Study on Invasive Alien Species – Development of risk assessments to tackle priority species and enhance prevention

Contract No 07.0202/2016/740982/ETU/ENV.D2

Final Report

Annex 5: Risk Assessment for *Limnoperna fortunei* Dunker (1857)

Risk assessment template developed under the "Study on Invasive Alien Species – Development of risk assessments to tackle priority species and enhance prevention" Contract No 07.0202/2016/740982/ETU/ENV.D2

Based on the Risk Assessment Scheme developed by the GB Non-Native Species Secretariat (GB Non-Native Risk Assessment - GBNNRA)

Name of organism: *Limnoperna fortunei* Dunker (1857)

Author(s) of the assessment:
Frances Lucy, CERIS, Institute of Technology, Sligo, Ireland
Elena Tricarico, University of Florence, Italy

Risk Assessment Area: The geographical coverage of the risk assessment is the territory of the European Union (excluding the outermost regions)

Peer review 1: Michael Millane, Inland Fisheries Ireland
Peer review 2: Robert Tanner, European and Mediterranean Plant Protection Organization (EPPO/OEPP), Paris, France

This risk assessment has been peer-reviewed by two independent experts and discussed during a joint expert workshop. Details on the review and how comments were addressed are available in the final project report "Study on Invasive Alien Species – Development of risk assessments to tackle priority species and enhance prevention".

Completed:
1st draft: 17/11/2017
2nd draft: addressing the review comments by the Scientific Forum, presented for the opinion of the Scientific Forum on 26/10/2018
3rd draft: addressing further comments received from Scientific Forum on 26/10/2018, presented for the opinion of the Scientific Forum on 26/03/2020

RISK SUMMARIES			
	RESPONSE	**CONFIDENCE**	**COMMENT**
Summarise Entry	likely	medium	Introduction via ballast waters is most likely pathway. Although the introduction via the other pathways are less likely, the possibility still exists.
Summarise Establishment	likely	medium	The species is currently absent from Europe, but can establish under the current climate conditions in Europe, particularly in Southern Europe.
Summarise Spread	rapidly	medium	This species is tolerant to a wide range of conditions and can be unintentionally spread by several vectors (nets, buoys, boats, and fishing gear). Previous models forecasted suitability for almost parts of Europe, particularly South Europe (Campos et al. 2014; Boltovsky 2015).
Summarise Impact	major	medium	The species can exert several impacts on biodiversity and ecosystem services as well as on economic activities. Moreover, being a highly adaptable species, it is likely that heavy and widespread impacts can occur.
Conclusion of the risk assessment	high	medium	The species is very similar to zebra mussel for biology and impacts (even more adaptable in term of climatic conditions). Europe is already experiencing the impacts of zebra mussel. Thus, even if confidence in the conclusion is limited due to transferability of data (the invaded area external to EU is limited), available evidence and its similarity to zebra mussel suggest that this species can pose a serious risk to biodiversity in the EU.

Distribution Summary (for explanations see EU chapeau):

Member States

	Recorded	Established (currently)	Established (future)	Invasive (currently)
Austria	-	-	Yes	-
Belgium	-	-	Yes	-
Bulgaria	-	-	Yes	-
Croatia	-	-	Yes	-
Cyprus	-	-	Yes	-
Czech Republic	-	-	Yes	-
Denmark	-	-	Yes	-
Estonia	-	-	Yes	-
Finland	-	-	Yes	-
France	-	-	Yes	-
Germany	-	-	Yes	-
Greece	-	-	Yes	-
Hungary	-	-	Yes	-
Ireland	-	-	Yes	-
Italy	-	-	Yes	-
Latvia	-	-	Yes	-
Lithuania	-	-	Yes	-
Luxembourg	-	-	Yes	-
Malta	-	-	Yes	-
Netherlands	-	-	Yes	-
Poland	-	-	Yes	-
Portugal	-	-	Yes	-
Romania	-	-	Yes	-
Slovakia	-	-	Yes	-
Slovenia	-	-	Yes	-
Spain	-	-	Yes	-
Sweden	-	-	Yes	-
United Kingdom	-	-	Yes	-

EU biogeographical regions

	Recorded	Established (currently)	Established (future)
Alpine	-	-	Yes
Atlantic	-	-	Yes
Black Sea	-	-	Yes
Boreal	-	-	Yes
Continental	-	-	Yes
Mediterranean	-	-	Yes
Pannonian	-	-	Yes
Steppic	-	-	Yes

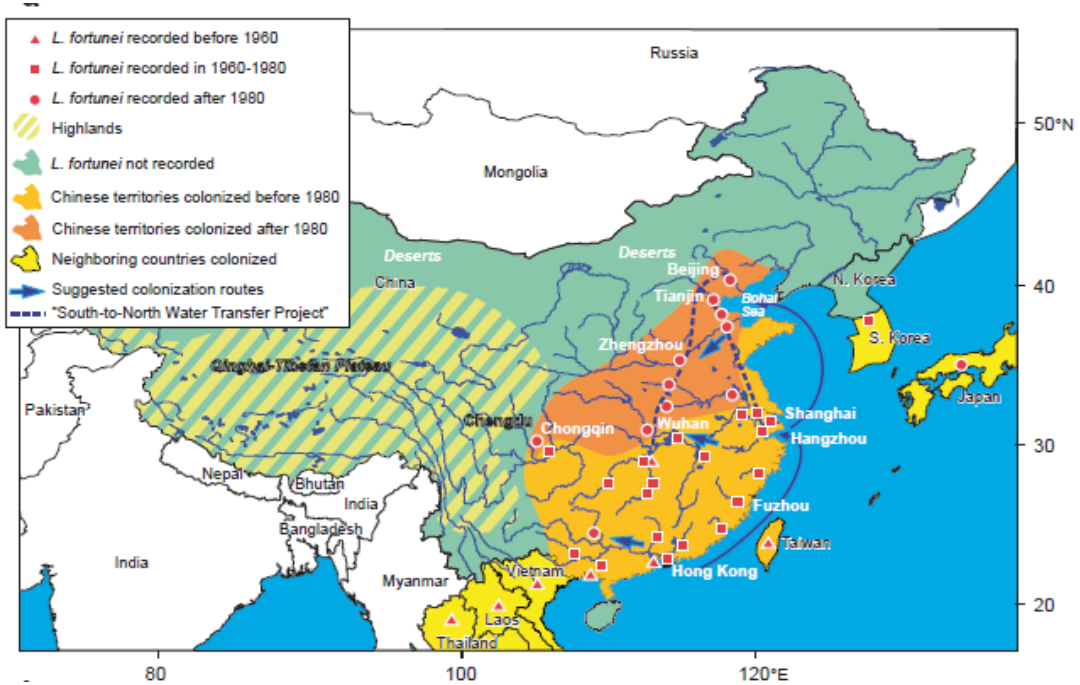
ANNEX I - Scoring of Likelihoods of Events 42
ANNEX II - Scoring of Magnitude of Impacts 43
ANNEX III - Scoring of Confidence Levels 44

EU CHAPEAU		
QUESTION	**RESPONSE**	**COMMENT**
Ch1. In which EU biogeographical region(s) or marine subregion(s) has the species been recorded and where is it established?	None	
Ch2. In which EU biogeographical region(s) or marine subregion(s) could the species establish in the future under current climate and under foreseeable climate change?	Current climate conditions: Atlantic, Continental, Mediterranean, Pannonian, Black Sea Foreseeable climate change: Atlantic, Continental, Mediterranean, Pannonian, Black Sea, Boreal, Alpine, Steppic	The potential regions were selected according to the already invaded areas in other continents, predicting models in other areas (Oliverira et al. 2010a,b) and to the species biological traits (temperature tolerance). Species distribution model was not performed for the low number of records in native range. *Limnoperna fortunei* is a freshwater bivalve mussel species, capable of tolerating brackish waters and maintaining substantial populations in estuarine habitats. It is tolerant to polluted waters, with low level of calcium, oxygen, and pH levels (Crosier et al. 2007; Boltovskoy 2015; Mackie & Brinsmead 2017). Temperature range is comprised between 8 and 32°C, with confirmed reports at 35°C (Crosier et al. 2007). The literature supports 16-17°C being required for reproduction and > 5°C for long-term survival (Mackie & Brinsmead 2017). The warmer the water, the more cohorts are produced.
Ch3. In which EU member states has the species been recorded? List them with an indication of the timeline of observations.	None	
Ch4. In which EU member states has this species established populations? List them with an	None	

indication of the timeline of establishment and spread.		
Ch5. In which EU member states could the species establish in the future under current climate and under foreseeable climate change?	**Current Climate**: Italy, Malta, Cyprus, Greece, Spain, France **Foreseeable Climate Change**: Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, Germany, Hungary, Ireland, Latvia, Lithuania, Luxembourg, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Sweden	In current climate conditions the species can establish in waterbodies that do not drop below 5°C during winter, where they can exist throughout the year. Under foreseeable climate change, all member states are selected because should temperature rise sufficiently they all contain fresh water systems environmentally suited to the species biological traits (temperature tolerance). Temperature range is comprised between 8 and 32°C, with confirmed reports at 35°C (Crosier et al. 2007). The literature supports 16-17°C being required for reproduction and > 5°C for long-term survival (Mackie & Brinsmead 2017).
Ch6. In which EU member states has this species shown signs of invasiveness?	None	
Ch7. In which EU member states could this species become invasive in the future under current climate and under foreseeable climate change?	The species could potentially become invasive in the member states of Southern Europe under current climate conditions, in almost the member states under future conditions.	The potential regions were selected according to the already invaded areas in other continents and to the species biological traits (temperature tolerance).

SECTION A – Organism Information and Screening		
Organism Information	**RESPONSE**	**COMMENT**
A1. Identify the organism. Is it clearly a single taxonomic entity and can it be adequately distinguished from other entities of the same rank?	Golden mussel *Limnoperna fortunei* Dunker (1857) Class Bivalvia, Order Mollusca, Family Mytilidae This is one distinct species and there are therefore no common varieties, breeds or hybrids.	Synonyms: *Dreissena siamensis* Morelet, 1866 *Limnoperna depressa* Brandt and Temcharoen, 1971 *Limnoperna lemeslei* Rochebrune, 1882 *Limnoperna supoti* Brandt, 1974 *Volsella fortunei* Dunker, 1857 *Modiola cambodjensis* Clessin, 1889 *Modiola lacustris* Martens, 1875 *Mytilus martensi* Neumayer 1898 *Limnoperna coreana* Park and Choi 2008 (WoRMs register, http://www.marinespecies.org)
A2. Provide information on the existence of other species that look very similar	Could be confused with the native European marine blue mussel *Mytilus edulis* as it belongs in the same family and is quite similar in morphology and size. It could also be mistaken for invasive freshwater *Dreissena* species, i.e. *Dreissena polymorpha*, zebra mussel and *Dreissena bugensis*, quagga mussel. It could also possibly be confused with *Mytilopsis leucophaeata*	*Limnoperna fortunei*, *M. edulis* and *Dreissena* species can all grow in aggregated dense clumps due to the production of byssal threads (Lucy et al. 2005). So, both shape of individual mussels and characteristics can lead to misidentification. *Limnoperna* and *Dreissena* require different risk assessments. *Dreissena* is already widespread within Europe and, although similar in some respects, has a distinct specific ecology.
A3. Does a relevant earlier risk assessment exist? (give details of any previous risk assessment and its validity in relation to the EU)	Yes, the information provided in a Canadian risk assessment (Mackie & Brinsmead 2017) is relevant to Member States in terms of probability of arrival and dispersal.	There is a risk assessment for Ontario, Canada (Mackie & Brinsmead 2017) that maybe relevant for some northern Member States. The overall probability of arrival in Ontario through ballast waters and/or overland dispersal (e.g. trailered boats) was ranked low. The probability of survival,

		establishment, and spread of golden mussel in Ontario was deemed to be low, primarily because of its physiological intolerance of cold, winter waters.
A4. Where is the organism native?	Native to Southeast China (Dunker 1856) Pearl, Yangtze and river basins in the Fujian and Zhejiang regions are the main habitats (Xu 2015). After 1980, its range expanded to the Huaihe, Yellow, and Haihe River basins. In 1980, *L. fortunei* was found in Tianjin, a city on the Bohai Sea in northern China, most probably introduced by coastal shipping activities. At present, golden mussels are present in the middle reaches of the Yellow River basin and even further north, around Beijing (Xu 2015)	In China populations are present from 20°N to 40°N. Due to the mountainous terrain in western China, dispersion of *L. fortunei* to this area will not take place without human involvement. Golden mussels could potentially colonize the Liao River basin and the Inland River basin in Northeast China if the water temperature increases due to climate change (Xu 2015).
A5. What is the global non-native distribution of the organism (excluding the Union, but including neighbouring European (non-Union) countries)?	In South East Asia: Hong Kong, Taiwan, Vietnam, Lagos, Thailand, Japan, S. Korea. 20°N to 40°N. See map below (Xu 2015). In South America: Argentina, Bolivia, Brazil, Paraguay and Uruguay. 10°S to 30°S. Please see map below (Oliveira et al. 2015).	
A6. Is the organism known to be invasive (i.e. to threaten organisms, habitats or ecosystems) anywhere in the world?	Yes – invasive in both South East Asia and South America.	High impact on phytoplankton (Boltovsky et al. 2015b) and zooplankton (Molina et al. 2015), clearance due to filter feeding. Biofoul native species (Sylvester & Sardina 2015). Enhanced blooms of toxic cyanobacteria, *Microsystis* spp. (Boltovsky et al. 2015b). Increased macrophyte and periphyton growth due to increased transparency (in Boltovsky et al. 2015b).


L. fortunei recorded before 1960
L. fortunei recorded in 1960-1980
L. fortunei recorded after 1980
Highlands
L. fortunei not recorded
Chinese territories colonized before 1980
Chinese territories colonized after 1980
Neighboring countries colonized
Suggested colonization routes
"South-to-North Water Transfer Project"
Russia
Mongolia
China
Deserts
Deserts
Beijing
Tianjin
Bohai Sea
N. Korea
S. Korea
Japan
Zhengzhou
Shanghai
Hangzhou
Wuhan
Chongqin
Chengdu
Fuzhou
Taiwan
Hong Kong
Vietnam
Laos
Thailand
Myanmar
India
Bangladesh
Bhutan
Nepal
Pakistan
50°N
40
30
20
80
100
120°E

Magdalena basin
Orinoco basin
Amazonas basin
São Francisco basin
Tocantins basin
Rio de la Plata basin
Tramandaí basin
Guaíba basin
Patos-Mirim basin
Mar Chiquita basin
Colonized basins
Limits between basins
Rivers
Lakes and reservoirs
Cities
10°N
0
10°S
20
30
40
50
60
80°W
70
60
50
40
30

A7. Describe any known socio-economic benefits of the organism in the risk assessment area.	No known socio-economic benefits. No information has been found.	including the following elements: • Description of known uses for the species, including a list and description of known uses in the Union and third countries, if relevant. • Description of social and economic benefits deriving from those uses, including a description of the environmental, social and economic relevance of each of those uses and an indication of associated beneficiaries, quantitatively and/or qualitatively depending on what information is available, and description of the opportunity costs for stakeholders if the species would be listed.

SECTION B – Detailed assessment

Important instructions:

- In the case of lack of information the assessors are requested to use a standardized answer: "No information has been found."
- For detailed explanations of the CBD pathway classification scheme consult the IUCN/CEH guidance document.
- With regard to the scoring of the likelihood of events or the magnitude of impacts see Annex.
- With regard to the confidence levels, see Annex.

PROBABILITY OF INTRODUCTION and ENTRY

Important instructions:

- Introduction is the movement of the species into the EU.
- Entry is the release/escape/arrival in the environment, i.e. occurrence in the wild. Not to be confused with spread, the movement of an organism within Europe.
- For organisms which are already present in Europe, only complete this section for current active or if relevant potential future pathways. This section need not be completed for organisms which have entered in the past and have no current pathway of introduction and entry.

QUESTION	RESPONSE [chose one entry, delete all others]	CONFIDENCE [chose one entry, delete all others]	COMMENT
1.1. How many active pathways are relevant to the potential entry of this organism? (If there are no active pathways or potential future pathways respond N/A and move to the Establishment section)	few	medium	
1.2. List relevant pathways through which the organism could enter. Where possible give detail about the specific origins and end points of the pathways as well as a description of the associated commodities.	1) Transport stowaway-ship/ballast waters		Pathways include 1) Transport stowaway ship/ballast waters: larval stages in ballast water (Oliveira et al. 2015)

For each pathway answer questions 1.3 to 1.10 (copy and paste additional rows at the end of this section as necessary). Please attribute unique identifiers to each question if you consider more than one pathway, e.g. 1.3a, 1.4a, etc. and then 1.3b, 1.4b etc. for the next pathway.	2) Transport-Contaminant on animals 3) Transport-Contaminant on plants		2) Transport contaminant on animals (imported with live food) (Nakano et al. 2014; Ito 2015) 3) Transport contaminant on plants (on ornamental plants) (Correa et al. 2015)
Pathway name:	**Transport stowaway ship/ballast water**		
1.3.a Is entry along this pathway intentional (e.g. the organism is imported for trade) or accidental (the organism is a contaminant of imported goods)?	unintentional	medium	There is no commercial value attached to this species. It is therefore very highly unlikely that it will be introduced intentionally by this pathway.
1.4.a How likely is it that large numbers of the organism will travel along this pathway from the point(s) of origin over the course of one year? Subnote: In your comment discuss how likely the organism is to get onto the pathway in the first place. Subnote: In your comment discuss the volume of movement along this pathway.	likely	medium	Introduction to Europe is likely to come from *Limnoperna* infested ballast water in ships originating from either South America or South East Asia, via multiple introductions, as there are ships (still using ballast tanks) trading with Hamburg and Rotterdam and other ports in vulnerable Member States. In context, in the first transcontinental invasion of this species, it is likely that the spread of *Limnoperna* to South America was in the ballast water of transoceanic ships from SE Asia (around 1990) with multiple introductions (Oliveira et al. 2015). *Limnoperna* exhibits high fecundity and is a broadcast spawner with larval densities of 20,000-35,000/m^3 in waters (Cataldo et al. 2000; Nakana et al. 2010a). Mortality rates can be as high as 80-90% during larval development (Cataldo et al. 2005). High density of larva in ballast increases the probability of successful establishment at European port discharge, even if mortality rates are very high.
1.5.aHow likely is the organism to survive during passage along the pathway (excluding management practices that would kill the organism)?	moderately likely	medium	Larva are likely to survive as long as salinity is low (2 ppt; Sylvester et al. 2013), adequate and appropriately sized phytoplankton are present for food and dissolved

Subnote: In your comment consider whether the organism could multiply along the pathway.			oxygen is at least 0.5mg/L (Boltovsky et al 2006). Settlement rates of juveniles occur at 20 days at 20°C (Cataldo et al. 2005) but are likely to be longer at lower temperatures (Brugnoli et al. 2011). This allows sufficient survival time in infested ballast water for transoceanic crossing. Late stage larvae (at time of ballast intake) are unlikely to survive the journey as they will likely settle and die in ballast sediments.
1.6.a How likely is the organism to survive existing management practices during passage along the pathway?	moderately likely	medium	It depends if ballast water exchange occurs in open waters as recommended by Ballast Water Management Convention.
1.7.a How likely is the organism to enter Europe undetected?	very likely	medium	Larva are microscopic (<0.5mm) and will not be detected at point of discharge (Cataldo et al. 2005).
1.8.a How likely is the organism to arrive during the months of the year most appropriate for establishment?	moderately likely	medium	When both South America and South-east Asia are considered together, then spawning season spans the entire year, increasing the potential for all-round invasion to Europe. Temperatures >0°C required for survival (Choi and Shin 1985) but also depends on food availability. Survival less likely in winter cold water conditions.
1.9.aHow likely is the organism to be able to transfer from the pathway to a suitable habitat or host?	moderately likely	medium	Most freshwater ports serving ocean-going ships are located in estuarine areas, which may be too brackish for *Limnoperna* to survive. The species could survive discharge of ballast water in low salinities [a) continuous 2 ppt. b) discontinuous, punctuated by periods of freshwater: up to 23 ppt (Sylvester et al 2013)]. Not just geographical, also depends on environmental factors, tidal ranges, winds and freshwater volumes at time of discharge.
1.10.a Estimate the overall likelihood of entry into Europe based on this pathway?	moderately likely	medium	No added comments.

Pathway name:	**Transport-Contaminant on animals**		
1.3b. Is entry along this pathway intentional (e.g. the organism is imported for trade) or accidental (the organism is a contaminant of imported goods)? (If intentional, only answer questions 1.4, 1.9, 1.10, 1.11)	unintentional	medium	The species has been presumably introduced to Japan as contaminant on Asian clam imported for food (*Corbicula* spp.) (Nakano et al. 2014; Ito 2015).
1.4b. How likely is it that large numbers of the organism will travel along this pathway from the point(s) of origin over the course of one year? Subnote: In your comment discuss how likely the organism is to get onto the pathway in the first place. Subnote: In your comment discuss the volume of movement along this pathway.	unlikely	medium	Freshwater molluscs are not common items sold in European markets. They could possibly be introduced in oriental food market with Asian clam or other edible freshwater molluscs. It is not possible to estimate propagule pressure as well as likelihood of reinvasion.
1.5b. How likely is the organism to survive during passage along the pathway (excluding management practices that would kill the organism)? Subnote: In your comment consider whether the organism could multiply along the pathway.	moderately likely	low	It depends on shipping and storage facilities of the associated molluscs. It could not multiply along the pathway. Adult zebra mussels are known to survive in damp conditions for several weeks (Minchin et al. 2002). *Limnoperna* have been observed to survive up to 108 hours in outdoor exposures before desiccation took place (Montalto and Ezcurra de Drago 2003).
1.6b. How likely is the organism to survive existing management practices during passage along the pathway?	moderately likely	low	It depends on shipping and storage facilities of the associated molluscs as no management practices exist.
1.7b. How likely is the organism to enter Europe undetected?	very likely	high	It can remain undetected by people if present as juveniles of less than 5mm.
1.8b. How likely is the organism to arrive during the months of the year most appropriate for establishment?	likely	high	Oriental food markets are held all over the year and therefore the species can arrive at the most appropriate season for establishment.

1.9b. How likely is the organism to be able to transfer from the pathway to a suitable habitat or host?	moderately likely	low	Possibly Asian clam may be re-laid (intentional transfer) in European waters and, if contaminated with *Limnoperna*, successful transfer of the species to a new suitable habitat may take place.
1.10b. Estimate the overall likelihood of entry into Europe based on this pathway?	moderately likely	low	See comment on 1.4b.
Pathway name:	**Transport contaminant on plants**		
1.3c. Is entry along this pathway intentional (e.g. the organism is imported for trade) or accidental (the organism is a contaminant of imported goods)? (If intentional, only answer questions 1.4, 1.9, 1.10, 1.11)	unintentional	medium	
1.4c. How likely is it that large numbers of the organism will travel along this pathway from the point(s) of origin over the course of one year? Subnote: In your comment discuss how likely the organism is to get onto the pathway in the first place. Subnote: In your comment discuss the volume of movement along this pathway.	unlikely	low	Other alien freshwater molluscs (e.g. *Potamopyrgus antipodarum*, *Physella acuta*) were introduced in Europe as contaminants of ornamental plants for aquaria, and the species can attach to aquatic plants (Correa et al. 2015). It is not possible to estimate propagule pressure as well as likelihood of reinvasion.
1.5c. How likely is the organism to survive during passage along the pathway (excluding management practices that would kill the organism)? Subnote: In your comment consider whether the organism could multiply along the pathway.	moderately likely	low	Based on successful introductions of other freshwater molluscs attached to plants, it is moderately likely that *Limnoperna* can survive passage along this pathway (Cianfanelli et al. 2007).
1.6c. How likely is the organism to survive existing management practices during passage along the pathway?	moderately likely	low	Based on successful introductions of other freshwater molluscs attached to plants. No management practices exist.

1.7c. How likely is the organism to enter Europe undetected?	very likely	medium	Specimens are small in size and can be undetected by people even if there is attention given to controlling this organism.
1.8c. How likely is the organism to arrive during the months of the year most appropriate for establishment?	likely	medium	Plants import occur throughout the year and therefore the species can arrive at the most appropriate season for establishment. Moreover, possibly contaminated aquatic ornamental plants are sold via internet trade from infested areas.
1.9c. How likely is the organism to be able to transfer from the pathway to a suitable habitat or host?	moderately likely	low	If contaminated plants are released into the water bodies, the species can be transferred to a suitable habitat.
1.10c. Estimate the overall likelihood of entry into Europe based on this pathway?	moderately likely	low	See comment at 1.4c
1.11. Estimate the overall likelihood of entry into Europe based on all pathways in relevant biogeographical regions in current conditions (comment on the key issues that lead to this conclusion).	likely	medium	Introduction via ballast waters is most likely pathway. Although the introduction via the other pathways are less likely, the possibility still exists.
1.12. Estimate the overall likelihood of entry into Europe based on all pathways in relevant biogeographical regions in foreseeable climate change conditions?	likely	medium	All the pathways are unintentional and can persist in the future; their management is also more complex.

PROBABILITY OF ESTABLISHMENT

Important instructions:

- For organisms which are already established in parts of the Union, answer the questions with regard to those areas, where the species is not yet established. If the species is established in all Member States, continue with Question 1.16.

QUESTION	RESPONSE	CONFIDENCE	COMMENT
1.13. How likely is it that the organism will be able to establish in the EU based on the similarity between climatic conditions in Europe and the organism's current distribution?	likely	medium	According to Karatayev et al. (2015a), Glansis (2015) and Campos et al. (2014), the species could establish in Europe, specifically more in the southern part (not Nordic and Baltic states).
1.14. How likely is it that the organism will be able to establish in the EU based on the similarity between other abiotic conditions in Europe and the organism's current distribution?	likely	medium	According to the requirements of the species (Boltovskoy et al. 2015a), suitable abiotic conditions exist in Europe for the species. See answer to Q 1.23
1.15. How likely is it that the organism will become established in protected conditions (in which the environment is artificially maintained, such as wildlife parks, glasshouses, aquaculture facilities, terraria, zoological gardens) in Europe? Subnote: gardens are not considered protected conditions	likely	medium	The species can establish in ornamental ponds, aquaculture facilities as happened in Japan (Ito 2015).
1.16. How widespread are habitats or species necessary for the survival, development and multiplication of the organism in Europe?	widespread	medium	The species shows some high levels of adaptability and can survive many freshwater habitats (both lotic and lentic) both in its native and invasive range (Boltovskoy 2015; Ito 2015; Oliveira et al. 2015; Xu 2015).
1.17. If the organism requires another species for critical stages in its life cycle then how likely is the organism to become associated with such species in Europe?	NA	medium	

1.18. How likely is it that establishment will occur despite competition from existing species in Europe?	likely	medium	Potentially it can outcompete other molluscs due to high filtration rate and relatively wide feeding habit (Boltovskoy et al. 2015a).
1.19. How likely is it that establishment will occur despite predators, parasites or pathogens already present in Europe?	likely	medium	Fish can predate the species but cannot affect the likelihood of establishment (Cataldo 2015).
1.20. How likely is the organism to establish despite existing management practices in Europe?	likely	low	No information has been found on management practices. For other invasive alien molluscs present in Europe, in some countries some biosecurity measures (e.g. check/clean and dry), e.g. UK may prevent new introductions, while mechanical removal is used for zebra mussel and Asian clam in very few invaded areas.
1.21. How likely are existing management practices in Europe to facilitate establishment?	N/A	medium	No management practices in place.
1.22. How likely is it that biological properties of the organism would allow it to survive eradication campaigns in Europe?	likely	medium	Eradication is only possible for very localised populations, mainly in artificial environments.
1.23. How likely are the biological characteristics of the organism to facilitate its establishment?	very likely	medium	It is a freshwater species, capable of tolerating brackish waters and maintaining substantial populations in estuarine habitats. It is tolerant to polluted waters, with low level of calcium, oxygen, and pH levels (Crosier et al. 2007; Boltovskoy 2015; Mackie & Brinsmead 2017). Temperature range is comprised between 8 and 32°C, with confirmed reports at 35°C (Crosier et al. 2007). The literature supports 16-17°C being required for reproduction and > 5°C for long-term survival (Mackie & Brinsmead 2017). The warmer the water, the more cohorts are produced. The species is a filter feeder (algae, zooplankton and organic

			matter). The larval stages feed on bacteria. The species is dioecious spawner. Sexual maturity is reached by 1 year, life span is 2-3 years in South America, 5-10 years maximum in Korea and China. Larval stage lasts 30-70 days. In tropical and subtropical South America, larval output is more or less continuous for 6-10 months of the year; in Japan 1-2 months in the summer (Ito 2015). Peak larval densities can exceed 20,000 ind/m^3, but normally values range around 6000 ind/m^3 (Boltovsky 2015). Adults are capable of adapting to various habitats; they attach byssally to available substrates, forming dense aggregations (colonies with densities > 80,000/m^2; Crosier et al. 2007). Densities of over 200, 000 ind/m^2 have been reported occasionally; densities of adults (>5-7 mm) are usually below 10,000 ind/m^2 (Boltovsky 2015).
1.24. How likely is the capacity to spread of the organism to facilitate its establishment?	likely	medium	The species has veliger larvae that can be passively transported from colonized areas through connected streams (Xu 2015).
1.25. How likely is the adaptability of the organism to facilitate its establishment?	very likely	medium	See comment on Q.13
1.26. How likely is it that the organism could establish despite low genetic diversity in the founder population?	NA	medium	The species has a high genetic diversity (Uliano-Silva et al. 2015).
1.27. Based on the history of invasion by this organism elsewhere in the world, how likely is it to establish in Europe? (If possible, specify the instances in the comments box.)	very likely	medium	According to Karatayev et al. (2015) and Campos et al. (2014), the species could establish in Europe, specifically more in the southern part (not Nordic and Baltic states).
1.28. If the organism does not establish, then how likely is it that casual populations will continue to occur?	very unlikely	medium	Continual release is unlikely due to the nature of pathways (accidentally not intentional).

Subnote: Red-eared Terrapin, a species which cannot re-produce in GB but is present because of continual release, is an example of a transient species.			
1.29. Estimate the overall likelihood of establishment in relevant biogeographical regions in current conditions (mention any key issues in the comment box).	likely	medium	The species is highly adaptable, environmentally. tolerant and shows genetic diversity. Under current conditions, establishment is likely as suitable waterbodies are present in Mediterranean areas and there is no evidence of management practices.
1.30. Estimate the overall likelihood of establishment in relevant biogeographical regions in foreseeable climate change conditions	likely	medium	In the event that climate change increases ambient winter water temperatures to 5°C or more, establishment is likely in all biogeographical regions.

PROBABILITY OF SPREAD

Important notes:

- Spread is defined as the expansion of the geographical distribution of an alien species within the assessment area.
- Repeated releases at separate locations do not represent spread and should be considered in the probability of introduction and entry section.

QUESTION	RESPONSE	CONFIDENCE	COMMENT
2.1. How important is the expected spread of this organism in Europe by natural means? (Please list and comment on each of the mechanisms for natural spread.)	moderate	medium	As for zebra mussel, the species has veliger larvae that can be passively transported from colonized areas through connected waterways. The natural dispersal is downstream and dependent on water currents. The natural physical barrier to their spread will be cold, winter temperatures, implying a low probability of spread. It is a freshwater species, capable of tolerating brackish waters and maintaining substantial populations in estuarine habitats. It is tolerant to polluted waters, with low level of calcium, oxygen, and pH levels (Crosier et al. 2007; Boltovskoy 2015; Mackie & Brinsmead 2017). Temperature range is comprised between 8 and 32°C, with confirmed reports at 35°C (Crosier et al. 2007). The literature supports 16-17°C being required for reproduction and > 5°C for long-term survival (Mackie & Brinsmead 2017). The warmer the water, the more cohorts are produced. The species is a filter-feeder (algae, zooplankton and organic matter; Tokumon et al. 2015). The larval stages feed on bacteria. The species is dioecious spawner. Sexual maturity is reached by 1 year, life span is 2-3 years in South America, 5-10 years maximum in Korea and China. Larval stage lasts 30-70 days. In tropical and

			subtropical South America larval output is more or less continuous for 6-10 months of the year; in Japan 1-2 months in the summer (Boltovsky 2015). Peak larval densities can exceed 20,000 ind/m^3, but normally values range around 6000 ind/m^3 (Boltovsky 2015). Adults are capable of adapting to various habitats; they attach byssally to available substrates, forming dense aggregations (colonies with densities > 80,000/m^2; Crosier et al. 2007). Densities of over 200, 000 ind/m^2 have been reported occasionally; densities of adults (>5-7 mm) are usually below 10,000 ind/m^2 (Boltovsky 2015).
2.2. How important is the expected spread of this organism in Europe by human assistance? (Please list and comment on each of the mechanisms for human-assisted spread) and provide a description of the associated commodities.	major	medium	As for zebra mussel, the species can be transported as a contaminant of nets, buoys, boats, and fishing gear. It spreads up stream in the main rivers of the Plata basin (South America) (240 km/year), using different vectors (Darrigran et al. 2011).
2.2a. List and describe relevant pathways of spread. Where possible give detail about the specific origins and end points of the pathways. For each pathway answer questions 2.3 to 2.9 (copy and paste additional rows at the end of this section as necessary). Please attribute unique identifiers to each question if you consider more than one pathway, e.g. 2.3a, 2.4a, etc. and then 2.3b, 2.4b etc. for the next pathway.	1) Transport-Stowaway Angling/fishing equipment 2) Transport-Stowaway ship/boat hull fouling 3) Corridor 4) Unaided		including the following elements: • a list and description of pathways with an indication of their importance and associated risks (e.g. the likelihood of spread in the Union, based on these pathways; likelihood of survival, or reproduction, or increase during transport and storage; ability and likelihood of transfer from the pathway to a suitable habitat or host). Where possible details about the specific origins and end points of the pathways shall be included. • an indication of the propagule pressure (e.g. estimated volume or number of specimens, or frequency of passage through pathway), including the likelihood of reinvasion after eradication.

			• All relevant pathways should be considered. The classification of pathways developed by the Convention of Biological Diversity shall be used
Pathway name:	**1) Transport-Stowaway Angling/fishing equipment**		
2.3a. Is spread along this pathway intentional (e.g. the organism is released at distant localities) or unintentional (the organism is a contaminant of imported goods)?	unintentional	medium	
2.4a. How likely is it that large numbers of the organism will spread along this pathway from the point(s) of origin over the course of one year?	moderately likely	medium	The species is a macrofouling bivalve, and usually colonizes hard surfaces for example, boats, nets, and other equipment, and can be transported with them, and also with fragmented plants associated with the nets. In South America, it spreads up stream in the main rivers of the Plata basin (240 km/year), using different vectors (e.g. commercial and tourist ships, fixed to nets, buoys; Darrigran et al. 2011, 2012). Spread may occur via Corridor-Interconnected waterways/basins/seas in Europe similar to the rapid spread of zebra and quagga mussel through the international network of European waterways (interconnected river basins) (Minchin et al. 2002; bij de Vaate et al. 2013). Biosecurity measures and cleaning procedures are necessary to avoid its dispersal by nets.
2.5a. How likely is the organism to survive during passage along the pathway (excluding management practices that would kill the organism)? Subnote: In your comment consider whether the organism could multiply along the pathway.	likely	medium	As the species (and related species) have been reported to be successfully spread by nets, the likelihood of survival is high. It can survive up to 120-168 hours of emersion: Darrigran et al. (2004) exposed specimens to air without humidity control (49 to 63% relative humidity) and the mussels did not survive more than 120 hours, while those held in an elevated humidity environment survived up to 168 hours. Smaller mussels reached 100% mortality before larger ones. According to Montalto et al. (2003), about 72 h was

			required to kill small mussels (up to 6 mm), 192 h to kill medium-sized adults (>6–15 mm) and 276 h to kill maximum-sized mussels adults (>15–27 mm) in laboratory exposures, and 72 h, 96 h and 108 to kill small, medium-sized and maximum sized mussels in outdoor exposures.
2.6a. How likely is the organism to survive existing management practices during spread?	unlikely	low	It depends if a good biosecurity code of practices is in place and implemented: e.g. chemical/desiccation/hot water treatment control should kill the organism (Boltovsky 2015). In some Member States (e.g. UK, Ireland), the campaign check/clean and dry is promoted to avoid new introductions of aquatic invaders.
2.7a. How likely is the organism to spread in Europe undetected?	very likely	medium	If not cleaned, encrusted nets, fishing gear, and associated contaminated plants can disperse the species (Darrigran et al. 2011, 2012).
2.8a. How likely is the organism to be able to transfer to a suitable habitat or host during spread?	very likely	medium	As the species has been reported to spread by fishing nets, the likelihood to be transferred to a suitable habitat is high (Darrigran et al. 2011, 2012).
2.9a. Estimate the overall likelihood of spread into or within the Union based on this pathway?	very likely	medium	This pathway could be very effective particularly for short-term spread.
Pathway name:	**2) Transport-Stowaway ship/boat hull fouling**		
2.3b. Is spread along this pathway intentional (e.g. the organism is released at distant localities) or unintentional (the organism is a contaminant of imported goods)?	unintentional	medium	
2.4b. How likely is it that large numbers of the organism will spread along this pathway from the point(s) of origin over the course of one year?	moderately likely	medium	The species is a macrofouling bivalve, and usually colonizes boats, nets, and other equipment, and can be transported with them. In South America, it spreads up stream in the main rivers of the Plata basin (240 km/year), using different vectors (e.g. commercial and tourist ships, fixed to nets, buoys; Darrigran et al. 2011, 2012). Biosecurity measures and cleaning procedures are necessary to avoid its dispersal by nets. In some

			Member States, the already ongoing biosecurity campaign could reduce the potential of its spread.
2.5b. How likely is the organism to survive during passage along the pathway (excluding management practices that would kill the organism)? Subnote: In your comment consider whether the organism could multiply along the pathway.	likely	medium	As the species has been reported to spread by boats, the likelihood of survival is high. However, if adults or contaminated plants are attached to trailers, the likelihood of survival across the Prairies in South America was reported to be almost nil (Mackie & Brinsmead 2017). Darrigran et al. (2004) exposed specimens to air without humidity control (49 to 63% relative humidity) and the mussels did not survive more than 120 hours, while those held in an elevated humidity environment survived up to 168 hours. Smaller mussels reached 100% mortality before larger ones.
2.6b. How likely is the organism to survive existing management practices during spread?	unlikely	low	It depends if a good biosecurity code of practices is in place and implemented: e.g. chemical/desiccation/hot water treatment control should kill the organism (Boltovsky 2015).
2.7b. How likely is the organism to spread in Europe undetected?	very likely	medium	If not cleaned, encrusted boats can disperse the species.
2.8b. How likely is the organism to be able to transfer to a suitable habitat or host during spread?	very likely	medium	As the species has been reported to spread by boats, the likelihood to be transferred to a suitable habitat is high.
2.9b. Estimate the overall likelihood of spread into or within the Union based on this pathway?	very likely	medium	This pathway could be very effective for spread (even if zebra mussel, a species very similar to golden mussel, seems to have arrived in Italy from Germany on encrusted boats; Quaglia et al. 2008). It is also a very effective means of upstream spread (Minchin et al. 2002).
Pathway name:	**3) Corridor-Interconnected waterways/basins/seas**		
2.3c. Is spread along this pathway intentional (e.g. the organism is released at distant localities) or unintentional (the organism is a contaminant of imported goods)?	unintentional	medium	This could occur in Central Europe in interconnected waterways by human actions.

2.4c. How likely is it that large numbers of the organism will spread along this pathway from the point(s) of origin over the course of one year?	likely	medium	As for zebra mussel, the species has veliger larvae that can be passively transported from colonized areas through connected waterways in Central Europe. Peak larval densities can exceed 20,000 ind/m^3, but normally values range around 6000 ind/m^3 (Boltovsky 2015). The natural dispersal is downstream and dependent on water currents. The natural physical barrier to their spread will be cold, winter temperatures, implying a low probability of spread (Boltovskoy 2015).
2.5c. How likely is the organism to survive during passage along the pathway (excluding management practices that would kill the organism)? Subnote: In your comment consider whether the organism could multiply along the pathway.	likely	medium	The species has been reported to have passively dispersed in South America, thus it can survive during passage. Downstream transport of zebra mussel has shown varied survival rates (Lucy et al. 2008).
2.6c. How likely is the organism to survive existing management practices during spread?	likely	medium	No management practices as this is happening as natural dispersal.
2.7c. How likely is the organism to spread in Europe undetected?	very likely	medium	Larvae can likely spread undetected in the water systems.
2.8c. How likely is the organism to be able to transfer to a suitable habitat or host during spread?	very likely	medium	As the species has been reported to passively spread in South America, the likelihood to be transferred to a suitable habitat is high.
2.9c. Estimate the overall likelihood of spread into or within the Union based on this pathway?	likely	medium	This pathway could be very effective on long and short-term spread. Local environmental conditions can play an important role.
Pathway name:	**4) Unaided**		
2.3d. Is spread along this pathway intentional (e.g. the organism is released at distant localities) or unintentional (the organism is a contaminant of imported goods)?	unintentional	medium	This could occur in big natural rivers connecting different Member States (e.g. Danube, Douro, Tago, Guadalquivir rivers).

2.4d. How likely is it that large numbers of the organism will spread along this pathway from the point(s) of origin over the course of one year?	likely	medium	As for zebra mussel, the species has veliger larvae that can be passively transported from colonized areas through connected waterways in Central Europe. Peak larval densities can exceed 20,000 ind/m^3, but normally values range around 6000 ind/m^3 (Boltovsky 2015). The natural dispersal is downstream and dependent on water currents. The natural physical barrier to their spread will be cold, winter temperatures, implying a low probability of spread (Boltovskoy 2015).
2.5d. How likely is the organism to survive during passage along the pathway (excluding management practices that would kill the organism)? Subnote: In your comment consider whether the organism could multiply along the pathway.	likely	medium	The species has been reported to have passively dispersed in South America, thus it can survive during passage. Downstream transport of zebra mussel has shown varied survival rates (Lucy et al. 2008).
2.6d. How likely is the organism to survive existing management practices during spread?	likely	medium	No management practices as this is happening as natural dispersal.
2.7d. How likely is the organism to spread in Europe undetected?	very likely	medium	Larvae can likely spread undetected in the water systems.
2.8d. How likely is the organism to be able to transfer to a suitable habitat or host during spread?	very likely	medium	As the species has been reported to passively spread in South America, the likelihood to be transferred to a suitable habitat is high.
2.9d. Estimate the overall likelihood of spread into or within the Union based on this pathway?	likely	medium	This pathway could be very effective on long and short-term spread. Local environmental conditions can play an important role.
2.10. Within Europe, how difficult would it be to contain the organism?	very difficult	medium	The species is ecologically similar to zebra mussel, which once established cannot be eradicated, because it can rapidly form dense and widespread aggregations that are very difficult to remove without destroying the environment.

2.11. Based on the answers to questions on the potential for establishment and spread in Europe, define the area endangered by the organism.	Mediterranean countries	medium	Freshwater bodies in Mediterranean countries where the water temperature does not drop below 5°C in winter, are endangered by *Limnoperna* invasion.
2.12. What proportion (%) of the area/habitat suitable for establishment (i.e. those parts of Europe were the species could establish), if any, has already been colonised by the organism?	0	medium	The species has not yet established in the assessment area.
2.13. What proportion (%) of the area/habitat suitable for establishment, if any, do you expect to have been invaded by the organism five years from now (including any current presence)?	0-10	low	Considering the dispersal rate in South America and the different climates present in Europe, it is likely that the species will be able to colonize hypothesize such proportion, but it depends on propagule pressure.
2.14. What other timeframe (in years) would be appropriate to estimate any significant further spread of the organism in Europe? (Please comment on why this timeframe is chosen.)	10	medium	The species is a fast colonizer and can be unintentionally spread by several vectors (Boltovsky 2015), therefore spread would be quick.
2.15. In this timeframe what proportion (%) of the endangered area/habitat (including any currently occupied areas/habitats) is likely to have been invaded by this organism?	10-33	low	Considering the dispersal rate in South America and the different climates present in Europe, it is likely that the species will be able to colonize such proportion for the endangered area.
2.16. Estimate the overall potential for spread in relevant biogeographical regions under current conditions for this organism in Europe (using the comment box to indicate any key issues).	rapidly	medium	This species is more tolerant to a wide range of conditions than zebra mussel and can be unintentionally spread by several vectors (Boltovsky 2015) and increase the area that can potentially be infested. Thus, golden mussel could possibly occupy EU areas currently inaccessible to zebra mussel. Previous models forecasted suitability for almost Europe, particularly South Europe (Campos et al. 2014; Boltovsky 2015).
2.17. Estimate the overall potential for spread in relevant biogeographical regions in foreseeable climate change conditions	likely	medium	This species tolerates and prefers high temperatures (Boltovsky 2015), thus it is likely that climate change

			will certainly increase the probability of invasion (Mackie & Brinsmead 2017).

MAGNITUDE OF IMPACT

Important instructions:

- Questions 2.18-2.22 relate to environmental impact, 2.23-2.25 to impacts on ecosystem services, 2.26-2.30 to economic impact, 2.31-2.32 to social and human health impact, and 2.33-2.36 to other impacts. These impacts can be interlinked, for example a disease may cause impacts on biodiversity and/or ecosystem functioning that leads to impacts on ecosystem services and finally economic impacts. In such cases the assessor should try to note the different impacts where most appropriate, cross-referencing between questions when needed.
- Each set of questions above starts with the impact elsewhere in the world, then considers impacts in Europe separating known impacts to date (i.e. past and current impacts) from potential future impacts (including foreseeable climate change).
- Assessors are requested to use and cite original, primary references as far as possible.

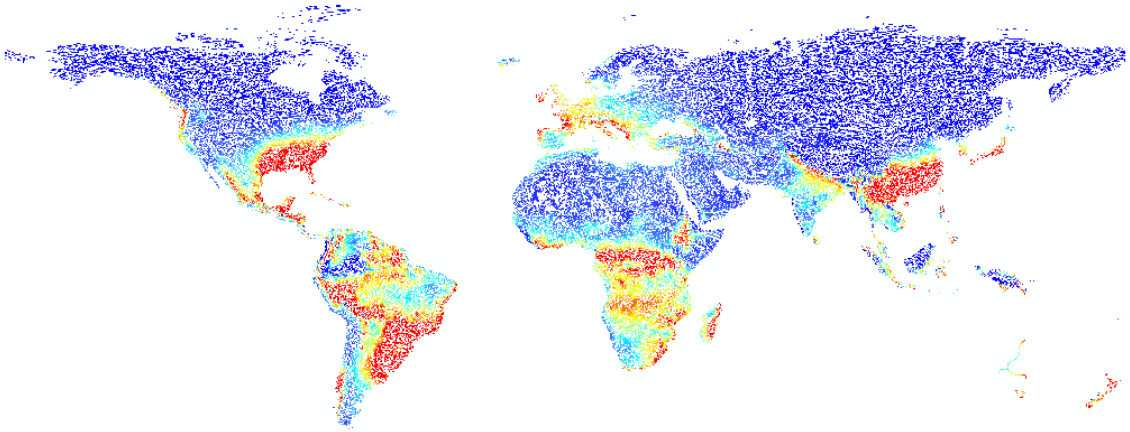
QUESTION	RESPONSE	CONFIDENCE	COMMENTS
Biodiversity and ecosystem impacts			
2.18. How important is impact of the organism on biodiversity at all levels of organisation caused by the organism in its non-native range excluding the Union?	major	medium	Similar to zebra mussel, golden mussel exerts relevant documented impacts. It is a biofouler, has the ability to disturb nutrient cycles through its filtering activity (Darrigran 2002; Boltovskoy et al. 2006, 2015b; US Fish and Wildlife Service 2014), and is associated to a substantial change in macroinvertebrate and macrophyte communities, leading to a general increase in abundance and richness (because it provides food and shelter to other invertebrates), but with a decline in gastropod and molluscs abundance and diversity (habitat and food competition). An increase in cyanobacterial blooms as well as active feeding in zooplankton are reported (Cataldo et al. 2012; Rojas Molina et al. 2015). The species is also preyed on by fish, whose change in diet has unknown consequences but has been hypothesised to be positive (a new trophic resource: Boltovsky et al. 2006; Boltovsky 2015; Cataldo 2015). Similar to zebra mussel, it is considered an ecosystem engineer, with dense colonies increasing the structural complexity of the

			substrate and providing shelter and food for other benthic invertebrates (Sylvester & Sardina 2015). It can be the intermediate host of trematodes that can affect fish (as documented in Japan; Ito 2015).
2.19. How important is the impact of the organism on biodiversity at all levels of organisation (e.g. decline in native species, changes in native species communities, hybridisation) currently in the different biogeographical regions or marine sub-regions where the species has established in Europe (include any past impact in your response)?	N/A	medium	The species has not yet established in the assessment area.
2.20. How important is the impact of the organism on biodiversity at all levels of organisation likely to be in the future in the different biogeographical regions or marine sub-regions where the species can establish in Europe?	major	medium	Considering the impacts already exerted by zebra mussel in the invaded European range and the impacts already reported by golden mussel in South America, we can expect similar impacts in Europe on biodiversity and ecosystem services.
2.21. How important is decline in conservation value with regard to European and national nature conservation legislation caused by the organism currently in Europe?	N/A	medium	The species has not yet established in the assessment area.
2.22. How important is decline in conservation value with regard to European and national nature conservation legislation caused by the organism likely to be in the future in Europe?	major	medium	Golden mussel can outcompete threatened molluscs (e.g. *Unio* and *Margaritifera* spp. as well as other invertebrates; it can transmit parasites to fish. It can colonize different habitats, also the protected and endangered ones (Boltovskoy 2015) (e.g. Habitat 3150: Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition* - type vegetation; Habitat 3250: Constantly flowing Mediterranean rivers with *Glaucium flavum*; Habitat 3260: Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* Vegetation; Habitat 3280: Constantly flowing Mediterranean rivers with *Paspalo-Agrostidion* species and hanging curtains of *Salix* and *Populus alba*). With its impact, it has the potential to affect the

			ecological status of water bodies according to Water Framework Directive 2000.
Ecosystem Services impacts			
2.23 How important is the impact of the organism on provisioning, regulating, and cultural services in its non-native range excluding the Union?	major	low	It is a biofouler, and has the ability to disturb nutrient cycles through its filtering activity (Boltovskoy et al. 2015b). It could change provisioning and regulating services, particularly water quality. Cyanobacterial blooms are enhanced, leading to possible problems of toxins in potable water (Cataldo et al. 2012): in mesocosms with mussels, *Microcystis* spp. numbers soared to 200,000 cells/ml with mussels, and *Microcystis* colonies increased. However, high concentration of toxic *Microcystis* can inhibit recruitment of golden mussel (Boltovskoy et al. 2013).
2.24. How important is the impact of the organism on provisioning, regulating, and cultural services currently in the different biogeographical regions or marine sub-regions where the species has established in Europe (include any past impact in your response)?	N/A	medium	The species has not yet established in the assessment area.
2.25. How important is the impact of the organism on provisioning, regulating, and cultural services likely to be in the different biogeographical regions or marine sub-regions where the species can establish in Europe in the future?	major	low	See the comment for Q 2.23
Economic impacts			
2.26. How great is the overall economic cost caused by the organism within its current area of distribution, including both costs of damage and the cost of current management	major	low	Being a fouler organism, it can clog/foul water intake sieves and filters, pipes, heat exchangers, and condensers; it has become a common difficulty in industrial and power plants that use raw water, chiefly for cooling purposes (Mata 2011; Boltovskoy 2015). In China, over 1 million USD $ per year are reported for maintenance and cleaning tasks of two water diversion works (Boltovskoy et al. 2015c).

2.27. How great is the economic cost of damage* of the organism currently in the Union (include any past costs in your response)? *i.e. excluding costs of management	N/A	medium	The species has not yet established in the assessment area.
2.28. How great is the economic cost of damage* of the organism likely to be in the future in the Union? *i.e. excluding costs of management	major	low	No information has been found on the issue, but it is likely that we can hypothesize similar costs to those ones caused by zebra mussel can occur. The costs include the awareness campaigns (e.g. check/clean and dry), the damages to hydropower plants, and all the artificial structures in the water; the contamination of food for markets and also costs of blockage to irrigation systems.
2.29. How great are the economic costs associated with managing this organism currently in the Union (include any past costs in your response)?	N/A	medium	
2.30. How great are the economic costs associated with managing this organism likely to be in the future in the Union?	major	low	No information has been found on the issue, but it is likely that similar costs to those ones caused by zebra mussel management can occur (Kettunen et al. 2009). The cost to Great Lakes' utilities to control zebra mussels in water intake pipes from 1989 to 2004 was 267 million US Dollars (www. Seagrant.wisc.edu).
Social and human health impacts			
2.31. How important is social, human health or other impact (not directly included in any earlier categories) caused by the organism for the Union and for third countries, if relevant (e.g. with similar eco-climatic conditions).	N/A	medium	The species has not yet established in the assessment area.
2.32. How important is social, human health or other impact (not directly included in any earlier categories) caused by the organism in the future for the Union.	minor	low	No information has been found on the issue. Potential impact related to toxic cyanobacterial blooms (see comment for Q. 2.23) and increased biosecurity measures.

Other impacts			
2.33. How important is the impact of the organism as food, a host, a symbiont or a vector for other damaging organisms (e.g. diseases)?	minor	low	It can transmit parasites to fish and affect their population, decreasing their fitness and survival (Ito 2015).
2.34. How important might other impacts not already covered by previous questions be resulting from introduction of the organism? (specify in the comment box)	N/A	medium	
2.35. How important are the expected impacts of the organism despite any natural control by other organisms, such as predators, parasites or pathogens that may already be present in Europe?	major	medium	Fish can prey on golden mussel and can switch their diet as the species becomes more available (Cataldo 2015). Considering the predators of zebra mussel, it is likely that aquatic birds, mammals and crustaceans can prey on adults and larvae, even if no studies have quantified their predation rate (Boltovsky 2015). Predators could decrease the population abundance, but not eradicate the species.
2.36. Indicate any parts of Europe where any of the above impacts are particularly likely to occur (provide as much detail as possible).	Southern Europe; please see the map below	medium	Southern Europe has been indicated as the most suitable for the species (Campos et al. 2014) and we can expect major impacts there.



Potential distribution of *L fortunei*, with records of presence from South America and Asia, generated MAXENT. Yellow and red are most likely areas for establishment of *Limnoperna* (Campos et al. 2014)

RISK SUMMARIES			
	RESPONSE	**CONFIDENCE**	**COMMENT**
Summarise Entry	likely	medium	Introduction via ballast waters is most likely pathway. Although the introduction via the other pathways are less likely, the possibility still exists.
Summarise Establishment	likely	medium	The species can establish under the current conditions in Europe, particularly in Southern Europe.
Summarise Spread	rapidly	medium	This species is tolerant to a wide range of conditions and can be unintentionally spread by several vectors (Boltovsky 2015). Previous models forecasted suitability for almost parts of Europe, particularly South Europe (Campos et al. 2014; Boltovsky 2015).
Summarise Impact	major	medium	The species can exert several impacts on biodiversity and ecosystem services as well as on economic activities. Moreover, being a highly adaptable species, it is likely that heavy and widespread impacts can occur.
Conclusion of the risk assessment	high	medium	The species is very similar to zebra mussel for biology and impacts (even more adaptable in term of climatic conditions). Europe is already experiencing the impacts of zebra mussel. Thus, even if confidence in the conclusion is limited due to transferability of data (the invaded area external to EU is limited), available evidence and its similarity to zebra mussel suggest that this species can pose a serious risk to biodiversity in the EU.

ADDITIONAL QUESTIONS - CLIMATE CHANGE			
3.1. What aspects of climate change, if any, are most likely to affect the risk assessment for this organism?	Temperature	medium	The species prefers higher temperatures that can currently occur in some parts of Europe; so we can expect an enhanced invasiveness with climate change.
3.2. What is the likely timeframe for such changes?	10 years	medium	Current rates of increasing temperature indicate this timeframe as likely.
3.3. What aspects of the risk assessment are most likely to change as a result of climate change?	establishment, spread and impacts	medium	See comment for Q3.1, and Q2.1
ADDITIONAL QUESTIONS - RESEARCH			
4.1. If there is any research that would significantly strengthen confidence in the risk assessment please summarise this here.	- More data from ecological studies - Impacts on ecosystem services - Potential predators - Economic impacts - Management	medium	More information on the mentioned issues will increase the confidence of the risk assessment.

REFERENCES:

Boltovskoy D (ed) (2015) *Limnoperna fortunei*, The ecology, distribution and control of a swiftly spreading invasive fouling mussel. Invading Nature - Springer International Publishing Switzerland - Springer Series in Invasion Ecology Volume 10, 476 pp, https://doi.org/10.1007/978-3-319-13494-9

Boltovskoy D, Cataldo D, Sylvester F (2006) Dispersion and ecological impact of the invasive freshwater bivalve *Limnoperna fortunei* in the Río de la Plata watershed and beyond. *Biological Invasions* 8: 947–963, https://doi.org/10.1007/s10530-005-5107-z

Boltovskoy D, Morton B, Correa N, Cataldo D, Damborenea C, Penchaszadeh PE, Sylvester F (2015a) Reproductive output and seasonality of *Limnoperna fortunei*. In: Boltovskoy D (ed), *Limnoperna fortunei*: the ecology, distribution and control of a swiftly spreading invasive fouling mussel, Springer International Publishing, Cham (Switzerland), pp 67–103, https://doi.org/10.1007/978-3-319-13494-9_5

Boltovskoy D, Correa N, Sylvester F, Cataldo D (2015b) Nutrient recycling phytoplankton grazing and associated impacts of *Limnoperna fortunei*. In: Boltovskoy D (ed), *Limnoperna fortunei*: the ecology, distribution and control of a swiftly spreading invasive fouling mussel, Springer International Publishing, Cham (Switzerland), pp 153–176

Boltovskoy D, Xu M, Nakano D (2015c) Impacts of *Limnoperna fortunei* on man-made structures and control strategies: general overview. In: Boltovskoy D (ed), *Limnoperna fortunei*: the ecology, distribution and control of a swiftly spreading invasive fouling mussel, Springer International Publishing, Cham (Switzerland), pp 375–393

Boltovskoy D, Correa N, Bordet F, Leites V, Cataldo D (2013) Toxic *Microcystis* (cyanobacteria) inhibit recruitment of the bloom-enhancing invasive bivalve *Limnoperna fortunei*. *Freshwater Biology* 58: 1968-1981

Brugnoli E, Dabezies MJ, Clemente JM, Muniz P (2011) *Limnoperna fortunei* (Dunker 1857) en el sistema de embalses del Rio Negro, Uruguay. *Oecologia Australis* 15: 576–592

Campos MCS, Andrade FA de, Kunzmann B, Galvão DD, Silva FA, Cardoso AV, Carvalho MD, Mota HR (2014) Modelling of the potential distribution of *Limnoperna fortunei* (Dunker, 1857) on a global scale. *Aquatic Invasions* 9: 253–265, https://doi.org/10.3391/ai.2014.9.3.03

Cataldo DH (2015) Trophic relationships of *Limnoperna fortunei* with adult fishes. In: Boltovskoy D (ed), *Limnoperna fortunei*: the ecology, distribution and control of a swiftly spreading invasive fouling mussel, Springer International Publishing, Cham (Switzerland), pp 231-245

Cataldo DH, Boltovskoy D (2000) Yearly reproductive activity of *Limnoperna fortunei* (Bivalvia) as inferred from the occurrence of its larvae in the plankton of the lower Paraña River and the Río de la Plata estuary (Argentina). *Aquatic Ecology* 34: 307–317, https://doi.org/10.1023/A:1009983920942

Cataldo DH, Boltovskoy D, Hermosa JL, Canzi C (2005) Temperature-dependent larval development rates of *Limnoperna fortunei* (Bivalvia: Mytilidae). *Journal of Molluscan Studies* 71: 41-46

Cataldo C, Vinocur A, o' Farrell I, Paolucci E, Leites V, Boltovskoy D (2012) The introduced bivalve *Limnoperna fortunei* boosts Microcystis growth in Salto Grande reservoir (Argentina): evidence from mesocosm experiments. *Hydrobiologia* 680: 25-38.

Cianfanelli S, Lori E, Bodon M (2007) Alien freshwater molluscs in Italy and their distribution. In Gherardi F (ed), Biological invaders in inland waters: profiles, distribution, and threats. Springer, Dordrecht, The Netherlands, pp 103-121

Correa N, Sardiña P, Perepelizin PV, Boltovskoy D (2015). *Limnoperna fortunei* colonies: structures, distribution and dynamics. In: Boltovskoy D (ed), *Limnoperna fortunei*: the ecology, distribution and control of a swiftly spreading invasive fouling mussel, Springer International Publishing, Cham (Switzerland), pp 119-143

Crosier DM, Molloy DP, Ricciardi A, Boeger WG (2007). *Limnoperna fortunei* – Golden mussel. Available: http://el.erdc.usace.army.mil/ansrp/ANSIS/html/limnoperna_fotunei_golden_mussel.htm

Darrigran G (2002) Potential impact of filter-feeding invaders on temperate inland freshwater. *Biological Invasions* 4: 145–156, https://doi.org/10.1023/A:1020521811416

Darrigran G, Maronas M, Colautti, DC (2004) Air exposure as a control mechanism for the golden mussel, *Limnoperna fortunei* (Bivalvia: Mytilidae). *Journal of Freshwater Ecology* 19(3): 461-464

Darrigran G, Damborenea MC, Edmundo C, Ezcurra de Drago DI, Paira A (2011) Environmental factors restrict the invasion process of *Limnoperna fortunei* (Mytilidae) in the Neotropical region: A case study from the Andean tributaries. *Annals of Limnology International Journal of Limnology* 47:221–229

Darrigran G, Damborenea MC, Drago EC, Ezcurra de Drago DI, Paira A, Archuby F (2012) Invasion process of *Limnoperna fortunei* (Bivalvia: Mytilidae): The case of Uruguay River and emissaries of the Esteros del Iberá Wetland, Argentina. *Zoologia* 29: 531–539, https://doi.org/10.1590/S1984-46702012000600004

Dunker W (1856) Mytilacea nova collectionis Cumingianae. *Proceedings of Zoological Society London* 24:358-366

GLANSIS (Great Lakes Aquatic Nonindigenous Species Information System) (2015) *Limnoperna fortunei* USGS Nonindigenous Aquatic Species Database, Gainesville, FL, and NOAA Great Lakes Aquatic Nonindigenous Species Information System, Ann Arbor, MI

Ito K (2015) Colonization and spread of *Limnoperna fortunei* in Japan. In: Boltovskoy D (ed), *Limnoperna fortunei*: the ecology, distribution and control of a swiftly spreading invasive fouling mussel, Springer International Publishing, Cham (Switzerland), pp 321–332, https://doi.org/10.1007/978-3-319-13494-9_18

Karatayev A, Boltovskoy D, Burlakova L, Padilla L (2015) Parallels and contrasts between *Limnoperna fortunei* and species of *Dreissena*. In: Boltovskoy D (ed), *Limnoperna fortunei* The ecology, distribution and control of a swiftly spreading invasive fouling mussel. Invading Nature – Springer Series in Invasion Ecology, pp 261–297, https://doi.org/10.1007/978-3-319-13494-9_15

Lucy FE, Sullivan M, Minchin D (2005) Nutrient levels and the zebra mussel population in Lough Key. ERTDI Report Series No. 34. EPA, Wexford. www.epa.ie

Lucy FE, Minchin D, Boelens R (2008) From lakes to rivers: downstream larval distribution of *Dreissena polymorpha* in Irish river basins. *Aquatic Invasions* 3: 297-304

Mackie GL, Brinsmead JK (2017) A risk assessment of the golden mussel *Limnoperna fortunei* (Dunker 1857) for Ontario, Canada. Management of Biological Invasions 8: 383-402

Mata FAR (2011) Abundância e distribução temporal de *Limnoperna fortunei* Dunker, 1857 (Mollusca, Bivalvia) e os impactos da incrustação em usinas geradoras de enegia elétrica. MSc Thesis, Universidade Federal de Oura Preto (Brazil), pp 1-91

Minchin D, Lucy F, Sullivan M (2002) Zebra mussel: Impacts and Spread. In: Leppakoski E, Gollasch S, Olenin S (eds) Invasive Aquatic Species of Europe: Distribution, Impacts and Spread. Kluwer Press, Dordrecht, pp 135-146

Montalto L, Ezcurra de Drago I (2003) Tolerance to desiccation of an invasive mussel, *Limnoperna fortunei* (Dunker, 1857) (Bivalvia, Mytilidae), under experimental conditions. *Hydrobiologia* 498: 161–167, https://doi.org/10.1023/A:1026222414881

Nakano D, Baba T, Endo N, Nagayama S, Fujinaga A, Uchida A, Shiragane A, Urabe M, Kobayashi T (2014) Invasion, dispersion, population persistence and ecological impacts of a freshwater mussel (*Limnoperna fortunei*) in the Honshu Island of Japan. *Biological Invasions* 17: 1743–1759, https://doi.org/10.1007/s10530-014-0765-3

Nakano D, Kobayashi T, Sakaguchi I (2010a) Difference in larval dynamics of golden mussel *Limnoperna fortunei* between dam reservoirs with and without an aeration system. *Landscape and Ecological Engineering* 6: 53–60, https://doi.org/10.1007/s11355-009-0082-7

Nakano D, Kobayashi T, Sakaguchi I (2010b) Predation and depth effects on abundance and size distribution of an invasive bivalve, the golden mussel *Limnoperna fortunei*, in a dam reservoir. *Limnology* 11: 259–266, https://doi.org/10.1007/s10201-010-0314-4

Nakano D, Kobayashi T, Endo N, Sakaguchi I (2011) Growth rate and settlement of *Limnoperna fortunei* in a temperate reservoir. *Journal of Molluscan Studies* 7: 142–148, https://doi.org/10.1093/mollus/eyq048

Oliveira MD, Hamilton SK, Calheiros DF, Jacobi CM, Latini RO (2010a) Modeling the potential distribution of the invasive golden mussel *Limnoperna fortunei* in the Upper Paraguay River system using limnological variables. *Brazilian Journal of Biology* 70: 831–840, https://doi.org/10.1590/S1519-69842010000400014

Oliveira MD, Hamilton SK, Jacobi CM (2010b) Forecasting the expansion of the invasive golden mussel *Limnoperna fortunei* in Brazilian and North American rivers based on its occurrence in the Paraguay River and Pantanal wetland of Brazil. *Aquatic Invasions* 5: 59–73, https://doi.org/10.3391/ai.2010.5.1.8

Oliveira MD, Campos MCS, Paolucci EM, Mansur MCD, Hamilton SK (2015) Colonization and spread of *Limnoperna fortunei* in South America. In: Boltovskoy D (ed), *Limnoperna fortunei*: the ecology, distribution and control of a swiftly spreading invasive fouling mussel. Springer International Publishing, Cham (Switzerland), pp 333–355, https://doi.org/10.1007/978-3-319-13494-9_19

Quaglia F, Lattuada L, Mantecca P, Bacchetta R (2008) Zebra mussels in Italy: where do they come from? *Biological Invasions* 10: 555-560

Rojas Molina F, de Paggi SBJ, Paggi JC (2015) Impacts of *Limnoperna fortunei* on zooplankton. In: Boltovskoy D (ed), *Limnoperna fortunei*: the ecology, distribution and control of a swiftly spreading invasive fouling mussel. Springer International Publishing, Cham (Switzerland), pp 177–190

Sylvester F, Cataldo DH, Notaro C, Boltovskoy D (2013) Fluctuating salinity improves survival of the invasive freshwater golden mussel at high salinity: implications for the introduction of aquatic species through estuarine ports. *Biological Invasions* 15: 1355–1366, https://doi.org/10.1007/s10530-012-0373-z

Sylvester F, Sardina P (2015) Relationships of *Limnoperna fortunei* with benthic animals. In: Boltovskoy D (ed), *Limnoperna fortunei*: the ecology, distribution and control of a swiftly spreading invasive fouling mussel. Springer International Publishing, Cham (Switzerland), pp 333–355, https://doi.org/10.1007/978-3-319-13494-9_19

Uliano-Silva M, Américo JA, Brindeiro R, Dondero F, Prosdocimi F, Rebelo MF (2015). The genetics of the golden mussel (*Limnoperna fortunei*): are genes related to invasiveness? In: Boltovskoy D (ed), *Limnoperna fortunei*: the ecology, distribution and control of a swiftly spreading invasive fouling mussel. Springer International Publishing, Cham (Switzerland), pp 67–75

U.S. Fish and Wildlife Service (2014) Golden mussel (*Limnoperna fortunei*) ecological risk screening summary. https://www.fws.gov/injuriouswildlife/pdf_files/Limnoperna_fortunei_WEB-7-24-2014.pdf

Tokumon R, Cataldo D, Boltovskoy D (2015) Effects of suspended inorganic matter on filtration and grazing rates of the invasive mussel *Limnoperna fortunei* (Bivalvia, Mytiloidea). *Journal of Molluscan Studies* 82: 201–204

bij de Vaate, Abraham & Van der Velde, Gerard & Leuven, Rob S.E.W. & Heiler, K.C.M.. (2013). Spread of the Quagga Mussel (*Dreissena rostriformis bugensis*) in Western Europe. Quagga and Zebra Mussels: Biology. 83-92. 10.1201/b15437-11.

Xu M, (2015) Distribution and spread of *Limnoperna fortunei* in China. In: Boltovskoy D (ed), *Limnoperna fortunei*: the ecology, distribution and control of a swiftly spreading invasive fouling mussel. Springer International Publishing, Cham (Switzerland), pp 313–320

ANNEX I Scoring of Likelihoods of Events

(taken from UK Non-native Organism Risk Assessment Scheme User Manual, Version 3.3, 28.02.2005)

Score	Description	Frequency
Very unlikely	This sort of event is theoretically possible, but is never known to have occurred and is not expected to occur	1 in 10,000 years
Unlikely	This sort of event has not occurred anywhere in living memory	1 in 1,000 years
Possible	This sort of event has occurred somewhere at least once in recent years, but not locally	1 in 100 years
Likely	This sort of event has happened on several occasions elsewhere, or on at least one occasion locally in recent years	1 in 10 years
Very likely	This sort of event happens continually and would be expected to occur	Once a year

ANNEX II Scoring of Magnitude of Impacts

(modified from UK Non-native Organism Risk Assessment Scheme User Manual, Version 3.3, 28.02.2005)

Score	**Biodiversity and ecosystem impact**	**Ecosystem Services impact**	**Economic impact (Monetary loss and response costs per year)**	**Social and human health impact**
	Question 2.18-22	*Question 2.23-25*	*Question 2.26-30*	*Question 2.31-32*
Minimal	Local, short-term population loss, no significant ecosystem effect	No services affected[1]	Up to 10,000 Euro	No social disruption. Local, mild, short-term reversible effects to individuals.
Minor	Some ecosystem impact, reversible changes, localised	Local and temporary, reversible effects to one or few services	10,000-100,000 Euro	Significant concern expressed at local level. Mild short-term reversible effects to identifiable groups, localised.
Moderate	Measureable long-term damage to populations and ecosystem, but little spread, no extinction	Measureable, temporary, local and reversible effects on one or several services	100,000-1,000,000 Euro	Temporary changes to normal activities at local level. Minor irreversible effects and/or larger numbers covered by reversible effects, localised.
Major	Long-term irreversible ecosystem change, spreading beyond local area	Local and irreversible or widespread and reversible effects on one / several services	1,000,000-10,000,000 Euro	Some permanent change of activity locally, concern expressed over wider area. Significant irreversible effects locally or reversible effects over large area.
Massive	Widespread, long-term population loss or extinction, affecting several species with serious ecosystem effects	Widespread and irreversible effects on one / several services	Above 10,000,000 Euro	Long-term social change, significant loss of employment, migration from affected area. Widespread, severe, long-term, irreversible health effects.

[1] Not to be confused with „no impact“.

ANNEX III Scoring of Confidence Levels

(modified from Bacher et al. 2017)

Confidence level	Description
Low	There is no direct observational evidence to support the assessment, e.g. only inferred data have been used as supporting evidence *and/or* Impacts are recorded at a spatial scale which is unlikely to be relevant to the assessment area *and/or* Evidence is poor and difficult to interpret, e.g. because it is strongly ambiguous *and/or* The information sources are considered to be of low quality or contain information that is unreliable.
Medium	There is some direct observational evidence to support the assessment, but some information is inferred *and/or* Impacts are recorded at a small spatial scale, but rescaling of the data to relevant scales of the assessment area is considered reliable, or to embrace little uncertainty *and/or* The interpretation of the data is to some extent ambiguous or contradictory.
High	There is direct relevant observational evidence to support the assessment (including causality) *and* Impacts are recorded at a comparable scale *and/or* There are reliable/good quality data sources on impacts of the taxa *and* The interpretation of data/information is straightforward *and/or* Data/information are not controversial or contradictory.
Very high	There is direct relevant observational evidence to support the assessment (including causality) from the risk assessment area *and* Impacts are recorded at a comparable scale *and* There are reliable/good quality data sources on impacts of the taxa *and* The interpretation of data/information is straightforward *and* Data/information are not controversial or contradictory.