tourism (e.g., through frequent water closures, equipment damage, decline of recreational species)?

Yes, it has caused widespread, frequent, or otherwise expensive inhibition of recreation and tourism	6 √
Yes, but negative consequences have been small	1
Not significantly	0
Unknown	U

- *The State of Ohio has shut down the smallmouth bass (*Micropterus dolomieu*) fishery in Lake Erie during the months of May and June because high predation rates by round goby on nests are affecting smallmouth bass recruitment. May and June normally account for 50 percent of the total smallmouth catch in Lake Erie (NISC 2004).*

- *Any fisherman can testify to their ability to strip night crawlers from fishing lines (Jude 1993). Walleye anglers (*Sander vitreus*) in Detroit report that at times, all they can catch are gobies, which eagerly attack bait (Marsden and Jude 1995).*
- *Habitat enhancement projects can restructure a fish community because these projects may provide ideal habitat for the reproduction and expansion of round gobies, which prefer large interstitial spaces among rocks for refuge and spawning (Jude and DeBoe 1996).*
- *It was noted in a survey-based study that round goby catches led to a perception of poor fishing quality and frustration among anglers (Dunning et al. 2006).*

Does it diminish the perceived aesthetic or natural value of the areas it inhabits?

Yes, the species has received significant attention from the media/public, significantly diminished the natural or cultural character of the area, or significantly reduced the area's value for future generations	6
Yes, but negative consequences have been small	1 √
Not significantly	0
Unknown	U

- *It was noted in a survey-based study that round goby catches led to a perception of poor fishing quality and frustration among anglers (Dunning et al. 2006).*

Socio-Economic Impact Total	8
Total Unknowns (U)	0

BENEFICAL IMPACT

Does it act as a biological control agent for aquatic weeds or other harmful nonindigenous organisms?

Yes, it has succeeded significantly as a control agent	6
Yes, it has had some success as a control agent, but may be inconsistent or lack a desired level of effectiveness	1
Not significantly	0√
Unknown	U

- *Round goby consume zebra and quagga mussels; a significant gap in the food web is thus lessened (Vanderploeg 2002; Johnson et al. 2005), although predation only affected ~1% of dreissenid populations in Lake Erie*
- *Elimination of invasive* Neogobius melanostomus *may lead to utilization of the empty niche by alien* Proterorhinus semilunaris *with similar ecological impact (Gebauer et al. 2019).*

Is it commercially valuable (e.g., for fisheries, aquaculture, agriculture, bait, ornamental trade)?

Yes, it is economically important to at least one of these industries	6
Yes, but its economic contribution is small	1 √
Not significantly	0
Unknown	U

- *Fishermen in the Baltic Sea readily catch and (personally) eat* N. melanostomus *when captured. They are not readily sold since markets to sell these fish are often not established. Round goby are subsequently considered by-catch, but are commonly eaten due to their abundance and good taste (Ojaveer 2006). There is no market for this species in the Great Lakes region.*

Is it recreationally valuable (e.g., for sport or leisurely fishing, as a pet, or for any other personal activity)?

Yes, it is commonly employed recreationally and has some perceived value for local communities and/or tourism	6
Yes, it is sometimes employed recreationally, but adds little value to local communities or tourism	1
Not significantly	0 √
Unknown	U

- *Fishermen in the Baltic Sea readily catch and (personally) eat* N. melanostomus *when captured. They are not readily sold since markets to sell these fish are often not established. Round goby are subsequently considered by-catch, but are commonly eaten due to their abundance and good taste (Ojaveer 2006). There is no market for this species in the Great Lakes region.*

Does the species have some medicinal or research value (outside of research geared towards its control)?

Yes, it has significant medicinal or research value	6
It is potentially important to medicine or research and is currently being or scheduled to be studied	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to have medicinal or research value in this review.*

Does the species remove toxins or pollutants from the water or otherwise increase water quality?

Yes, it has caused widespread, frequent, or otherwise expensive inhibition of recreation and tourism	6
Yes, but negative consequences have been small	1
Not significantly	0 √
Unknown	U

- *This species bioaccumulates toxins, but passes them up the food chain, it does not removes them from the food chain.*

Does the species have a positive ecological impact outside of biological control (e.g., increases the growth or reproduction rates of other species, fills an important gap in the food web, supports the survival of a species which is threatened, endangered species, or commercially valuable)?

Yes, it significantly contributes to the ecosystem in one or more of these ways	6
Yes, it provides some positive contribution to the ecosystem, but is not vital	1 √
Not significantly	0
Unknown	U

- *Round goby consume zebra and quagga mussels; a significant gap in the food web is thus lessened (Vanderploeg 2002; Johnson et al. 2005), although predation only affected ~1% of dreissenid populations in Lake Erie.*
- *Round goby appeared to make up approximately 75% of burbot (*Lota lota*) and smallmouth bass diet in Lake Erie and 36% of lake trout diet in Lake Ontario, indicating that a new energy source may be travelling up the food chain (Johnson et al. 2005; Dietrich et al. 2006; Hensler and Jude).*
- *Round goby also supplements the diet of yellow perch (Weber et al. 2011).*
- *Round gobies compose the majority of the diet for Lake Erie water snakes (*Nerodia sipedon insularum*), and the abundance of gobies has been credited for the increase in population size, increased growth rates, and larger body size of the snakes (King et al. 2006).*

- *Abundant round gobies may facilitate the transition to piscivory for YOY smallmouth bass, resulting in higher YOY growth rates during 1999–2001 (1.2 mm/d) than in the 1940s, 1950s, or 1970s (0.58–0.85 mm/d). By consuming round gobies, juvenile smallmouth bass growth rate has increased, which has possible consequences for survival, reproduction, and age at maturity (Steinhart et al. 2004).*
- *Round goby was the most important lake sturgeon prey item (86% by weight) in 2014, which corroborated results of d15N and d13C. Lake sturgeon captured after the invasion of round goby exhibited ontogenetic changes in d15N that differed from pre-round goby introduction (Jacobs et al. 2017).*
- Osmerus mordax*,* Micropterus dolomieu*, several had eaten easily identified round gobies. Other predators we have examined that contained round gobies in their stomachs included: rock bass, yellow perch (ate young-of-the-year round gobies), tubenose gobies, and stonecats (Jude et al. 1995).*
- *In the River Dyje, round goby hosted glochidia for multiple species of unionid mussels (Slapansky et al. 2016).*
- *Brey (2006) speculates switch from alewife to round goby may be beneficial, as round gobies do not cause thiamine deficiencies (as alewife do).*

Beneficial Impact Total	2
Total Unknowns (U)	0

Scientific Name: *Osmerus mordax*

Common Name: Rainbow smelt

Organism Impact Assessment

IMPACT RESULTS

Environmental: High
Socio-Economic: Low
Beneficial: High

Comments: Environmental impact score increased by one, remaining in the high category. Socio-economic impact changed from unknown to low.

ENVIRONMENTAL IMPACT

Does the species pose some hazard or threat to the health of native species (e.g., it magnifies toxin levels, is poisonous, a virus, bacteria, parasite, or a vector of one)?

Yes, and it has resulted in the reduction or extinction of one or more native species populations, affects multiple species, or is a reportable disease	6
Yes, but negative consequences have been small (e.g., limited number of infected individuals, limited pathogen transmissibility, mild effects on populations and ecosystems) AND/OR It has significantly affected similar species in past invasions outside of the Great Lakes	1√
Not significantly	0
Unknown	U

- *Rainbow smelt can contain high concentrations of thiaminase which when consumed in large quantities has been shown to decrease swimming performance and body condition, and decrease yellow pigmentation in Atlantic salmon (*Salmo salar*) (Houde et al. 2015). The consumption of thiaminase and subsequent deficiency in thiamine can also cause early mortality syndrome (EMS) in lake trout (*Salvelinus namaycush*) (Honeyfield et al. 2005).*
- *Blukacz-Richards et al. (2017) identified a strong trophic interaction between mercury concentrations in rainbow smelt and herring gull (*Larus argentatus*) eggs in Lake Superior and Lake Ontario. However, trophic elevation in forage fish is unlikely to result in harmful bioaccumulation (Swanson et al. 2003, 2006).*

Does it out-compete native species for available resources (e.g., habitat, food, nutrients, light)?

Yes, and it has resulted in significant adverse effects (e.g., critical reduction, extinction, behavioral changes) on one or more native species populations	6√
Yes, and it has caused some noticeable stress to or decline of at least one native species population	1
Not significantly	0
Unknown	U

- *In the Great Lakes, rainbow smelt may compete with cisco (*Coregonus artedi*) for food (Becker 1983) and habitat (Rosinski et al. 2020). Christie (1974) supplied some evidence to support this, correlating cisco decline with smelt increases in most of the lake.*

- *Both predation by and competition with rainbow smelt have been implicated in the declines of several endangered or special concern species in Canada, including blackfin cisco (*Coregonus reighardi*) and shortnose cisco (*Coregonus reighardi*), as well as deepwater sculpin (*Myoxocephalus thompsonii*) (COSEWIC 2005, 2006, 2007). Todd (1986) also reported that smelt may be partially responsible for the decline of whitefishes (*Coregonus *spp.) in the Great Lakes.*
- *Hrabik et al. (1998) found evidence of competition for food between introduced rainbow smelt and native yellow perch (*Perca flavescens*) in Wisconsin lake habitats.*
- *In a review of rainbow smelt introductions in inland Ontario lakes, Evans and Loftus (1987) found that 13 of 24 lakes with introduced rainbow smelt experienced a decline in lake whitefish* (Coregonus clupeaformis) *recruitment while 5 of 19 reported declines in cisco.*
- *A study of Wisconsin inland lakes with and without introduced rainbow smelt from 1985-2004 found that young-of-the-year walleye (*Sander vitreus*) density was significantly lower in invaded lakes (Mercado-Silva et al. 2007).*

Does it alter predator-prey relationships?

Yes, and it has resulted in significant adverse effects (e.g., added pressure to threatened/endangered species, significant reduction or extinction of any native species populations, creation of a dead end or any other significant alteration in the food web)	6√
Yes, and it has resulted in some noticeable stress to or decline of at least one native species population AND/OR Yes, and it has resulted in some alteration of the food web structure or processes, the effects of which have not been widespread or severe	1
Not significantly	0
Unknown	U

- *In different ecosystems, rainbow smelt may be an important prey item, predator, or competitor (Evans and Loftus 1987); in many cases, it may participate in multiple roles relative to a native species.*
- *Declines, local extirpations, and limitations to recovery of cisco populations have also been attributed to rainbow smelt predation on larval fish rather than competition (Hrabik et al. 1998, Stockwell et al. 2009).*
- *In a review of rainbow smelt introductions in inland Ontario lakes, Evans and Loftus (1987) found that 13 of 24 lakes with introduced rainbow smelt experienced a decline in lake whitefish (*Coregonus clupeaformis*) recruitment; rainbow smelt are known to feed on the young of lake whitefish.*
- *A study of Wisconsin inland lakes with and without introduced rainbow smelt from 1985-2004 found that young-of-the-year walleye (*Sander vitreus*) density was significantly lower in invaded lakes (Mercado-Silva et al. 2007).*
- *Both predation by and competition with rainbow smelt have been implicated in the declines of several endangered or special concern species in Canada, including blackfin cisco (*Coregonus reighardi*) and shortnose cisco (*Coregonus reighardi*), as well as deepwater sculpin (*Myoxocephalus thompsonii*) (COSEWIC 2005, 2006, 2007). Todd (1986) also reported that smelt may be partially responsible for the decline of whitefishes (*Coregonus *spp.) in the Great Lakes. Hartman (1973) also stated that heavy predation on blue pike (*Stizostedion vitreum glaucum*) larvae by rainbow smelt led to their extinction in Lake Superior and Lake Ontario.*

Has it affected any native populations genetically (e.g., through hybridization, selective pressure, introgression)?

Yes, and it has caused a loss or alteration of genes which may be irreversible or has led to the decline or extinction of one or more native species	6

Yes, some damage to markets or sectors has been observed, but negative consequences have been small AND/OR It has a history of harming markets or economic sectors in past invasions outside of the Great Lakes	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to affect native populations genetically in this review.*

Does it negatively affect water quality (e.g., increased turbidity or clarity, altered nutrient, oxygen, or other chemical levels/cycles)?

Yes, it has caused widespread, frequent, or otherwise expensive inhibition of recreation and tourism	6
Yes, but negative consequences have been small	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to affect water quality in this review.*

Does it alter the physical ecosystem in some way (e.g., facilitated erosion/siltation, altered hydrology, altered macrophyte/phytoplankton communities, changes to substrate (physical or chemical))?

Yes, and it has had a widespread, long term, or severe negative effect on the physical ecosystem AND/OR Yes, and it has resulted in significant negative consequences for at least one native species	6
Yes, it has affected the physical ecosystem to some extent, but the alterations and resulting adverse effects have been mild AND/OR It has significantly altered physical ecosystems in past invasions outside of the Great Lakes	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to alter the physical ecosystem in this review.*

Environmental Impact Total	13
Total Unknowns (U)	0

SOCIO-ECONOMIC IMPACT

Does the species pose some hazard or threat to human health (e.g., it magnifies toxin levels, is poisonous, a virus, bacteria, parasite, or a vector of one)

Yes, significant effects on human health have already been observed	6
Yes, but negative consequences have not been widespread, long lasting, or severe AND/OR It has significantly affected human health in past invasions outside of the Great Lakes	1
Not significantly	0√
Unknown	U

- *This species has not been reported to pose a hazard to human health in this review.*

Does it cause damage to infrastructure (such as water intakes, pipes, or any other industrial or recreational infrastructure)?

Yes, it is known to cause significant damage	6
Yes, but the costs have been small and are largely reparable or preventable AND/OR It has a history of causing significant infrastructural damage in past invasions outside of the Great Lakes	1
Not significantly	0√
Unknown	U

- *This species has not been reported to damage infrastructure in this review.*

Does it negatively affect water quality?

Yes, it has significantly affected water quality, and is costly or difficult to reverse	6
Yes, but the effects are negligible and/or easily reversed AND/OR It has a history of significantly affecting water quality in past invasions outside of the Great Lakes	1
Not significantly	0√
Unknown	U

- *This species has not been reported to negatively impact water quality in this review.*

Does it harm any markets or economic sectors (e.g., commercial fisheries, aquaculture, agriculture)?

Yes, it has caused significant damage to one or more markets or economic sectors	6
Yes, some damage to markets or sectors has been observed, but negative consequences have been small AND/OR It has a history of harming markets or economic sectors in past invasions outside of the Great Lakes	1√
Not significantly	0
Unknown	U

- *Rainbow smelt are believed to have severely impacted native brook trout fisheries in Maine lakes (Halliwell 2003).*

Does it inhibit recreational activities and/or associated tourism (e.g., through frequent water closures, equipment damage, decline of recreational species)?

Yes, it has caused widespread, frequent, or otherwise expensive inhibition of recreation and tourism	6
Yes, but negative consequences have been small	1
Not significantly	0
Unknown	U √

- *Important recreational species such as walleye and lake trout may both benefit and suffer from introductions of rainbow smelt depending on the extent to which rainbow smelt acts as a prey item, predator, or competitor (Evans and Loftus 1987).*

Does it diminish the perceived aesthetic or natural value of the areas it inhabits?

Yes, the species has received significant attention from the media/public, significantly diminished the natural or cultural character of the area, or significantly reduced the area's value for future generations	6
Yes, but negative consequences have been small	1
Not significantly	0√
Unknown	U

- *This species has not been reported to diminish aesthetic or natural value in this review.*

Socio-Economic Impact Total	1
Total Unknowns (U)	1

BENEFICAL IMPACT

Does it act as a biological control agent for aquatic weeds or other harmful nonindigenous organisms?

Yes, it has succeeded significantly as a control agent	6
Yes, it has had some success as a control agent, but may be inconsistent or lack a desired level of effectiveness	1
Not significantly	0√
Unknown	U

- *This species has not been reported to act as a biological control agent in this review.*

Is it commercially valuable (e.g., for fisheries, aquaculture, agriculture, bait, ornamental trade)?

Yes, it is economically important to at least one of these industries	6 √
Yes, but its economic contribution is small	1
Not significantly	0
Unknown	U

- *It was estimated in 2003 that the commercial smelt harvest in the U.S. Great Lakes alone was worth over \$750,000 yr^{-1}—more than lake trout, cisco, or Pacific salmons (Dann and Schroeder 2003).*
- *From 2010 to 2018, over 63 million pounds of rainbow smelt worth \$14.6 million CAD was commercially harvested from Lake Erie and Lake St. Clair, primarily by the Canadian based Great Lakes Food Company Ltd. (OFCA 2018).*

Is it recreationally valuable (e.g., for sport or leisurely fishing, as a pet, or for any other personal activity)?

Yes, it is commonly employed recreationally and has some perceived value for local communities and/or tourism	6
Yes, it is sometimes employed recreationally, but adds little value to local communities or tourism	1√
Not significantly	0
Unknown	U

- *Rainbow smelt provides a food source to many recreationally important piscivores in the Great Lakes, including native burbot (*Lota lota*), yellow perch, and introduced salmonids. Species such as walleye and lake trout may both benefit and suffer from introductions of rainbow smelt depending on the extent to which rainbow smelt acts as a prey item, predator, or competitor (Evans and Loftus 1987).*
- *Historically, recreational harvest of rainbow smelt has also been popular (Scott and Crossman 1998); an annual harvest of over 150,000 rainbow smelt in the Great Lakes system was recently reported in a 2005 survey of anglers in Canada (Fisheries and Oceans Canada 2008).*

Does the species have some medicinal or research value (outside of research geared towards its control)?

Yes, it has significant medicinal or research value	6
It is potentially important to medicine or research and is currently being or scheduled to be studied	1√
Not significantly	0
Unknown	U

- *Rainbow smelt has been used by USGS to monitor contaminant levels in the Great Lakes (Chernyak et al. 2005).*
- *Larval recruitment success of rainbow smelt is used as an indicator of environmental change in the St. Lawrence estuary (Couillard et al. 2016).*

Does the species remove toxins or pollutants from the water or otherwise increase water quality?

Yes, it has caused widespread, frequent, or otherwise expensive inhibition of recreation and tourism	6
Yes, but negative consequences have been small	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to improve water quality in this review.*

Does the species have a positive ecological impact outside of biological control (e.g., increases the growth or reproduction rates of other species, fills an important gap in the food web, supports the survival of a species which is threatened, endangered species, or commercially valuable)?

Yes, it significantly contributes to the ecosystem in one or more of these ways	6√
Yes, it provides some positive contribution to the ecosystem, but is not vital	1
Not significantly	0
Unknown	U

- *Because so many species—including recreational and commercial species—depend on rainbow smelt as a food source, rainbow smelt is a vital member of the current food web and are considered by some to be an important species to manage and conserve (Schmidt et al. 2009).*
- *Landlocked Atlantic salmon (*Salmo salar*) prey on rainbow smelt, facilitating large salmon body sizes (50-85 cm at maturity) and persistence in high diversity (>20 fish species) environment, however, Atlantic salmon are considered invasive in all the Great Lakes except for Lake Ontario (Hutchings et al. 2019).*

Beneficial Impact Total	14
Total Unknowns (U)	0

Scientific Name: *Petromyzon marinus*

Common Name: Sea lamprey

Organism Impact Assessment

IMPACT RESULTS

Environmental: High
Socio-Economic: High
Beneficial: Low

Comments: No change in qualitative statements. Beneficial impact score increased from zero to one. Other scores were unchanged.

ENVIRONMENTAL IMPACT

Does the species pose some hazard or threat to the health of native species (e.g., it magnifies toxin levels, is poisonous, a virus, bacteria, parasite, or a vector of one)?

Yes, and it has resulted in the reduction or extinction of one or more native species populations, affects multiple species, or is a reportable disease	6√
Yes, but negative consequences have been small (e.g., limited number of infected individuals, limited pathogen transmissibility, mild effects on populations and ecosystems) AND/OR It has significantly affected similar species in past invasions outside of the Great Lakes	1
Not significantly	0
Unknown	U

- *Attack and parasitic feeding on other fishes by adult lampreys often result in death of the prey, either directly from the loss of fluids and tissues or indirectly from secondary infection of the wound (Phillips et al. 1982). Of the fish that survived attacks by lampreys, 85% of various species had been attacked up to five times (Scott and Crossman 1973).*
- *In combination with other factors (e.g., overfishing and hybridization with more common cisco species), sea lamprey predation led to the extinction of the deepwater cisco (*Coregonus johannae*) and the decline of the blackfin cisco (*C. nigripinnis*), both endemic to the Great Lakes (Miller et al. 1989).*
- *Although the number of sea lamprey in the Great Lakes has been reduced, it still wounds or kills substantial numbers of lake trout in some areas and thus is impeding the rebuilding of established populations (Schneider et al. 1996, and references therein, Adair and Young 2007, Madenjian et al. 2008a).*
- *A recent study in northern Lake Michigan found that sea lamprey wounding rates in this region have increased from 1990-1999 to 2000-2008, despite continued management of sea lamprey populations (Madenjian and Desorcie 2010).*

Does it out-compete native species for available resources (e.g., habitat, food, nutrients, light)?

Yes, and it has resulted in significant adverse effects (e.g., critical reduction, extinction, behavioral changes) on one or more native species populations	6
Yes, and it has caused some noticeable stress to or decline of at least one native species population	1
Not significantly	0√

Unknown	U

- *The sea lamprey is a top predator in the Great Lakes, but its primary competition is humans.*

Does it alter predator-prey relationships?

Yes, and it has resulted in significant adverse effects (e.g., added pressure to threatened/endangered species, significant reduction or extinction of any native species populations, creation of a dead end or any other significant alteration in the food web)	6√
Yes, and it has resulted in some noticeable stress to or decline of at least one native species population AND/OR Yes, and it has resulted in some alteration of the food web structure or processes, the effects of which have not been widespread or severe	1
Not significantly	0
Unknown	U

- *Because the sea lamprey greatly reduced the population of large predators, alewife populations exploded and were followed by tremendous die-offs, resulting in additional changes to fish species composition in the lakes (Smith and Tibbles 1980).*
- *The species' introduction to the Great Lakes and its later abundance, combined with water pollution and overfishing, resulted in the decline of several large native species, including several ciscoes (*Coregonus *spp.), lake trout (*Salvelinus namaycush*), and walleye (*Stizostedion vitreum*), among others.*

Has it affected any native populations genetically (e.g., through hybridization, selective pressure, introgression)?

Yes, and it has caused a loss or alteration of genes which may be irreversible or has led to the decline or extinction of one or more native species	6
Yes, some damage to markets or sectors has been observed, but negative consequences have been small AND/OR It has a history of harming markets or economic sectors in past invasions outside of the Great Lakes	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to affect native populations genetically in this review.*

Does it negatively affect water quality (e.g., increased turbidity or clarity, altered nutrient, oxygen, or other chemical levels/cycles)?

Yes, it has caused widespread, frequent, or otherwise expensive inhibition of recreation and tourism	6
Yes, but negative consequences have been small	1
Not significantly	0 √
Unknown	U

- *Although indirect impacts may be more difficult to attribute to sea lamprey, changes in fish species composition spurred by sea lamprey introduction (especially the proliferation of alewife) have likely had far-reaching indirect effects on other biotic and abiotic components of the Great Lakes ecosystems, including plankton communities (J. Gunderson, MN Sea Grant, 2010, personal communication).*

Does it alter the physical ecosystem in some way (e.g., facilitated erosion/siltation, altered hydrology, altered macrophyte/phytoplankton communities, changes to substrate (physical or chemical))?

Yes, and it has had a widespread, long term, or severe negative effect on the physical ecosystem AND/OR Yes, and it has resulted in significant negative consequences for at least one native species	6
Yes, it has affected the physical ecosystem to some extent, but the alterations and resulting adverse effects have been mild AND/OR It has significantly altered physical ecosystems in past invasions outside of the Great Lakes	1
Not significantly	0 √
Unknown	U

- *Although indirect impacts may be more difficult to attribute to sea lamprey, changes in fish species composition spurred by sea lamprey introduction (especially the proliferation of alewife) have likely had far-reaching indirect effects on other biotic and abiotic components of the Great Lakes ecosystems, including plankton communities (J. Gunderson, MN Sea Grant, 2010, personal communication).*

Environmental Impact Total	12
Total Unknowns (U)	0

SOCIO-ECONOMIC IMPACT

Does the species pose some hazard or threat to human health (e.g., it magnifies toxin levels, is poisonous, a virus, bacteria, parasite, or a vector of one)

Yes, significant effects on human health have already been observed	6
Yes, but negative consequences have not been widespread, long lasting, or severe AND/OR It has significantly affected human health in past invasions outside of the Great Lakes	1
Not significantly	0√
Unknown	U

- *Though lampreys are eaten by humans in some parts of the world and may contain high levels of mercury and other pollutants, the species is not consumed in the Great Lakes region, and this hazard is thus negligible.*

Does it cause damage to infrastructure (such as water intakes, pipes, or any other industrial or recreational infrastructure)?

Yes, it is known to cause significant damage	6
Yes, but the costs have been small and are largely reparable or preventable AND/OR It has a history of causing significant infrastructural damage in past invasions outside of the Great Lakes	1
Not significantly	0√
Unknown	U

- *This species has not been reported to damage infrastructure in this review.*

Does it negatively affect water quality?

Yes, it has significantly affected water quality, and is costly or difficult to reverse	6
Yes, but the effects are negligible and/or easily reversed AND/OR It has a history of significantly affecting water quality in past invasions outside of the Great Lakes	1
Not significantly	0
Unknown	U√

- *By changing the composition of Great Lakes fisheries, the lamprey may have affected water quality, but its direct impacts for this category are unknown.*

Does it harm any markets or economic sectors (e.g., commercial fisheries, aquaculture, agriculture)?

Yes, it has caused significant damage to one or more markets or economic sectors	6√
Yes, some damage to markets or sectors has been observed, but negative consequences have been small AND/OR It has a history of harming markets or economic sectors in past invasions outside of the Great Lakes	1
Not significantly	0
Unknown	U

- *The introduction of sea lamprey caused a collapse in the commercial fisheries during the 1940s and 1950s in many parts of the Great Lakes, particularly in lakes Huron and Michigan, and in eastern Lake Superior (e.g., Lawrie 1970; Scott and Crossman 1973; Christie 1974; Lee et al. 1980 et seq.; Smith and Tibbles 1980; Becker 1983; Emery 1985; Courtenay 1993).*
- *Furthermore, the cascading impact of sea lamprey introduction, beginning with the decline of native commercially fished species and resulting in the explosion of introduced forage fishes and Pacific salmonid stocking, was the major force resulting in the transition of the Great Lakes fisheries from being primarily commercial-based to primarily recreation-based (J. Gunderson, MN Sea Grant, 2010, personal communication).*

Does it inhibit recreational activities and/or associated tourism (e.g., through frequent water closures, equipment damage, decline of recreational species)?

Yes, it has caused widespread, frequent, or otherwise expensive inhibition of recreation and tourism	6√
Yes, but negative consequences have been small	1
Not significantly	0
Unknown	U

- *Besides causing declines of lake trout* Salvelinus namaycush*, and walleye* Stizostedion vitreum*, sea lamprey also took a toll on the introduced salmon in the Great Lakes, harming anglers and state fish agencies (Scott and Crossman 1973).*

Does it diminish the perceived aesthetic or natural value of the areas it inhabits?

Yes, the species has received significant attention from the media/public, significantly diminished the natural or cultural character of the area, or significantly reduced the area's value for future generations	6√
Yes, but negative consequences have been small	1
Not significantly	0
Unknown	U

- *Following the collapse of fish stocks in the mid-20th century, sea lamprey was reportedly the most well-publicized cause of the problem (Francis et al. 1979).*

Socio-Economic Impact Total	18
Total Unknowns (U)	1

BENEFICAL IMPACT

Does it act as a biological control agent for aquatic weeds or other harmful nonindigenous organisms?

Yes, it has succeeded significantly as a control agent	6
Yes, it has had some success as a control agent, but may be inconsistent or lack a desired level of effectiveness	1
Not significantly	0√
Unknown	U

- *This species has not been reported to act as a biological control agent in this review.*

Is it commercially valuable (e.g., for fisheries, aquaculture, agriculture, bait, ornamental trade)?

Yes, it is economically important to at least one of these industries	6
Yes, but its economic contribution is small	1
Not significantly	0√
Unknown	U

- *This species has not been reported to be commercially valuable in this review.*

Is it recreationally valuable (e.g., for sport or leisurely fishing, as a pet, or for any other personal activity)?

Yes, it is commonly employed recreationally and has some perceived value for local communities and/or tourism	6
Yes, it is sometimes employed recreationally, but adds little value to local communities or tourism	1
Not significantly	0√
Unknown	U

- *This species has not been reported to be recreationally valuable in this review.*

Does the species have some medicinal or research value (outside of research geared towards its control)?

Yes, it has significant medicinal or research value	6
It is potentially important to medicine or research and is currently being or scheduled to be studied	1√
Not significantly	0
Unknown	U

- *The sea lamprey is sometimes used as a model organism in medical research and are used to trace the evolution of the vertebrate nervous system, but is generally low-priority (Xu et al. 2016).*

Does the species remove toxins or pollutants from the water or otherwise increase water quality?

Yes, it has caused widespread, frequent, or otherwise expensive inhibition of recreation and tourism	6
Yes, but negative consequences have been small	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to improve water quality in this review.*

Does the species have a positive ecological impact outside of biological control (e.g., increases the growth or reproduction rates of other species, fills an important gap in the food web, supports the survival of a species which is threatened, endangered species, or commercially valuable)?

Yes, it significantly contributes to the ecosystem in one or more of these ways	6
Yes, it provides some positive contribution to the ecosystem, but is not vital	1
Not significantly	0√
Unknown	U

- *This species has not been reported to have any positive ecological impact outside of biological control in this review.*

Beneficial Impact Total	1
Total Unknowns (U)	0

Scientific Name: *Proterorhinus semilunaris*

Common Name: Tubenose goby

Organism Impact Assessment

IMPACT RESULTS

Environmental: Low
Socio-Economic: Low
Beneficial: Low

Comments: Environmental impact changed from unknown to low.

ENVIRONMENTAL IMPACT

Does the species pose some hazard or threat to the health of native species (e.g., it magnifies toxin levels, is poisonous, a virus, bacteria, parasite, or a vector of one)?

Yes, and it has resulted in the reduction or extinction of one or more native species populations, affects multiple species, or is a reportable disease	6
Yes, but negative consequences have been small (e.g., limited number of infected individuals, limited pathogen transmissibility, mild effects on populations and ecosystems) AND/OR It has significantly affected similar species in past invasions outside of the Great Lakes	1
Not significantly	0√
Unknown	U

- *USFWS ERSS (2015) documents the co-introduction of the Ponto-Caspian* Gyrodactylus proterorhini *Ergens, 1967, originally described on tubenose goby in southern Slovakia. Because of their direct life cycle and extraordinary reproductive capacities,* gyrodactylid *monogenean parasites can readily invade new areas together with the host. Moreover*, G. proterorhini *has a wide host range and might therefore represent a threat to other gobiid fishes." (Belgium – Huyse et al. 2015; Ionian Sea – Vanhove et al. 2016).*
- *Prevalence, abundance and infection intensity of ectoparasites was much higher in tubenose goby (introduced by dispersal) than by round goby (introduced by ballast), which might be the consequence of a different introduction pathway. Parasites included fungi and* Gyrodactylus *spp. – Belgium (Mombaerts et al. 2014).*
- *P. semilunaris has been identified as a paratenic host of* Anguillicola crassus*, an eel parasite with severe pathological effects with, nevertheless, a low prevalence (Koubková and Baruš, 2000 – cited in Manne and Poulet 2008 … original paper not available in English).*
- *Identified as a host of* Loma acerinae *in the Dnieper River and Black Sea (Ovcharenko et al. 2017)*
- *Identified as a host of Unionid larvae,* Paracoenogonimus ovatus, Diplostomum *sp.,* Ichthiocotylurus platycephalus*,* Posthodiplostomum cuticola*, and* Camallanus lacustris *in the Rybinsk Reservoir (Zhokhov et al. 2017).*
- *Host for* Holostephanus *spp.,* Apatemon gracilis*,* Diplostomum gobiorum *and glochidia in the Vistula River (Mierzejewska et al. 2014).*
- *Host for* Holostephanus cobitidis*,* Diplostomum *spp.,* Paracoenogonimus ovatus*,* Apatemon gracilis*, and* Apharhyngostrigea cornu *in the Saratov Reservoir (Mineeva 2019).*
- *Host for* B. polymorphus *in River Morova – however, parasite showed higher mortality rates in the gobies than in native hosts (Ondrackova et al. 2015).*
- *Host for 13 parasite species, 4 in all examined fish in the River Rhine (Ondrackova et al. 2015).*

- *Host to 5 species of parasites (one monogenean, one cestode, one digenean, one nematode, and one acanthocephalan) in Tyligul Estuary, Hryhorivsky Estuary, Gulf of Odessa, Sukhyi Estuary, and Dniester River Delta (Kvach and Oguz 2009).*
- *PCB toxicokinetics in tubenose goby from the Detroit River were similar to small native fishes (Sun et al. 2016).*

Does it out-compete native species for available resources (e.g., habitat, food, nutrients, light)?

Yes, and it has resulted in significant adverse effects (e.g., critical reduction, extinction, behavioral changes) on one or more native species populations	6
Yes, and it has caused some noticeable stress to or decline of at least one native species population	1 √
Not significantly	0
Unknown	U

- *Tubenose goby are benthic omnivores, consuming a wide variety of benthic invertebrates, and has been shown to have a significant overlap in diet preference with rainbow darters (*Etheostoma caeruleum*) and northern madtoms (*Noturus stigmosus*) and may compete with these native fish for food (French and Jude 2001; Dawson 2019).*
- *There also is potential for competition between tubenose gobies and johnny darters (*Etheostoma nigrum*) for spawning sites. Tubenose goby shares a preference for rocky spawning sites with johnny darter (*E. nigrum*), but the results of this potential competition remain to be seen (Kocovsky et al. 2011). Both species spawn on the underside of fixed objects such as rocks (Balon 1975; Jude et al. 1995). Tubenose gobies are similar in total length to johnny darters, but johnny darters are more slender and smaller in overall body size, which may provide a competitive advantage to tubenose gobies. Johnny darters were more abundant around the Bass Islands in the past (Trautman 1957), but were absent from seine and trawl samples [after goby invasion] (Kocovsky et al. 2011).*
- *Tubenose goby association with rocky substrates (Jude and DeBoe 1996; French and Jude 2001; Eros et al. 2005) and vegetation creates the potential for competition for space with rainbow darters. Jude et al. (1995) and Jude and DeBoe (1996) reported that tubenose gobies used small crevices in rocky areas to avoid predation, and both tubenose gobies and rainbow darters preferred shallower habitats (Greenberg 1991; Gray et al. 1997). Thus, habitat overlap for these two species is possible in nearshore areas of Lake Erie near river outflows where rainbow darters occur (e.g., in several tributaries to Lake Erie).*
- *Tubenose goby have been observed to defend nesting sites under rocks and logs (WI Sea Grant 2016)*
- *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.) (Kocovsky et al. 2011).*
- *Tubenose gobies appeared to be more cryptic than the other benthic fish species, round goby, mottled sculpin (*Cottus bairdii*), logperch (*Percina caprodes*), and rainbow darter (*Etheostoma caeruleum*), with which they shared the aquarium. Tubenose gobies were not nearly as aggressive as these species at attacking food items introduced into the aquarium (Jude et al. 1992)*
- *Slimy sculpin (*Cottus cognatus*), spoonhead sculpin (*C. ricei*), logperch, johnny darter, bullheads (Ictalurus spp.) and channel catfish (*I. puncatus*) are other native benthic species in the St. Louis River estuary - but their lack of detection in this study suggests that this threat may be reduced in the St. Louis River due to different habitat preferences or life history strategies (Dawson 2019).*
- *NY Invasiveness Ranking form scores this species 7/10 for "Significantly alters community composition (e.g., produces a significant reduction in the population size of one or more native species in the community)" (Schwartzberg 2013)*
- *WI DNR (2018) considers this species a low risk for competition with native species based on expert assessment as follows: Species not spreading rapidly. They do not feed on zebra mussels like round gobies do and are also smaller and less aggressive than round gobies, so some experts expect their impacts to be low.*
- *USFWS ERSS (2015) notes potential for spatial competition citing VanKessel et al. (2011) habitat choice experiments in which* C. perifretum *(native to study location) was outcompeted and moved from the available shelter place to less preferred habitat types. Van der Velde and Leuven (2011) note* C. perifretum

appears particularly vulnerable to spatial competition with tubenose goby. Van Kessel et al. (2016) notes this is exacerbated further at sites with multiple invasive goby species. Blonska et al. 2016 note 'intruder effects of space competition in spring, but not autumn.

- *In France in some sites where densities dramatically increased, it may compete with the other benthic species (Manne and Poulet 2008 citing Freyhof 2003; Von Landwust 2006).*
- *Expansion of distributional range in Czech Republic resulted in this species becoming a dominant fish in littoral zones with up to 100% relative abundance of the reservoirs and rivers (Prasek and Jurajda 2005).*
- *the increase of the western tubenose goby population in the Border Meuse is likely to increase competition with the bullhead as they share the same ecological niche (Cammaerts et al. 2012: Cites Jurajda et al. 2005; Von Landwust 2006; Dorenbosch 2009; and van Kessel et al. 2011 for similar impacts elsewhere in Europe).*
- *Tubenose goby were first recorded in the Musov reservoir in 1994 (Lusk and Halacka 1995), and soon became dominant in the littoral fish assemblage (Vasek et al. 2014).*
- *Seems to form a dominant position in fish assemblage when other gobiid competitors are absent, as it is an inferior competitor (Valova et al. 2015).*
- *Although in relatively low densities, tubenose goby was consistently found along almost the entire upper Danube River during this five-year investigation period, making it the most successful gobiid invader from a perspective of range coverage (Cerwenka et al. 2018). However, although cottids were believed to be most vulnerable to gobiid invasion, Janac et al. (2017) observed no negative trend in bullhead abundance over the 8-year dataset, the population remaining stable and at similar abundances to gobiids.*
- *In a study of Turkish lakes, Tarkan et al. (2018) found that trophic niches of tubenose gobies were not significantly larger than co-existing fishes suggesting gobies might integrate into new fish communities via exploiting resources that are underexploited by native fishes.*
- *Large feeding niche overlap was found between* N. fluviatilis *and* P. semilunaris *and intermediate between* P. glenii *and* P. semilunaris. *Broad niche width was observed in* P. glenii *and* P. semilunaris *differently of* N. fluviatilis *in Borsa (Endrizalova et al. 2020).*

Does it alter predator-prey relationships?

Yes, and it has resulted in significant adverse effects (e.g., added pressure to threatened/endangered species, significant reduction or extinction of any native species populations, creation of a dead end or any other significant alteration in the food web)	6
Yes, and it has resulted in some noticeable stress to or decline of at least one native species population AND/OR Yes, and it has resulted in some alteration of the food web structure or processes, the effects of which have not been widespread or severe	1
Not significantly	0√
Unknown	U

- *NY Invasiveness Ranking form scores this species 3/10 for Minor impact (e.g., impacts 1 species, <20% population decline, limited host damage) citing potential impact to rainbow darters and northern madtoms (Schwartzberg 2013).*
- *Consumption of fish eggs and juveniles by gobies was very low (USFWS ERSS 2015). The diets of both species (round and tubenose gobies) consisted largely of benthic macroinvertebrates, and particularly insect larvae. These results indicate that invading gobies in the Dyje river system are likely to impact native fish fauna more through competitive effects than through direct predation on eggs and juveniles (Vasek et al. 2014). – However, three of nine tubenose gobies consumed round goby eggs (June, daytime) (French and Jude 2001).*
- *Tubenose goby is too small to efficiently feed on zebra mussels (French and Jude 2001). Ecological impacts, therefore, are expected to be minimal (Vanderploeg et al. 2002). However, Ricciardi (2001) anecdotally cites tubenose gobies as preying on both zebra and quagga mussels.*

- *Since tubenose gobies tend to approximate rather than exceed the size of native sculpins, feed almost exclusively on benthos, and are infrequently found outside macrophyte beds, their population will probably not reach high abundances in the St. Clair River, and are thus not expected to have substantial effects on native fishes in that river (Jude et al. 1995).*
- *Dipterans, small-bodied insects such as* Caenis *and* trichopterans *(Cheumatopsyche), and crustaceans (isopods and the amphipod* Gammarus*) were common food of tubenose gobies from May through late June and in December. Tubenose gobies also consumed numerous* dipterans *(French and Jude 2001).*
- *Tubenose gobies may prey on round goby larvae (anecdotal – Ricciardi 2001). 3 of 9 tubenose gobies were observed preying on round goby eggs (French and Jude 2001).*
- *Considering large amount of fish larvae consumed by both fishes (round and tubenose gobies) confirmed in our study, pelagic lifestyle of juveniles (Hensler and Jude 2007) and their preference for soft-bodied prey (Ray and Corkum 1997), the influence on fish populations by direct predation can be tremendous (Gebauer et al. 2017). Gebauer et al. (2019) also confirm that* Neogobius melanostomus *and* Proterorhinus semilunaris *can have a detrimental impact on fish larva populations based on laboratory feeding experiments.*
- *The tubenose goby diet in the Danube river included chironomids, ostracods, planktonic crustaceans, caddisfly larvae (*Hydropsyche *sp.,* Leptoceridae *and* Hydroptila sparsa*) and mayfly nympha (*Siphlonurus aestivalis*,* Potamanthus luteus *and* Caenis *sp.) and* Corophium curvispinum *(Adamek et al. 2007)*
- *In the Slovak River, diet included chironomids (60% of diet by weight in 70% of fish), ostracods (0.5% of diet in 50% of fish), planktonic crustaceans (5% of diet in 21% of fish), Caddisfly larvae (*Hydropsyche *sp.,* Leptoceridae and Hydroptila sparsa*) and mayfly nympha (*Siphlonurus aestivalis, Potamanthus luteus *and* Caenis *sp.) constituted 5.5% of diet in 36% of the fish.* Corophium curvispinum *(1.75% of diet in 14% of fish) (Adamek et al. 2007).*
- *In the River Dyje of the Danube basin, one of the few studied locations in which tubenose goby are the only goby species, it dominates the local fish assemblage (>66% of fish caught) (Valova et al. 2015) and feeds preferentially on chironomid (Chironomidae) larvae and waterlouse (*Asellus aquaticus*) predation here on fish eggs and juvenile fishes was very low (USFWS 2015 citing Vasek et al. 2014) In River Dyje, predators were estimated to have taken approximately 52 % of annual goby biomass (Round and Tubenose combined). Perch and catfish showed a strong selection for tubenose goby, pike and burbot showed no selectivity toward tubenose goby relative to native fish, while both sander species strongly preferred native prey (Mikl et al. 2017).*
- *A strong dependence on specific prey species, as indicated in the tubenose goby, could be a risk to food web stability following invasion, particularly in unstable food webs such as those that suffer perpetual invasions. (Pettitt-Wade et al. 2015 cites Ricciardi 2001 for the theory, the direct data here is that tubenose goby rely on a narrow range of food items (narrow niche)).*
- *According to preliminary results (Prasek and Adamek, personal observations) chironomid larvae and pupae, isopod (*Asellus aquaticus*) and water bugs (Corixidae) were the dominant food items in the diet of the tubenose goby in the Musov Reservoir (Adamek et al. 2007) In the Musov reservoir tubenose gobies quickly became the dominant species along the reservoir bankside, making them an attractive prey for =1 + perch (*Perca fluviatilis*). There was a clear increasing trend in the numbers of larger perch caught along the rip-rap, with the largest fish clearly specializing on gobies (Vsetickova et al. 2018).*
- *Despite a lack of difference in FR types among habitats, we found differences in model parameters. Proterorhinus semilunaris attack rate values significantly differed among habitats, with the highest value for substrate with artificial plants. Higher attack rate implies high efficiency at even low prey densities. Proterorhinus semilunaris showed significantly lower handling time in gravel habitat but no difference based on artificial plant cover. They observed significant differences among habitat conditions, with highest weight specific maximum feeding rate on gravel substrate, followed by gravel with artificial plant and sand. This reflects habitat preference and induced stress in non-sheltered habitats. Tubenose gobies forage efficiently in structured habitats that might otherwise serve as prey refugia (Gebauer et al. 2019).*
- *Tubenose goby are a Type 2 functional response predator (based on* Cyprinus carpio *larvae feeding experiments) and consequently, may have a destabilizing effect on population dynamics of cyprinids through high prey exploitation at low prey densities (Gebauer et al. 2018)*
- *Proterorhinus semilunaris reaches high densities in shallow macrophyte-rich habitats (Kocovsky et al. 2011), where it can pose serious threat for phytophilic fauna, including cyprinid larvae (Gebauer et al. 2018).*

Has it affected any native populations genetically (e.g., through hybridization, selective pressure, introgression)?

Yes, and it has caused a loss or alteration of genes which may be irreversible or has led to the decline or extinction of one or more native species	6
Yes, some damage to markets or sectors has been observed, but negative consequences have been small AND/OR It has a history of harming markets or economic sectors in past invasions outside of the Great Lakes	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to affect native populations genetically in this review.*

Does it negatively affect water quality (e.g., increased turbidity or clarity, altered nutrient, oxygen, or other chemical levels/cycles)?

Yes, it has caused widespread, frequent, or otherwise expensive inhibition of recreation and tourism	6
Yes, but negative consequences have been small	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to affect water quality in this review.*

Does it alter the physical ecosystem in some way (e.g., facilitated erosion/siltation, altered hydrology, altered macrophyte/phytoplankton communities, changes to substrate (physical or chemical))?

Yes, and it has had a widespread, long term, or severe negative effect on the physical ecosystem AND/OR Yes, and it has resulted in significant negative consequences for at least one native species	6
Yes, it has affected the physical ecosystem to some extent, but the alterations and resulting adverse effects have been mild AND/OR It has significantly altered physical ecosystems in past invasions outside of the Great Lakes	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to alter the physical ecosystem in this review.*

Environmental Impact Total	1
Total Unknowns (U)	0

SOCIO-ECONOMIC IMPACT

Does the species pose some hazard or threat to human health (e.g., it magnifies toxin levels, is poisonous, a virus, bacteria, parasite, or a vector of one)

Yes, significant effects on human health have already been observed	6
Yes, but negative consequences have not been widespread, long lasting, or severe	1

AND/OR It has significantly affected human health in past invasions outside of the Great Lakes	
Not significantly	0√
Unknown	U

- *USFWS ERSS (2015) cites Froese and Pauly (2015) in concluding 'harmless to human health'.*

Does it cause damage to infrastructure (such as water intakes, pipes, or any other industrial or recreational infrastructure)?

Yes, it is known to cause significant damage	6
Yes, but the costs have been small and are largely reparable or preventable AND/OR It has a history of causing significant infrastructural damage in past invasions outside of the Great Lakes	1
Not significantly	0√
Unknown	U

- *This species has not been reported to damage infrastructure in this review.*

Does it negatively affect water quality?

Yes, it has significantly affected water quality, and is costly or difficult to reverse	6
Yes, but the effects are negligible and/or easily reversed AND/OR It has a history of significantly affecting water quality in past invasions outside of the Great Lakes	1
Not significantly	0√
Unknown	U

- *This species has not been reported to negatively impact water quality in this review.*

Does it harm any markets or economic sectors (e.g., commercial fisheries, aquaculture, agriculture)?

Yes, it has caused significant damage to one or more markets or economic sectors	6
Yes, some damage to markets or sectors has been observed, but negative consequences have been small AND/OR It has a history of harming markets or economic sectors in past invasions outside of the Great Lakes	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to harm any markets or economic sectors in this review.*

Does it inhibit recreational activities and/or associated tourism (e.g., through frequent water closures, equipment damage, decline of recreational species)?

Yes, it has caused widespread, frequent, or otherwise expensive inhibition of recreation and tourism	6
Yes, but negative consequences have been small	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to inhibit recreation or tourism in this review.*

Does it diminish the perceived aesthetic or natural value of the areas it inhabits?

Yes, the species has received significant attention from the media/public, significantly diminished the natural or cultural character of the area, or significantly reduced the area's value for future generations	6
Yes, but negative consequences have been small	1
Not significantly	0√
Unknown	U

- *This species has not been reported to diminish aesthetic or natural value in this review.*

Socio-Economic Impact Total	0
Total Unknowns (U)	0

BENEFICAL IMPACT

Does it act as a biological control agent for aquatic weeds or other harmful nonindigenous organisms?

Yes, it has succeeded significantly as a control agent	6
Yes, it has had some success as a control agent, but may be inconsistent or lack a desired level of effectiveness	1
Not significantly	0√
Unknown	U

- *This species has not been reported to act as a biological control agent in this review.*

Is it commercially valuable (e.g., for fisheries, aquaculture, agriculture, bait, ornamental trade)?

Yes, it is economically important to at least one of these industries	6
Yes, but its economic contribution is small	1
Not significantly	0√
Unknown	U

- *This species has not been reported to be commercially valuable in this review.*

Is it recreationally valuable (e.g., for sport or leisurely fishing, as a pet, or for any other personal activity)?

Yes, it is commonly employed recreationally and has some perceived value for local communities and/or tourism	6
Yes, it is sometimes employed recreationally, but adds little value to local communities or tourism	1
Not significantly	0√
Unknown	U

- *This species has not been reported to be recreationally valuable in this review.*

Does the species have some medicinal or research value (outside of research geared towards its control)?

Yes, it has significant medicinal or research value	6
It is potentially important to medicine or research and is currently being or scheduled to be studied	1

Not significantly	0 √
Unknown	U

- *This species has not been reported to have medicinal or research value in this review.*

Does the species remove toxins or pollutants from the water or otherwise increase water quality?

Yes, it has caused widespread, frequent, or otherwise expensive inhibition of recreation and tourism	6
Yes, but negative consequences have been small	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to improve water quality in this review.*

Does the species have a positive ecological impact outside of biological control (e.g., increases the growth or reproduction rates of other species, fills an important gap in the food web, supports the survival of a species which is threatened, endangered species, or commercially valuable)?

Yes, it significantly contributes to the ecosystem in one or more of these ways	6
Yes, it provides some positive contribution to the ecosystem, but is not vital	1
Not significantly	0√
Unknown	U

- *Like round gobies, 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).*
- *This species is predicted to have moderate environmental consequences and low economic/sociopolitical consequences in the Mississippi River basin (Grippo et al. 2017).*
- *In the Musov Reservoir tubenose gobies quickly became the dominant species along the reservoir bankside, making them an attractive prey for =1 + perch. There was a clear increasing trend in the numbers of larger perch caught along the rip-rap, with the largest fish clearly specializing on gobies (Vsetickova et al. 2018).*
- *Tubenose goby in the River Dyje host glochidia of multiple unionid species (Slapansky et al. 2016) they may serve as a suitable host for rare/endangered Great Lakes unionids as well.*

Beneficial Impact Total	0
Total Unknowns (U)	0

Scientific Name: *Salmincola californiensis*

Common Name: A gill maggot

Organism Impact Assessment

IMPACT RESULTS

Environmental: High
Socio-Economic: Moderate
Beneficial: Low

Comments: New established species.

ENVIRONMENTAL IMPACT

Does the species pose some hazard or threat to the health of native species (e.g., it magnifies toxin levels, is poisonous, a virus, bacteria, parasite, or a vector of one)?

Yes, and it has resulted in the reduction or extinction of one or more native species populations, affects multiple species, or is a reportable disease	6√
Yes, but negative consequences have been small (e.g., limited number of infected individuals, limited pathogen transmissibility, mild effects on populations and ecosystems) AND/OR It has significantly affected similar species in past invasions outside of the Great Lakes	1
Not significantly	0
Unknown	U

- Realized:
- *Around 70% (n = 120) of rainbow trout and 39% (n = 223) of Chinook salmon caught in Lake Ontario were infected with* S. californiensis*. The rate of infection in Lake Ontario rainbow trout was two times that of the rate in their native range (Mullin and Reyda 2020).*
- *The mechanical action by which* S. californiensis *attaches and burrows into a fish can cause extensive tissue damage. The epithelium is the most extensively damaged tissue, typically resulting in severe gill injuries (Kabata and Cousens 1977). If a female fails to reach stainable support tissue when burrowing into a fish, it may continue to burrow into soft tissue and can eventually lead to the death of the fish (Kabata and Cousens 1977).*
- Potential:
- *Parasitized gill filaments were inflamed and their growth was inhibited in rainbow trout (Sutherland et al. 1985).*
- *The swimming ability of Chinook salmon was greatly diminished by* S. californiensis *and fatigue greatly increased, which suggests that gill infestation reduces gas exchange and osmotic regulation (Pawaputanon 1980; Herron et al. 2018). The osmotic imbalance can lead to anemia and increased blood clotting (Pawaputanon 1980).*
- *Secondary viral, fungal or bacterial infections may also be more prevalent where* S. californiensis *is attached (Bandilla et al. 2006).*
- *Parasitism by* S. californiensis *decreased egg production by rainbow trout in a California hatchery (Gall et al. 1972).*
- *Parasitized juvenile sockeye salmon were less able to cope with environmental stress and had increased mortality as temperatures rose above 21°C (Pawaputanon 1980).*

- *A telemetry study of Chinook salmon in a reservoir indicated a slight increase in short-term mortality (within 24 hours of tagging) as well as negative effects on fish movements in fish infested with* S. californiensis *(Beeman et al. 2015)..*

Does it out-compete native species for available resources (e.g., habitat, food, nutrients, light)?

Yes, and it has resulted in significant adverse effects (e.g., critical reduction, extinction, behavioral changes) on one or more native species populations	6
Yes, and it has caused some noticeable stress to or decline of at least one native species population	1
Not significantly	0√
Unknown	U

- *This species has not been reported to out-compete native species for resources in this review*

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Does it alter predator-prey relationships?

Yes, and it has resulted in significant adverse effects (e.g., added pressure to threatened/endangered species, significant reduction or extinction of any native species populations, creation of a dead end or any other significant alteration in the food web)	6
Yes, and it has resulted in some noticeable stress to or decline of at least one native species population AND/OR Yes, and it has resulted in some alteration of the food web structure or processes, the effects of which have not been widespread or severe	1
Not significantly	0
Unknown	U√

- Salmincola californiensis *can reduce fitness and increase mortality of salmonids, however, the broader impact on predator-prey relationships is unknown as most studies were conducted in hatchery environments.*

Has it affected any native populations genetically (e.g., through hybridization, selective pressure, introgression)?

Yes, and it has caused a loss or alteration of genes which may be irreversible or has led to the decline or extinction of one or more native species	6
Yes, some damage to markets or sectors has been observed, but negative consequences have been small AND/OR It has a history of harming markets or economic sectors in past invasions outside of the Great Lakes	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to affect native populations genetically in this review.*

Does it negatively affect water quality (e.g., increased turbidity or clarity, altered nutrient, oxygen, or other chemical levels/cycles)?

Yes, it has caused widespread, frequent, or otherwise expensive inhibition of recreation and tourism	6

Yes, but negative consequences have been small	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to affect water quality in this review.*

Does it alter the physical ecosystem in some way (e.g., facilitated erosion/siltation, altered hydrology, altered macrophyte/phytoplankton communities, changes to substrate (physical or chemical))?

Yes, and it has had a widespread, long term, or severe negative effect on the physical ecosystem AND/OR Yes, and it has resulted in significant negative consequences for at least one native species	6
Yes, it has affected the physical ecosystem to some extent, but the alterations and resulting adverse effects have been mild AND/OR It has significantly altered physical ecosystems in past invasions outside of the Great Lakes	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to alter the physical ecosystem in this review.*

Environmental Impact Total	6
Total Unknowns (U)	1

SOCIO-ECONOMIC IMPACT

Does the species pose some hazard or threat to human health (e.g., it magnifies toxin levels, is poisonous, a virus, bacteria, parasite, or a vector of one)

Yes, significant effects on human health have already been observed	6
Yes, but negative consequences have not been widespread, long lasting, or severe AND/OR It has significantly affected human health in past invasions outside of the Great Lakes	1
Not significantly	0√
Unknown	U

- *This species has not been reported to pose a hazard to human health in this review.*

Does it cause damage to infrastructure (such as water intakes, pipes, or any other industrial or recreational infrastructure)?

Yes, it is known to cause significant damage	6
Yes, but the costs have been small and are largely reparable or preventable AND/OR It has a history of causing significant infrastructural damage in past invasions outside of the Great Lakes	1
Not significantly	0√
Unknown	U

- *This species has not been reported to damage infrastructure in this review.*

Does it negatively affect water quality?

Yes, it has significantly affected water quality, and is costly or difficult to reverse	6
Yes, but the effects are negligible and/or easily reversed AND/OR It has a history of significantly affecting water quality in past invasions outside of the Great Lakes	1
Not significantly	0√
Unknown	U

- *This species has not been reported to negatively impact water quality in this review.*

Does it harm any markets or economic sectors (e.g., commercial fisheries, aquaculture, agriculture)?

Yes, it has caused significant damage to one or more markets or economic sectors	6
Yes, some damage to markets or sectors has been observed, but negative consequences have been small AND/OR It has a history of harming markets or economic sectors in past invasions outside of the Great Lakes	1√
Not significantly	0
Unknown	U

- Potential:
- *Lernaeopodids including* S. californiensis *were historically damaging to salmon hatcheries (Wilson 1915). Modern hatcheries are also negatively impacted by* S. californiensis*, and many are enacting control measures to limit damage (Modin and Veek 2002; Rash et al. 2017).*
- *Many of the fish species that* S. californiensis *infects (Chinook salmon, coho salmon, lake trout, and rainbow trout) are prevalent in the Great Lakes and negative impacts from infestations may harm commercial and recreational fishing (GLMRIS 2012).*

Does it inhibit recreational activities and/or associated tourism (e.g., through frequent water closures, equipment damage, decline of recreational species)?

Yes, it has caused widespread, frequent, or otherwise expensive inhibition of recreation and tourism	6
Yes, but negative consequences have been small	1√
Not significantly	0
Unknown	U

- Potential:
- *Many of the fish species that* S. californiensis *infects (Chinook salmon, coho salmon, lake trout, and rainbow trout) are prevalent in the Great Lakes and negative impacts from infestations may harm recreational fishing (GLMRIS 2012).*

Does it diminish the perceived aesthetic or natural value of the areas it inhabits?

Yes, the species has received significant attention from the media/public, significantly diminished the natural or cultural character of the area, or significantly reduced the area's value for future generations	6
Yes, but negative consequences have been small	1
Not significantly	0√
Unknown	U

- *This species has not been reported to diminish aesthetic or natural value in this review.*

Socio-Economic Impact Total	2

Total Unknowns (U)	0

BENEFICAL IMPACT

Does it act as a biological control agent for aquatic weeds or other harmful nonindigenous organisms?

Yes, it has succeeded significantly as a control agent	6
Yes, it has had some success as a control agent, but may be inconsistent or lack a desired level of effectiveness	1
Not significantly	0√
Unknown	U

- *This species has not been reported to act as a biological control agent in this review.*

Is it commercially valuable (e.g., for fisheries, aquaculture, agriculture, bait, ornamental trade)?

Yes, it is economically important to at least one of these industries	6
Yes, but its economic contribution is small	1
Not significantly	0√
Unknown	U

- *This species has not been reported to be commercially valuable in this review.*

Is it recreationally valuable (e.g., for sport or leisurely fishing, as a pet, or for any other personal activity)?

Yes, it is commonly employed recreationally and has some perceived value for local communities and/or tourism	6
Yes, it is sometimes employed recreationally, but adds little value to local communities or tourism	1
Not significantly	0√
Unknown	U

- *This species has not been reported to be recreationally valuable in this review.*

Does the species have some medicinal or research value (outside of research geared towards its control)?

Yes, it has significant medicinal or research value	6
It is potentially important to medicine or research and is currently being or scheduled to be studied	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to have medicinal or research value in this review.*

Does the species remove toxins or pollutants from the water or otherwise increase water quality?

Yes, it has caused widespread, frequent, or otherwise expensive inhibition of recreation and tourism	6
Yes, but negative consequences have been small	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to improve water quality in this review.*

Does the species have a positive ecological impact outside of biological control (e.g., increases the growth or reproduction rates of other species, fills an important gap in the food web, supports the survival of a species which is threatened, endangered species, or commercially valuable)?

Yes, it significantly contributes to the ecosystem in one or more of these ways	6
Yes, it provides some positive contribution to the ecosystem, but is not vital	1
Not significantly	0√
Unknown	U

- *This species has not been reported to have any positive ecological impact outside of biological control in this review.*

Beneficial Impact Total	0
Total Unknowns (U)	0

Scientific Name: *Scardinius erythrophthalmus*

Common Name: Rudd

Organism Impact Assessment

IMPACT RESULTS

Environmental: Moderate
Socio-Economic: Low
Beneficial: Moderate

Comments: Changed socioeconomic impact from unknown to low and beneficial impact changed from unknown to moderate.

ENVIRONMENTAL IMPACT

Does the species pose some hazard or threat to the health of native species (e.g., it magnifies toxin levels, is poisonous, a virus, bacteria, parasite, or a vector of one)?

Yes, and it has resulted in the reduction or extinction of one or more native species populations, affects multiple species, or is a reportable disease	6
Yes, but negative consequences have been small (e.g., limited number of infected individuals, limited pathogen transmissibility, mild effects on populations and ecosystems) AND/OR It has significantly affected similar species in past invasions outside of the Great Lakes	1√
Not significantly	0
Unknown	U

- *In the effluent impacted Niagara River, antidepressants had a bioaccumulation factor of up to 3000 in rudd, which was significantly more than in native fishes and could make rudd an important factor in biomagnification of these potentially harmful chemicals by predators (Arnnok et al. 2017).*

Does it out-compete native species for available resources (e.g., habitat, food, nutrients, light)?

Yes, and it has resulted in significant adverse effects (e.g., critical reduction, extinction, behavioral changes) on one or more native species populations	6
Yes, and it has caused some noticeable stress to or decline of at least one native species population	1√
Not significantly	0
Unknown	U

- *Cadwallader (1977) reviewed the potential impacts of the rudd in waters of the North Island of New Zealand. He concluded, in part, that rudd can be expected to compete for invertebrate food sources with native fishes. In addition, being omnivorous, the rudd can shift its diet to plants, unlike most native fishes. Because rudd is fairly hardy, Cadwallader (1977) also indicated that the fish will fare better than many native fishes in waters that are eutrophic or polluted.*

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Does it alter predator-prey relationships?

Yes, and it has resulted in significant adverse effects	6

(e.g., added pressure to threatened/endangered species, significant reduction or extinction of any native species populations, creation of a dead end or any other significant alteration in the food web)	
Yes, and it has resulted in some noticeable stress to or decline of at least one native species population AND/OR Yes, and it has resulted in some alteration of the food web structure or processes, the effects of which have not been widespread or severe	1
Not significantly	0
Unknown	U√

- *There is insufficient research to determine if rudd alters predator-prey relationships.*

Has it affected any native populations genetically (e.g., through hybridization, selective pressure, introgression)?

Yes, and it has caused a loss or alteration of genes which may be irreversible or has led to the decline or extinction of one or more native species	6
Yes, some damage to markets or sectors has been observed, but negative consequences have been small AND/OR It has a history of harming markets or economic sectors in past invasions outside of the Great Lakes	1√
Not significantly	0
Unknown	U

- *In a laboratory setting, Burkhead and Williams (1991) demonstrated that rudd readily hybridizes with native golden shiner (*Notemigonus crysoleucas*), a primary forage species of many native game fishes. First generation hybrids offspring should show heterosis (or hybrid vigor), but the "genetic pollution" in subsequent generations could prove detrimental due to a variety of factors (e.g., spawning behavior, recruitment success, and general loss of fitness) (Burkhead and Williams 1991; Courtenay and Williams 1992).*

Does it negatively affect water quality (e.g., increased turbidity or clarity, altered nutrient, oxygen, or other chemical levels/cycles)?

Yes, it has caused widespread, frequent, or otherwise expensive inhibition of recreation and tourism	6
Yes, but negative consequences have been small	1√
Not significantly	0
Unknown	U

- *Rudd can contribute to ecosystem modification due to their inefficiency of nutrient assimilation, which causes much of the nutrients they obtain from macrophytes to be returned to the water column through feces deposition (Lake et al. 2002).*
- *In New Zealand, its main source of food, the macrophyte* Egeria*, collapsed over time as secchi depth decreased. Rudd persisted even after the decline of* Egeria*, shifting its diet to other plants (Hicks 2003).*

Does it alter the physical ecosystem in some way (e.g., facilitated erosion/siltation, altered hydrology, altered macrophyte/phytoplankton communities, changes to substrate (physical or chemical))?

Yes, and it has had a widespread, long term, or severe negative effect on the physical ecosystem AND/OR Yes, and it has resulted in significant negative consequences for at least one native species	6

Yes, it has affected the physical ecosystem to some extent, but the alterations and resulting adverse effects have been mild AND/OR It has significantly altered physical ecosystems in past invasions outside of the Great Lakes	1√
Not significantly	0
Unknown	U

- *Rudd likely contributed to the shift in Hamilton Lake, New Zealand from a macrophyte to phytoplankton community; its main source of food, the macrophyte* Egeria*, collapsed over time as secchi depth decreased (Hicks 2003).*

Environmental Impact Total	5
Total Unknowns (U)	1

SOCIO-ECONOMIC IMPACT

Does the species pose some hazard or threat to human health (e.g., it magnifies toxin levels, is poisonous, a virus, bacteria, parasite, or a vector of one)

Yes, significant effects on human health have already been observed	6
Yes, but negative consequences have not been widespread, long lasting, or severe AND/OR It has significantly affected human health in past invasions outside of the Great Lakes	1
Not significantly	0
Unknown	U√

- *In the effluent impacted Niagara River, antidepressants had a bioaccumulation factor of up to 3000 in rudd, which was significantly more than in native fishes and could make rudd an important factor in biomagnification of these potentially harmful chemicals by predators but it is unknown if they may eventually impact humans who consume these fish (Arnnok et al. 2017).*

Does it cause damage to infrastructure (such as water intakes, pipes, or any other industrial or recreational infrastructure)?

Yes, it is known to cause significant damage	6
Yes, but the costs have been small and are largely reparable or preventable AND/OR It has a history of causing significant infrastructural damage in past invasions outside of the Great Lakes	1
Not significantly	0√
Unknown	U

- *This species has not been reported to damage infrastructure in this review.*

Does it negatively affect water quality?

Yes, it has significantly affected water quality, and is costly or difficult to reverse	6
Yes, but the effects are negligible and/or easily reversed AND/OR It has a history of significantly affecting water quality in past invasions outside of the Great Lakes	1√
Not significantly	0

Unknown	U

- *Rudd are estimated to consume 98 metric tons of macrophytes in Buffalo Harbor, Lake Erie which can threaten habitat and restoration projects and may impact water quality (Kapuscinski et al. 2015). Besides consuming macrophytes, rudd may also contribute to ecosystem modification due to their inefficiency of nutrient assimilation, which causes much of the nutrients they obtain from macrophytes to be returned to the water column through feces deposition (Dorenbosch and Bakker 2012)..*

Does it harm any markets or economic sectors (e.g., commercial fisheries, aquaculture, agriculture)?

Yes, it has caused significant damage to one or more markets or economic sectors	6
Yes, some damage to markets or sectors has been observed, but negative consequences have been small AND/OR It has a history of harming markets or economic sectors in past invasions outside of the Great Lakes	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to harm any markets or economic sectors in this review.*

Does it inhibit recreational activities and/or associated tourism (e.g., through frequent water closures, equipment damage, decline of recreational species)?

Yes, it has caused widespread, frequent, or otherwise expensive inhibition of recreation and tourism	6
Yes, but negative consequences have been small	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to inhibit recreation or tourism in this review.*

Does it diminish the perceived aesthetic or natural value of the areas it inhabits?

Yes, the species has received significant attention from the media/public, significantly diminished the natural or cultural character of the area, or significantly reduced the area's value for future generations	6
Yes, but negative consequences have been small	1
Not significantly	0√
Unknown	U

- *This species has not been reported to diminish aesthetic or natural value in this review.*

Socio-Economic Impact Total	1
Total Unknowns (U)	1

BENEFICAL IMPACT

Does it act as a biological control agent for aquatic weeds or other harmful nonindigenous organisms?

Yes, it has succeeded significantly as a control agent	6
Yes, it has had some success as a control agent, but may be inconsistent or lack a desired level of effectiveness	1

Not significantly	0√
Unknown	U

- *There is no literature available assessing this organism for biocontrol. While this species eats aquatic plants, there is no evidence of it being stocked for that purpose.*

Is it commercially valuable (e.g., for fisheries, aquaculture, agriculture, bait, ornamental trade)?

Yes, it is economically important to at least one of these industries	6
Yes, but its economic contribution is small	1
Not significantly	0
Unknown	U√

- *The interest in bait culture of rudd dramatically intensified in the early 1980s. The central Arkansas region of Lonoke and Prairie counties, an area known for its active fish farming industry, apparently became the largest producer of rudd in the United States. Rudd has been widely introduced through a combination of bait bucket releases, escapes from aquaculture facilities and farm ponds, and, presumably, by dispersal from various points of introduction (e.g., Burkhead and Williams 1991).*

Is it recreationally valuable (e.g., for sport or leisurely fishing, as a pet, or for any other personal activity)?

Yes, it is commonly employed recreationally and has some perceived value for local communities and/or tourism	6
Yes, it is sometimes employed recreationally, but adds little value to local communities or tourism	1√
Not significantly	0
Unknown	U

- *Rudd has become a popular sportfish in New Zealand (Hicks 2003) and is a popular baitfish in general (Litvak and Mandrak 1993; Marsden and Hauser 2009; see GLANSIS fact sheet). Bait bucket release seems to be the primary mechanism by which rudd has gained access into open waters. It appears that the greatest dispersal of rudd has been through interstate traffic rather than direct European import. In fact, much of its recent culture and spread can be attributed to its popularity as bait among striped bass (*Morone saxatilis*) anglers.*

Does the species have some medicinal or research value (outside of research geared towards its control)?

Yes, it has significant medicinal or research value	6
It is potentially important to medicine or research and is currently being or scheduled to be studied	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to have medicinal or research value in this review.*

Does the species remove toxins or pollutants from the water or otherwise increase water quality?

Yes, it has caused widespread, frequent, or otherwise expensive inhibition of recreation and tourism	6
Yes, but negative consequences have been small	1
Not significantly	0 √
Unknown	U

- *This species has not been reported to improve water quality in this review.*

Does the species have a positive ecological impact outside of biological control (e.g., increases the growth or reproduction rates of other species, fills an important gap in the food web, supports the survival of a species which is threatened, endangered species, or commercially valuable)?

Yes, it significantly contributes to the ecosystem in one or more of these ways	6
Yes, it provides some positive contribution to the ecosystem, but is not vital	1√
Not significantly	0
Unknown	U

- *Rudd is consumed by various predatory fish, including pike (*Esox lucius*), pikeperch (*Sander lucoperca*), and catfish (*Silurus glanis*) (Gubrik et al. 2015; Djait et al. 2019). Rudd have similar energy density to other Great Lakes fishes and may be a useful food source (Forzono et al. 2017).*

Beneficial Impact Total	2
Total Unknowns (U)	1

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