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2018 UPDATE TO "AN IMPACT ASSESSMENT OF GREAT LAKES AQUATIC NONINDIGENOUS SPECIES"

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Secretary

NATIONAL OCEANIC AND
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1.0 SUMMARY

This report includes all major changes to Risk Assessments conducted by the GLANSIS project between July 2014 and December 2018. 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" (TM-161). 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.

Six species were added to the list of established nonindigenous species during this period. At the time of TM-161, *Phragmites australis* was recognized as widespread in the Great Lakes basin, but considered native. Taxonomic separation of *Phragmites australis australis* (non-native) from *Phragmites australis americanus* (native) allowed us to list the former subspecies as an established nonindigenous species with an introduction date of 1869. *Salix caprea* was recognized as in cultivation in the Great Lakes region, but the extent of escape to natural areas and establishment was not recognized at the time of the previous publication. We add *Salix caprea* with an introduction date of 1905. *Procambarus clarkii* was added to the GLANSIS list around 2006 when the species began showing up in Wisconsin, Michigan and Illinois; however, close examination of historic records indicates this species likely became established in the Lake Erie watershed much earlier. We assign this species an introduction date of 1967 based on collections in Sandusky Bay. Three crustacean zooplankton have much more recently been introduced to the Great Lakes and become established. *Thermocyclops crassus* has been confirmed in samples from Lake Erie as early as 2014 and has recently spread to Lake Superior. *Diaphanosoma fluviatile* was confirmed in samples from Lake Erie in 2015 and has recently spread to Lake Michigan. *Mesocyclops pehpeiensis* has been confirmed in samples from Lake Erie as early as 2016. All 3 species exhibit evidence of reproduction and spread. New organism impact assessments were conducted for each of these species and are documented below.

Another species, *Phenacobius mirabilis*, was listed in TM-161 as an established nonindigenous species and is now considered to be native to the western Lake Erie drainages (particularly the Muskingum) in Ohio. Thus this species is now considered a range expander rather than nonindigenous. It is retained in the GLANSIS system, but designated as a range expander and will no longer be included in updates to this tech memo series.

More than 80 additional species included in TM-161 have been reviewed and re-assessed since that publication, but the qualitative impact assessments (high, medium, low, unknown for Environmental, Socioeconomic and Beneficial Impacts) did not change for any of these additional species. An updated Table 13 from TM-161 is presented below. General changes to the original table include:

1. Number of species with impact assessments increased in the crustaceans taxonomic group from 20 to 24 and in the plants taxonomic group from 55 to 57 while one fish specie was removed, with a change in the total number of species from 182 to 187.
2. Number of species increased in 8 of the 12overall impact categories and decreased in one category.

Table 1. TM-161 Table 13 updated. Summary of impact assessment results by taxonomic group. 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 TM-161, + indicates an increase in the number of species in the category, - indicates a decrease.

	Environmental				**Socio-Economic**				**Beneficial**			
Taxon	H	M	L	U	H	M	L	U	H	M	L	U
Fishes (n=27)-	8	5	0(-)	14	3	1	19(-)	4	8	2	12(-)	5
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=24)+	2	2(+)	0	20(+)	0	1(+)	21(+)	2	0	1(+)	20(+)	3(+)
Mollusks (n=18)	3	2	1	12	2	2	11	3	0	0	16	2
Plants (n=57)+	6(+)	20(+)	3	28	4	9(+)	41(+)	3	4	15(+)	33	5
Algae (n=27)	0	4	20	3	1	3	23	0	0	1	26	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=187)+	26(+)	34(+)	36(-)	91(+)	12	16(+)	145(+)	14	12	20(+)	139(+)	16(+)

In addition, none of the summary statements in the original TM-161 have substantively changed 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 48% instead of 49%) of the established species.
2. At least 32% (previously 31%) of the nonindigenous species found in the Great Lakes have significant (moderate to high) environmental impact. If the 91 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 and popular media to invasive species as approximately 10% of the total non-native species is a severe underestimate for the Great Lakes.
3. We estimate between 14 and 16% of the nonindigenous species found in the Great Lakes have moderate to high socioeconomic impact.
4. Of the 32 species assessed as having significant (moderate to high) benefits, only one – *Puccinellia distans* – is still assessed as having low environmental and socioeconomic impacts.

2.0 ADDENDA

Table 2. New species and major changes to the organism impact assessments (OIA) in TM-161.

Species	Addenda	Author, date added
Diaphanosoma fluviatile	New introduction, new OIA	Lower and Sturtevant, 8/10/18
Frangula alnus	Name change: formerly *Rhamnus frangula,* no change to OIA	Sturtevant, 9/11/2018
Heterosporis sutherlandae	Name change from *Heterosporis sp*., no change to OIA	Sturtevant, 9/10/2018
Mesocyclops pehpeiensis	New introduction, new OIA	Sturtevant, 9/5/2018
Phragmites australis australis	New OIA (added once the subspecies was separated)	Iott, 6/3/2016
Procambarus clarkii	The OIA for this species is new	Boucher, 2019
Salix caprea	The OIA for this species is new	Hopper, 9/11/2018
Schyzocotyle acheilognathi	Name change from *Bothriocephalus acheilognathi*, no change to OIA	Sturtevant, 8/17/2018
Thermocyclops crassus	New introduction, new OIA	Alsip, 7/25/17

Table 3. Additions to Tables 2 through 11 in TM-161. Organism Impact Scores.

Scientific Name	Common Name	Family	Environmental		Socio-Economic		Beneficial	
			Score	# Unknown	Score	# Unknown	Score	# Unknown
Diaphanosoma fluviatile	A cladoceran	Sididae	0	4	0	1	0	3
			Unknown		Low		Unknown	
Mesocyclops pehpeiensis	Cyclopoid copepod	Cyclopidae	1	5	0	1	0	3
			Unknown		Low		Unknown	
Phragmites australis australis	Common reed	Poaceae	18	0	5	0	2	0
			High		Moderate		Moderate	
Procambarus clarkii	Red swamp crayfish	Cambaridae	3	2	4	0	3	1
			Moderate		Moderate		Moderate	
Salix caprea	Goat willow	Salicaceae	3	3	1	0	4	0
			Moderate		Low		Moderate	
Thermocyclops crassus	Cyclopoid copepod	Cyclopidae	1	1	0	0	0	0
			Unknown		Low		Low	

2.1 Organism Impact Assessments

Scientific Name: *Diaphanosoma fluviatile*
Common Name: a cladoceran (no common name)

IMPACT RESULTS

Environmental: Unknown
Socio-Economic: Low
Beneficial: Unknown

Comments: Very limited literature on this species overall.

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

- *Not significantly.*

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 √

- *Could potentially compete with other cladocerans for algal food sources, but this has not been documented*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 √

- *Unknown.*

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 genetic effects have been observed, but consequences have been limited to the individual level AND/OR It has genetically affected the same or similar species in past invasions outside of the Great Lakes	1
Not significantly	0 √
Unknown	U

- *This species is parthenogenic, with offspring developing from unfertilized eggs (López et al. 2008).*

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

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

- Diaphanosoma fluviatile *feeds predominantly on tiny particles (bacteria and detritus) and algal food consisting mainly of green algae (Oocystis), and likely consumes nanoplanktonic algae as well (Cisneros et al. 1991b), potentially altering water clarity.*

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	**0**

Total Unknowns (U)	4

Scoring		
Score	# U's	Impact
>5	Any	High
2-5	Any	Moderate
0	0-1	Low
1	0	
0	≥2	**Unknown**
1	≥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

- *Not significantly.*

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

- *Not significantly.*

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 is not known to directly affect water quality, but indirect effects could be realized if it restructures the zooplankton community.*

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

- *Not significantly.*

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

- *Not significantly.*

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

- *Not significantly.*

Socio-Economic Impact Total	**0**
Total Unknowns (U)	**1**

Scoring		
Score	# U's	Impact
>5	Any	High
2-5	Any	Moderate
0	0-1	**Low**
1	0	
0	≥2	Unknown
1	≥1	

BENEFICIAL EFFECT

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 √

- *Unknown.*

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

- *Not significantly.*

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

- *Not significantly.*

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 has some medicinal or research value, but is not of high priority OR It is potentially important to medicine or research and is currently being or scheduled to be studied	1
Not significantly	0
Unknown	U √

- *Unknown.*

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

Yes, it reduces water treatment costs or has a significant positive impact for the health of humans and/or native species	6
Yes, but positive impact for humans or native species is considered negligible	1
Not significantly	0 √
Unknown	U

- *Not significantly.*

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 √

- *Unknown.*

Beneficial Effect Total	**0**
Total Unknowns (U)	**3**

Scoring		
Score	# U's	Impact
>5	Any	High
2-5	Any	Moderate
0	0-1	Low
1	0	
0	≥2	**Unknown**
1	≥1	

Scientific Name: *Mesocyclops pehpeiensis*
Common Name: cyclopoid copepod

Environmental: Unknown
Socio-Economic: Low
Beneficial: Unknown

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

- *Not reported.*

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 √

- Mesocyclops edax *populations in DC ponds disappeared shortly after the discovery of* M. pehpeiensis *in those systems (Reid 1996).*

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 √

- *Evidence from laboratory (Hwang et al 2009) and mesocosm (Chang 2005) experiments indicates that* M. pehpeiensis *has a negative effect on cladoceran populations and may restructure the zooplankton community.*

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 genetic effects have been observed, but consequences have been limited to the individual level AND/OR It has genetically affected the same or similar species in past invasions outside of the Great Lakes	1
Not significantly	0
Unknown	U √

- Mesocyclops edax *and* Mesocyclops americanus *are native to the Great Lakes. Whether members of this genus can hybridize is unknown.*

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

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

- *This species is not known to directly affect water quality, but indirect effects could be realized if it restructures the zooplankton community.*

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	**1**
Total Unknowns (U)	**5**

Scoring

Score	# U's	Impact
>5	Any	High
2-5	Any	Moderate
0	0-1	Low
1	0	
0	≥2	**Unknown**
1	≥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

- *Not reported.*

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

- *Not reported.*

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 is not known to directly affect water quality, but indirect effects could be realized if it restructures the zooplankton community.*

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	1

AND/OR It has a history of harming markets or economic sectors in past invasions outside of the Great Lakes	
Not significantly	0 √
Unknown	U

- *Not reported.*

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

- *Not reported.*

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

- *Not reported.*

Socio-Economic Impact Total	**0**
Total Unknowns (U)	**1**

Scoring		
Score	# U's	Impact
>5	Any	High
2-5	Any	Moderate
0	0-1	**Low**
1	0	
0	≥2	Unknown
1	≥1	

BENEFICIAL EFFECT

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 √

- M. pehpeiensis *has been evaluated as a potential biocontrol of dengue fever (*Aedes albopictus *mosquito larvae) and was deemed to merit consideration (Dieng et al 2002).*

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

- *Not reported.*

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

- *Not reported.*

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 has some medicinal or research value, but is not of high priority OR It is potentially important to medicine or research and is currently being or scheduled to be studied	1
Not significantly	0
Unknown	U √

- *Unknown.*

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

Yes, it reduces water treatment costs or has a significant positive impact for the health of humans and/or native species	6
Yes, but positive impact for humans or native species is considered negligible	1
Not significantly	0 √
Unknown	U

- *Not reported.*

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 √

- *Unknown.*

Beneficial Effect Total	**0**
Total Unknowns (U)	**3**

Scoring		
Score	# U's	Impact
>5	Any	High
2-5	Any	Moderate
0	0-1	Low
1	0	
0	≥2	**<u>Unknown</u>**
1	≥1	

Scientific Name: *Phragmites australis australis*
Common Name: Common reed, common reedgrass, giant reed, phrag

IMPACT RESULTS

Environmental: High
Socio-Economic: Moderate
Beneficial: Moderate
Comments:

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, etc.) AND/OR It has significantly affected similar species in past invasions outside of the Great Lakes	1
Not significantly	0
Unknown	U

- *Gallic acid released by* Phragmites *is degraded by ultraviolet light to produce mesoxalic acid, effectively hitting susceptible plants and seedlings with two harmful toxins (Rudrappa 2009).*

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

Yes, and it has resulted in significant adverse effects (e.g., critical reduction, extinction, behavioral changes, etc.) 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

- Phragmites *forms dense monocultures and is capable of dominating wetlands within a few years (Rudrappa 2009).*
- Phragmites *threatens the biodiversity of Michigan's coastal and interior wetlands. It displaces native species including sedges, rushes, and cattails; and reduces wildlife habitat diversity, resulting in loss of food and shelter for native wildlife (Avers et al 2014).*
- Phragmites *may reduce and degrade wetland wildlife habitat, due in part to its dense growth habit (Swearingen and Saltonstall 2010).*

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, etc.)	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

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

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 genetic effects have been observed, but consequences have been limited to the individual level AND/OR It has genetically affected the same or similar species in past invasions outside of the Great Lakes	1
Not significantly	0 √
Unknown	U

- *In controlled experiments, the introduced and native lineages of* Phragmites *can hybridize, which may act as a mechanism for further decline of native* Phragmites *in North America where it comes in contact with introduced stands. However, no naturally hybridizing populations have been found (Meyerson et al. 2010).*

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

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

- *Not reported.*

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), etc.)?

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

- Phragmites *alters wetland hydrology through increased evaporation and trapping of sediments, causing marsh soils to dry out (Avers et al 2014, Swearingen and Saltonstall 2010).*
- Phragmites *increases marsh canopy height and density.*

Environmental Impact Total	**18**
Total Unknowns (U)	**0**

Scoring		
Score	# U	Impact
>5	Any	**High**
2-5	Any	Moderate
0	0-1	Low
1	0	
0	≥2	Unknown
1	≥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

- *The Michigan Department of Transportation (MDOT) considers* Phragmites *to be a safety hazard as its height and dense growth may block signs and view of access roads, drives, curves, etc. (B. Batt, MDOT, pers. comm.).*
- *During its dormant season, when dry biomass is high, the introduced common reed also creates a potentially serious fire hazard (Avers et al 2014, Swearingen and Saltonstall 2010).*

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

- *During its dormant season, when dry biomass is high, the introduced common reed also creates a potentially serious fire hazard to structures (Avers et al 2014, Swearingen and Saltonstall 2010).*

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

- *Not significantly.*

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

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

- *Use impairment and restricted shoreline view due to dense stands of* Phragmites *reduce property values (Avers et al 2014).*

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

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

- *Tall, dense stands of the introduced* Phragmites *impede shore access, as penetration of a stand of introduced* Phragmites *can not only be difficult but can also result in abrasions from the sharp-edged vegetation (Avers et al 2014, USFWS 2007).*
- *Recreational value for birdwatchers, walkers, naturalists, boaters, and hunters is further diminished through reduction of native fish and wildlife populations (USFWS 2007).*

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

- Phragmites *restricts shoreline views due to tall dense stands (Avers et al 2014).*

Socio-Economic Impact Total	**5**
Total Unknowns (U)	**0**

Scoring		
Score	# U	Impact
>5	Any	High
2-5	Any	**Moderate**
0	0-1	Low
1	0	
0	≥2	Unknown
1	≥1	

BENEFICIAL EFFECT

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

- *Not significantly.*

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

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

- *In Europe,* Phragmites *is grown commercially and used for thatching, fodder for livestock, and cellulose production (Swearingen and Saltonstall 2010).*
- *In Canada, despite its status as the nation's "worst" invasive plant species,* Phragmites *is still found as an ornamental in some garden and landscape designs (MNR 2010).*

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

- *Not significantly.*

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 has some medicinal or research value, but is not of high priority OR It is potentially important to medicine or research and is currently being or scheduled to be studied	1
Not significantly	0 √
Unknown	U

- Phragmites *produces various potentially interesting pharmacological compounds, including polysaccharides, anthocyanins, alkaloids (DMT, dimethyltryptamine; Kiviat 2010), but to our knowledge there is no current research focus in this area.*

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

Yes, it reduces water treatment costs or has a significant positive impact for the health of humans and/or native species	6
Yes, but positive impact for humans or native species is considered negligible	1 √
Not significantly	0
Unknown	U

- *As a wetland plant,* Phragmites *improves water quality by filtration and nutrient removal (Ailstock 2004).*

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, etc.)?

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

- Phragmites *provides food and habitat for some organisms and serves to stabilize soils against erosion. Bobolink and sparrows eat its seed, while numerous insects eat the vegetation. Moreover, many insects, birds (including yellowthroat, marsh wren, salt marsh sparrow, least bittern, red-winged blackbird, and some wading birds), and muskrats use* Phragmites *as shelter or nest material (Kiviat 2010).*

Beneficial Effect Total	**2**
Total Unknowns (U)	**0**

Scoring		
Score	# U	Impact
>5	Any	High
2-5	Any	**Moderate**
0	0-1	Low
1	0	
0	≥2	Unknown
1	≥1	

Scientific Name: *Procambarus clarkii*
Common Name: Red swamp crayfish

IMPACT RESULTS

Environmental: Moderate
Socio-Economic: Moderate
Beneficial: 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, etc.) AND/OR It has significantly affected similar species in past invasions outside of the Great Lakes	1√
Not significantly	0
Unknown	U

- *Many crayfish, including* P. clarkii*, are known to be a source of transmittance of heavy metals among different trophic levels of the food web. Crayfish pass heavy metal contamination on through enriched levels of the metals or pesticides in their organs or tissues, which is then transferred to their consumers (Otero et al. 2003).*
- *The red swamp crayfish harbors numerous flatworm parasites that may be passed on to vertebrates and can carry the crayfish plague fungus (*Aphanomyces astaci*) as a chronic or latent infection (Huner and Barr 1991, Longshaw 2011). It has been implicated in the spread of the fungus to native crayfish in Europe following initial introduction by the signal crayfish (Barbaresi and Gherardi 2000, Mastitsky et al. 2010).North American crayfish species appear to be resistant to most of these diseases (Hunner and Barr 1991).*
- *The white spot syndrome virus, which has caused mass mortalities among shrimp in Europe, can also be carried by* P. clarkii. *Together with its ability to carry the crayfish plague virus, the red swamp crayfish has been characterized within its invaded range as a host to high impact parasites (Mastitsky et al. 2010).*

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

Yes, and it has resulted in significant adverse effects (e.g., critical reduction, extinction, behavioral changes, etc.) 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

- Procambarus clarkii *is a strong competitor with native crayfish species, such as the white river crayfish (*P. acutus*) or the signal crayfish (*Pacifastacus leniusculus*), and may exclude these species from their shelters (Arrignon et al. 1999, Gherardi and Daniels 2004, Mueller 2007).*

- *Aggression exhibited by the red swamp crayfish has been attributed to reduced breeding success among adult California newts (Gamradt et al. 1997).*
- *Extensive removal of macrophytes by the red swamp crayfish may have led to local extinction of two snails (*Lymnaea peregra, L. stagnalis*) and three plants (*Myriophyllum alterniflorum, Utricularia australis, Ceratophyllym demersum*) in Spain (Montes et al. 1993). Alternatively, direct predation on the snails may have led to the snails' disappearance (Alcorlo et al. 2004).*
- *Herbivorous bird populations (e.g., ducks) have also been severely impacted by the introduction of* P. clarkii *in Spain (Rodríguez et al. 2005).*
- *It has been suggested that populations of the water lily* Nymphaea nouchalii *var.* caerulea *declined in Lake Naivasha, Kenya as the result of* P. clarkii *herbivory (Hofkin et al. 1991, Lowery and Mendes 1977).*

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, etc.)	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

- *Red swamp crayfish juveniles have the potential to significantly reduce local macroinvertebrate diversity through predation (Correia and Anastácio 2008).*
- *The disappearance of a newt species in California has been attributed to predation, particularly on eggs and larvae, by* P. clarkii *(Diamond 1996, Gamradt and Kats 1996).*
- *Herbivory in red swamp crayfish has been found to have a significant impact on aquatic macrophytes and periphyton (Elser et al. 1994, Lodge 1991, Matthews et al. 1993, Weber and Lodge 1990) and to change the relationships of benthic insects with plants (Hanson et al. 1990, Lodge et al. 1994).*
- *Reduction of snails and other grazers through predation may lead to increased periphyton biomass relative to macrophytes. However, prey preference for predatory insects would promote grazer populations and instead decrease periphyton density. (Alcorlo et al. 2004)*
- *Consumption of detritus by* P. clarkii *can restructure energy flow (e.g., shortened pathways to top predators, simplified food web structure) through traditional trophic levels in an invaded system (Geiger et al. 2005).*
- *Found to prey on dragonfly nymphs in California which caused an increase in mosquitoes in the same area Gary M. Bucciarelli et al. Assessing effects of non-native crayfish on mosquito survival, Conservation Biology (2018)*

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

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 genetic effects have been observed, but consequences have been limited to the individual level AND/OR It has genetically affected the same or similar species in past invasions outside of the Great Lakes	1
Not significantly	0 √

Unknown	U

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

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

- *When foraging activities cease,* P. clarkii *constructs new burrows. This burrowing activity increases water turbidity and decreases primary production (Rodríguez et al. 2005).*
- *Foraging and burrowing behavior in* P. clarkii *can lead to changes in water quality and increased nutrient release from sediment, which may induce localized summer cyanobacteria blooms and eutrophic conditions (Angeler et al. 2001, Duarte et al. 1990, Geiger et al. 2005, Nyström et al. 1996, Yamamoto 2010).*
- *Increased turbidity from suspended sediment also can reduce light penetration and primary productivity (Anastácio and Marques 1997, Angeler et al. 2001).*

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), etc.)?

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

- *The red swamp crayfish builds its burrows at the water's edge, and collapse is common on soft sediment banks when burrows are abandoned (Barbaresi et al. 2004).*
- *Capable of removing macrophytes from large areas with its cutting feeding behavior (Feminella and Resh 1989, Smart et al. 2002),* P. clarkii *causes major shifts in habitat heterogeneity and reduces habitat availability for many invertebrates, amphibians, and juvenile fishes (summarized in Alcorlo et al. 2004, Nyström 1999).*
- *Burrowing activity can affect the nesting ground of demersal fish (Lowery and Mendes 1977).*

Environmental Impact Total	**5**
Total Unknowns (U)	**0**

Scoring		
Score	# U's	Impact
>5	Any	High
2-5	Any	**<u>Moderate</u>**
0	0-1	Low
1	0	
0	≥2	Unknown
1	≥1	

<u>SOCIO-ECONOMIC IMPACT</u>

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

- *Through accumulation of heavy metals and cyanobacteria toxins (e.g., microcystin), the red swamp crayfish facilitates biomagnification of these harmful materials and their trophic transfer to humans (Gherardi and Panov 2006).*
- *In parts of the world, undercooked* P. clarkii *may transmit parasites to humans, including lung fluke (*Paragonimus westermani*) and rat lungworm (*Angiostrongylus cantonensis*) (Matthews 2004).Louisiana populations of the red swamp crayfish have also been found to harbor the lung fluke*, P. kellicoti *(Huner and Barr 1991).*

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

- *In areas prone to water level fluctuation—such as around dams, levees , or irrigation systems—complex, deep burrows or numerous simple burrows built by red swamp crayfish are especially likely to damage these structures through bank destabilization. Where water levels are more constant (e.g., reservoirs, marshes), burrows tend to be shallow and simple (Correia and Ferreira 1995).*

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

- *Foraging and burrowing behavior in* P. clarkii *can lead to changes in water quality and increased nutrient release from sediment, which may induce localized summer cyanobacteria blooms and eutrophic conditions (Angeler et al. 2001, Duarte et al. 1990, Geiger et al. 2005, Nyström et al. 1996, Yamamoto 2010).*

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

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

- *Internationally,* P. clarkii *has had devastating effects on rice production, preferentially consuming seedlings following rice field flooding and planting, as well as causing water loss and bank collapse due to its burrowing activity (Anastácio et al. 2000, 2005; Correia and Ferreira 1995).*
- *Predation on fish eggs (e.g., lake trout, Mueller et al. 2006), food competition with commercial fish species, and destruction of fishery nesting and nursing grounds can negatively affect the fishing industry (summarized in Geiger et al. 2005).*
- *In Kenya, the red swamp crayfish has been implicated in the destruction of fishing nets and significant reduction in yield due to damaged fish (Lowery and Mendes 1977).*

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

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

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

Socio-Economic Impact Total	**4**
Total Unknowns (U)	**0**

Scoring		
Score	# U's	Impact
>5	Any	High
2-5	Any	**Moderate**
0	0-1	Low
1	0	
0	≥2	Unknown
1	≥1	

BENEFICIAL EFFECT

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

- *Red swamp crayfish actively predate chironomid larvae, a rice pest (Correia and Anastácio 2008).*
- *In Kenya,* P. clarkii *consumes and competes with the snail vector of schistosomiasis and has thus been used as a biological control agent (Lodge et al. 2005).*

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

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

- *While commercially fished from both native domestic and introduced foreign populations (e.g., Ackefors 1999, Barbaresi and Gherardi 2000), a red swamp crayfish fishery has not been established in the Great Lakes.*
- *MI DNR officers seized 2,000 lbs of live RSC at Sarnia border crossing https://content.govdelivery.com/accounts/MIDNR/bulletins/200b182*

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' striking red color has lead to commercial advertisement as freshwater "lobster" for aquariums (Simon et al. 2005).*
- *It is also popular among anglers as bait for largemouth bass (Washington Department of Fish and Wildlife 2003).*
- *Commonly fished for and eaten in its native and introduced ranges*

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 has some medicinal or research value, but is not of high priority OR It is potentially important to medicine or research and is currently being or scheduled to be studied	1 √
Not significantly	0
Unknown	U

- *The red swamp crayfish has been proposed for use as a bioindicator of heavy metals (As, Cd, Cr, Pb, Hg, Ni) and organic compounds (as found in fertilizers and pesticides, for example) due to its propensity to accumulate these environmental contaminants (summarized in Kouba et al. 2010, Richert and Sneddon 2007).*
- *The red swamp crayfish is readily available though the biological supply trade and might be released following classroom or laboratory use (Larson and Olden 2008).*

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

Yes, it reduces water treatment costs or has a significant positive impact for the health of humans and/or native species	6
Yes, but positive impact for humans or native species is considered negligible	1
Not significantly	0 √
Unknown	U

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, etc.)?

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 √

- *In Europe, it has been suggested that high densities of the red swamp crayfish may lead to greater numbers of herons, egrets, and cormorants (Barbaresi and Gherardi 2000, Rodríguez et al. 2005).*

Beneficial Effect Total	**3**
Total Unknowns (U)	**1**

Scoring		
Score	# U's	Impact
>5	Any	High
2-5	Any	**Moderate**
0	0-1	Low
1	0	
0	≥2	Unknown
1	≥1	

Scientific Name: *Salix caprea*
Common Name: goat willow, pussy willow

Environmental: Moderate
Socio-Economic: Low
Beneficial: Moderate

ENVIRONMENTAL IMPACTS

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, etc.) AND/OR It has significantly affected similar species in past invasions outside of the Great Lakes	1
Not significantly	0
Unknown	U √

- *Unknown.*

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

Yes, and it has resulted in significant adverse effects (e.g. critical reduction, extinction, behavioral changes, etc.) 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 √

- Salix caprea *is a pioneer species, it has been shown to outcompete other species via below ground competition and suppress biomass of other plants via aqueous leachate (Mudrák et al. 2016). However, this species is short lived and promotes soil formation activity of soil fauna through organic matter additions (Frouz et al. 2001). These studies were performed in the native range of the plant. No Great Lakes Basin research has been done. The ability of* Salix caprea *to outcompete other plants in its native range suggests potential to alter successional pathways found in Great Lakes Basin (ex. Changes to soil chemistry, suppression of native pioneer species).*

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, etc.)	6
Yes, and it has resulted in some noticeable stress to or decline of at least one native species population AND/OR 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 √

- *Unknown.*

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

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 genetic effects have been observed, but consequences have been limited to the individual level AND/OR It has genetically affected the same or similar species in past invasions outside of the Great Lakes	1 √
Not significantly	0
Unknown	U

- *Hybridizes with* Salix phylicifolia *(nonnative), but hybrids do not appear to be any more vulnerable to insect herbivores or fungal pathogens as evidenced by their persistence (Hjalten et al. 2000). Well known to hybridize with other European willows including* S. cinerea, S. atrocinerea *and* S. aurita, *many of which have been introduced into North America (Fogelqvist et al. 2015). There are no known records of hybridization with native North American willow species.*

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

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

- *Willow invasions in Australia have had negative effects on water quality: dense shade during the growing season decreases the temperature and oxygen content of the water with negative consequences (Cremer 2003). This paper speaks of willows in general, but* Salix caprea *is listed in the document. No known references include impacts to the Great Lakes Basin.*

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), etc.)?

Yes, and it has had a widespread, long term, or severe negative effect on the physical ecosystem AND/OR 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

- *Significantly altered hydrology and riparian systems in Australia, where underwater roots modify banks and cover ground in shallow streams eliminating niches for native organisms (Cremer 2003). This source speaks of willows in general, but* Salix caprea *is listed in document. No known references of impacts to the Great Lakes Basin.*

Environmental Impact Total	**3**
Total Unknowns (U)	**3**

Scoring		
Score	# U's	Impact
>5	Any	High
2-5	Any	**<u>Moderate</u>**
0	0-1	Low
1	0	
0	≥2	Unknown
1	≥1	

<u>SOCIO-ECONOMIC IMPACT</u>

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 wid espread, 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

- *Not reported.*

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

- *Not reported.*

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	1√

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

- *Willow invasions in Australia have had negative effects on water quality, causing dense shade during the growing season decreases the temperature and oxygen content of the water with negative consequences (Cremer 2003). References discuss willows in general, but* Salix caprea *is listed. No known references of impacts to the Great Lakes Basin.*

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

Yes, it has caused significant damage to one or more markets or economic sectors	6
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

- *S*alix X rubens *was found to have detrimental effects on abundance and populations of terrestrial arthropods. Terrestrial arthropods serve as food for fish including native galaxids and introduced trout, which could change fish diet. Thus the impact of a potential trophic cascade could affect recreational and commercial fishing (Greenwood et al. 2004). However, there is no indication in the literature that* Salix caprea *has this effect, and no literature specific to the Great Lakes Basin has been found.*

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

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

- *Not reported.*

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

- *Willows are purposefully cultivated; however, in Australia, willows have seriously infested thousands of kilometers of stream. In particular,* Salix cinera *is the most invasive (Cremer 2003). Domination of habitat could be perceived as disruption of natural environment and its aesthetic value, but no evidence of this happening in Great Lakes region due to* Salix caprea *has been reported.*

Socio-Economic Impact Total	**1**
Total Unknowns (U)	**0**

Scoring		
Score	# U's	Impact
>5	Any	High
2-5	Any	Moderate
0	0-1	**Low**
1	0	
0	≥2	Unknown
1	≥1	

BENEFICIAL EFFECT

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

- *Naturalized hybrids with* Salix cinera *in New Zealand have shown the possibility of biological control (Harman 2004). No resources exist for the Great Lakes.*

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

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

- Salix caprea *is thought to be of little economic value. It has been used in northern Europe as wind shielding when growing in ditches between fields. Because it grows quickly, there exists potential use for bioenergy production (Pohjamo et al. 2003).*

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
It is sometimes employed recreationally, but adds little value to local communities or tourism	1 √
Not significantly	0
Unknown	U

- *Currently being sold for cultivation and aesthetic purposes.*

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 has some medicinal or research value, but is not of high priority OR It is potentially important to medicine or research and is currently being or scheduled to be studied	1 √

Not significantly	0
Unknown	U

- Salix caprea *contains potent antioxidants including luteolin, dihydrokaemferol and quercetin and catechin and isorhamnetin as minor constituents. Flavonoids have anti-fungal properties, includes dihydrokaempferide, naringenin, aromadendrin, taxifolin, prunin and catechin. Overall this species contains important constituents which have potential to treat various diseases, and further review of* Salix caprea *could be valuable (Ahmed, Shah, et al. 2011)*

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

Yes, it reduces water treatment costs or has a significant positive impact for the health of humans and/or native species	6
Yes, but positive impact for humans or native species is considered negligible	1 √
Not significantly	0
Unknown	U

- Salix caprea *has been shown to tolerate high levels of accumulated metals, suggesting high tolerance to heavy metal pollution and making it suitable for phytoremediation efforts (Regvar et al. 2010).* Salix caprea's *ability to accumulate heavy metals is further discussed in Unterbrunnerand Pushenreiter et al. 2007 and Kuffner and De Maria et al. 2010. Heavy metals including Ni, Cu, Zn, Cd, and Pb have the potential to leach from soil to water to various degrees (Dijkstra et al. 2004).* Salix caprea *is a Facultative Wetland plant and its tolerance suggests it could remove heavy metals from wetlands soil and metals that are potentially dissolved in water, preventing the spread of metals to other bodies of water via hydrology.*

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, etc.)?

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

- Salix caprea *is a source of nectar and pollen for bumblebees and insects (Kay 1985).*

Beneficial Impact Total	**4**
Total Unknowns (U)	**0**

Scoring		
Score	# U's	Impact
>5	Any	High
2-5	Any	**<u>Moderate</u>**
0	0-1	Low
1	0	
0	≥2	Unknown
1	≥1	

Scientific Name: *Thermocyclops crassus*

Common Name: Thermocyclops

Environmental: Unknown
Socio-Economic: Low
Beneficial: Low

Comments: Reid and Pinto-Coelho (1994) outlined various intercontinental copepod introductions and concluded that the ecological impacts of these introductions are often difficult to determine. While in some rare cases introduced exotic copepod species appeared to displace native copepod species. In most documented exotic copepod introductions to the western hemisphere, no impacts on native copepod species could be directly attributed to the introduced 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

- *Between 1930 and 1960, T. crassus replaced* Thermocyclops oithonodies *in Lake Donk, Belgium, as the lake became more eutrophic over time (Dumont 1965).*

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 Lake George, Uganda, this species owes its dominance in the zooplankton community to its ability to feed raptorially on Microcystis (Moriarty et al. 1973). Microcystis blooms in the Great Lakes may give this species an advantage over native species that are incapable of feeding on Microcystis. However, in Lake Erie* Thermocyclops crassus *is much less prevalent than the most similar copepod species,* Mesocyclops edax *(EPA 2016; Connolly et al. 2017), suggesting that Microcystis has not yet facilitated dominance by* T. crassus**.**
- *The diets and habitats of* M. edax *and* T. crassus *likely overlap with each other and both species have similar seasonal life cycles. However, in Germany* T. crassus *is known to coexist with other cyclopoids such as* Mesocyclops leuckarti, *which is closely related to* M. edax *(Maier 1989a). In warm years,* T. crassus *was more abundant than* M. leuckarti *in the Gronne, and in some eutrophic environments this species has outcompeted and replaced other Thermocyclops spp. (Maier 1989a; Dumont 1965). Therefore, we conclude* T. crassus *likely will not displace* M. edax *or other zooplankton in the Great Lakes, but rising temperatures associated with climate change may benefit this species and confer it a competitive advantage over native copepods in nearshore, productive embayments.*

- *In the Gronne, egg production and instar duration times of* T. crassus *did not give this species a competitive advantage over* Cyclops vicinus *and* M. leuckarti. *However,* T. crassus *was found to have a competitive advantage over* C. vicinus *and* M. leuckarti *in situations with high fish predation (Maier 1989a).*
- *Reid and Pinto-Coelho (1994) outlined various intercontinental copepod introductions and concluded that the ecological impacts of these introductions are often difficult to determine. While in some rare cases introduced exotic copepod species appeared to displace native copepod species. In most documented exotic copepod introductions to the western hemisphere no impacts on native copepod species could be directly attributed to the introduced species.*

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

- *Reid and Pinto-Coelho (1994) outlined various intercontinental copepod introductions and concluded that the ecological impacts of these introductions are often difficult to determine. While in some rare cases introduced exotic copepod species appeared to displace native copepod species. In most documented exotic copepod introductions to the western hemisphere, no impacts on native copepod species could be directly attributed to the introduced species.*

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 genetic effects have been observed, but consequences have been limited to the individual level AND/OR It has genetically affected the same or similar species in past invasions outside of the Great Lakes	1
Not significantly	0
Unknown	U √

- *Unknown.*

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

Yes, and it has had a widespread, long term, or severe negative effect on water quality AND/OR Yes, and it has resulted in significant negative consequences for at least one native species	6
Yes, it has affected water quality to some extent, but the alterations and resulting adverse effects have been mild	1

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

- *Not reported.*

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

- *Not reported.*

Environmental Impact Total	**1**
Total Unknowns (U)	**1**

Scoring		
Score	# U's	Impact
>5	Any	High
2-5	Any	Moderate
0	0-1	Low
1	0	
0	≥2	**Unknown**
1	≥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

- *Not reported.*

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

- *Not reported.*

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

- *Not reported.*

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

- *Not reported.*

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

- *Zooplankton grazing on Microcystis can recycle nutrients that help sustain the biomass of a Microcystis bloom (Paerl and Otten 2013). T. crassus is known to graze on Microcystis (Moriarty et al. 1973) suggesting that this species could help sustain HABs. However, there is no other evidence in the literature that this species significantly impacts the sustainability of a bloom.*

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

- *Not reported.*

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

Scoring		
Score	# U's	Impact
>5	Any	High
2-5	Any	Moderate
0	0-1	**Low**
1	0	
0	≥2	Unknown
1	≥1	

BENEFICIAL EFFECT

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

- *Cyclopoid copepods have been found to be effective mosquito control agents in several cases (Nam et al. 1998; Marten et al. 1994). Several different species of Mesocyclops and* Thermocyclops crassus *were used to control the mosquito* Aedes aegypti *-- the principal vector in the transmission of dengue fever -- in a Vietnamese village. Within the first 12 months the copepod-treated village had 30-97% less mosquito larvae than the control village. The researchers employed a community-based approach that had community members recycle to eliminate unused and discarded containers that collected rainwater and provided breeding habitat for mosquitoes that were not treated with Mesocyclops or Thermocyclops. The use of cyclopoid copepods in combination with community recycling completely eradicated the mosquito from the village within 18 months (Nam et al. 1998).*
- *Use of* Thermocyclops crassus *for mosquito control would be unwarranted in the Great Lakes region as native cyclopoids (e.g.* Mesocyclops edax*) would be more appropriate.*

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

- *Copepods are ideal and adequate food for fish larvae in aquaculture facilities . However, another species of copepod,* M. aspericornis*, was found to be more nutritious than* T. hyalinus *(read* T. crassus*) (Vidhya et al. 2014).*

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

- *Not reported.*

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 has some medicinal or research value, but is not of high priority OR It is potentially important to medicine or research and is currently being or scheduled to be studied	1
Not significantly	0 √
Unknown	U

- *Not reported.*

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

Yes, it reduces water treatment costs or has a significant positive impact for the health of humans and/or native species	6
Yes, but positive impact for humans or native species is considered negligible	1
Not significantly	0 √
Unknown	U

- *Not reported.*

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

Beneficial Effect Total	**0**
Total Unknowns (U)	**0**

Scoring		
Score	# U's	Impact
>5	Any	High
2-5	Any	Moderate
0	0-1	**Low**
1	0	
0	≥2	Unknown
1	≥1	

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