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 6: Risk Assessment for *Faxonius rusticus* (Girard, 1852)

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: *Faxonius rusticus* (Girard, 1852) (rusty crayfish) Synomym: *Orconectes rusticus, Cambarus rusticus*

Author(s) of the assessment:
Paul Stebbing, CEFAS, Weymouth, UK
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: Christoph Chucholl, Eco Surv, Bad Schussenried, Germany
Peer review 2: Frances Lucy, CERIS, Institute of Technology, Sligo, Ireland
Peer review 3: Robert Tanner, European and Mediterranean Plant Protection Organization (EPPO/OEPP), Paris, France

This risk assessment has been peer-reviewed by three 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: 17/11/2017

RISK SUMMARIES			
	RESPONSE	**CONFIDENCE**	**COMMENT**
Summarise Entry	likely	high	The species is already in the ornamental trade in Europe (Chucholl 2013; Mrugala et al. 2015), but has not yet been found in the wild. Specimens could be released by people into the wild.
Summarise Establishment	likely	high	The species is an adaptable species and can live in a variety of habitats as already showed by its invasion history in North America (Philips 2010; Conard et al. 2015).
Summarise Spread	rapidly	high	The species has a high dispersal capability and can spread both unaided and facilitated by humans (Conard et al. 2015).
Summarise Impact	major	high	The species is considered one of the most invasive crayfish where introduced (Lodge et al. 2012). Its negative impact can be highly relevant in Europe.
Conclusion of the risk assessment	high	high	Based on the evidence from the literature and the presence of congeneric in Europe, the species could pose a high risk to the European ecosystems.

Distribution Summary (for explanations see EU chapeau and Annex IV):

Member States

	Recorded	Established (currently)	Established (future)	Invasive (currently)
Austria	-	-	Yes	-
Belgium	-	-	Yes	-
Bulgaria	-	-	Yes	-
Croatia	-	-	Yes	-
Cyprus	-	-	-	-
Czech Republic	-	-	Yes	-
Denmark	-	-	?	-
Estonia	-	-	Yes	-
Finland	-	-	?	-

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	-	-	?	-
United Kingdom	-	-	Yes	-

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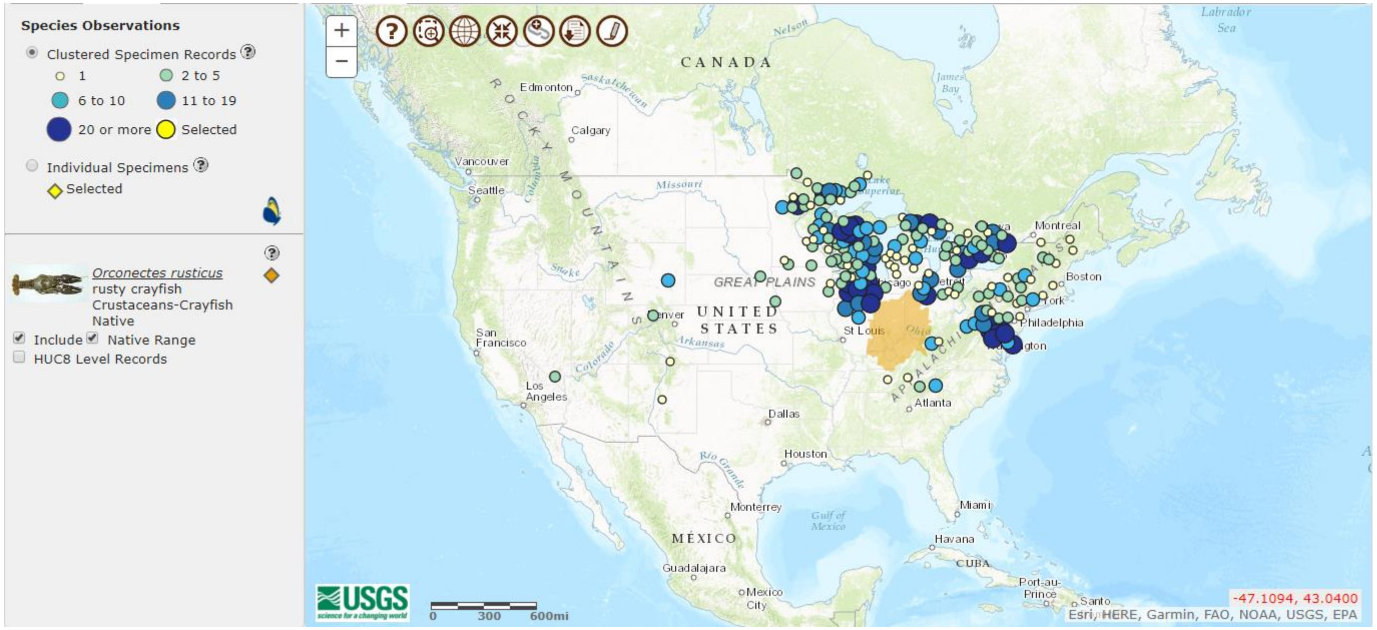
EU biogeographical regions

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

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	The Crayfish Atlas (Souty-Grosset et al. 2006) referred to *F. rusticus* for specimens found in France, but morphological analyses and DNA barcoding revealed they belong to *F. juvenilis* (Chucholl & Daudey 2008; Filipová et al. 2011).
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: Atlantic, Mediterranean and Continental sub-regions. Future climate: Atlantic, Mediterranean and Continental sub-regions.	The classification is based on EEA (2016). Range is hypothesized based on native and introduced distribution in North America, and its temperature tolerance. Information based on modelling conducted by Daniel Chapman at CEH, unpublished data.
Ch3. In which EU member states has the species been recorded? List them with an indication of the timeline of observations.	None	See response to 1.
Ch4. In which EU member states has this species established populations? List them with an indication of the timeline of establishment and spread.	None	See response to 1.
Ch5. In which EU member states could the species establish in the future under current climate and under foreseeable climate change?	Current climate: North, Central and most of South Europe Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland (lower part), France, Germany, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Poland, Romania, Slovakia, Slovenia, Spain, Sweden (lower part) and UK Future climate: North and Central Europe	The species is native to Ohio river basin (US). It has been introduced in 22 states (also in Colorado and New Mexico) and in the Great Lakes. It is generally tolerant of thermal extremes, exposed to water in their native habitats ranging from near 0°C to 39°C (Mundahl & Benton 1990). However, the preferred range is between 20 and 25°C, and the authors suggest that this often results in adults forcing juveniles from preferred habitats into warmer waters causing the latter to be found in

	Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Ireland, Latvia, Lithuania, Luxembourg, Netherlands, Poland, Romania, Slovakia, Slovenia, Sweden and UK Current and future modelling was conducted by Daniel Chapman (CEH), unpublished data.	water 1.5 to 6.8°C warmer than adults. At temperatures exceeding 30°C adults have been observed burrowing in sand and gravel beneath rocks near the shore to escape the heat (Mundahl 1989).
Ch6. In which EU member states has this species shown signs of invasiveness?	None	See response to 1.
Ch7. In which EU member states could this species become invasive in the future under current climate and under foreseeable climate change?	Current climate: Northern, Central and part of Southern states of Europe Future climate: Northern and Central states of Europe	The species is classified as invasive in almost all the states where it was introduced (Lodge et al. 2012). It was also listed among the species with the highest potential invasiveness according to the FI-ISK analysis (Tricarico et al. 2010). Information based on modelling conducted by Daniel Chapman at CEH, unpublished data.



Map updated Thu Aug 03 2017, USGS

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?	Yes it is. *Faxonius rusticus* (Girard, 1852) (Malacostraca, Decapoda, Cambaridae) Synomym: *Orconectes rusticus*, *Cambarus rusticus* Common name: rusty crayfish It can hybridize with *Faxonius propinquus*.	The species is reported to hybridize with *F. propinquus* in the Great Lakes and their offspring are fertile (Lodge et al. 2012). There is a strong possibility that the species may therefore hybridise with other congeneric species, but not with native European crayfish.
A2. Provide information on the existence of other species that look very similar	*Faxonius juvenilis*, already reported in EU (France), that was misidentified as *F. rusticus* (Kouba et al. 2014) *Faxonius limosus*, already present in EU, particularly invasive in France, Germany, Holland, Switzerland, Czech Republic, Poland and Lithuania (Kouba et al. 2014). *Faxonius immunis* and *virilis*, already reported in EU (the first in Germany and France, the second in Netherlands and UK; Kouba et al. 2014).	No native species in EU that can be misidentified as this species. Other congeneric species are already present in the EU but can be easily distinguished based on morphological and colour characters (Souty-Grosset et al. 2006; Kouba et al. 2014). *F. rusticus* has brownish-green body with dark, rusty-red spots on either side of carapace, a dark brown section on dorsal abdomen, and large chelae with an oval gap when closed. The dactyl is smooth and S-shaped; the tips of chelae are red with black bands.
A3. Does a relevant earlier risk assessment exist? (give details of any previous risk assessment and its validity in relation to the EU)	Yes, entry was considered likely, establishment very likely, spread rapid, and impact as major.	RA by GB-NNSS (2015); FI-ISK (Tricarico et al. 2010) for Europe; in US, Sorensen (2010) and Conard et al. (2015).
A4. Where is the organism native?	North America (Ohio river basin)	In the US, the species is native to Ohio river basin, spanning tributaries in Western Ohio, Indiana,

		Kentucky, and Northern Tennessee, and inhabiting streams, ponds and lakes with varying substrates from silt to rock and plenty of debris for cover. It can colonize slower, deeper pools with aquatic macrophytes as well as shallow fast water of streams (Hamr 2002). It needs permanent water, and it is generally considered a tertiary burrower (i.e. building burrow only for reproduction or to escape extreme conditions (Thoma 2015)). Indeed, immediately following copulation, female *F. rusticus* construct horizontal burrows in the banks near the water line (Crocker and Barr 1968).
A5. What is the global non-native distribution of the organism (excluding the Union, but including neighbouring European (non-Union) countries)?	The species has only been introduced within North America.	It has been found in 22 states beyond its native range spanning the entire US, including Colorado, Connecticut (Titicus River), Illinois (Illinois River at Peoria and Peoria Lake), Indiana (upper West Fork White River near Muncie; it is dominant in tributaries extending from the Ohio state line west to Indianapolis, including Whitewater and Maumee River basins), Iowa, Maine (Adroscoggin and Kennebec drainages), Maryland (Conowingo Creek, Cecil County; upper portion of Monocacy River, Frederick County), Massachusetts, Michigan, Minnesota (Carlton, Cook, Itasca, Lake, Pine, and St. Louis counties), Nebraska (Lakeside Lake, Omaha, Douglas County), New Hampshire, New Jersey, New Mexico, New York (Hudson River drainage; Mohawk watershed; Otsego Lake), North Carolina, Oregon (Dixon Creek, Benton County; John Day River, Grant County), Pennsylvania, Vermont, West Virginia (Kanawha River), Wisconsin (Amnicon River, Big Lake, Villas County), and Wyoming (eradicated after found to have been illegally stocked) (Philips 2010; Conard et al. 2015). It was introduced also

		in Canada (Philips 2010).
A6. Is the organism known to be invasive (i.e. to threaten organisms, habitats or ecosystems) anywhere in the world?	Yes	It is one of the most invasive crayfish where it has been introduced in US (Lodge et al. 2012), affecting local biodiversity and ecosystems by its predatory and omnivorous habit (on aquatic plants, macroinvertebrates, fish eggs) and competitiveness. It can potentially transmit crayfish plague, lethal for native European crayfish. It can hybridize with native *F. propinquus* in the great Lakes (Lodge et al. 2012). Its impact on fish can affect fisheries.
A7. Describe any known socio-economic benefits of the organism in the risk assessment area.	The species is present in the aquarium trade within Europe, but in very small numbers (but one female carrying viable sperm could begin a new population if introduced into a suitable environment; Conard et al. 2015), making the assessment of any socio-economic benefit induced by the species very difficult. It could have a moderate value as an aquarium species, amongst other potential uses; however, its negative impacts overcome this potential benefit, being one of the most invasive crayfish where it has been introduced (Lodge et al. 2002).	In US, the species may have value as a recreational bait species in the Great Lakes and is commonly sold to schools and biological supply houses. It has also a commercial value as aquaculture species. It has been intentionally introduced in some lakes to remove nuisance weeds, with positive effect in many northern Wisconsin lakes (Hamr 2002; Philips 2010; Conard et al. 2015). In Europe, it could have a moderate value as an aquarium species (less as food), even if not too much due to its rather unappealing coloration compared to other alien crayfish (Chucholl & Wendler 2017). It could also have the potential to be promoted as a weed control species.

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)	very few	medium	The species has spread within North America through many pathways. However, we can only hypothesize the main pathways for the species entry into Europe based on the introduction history of other alien crayfish already present.
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) Escape from confinement (Live food and live bait)		In North America, the species has been introduced as live bait for anglers or for commercial purposes, as species to be used in schools and biological supply houses, and as biocontrol for aquatic weeds (Hamr

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) Escape from confinement (Pet/aquarium/terrarium species)		2002; Conard et al. 2015). In Europe, the species could be introduced as food/bait. *F. juvenilis,* which was misidentified with *F. rusticus* was introduced into France probably for the food trade (Chucholl & Daudey 2008). In the past almost all the alien crayfish currently present in Europe were intentionally introduced for live food and aquaculture or as ornamental species (it has already been reported in the trade of ornamental crayfish in Europe; Mrugala et al. 2015).
Pathway name:	**Escape from confinement (Live food and live bait)**		
1.3a. 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)	intentional	very high	This pathway is assessed as intentional release of the species, either with the intention of establishing populations for future harvest for food, or deliberate use of the species as live bait for angling purposes. The deliberate importation and release of non-native crayfish species for the purpose of establishing populations for harvest is recognized as a pathway of introduction and spread (for examples see Souty-Grosset et al. 2006). Likewise, the use of non-native crayfish as bait is equally well documented by the same authors. The use of the word escape in the pathway description is therefore a misnomer.Only questions 1.4, 1.9, 1.10 and 1.11 are, therefore, answered.
1.4a. 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.	moderately likely	medium	Introduction of crayfish as food and bait in Europe has decreased in importance through the years, although it still continues in some areas, so we can expect a low number of introduction for this purpose (two confirmed introductions of other alien crayfish for this purpose in the last 20 years in France and Germany, *F. juvenilis* and *F. immunis*, respectively; Kouba et al. 2014). Seeding of new populations of other invasive alien crayfish, such as the

			signal crayfish *Pacifastacus leniusculus*, for the purposes of establishing new populations for human consumption is still considered the main cause of spread in the UK (Martin James, pers. coms). However, this is the movement of animals from populations already established. In this case, we are considering the introduction of a new species of crayfish for this purpose. Therefore, we only consider it to be moderately likely to occur. The most recent introductions of alien crayfish have been mainly for ornamental purposes (see below). Sourcing of animals for this purpose will have to be from North America, possibly via the ornamental trade, such as via reported online trade within Europe. We can hypothesize between 50 and 100 crayfish per introduction, even if no data are available.
1.5a. 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.	N/A	N/A	
1.6a. How likely is the organism to survive existing management practices during passage along the pathway?			
1.7a. How likely is the organism to enter Europe undetected?			
1.8a. How likely is the organism to arrive during the months of the year most appropriate for establishment?			
1.9a. How likely is the organism to be able to transfer from the pathway to a suitable habitat or host?	very likely	very high	When introduced as food or bait the species can be stocked in ponds and from there escape into streams and rivers, as happened for *F. juvenilis* (Chucholl & Daudey

			2008) or *F. immunis* (Kouba et al. 2014). The rusty crayfish *F. rusticus* shows a high degree of plasticity and therefore one female carrying viable (stored) sperm could begin a new population if introduced into a suitable environment (Conard et al. 2015).
1.10a. Estimate the overall likelihood of entry into Europe based on this pathway?	moderately likely	low	Considering the comment on Q1.4, the overall likelihood is moderately likely, but the confidence is only low due to a lack of information. Given the abundance of other invasive alien crayfish species within Europe suitable for human consumption and/or bait, there is no specific reasons why someone would decide to intentionally introduce yet another species, especially given the trouble in actually sourcing animals from North America, importing them and then releasing them into a likely location for establishment.
Pathway name:	**Escape from confinement (Pet/aquarium/terrarium species)**		
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)	intentional	very high	For the purpose of this pathway we are considering the intentional release of the species from the aquarium trade. This has been observed for other crayfish species, when animals have reproduced or grown too large for tanks, and owners have released the animals rather than destroy them. As the importation and then subsequent release of the animals are deliberate then the word escape in the pathway description is a misnomer. Therefore, only questions 1.4, 1.9, 1.10 and 1.11 are answered.
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.	moderately likely	medium	Very few European Member States have legislation to regulate trade of crayfish, and the species is already present in the ornamental trade in Europe since 2009 (Chucholl 2013; Mrugala et al. 2015). However, numbers may be low for the less appealing colour compared to other alien crayfish (Chucoll & Wendler 2017). Thus, although we can expect new individuals available for this purpose from the US, it is likely that

			numbers being introduced may be very low. Indeed, for example individual animals in cases were animals have out grown tanks. However, this may be higher if animals are being discarded as a result of breeding while in captivity, for example between 50 and 100 crayfish per introduction, even if no data are available. However, new *Faxonius* species are still appearing in the ornamental trade, particularly flourishing in Central and East Europe (in Germany this is an important sector, while Czech Republic is the entry point for many aquatic ornamental species; Chucholl 2013).
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.			
1.6b. How likely is the organism to survive existing management practices during passage along the pathway?			
1.7b. How likely is the organism to enter Europe undetected?			
1.8b. How likely is the organism to arrive during the months of the year most appropriate for establishment?			
1.9b. How likely is the organism to be able to transfer from the pathway to a suitable habitat or host?	very likely	very high	The rusty crayfish *F. rusticus* is an adaptable species and therefore one female carrying viable sperm could begin a new population if released into a suitable environment (Conard et al. 2015), although more than one specimen is likely to be released via this pathway. When introduced as ornamental species people may release it into open waters as has happened in the past with other crayfish (Kouba et al. 2014).

1.10b. Estimate the overall likelihood of entry into Europe based on this pathway?	likely	medium	Considering that the last introductions of alien crayfish in EU were due to ornamental reasons and that *F. rusticus* is already in the ornamental trade (Souty-Grosset et al. 2006), introductions along this pathway is a threat, even if numbers are low (the species still appears in the ornamental trade despite its well-known invasiveness due to the lack of awareness amongst wholesalers and importers; Chucoll 2013).
End of pathway assessment, repeat as necessary.			
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	high	The species is already in the ornamental trade in Europe since 2009 (Chucoll 2013; Mrugala et al. 2015). We can highly expect its entry into European water bodies, as dumping unwanted pets is a recognised practice.
1.12. Estimate the overall likelihood of entry into Europe based on all pathways in relevant biogeographical regions in foreseeable climate change conditions?	likely	high	If the species is not officially banned (considering also the internet trade), no change is expected in the near future.

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?	very likely	very high	*F. rusticus* has a high thermal tolerance (0-39°C). See Q.2of the EU chapeau.
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?	very likely	high	The species is reported to have few constraints (e,g. pH) in its current range (Hamr 2002), even if work is still needed to better understand its physiological tolerances (Philips 2010). In North America, due to the species superior streamlining and station holding capabilities (ability to maintain its position in high flow condition) it has been able to colonise upstream portions of fast flowing rivers (Hamr 2002). Given the species high degree of plasticity in North America, it is likely to be very adaptive to a broad range of environmental conditions also in Europe.
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	very likely	very high	The species has been harvested in US in tanks and it is reared in aquaria for ornamental reasons, so it can establish in environments artificially maintained (Hamr 2002).
1.16. How widespread are habitats or species necessary	widespread	very high	As reported at Q1.14, the species has very few

for the survival, development and multiplication of the organism in Europe?			constraints and can thus establish in a variety of habitats (in lakes and streams, including rocky and soft bottoms, and vegetated and unvegetated habitats).
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	very high	No other species are necessary to complete its life cycle.
1.18. How likely is it that establishment will occur despite competition from existing species in Europe?	likely	medium	The species is aggressive and can outcompete its congeneric already present in Europe for resources via direct interaction as well as the native crayfish (since the species is a recognised vector for crayfish plague, lethal for European crayfish) (Lodge et al. 2012). However, its competition with *Pacifastacus leniusculus* and *Procambarus clarkii*, the most widespread introduced crayfish in Europe together with *F. limosus*, has never been tested.
1.19. How likely is it that establishment will occur despite predators, parasites or pathogens already present in Europe?	very likely	very high	As with other crayfish, birds, fish and aquatic mammals can predate the species (Hamr 2002), but they do not have major impact on the population, as they usually maintain it at low level of density and do not cause extinction. Moreover, although *F. rusticus* can carry the crayfish plague, it is not affected.
1.20. How likely is the organism to establish despite existing management practices in Europe?	likely	high	Management practices can be more effective at the early stage of invasion in a closed system (e.g. a pond), but not in an open system, such as a river. This is hypothesized considering the management practices existing in Europe for other alien crayfish and those existing in US for the species (i.e. harvesting by baited traps and use of the synthetic pyrethroid Baythroid in the water that, however, could not be allowed in all the Member States; please see Management section below). Early warning and rapid response processes for

			crayfish are only present in a small number of EU countries and therefore would not limit/prevent establishment in some cases. Legislation in some countries, making the release of non-native organism, would also counter the potential for the species to become established, but such legislation is difficult to enforce, and other than acting as a deterrent, is normally applied post introduction.
1.21. How likely are existing management practices in Europe to facilitate establishment?	likely	high	See Q1.20. Management practices directed towards preventing the introduction and spread of invasive crayfish would not facilitate establishment, in fact the complete opposite. Management practices in relation to the use of invasive crayfish as a product e.g. food or bait, may facilitate establishment, such as establishing a new fishery. As there is a history of establishing fisheries based on the deliberate management practice of stocking waters with invasive crayfish then it is perceivable that this could occur with this species. Under these circumstances then the management practice is likely to result in establishment.
1.22. How likely is it that biological properties of the organism would allow it to survive eradication campaigns in Europe?	likely	high	It depends by the invaded habitat, the used methodology and the state where eradication is performed. This is hypothesized considering the management practices existing in Europe for other alien crayfish and those existing in US for the species (i.e. harvesting and use of the synthetic pyrethroid Baythroid). As with all crayfish species, this species is difficult to detect at low densities, and it not easily removed by physical means. Given the plasticity of the species and high levels of tolerance, it may prove difficult to remove with the use of chemicals as has been observed for other invasive crayfish

			species, especially those that burrow.
1.23. How likely are the biological characteristics of the organism to facilitate its establishment?	very likely	very high	The species is aggressive and omnivorous, with a high dispersal capability. It is tolerant to a broad spectrum of temperatures and conditions (see Q.5 of the EU chapeau). Reproduction can occur 1-2 times per year and a female can carry up to approximately 600 eggs. Females can store sperm, so males do not have to be introduced to establish a population. In cold climates, reproduction starts when water temperature rises above 5°C. Hatchings usually occur within one month and young become free-living 10-20 days later. Moulting ceases in temperatures below 10 to 12°C. Individuals become torpid at temperatures less than 4°C. Sexual maturity is reached early in both sexes (also within less one year of hatching). Life span is 3 to 4 years (all the info available in Hamr 2002).
1.24. How likely is the capacity to spread of the organism to facilitate its establishment?	very likely	high	It has a high potential to rapidly colonize connecting watersheds (Hamr 2002). It has been reported to spread downstream 0.9 to 3.7 km per year and upstream 0.45 to 1.5 km per year (Momot 1997). Although highly variable, it is not exceptional for *F. rusticus* to travel around 220 m in 48 h (Byron & Wilson 2001).
1.25. How likely is the adaptability of the organism to facilitate its establishment?	very likely	very high	The species has very few constraints and can thus establish in a variety of habitats (Hamr 2002).
1.26. How likely is it that the organism could establish despite low genetic diversity in the founder population?	very likely	very high	One female carrying viable sperm could begin a new population if introduced into a suitable environment, thus low genetic diversity is unlikely to prevent establishment (Conard et al. 2015).
1.27. Based on the history of invasion by this organism	very likely	very high	The species has been introduced in 22 US States

elsewhere in the world, how likely is it to establish in Europe? (If possible, specify the instances in the comments box.)			and in Canada in different climatic zones, showing its capability to establish in different conditions as present in Member States (Philips 2010; Conard et al. 2015).
1.28. If the organism does not establish, then how likely is it that casual populations will continue to occur? 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.	very unlikely	medium	Introductions always lead to either establishment or not. Continuous release of the species is unlikely to be common. Therefore, casual (or transient) populations would be unlikely to occur.
1.29. Estimate the overall likelihood of establishment in relevant biogeographical regions in current conditions (mention any key issues in the comment box).	Very likely	very high	Considering its biological characteristics, its tolerance to a broad spectrum of conditions and its invasion history, its establishment is very likely.
1.30. Estimate the overall likelihood of establishment in relevant biogeographical regions in foreseeable climate change conditions	very likely	high	Based on climatic modelling conducted by Daniel Chapman at CEH (for details please see the Species Model section further on), Southern Europe will probably become too hot, but Northern and Central Europe, considered suitable at the current climate conditions, will still remain suitable in the future.

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.)	major	high	Natural spread of the species is likely to occur through individual locomotion and population expansion within contiguous water systems (Hamr 2002). Spread across land between nearby water bodies could also occur as has been seen in other crayfish species (Souty-Grosset et al. 2006). Its dispersal rate varies, but, in Thunder Bay region in the Great Lakes, it is reported to spread 0.5 km (upstream) and 3.7 km (downstream) annually (Souty-Grosset et al. 2006).
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	high	Spread mechanisms that have been identified for this species include: • Use of the species gathered from existing populations as live bait for angling (Conard et al. 2015). • Deliberate translocation of the species into novel water courses with the view of establishing new populations for future wild harvest/ of releasing specimens from the aquarium (Conard et al. 2015). Given the wide spread availability of suitable habitat and the keen interest in Europe for both angling and ornamental crayfish, both mechanisms would seem very likely. It should be noted, however, that the use

			of live crayfish as bait is illegal (at least in the UK), and not very common amongst the angling community in other countries. This is evident from the lack of live crayfish for sale as bait, despite their reputation as being excellent for catching fish.
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.	UNAIDED ESCAPE FROM CONFINEMENT (live food and live bait) ESCAPE FROM CONFINEMENT (Pet/aquarium/terrarium species)		• UNAIDED- natural dispersal. This is likely to be a major ongoing issue where ever populations of the species occur. Dispersal can occur through contiguous water courses, or into non-contiguous water courses via overland migration (Conard et al. 2015). This pathway will only occur within catchments or between catchments in close proximity. Given the broad habitat range of the species and its spread capacity, it is likely that it will disperse into suitable habitat and environmental conditions. • ESCAPE FROM CONFINEMENT- live food and live bait. These events are likely to occur periodically and seasonally, where animals are taken from existing populations and are either accidentally (escape from hook) or deliberately (placed into water to facilitate establishing a food source, or from discarded bait) placed into novel water systems. This process could result in the establishment of populations some distance from the point of origin. This has led to establishment of population in US (Hamr 2002). • ESCAPE FROM CONFINEMENT- Pet/aquarium/terrarium species. The species is already in the ornamental trade in Europe and can be sold to citizens who can then release it into the wild in several places, as happened for other ornamental species and

			crayfish (Kouba et al. 2014).
Pathway name:	UNAIDED (natural dispersal)		
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	very high	
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?	very likely	high	The species can reach high densities (up to 113 crayfish/m^2; Hamr 2002) and spread rapidly through contiguous water courses as previously indicated. Propagule pressure is therefore likely to be high. For example, if the species moves 2km a year through a river system with an average width of 5m, maintaining a density of 57 crayfish m^{-2} (half of the maximum recorded density) throughout the newly invaded area, this would mean approximate 570,000 animals moving into this newly established area. These are only very rough calculations with many assumptions but could provide some indication of the numbers. Within contiguous water bodies the whole population would have to be treated along with nearby water bodies containing the species to prevent re-invasion.
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.	very likely	very high	The species would survive natural dispersal through water systems, but less likely to survive movement over land (Hamr 2002). Although there is no assessment of the species capacity to move across land, as with other invasive crayfish species, it is likely to survive.
2.6a. How likely is the organism to survive existing management practices during spread?	likely	high	See Q1.19. Management practices can be more effective at the early stage of invasion in a closed system (e.g. a pond), but not in an open system. This is hypothesized considering the management practices existing in Europe for other alien crayfish and those existing in US for the species (i.e. harvesting and use

			of the synthetic pyrethroid Baythroid).
2.7a. How likely is the organism to spread in Europe undetected?	likely	high	For aquatic species, there will inevitably be some delay between introduction and detection. This will depend on a number of factors such as propagule pressure, how extensively the invaded water system is used, what it is used for and if it is part of an existing biological monitoring programme. Eventually most populations will be detected, but this could be some years after the initial introduction event in some cases.
2.8a. How likely is the organism to be able to transfer to a suitable habitat or host during spread?	likely	high	Spread within a single contiguous water system is very likely, as given the generalist nature of the species suitable habitat is likely to be found (Hamr 2002). In relation to movement between catchments, where water bodies are separate by some distance then this would be less likely without some form of human intervention, although there is some possibility that the species could travel overland. As many water systems within Europe are interconnected (e.g. through canalisation), then the species is likely to utilise these where possible.
2.9a. Estimate the overall likelihood of spread into or within the Union based on this pathway?	moderately likely	high	The species is likely to spread via this pathway to an extent, i.e. throughout a catchment, with relative ease. However, movement between catchments via this pathway would be less likely as it will depend on either a form of connection, such as a canal, or movement overland to spread further.
Pathway name:	ESCAPE- (live food and live bait)		
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/Intentional	high	This pathway includes intentional and unintentional use of the species as fishing bait and food. For live bait the unintentional release of the specimens being used as bait in addition to the intentional discarding of unused bait. Also, it will include the intentional transfer of the species between water bodies with the intention of establishing populations for future harvest

			(Hamr 2002).
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	Most likely relatively small number of animals would be used as bait (and potentially) discarded by anglers. Although exact numbers are unknown. If intentionally trying to establish a population then it is likely that larger numbers would be transferred, but this would depend on being able to obtain and transfer the animals.
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.	very likely	very high	Crayfish can be easily moved alive. If the intention is to move the animals live either for stocking or use as bait then those undertaking the activity would ensure this is the case. It is unlikely that the species would multiply during transport, although females can store and therefore transfer sperm.
2.6b. How likely is the organism to survive existing management practices during spread?	likely	high	Within some parts of Europe (i.e. France and the UK) it is illegal to introduce species not normally resident or listed without a suitable licence, or to use crayfish as live bait. However, this is difficult to enforce, so it is likely that under such circumstances, the organisms would survive. See also Q 2.6 of UNAIDED.
2.7b. How likely is the organism to spread in Europe undetected?	likely	high	There will inevitably some delay between introduction and detection. This will depend on a number of factors such as propagule pressure, how extensively the invaded water system is used, what it is used for and if it is part of an existing biological monitoring programme. Eventually most populations will be detected, but this could be some years after the initial introduction event in some cases. With anthropogenic activities, it is less likely to go unnoticed than with natural spread, especially if there a multiple introduction event.
2.8b. How likely is the organism to be able to transfer to a suitable habitat or host during spread?	likely	high	Given the generalist nature of the species suitable habitat is likely to be found (Hamr 2002).

2.9b. Estimate the overall likelihood of spread into or within the Union based on this pathway?	likely	high	Other crayfish species have spread throughout Europe partly as a result of anthropogenic activities described here (Kouba et al. 2014). Without intervention, there is no reason for this not also be the case for this species.
Pathway name:	ESCAPE- (Pet/aquarium/terrarium species))		
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)?	intentional	high	This pathway includes intentional use of the species as ornamental crayfish, which will include the intentional discarding of unwanted specimens (Kouba et al. 2014).
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?	moderately likely	medium	Most likely relatively small number of animals would be discarded by citizens, although exact numbers are unknown. But few individuals can be sufficient to establish a population.
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.	very likely	very high	Crayfish can be easily moved alive, as proved by the several alien species present in Europe (Kouba et al. 2014).
2.6c. How likely is the organism to survive existing management practices during spread?	likely	high	Within some parts of Europe (i.e. the UK, France, Italy, Denmark, Spain, Portugal) it is illegal to introduce species not normally resident or listed, without a suitable licence. However, this is difficult to enforce, so it is likely that under such circumstances, the organisms would survive. See also Q 2.6 of UNAIDED.
2.7c. How likely is the organism to spread in Europe undetected?	likely	high	With the detection of aquatic species there will inevitably some delay between introduction and detection. This will depend on a number of factors such as propagule pressure, how extensively the invaded water system is used, what it is used for and if it is part of an existing biological monitoring

			programme. Eventually most populations will be detected, but this could be some years after the initial introduction event in some cases. With anthropogenic activities, it is less likely to go unnoticed than with natural spread, especially if there a multiple introduction event.
2.8c. How likely is the organism to be able to transfer to a suitable habitat or host during spread?	likely	high	Given the generalist nature of the species suitable habitat is likely to be found (Hamr 2002).
2.9c. Estimate the overall likelihood of spread into or within the Union based on this pathway?	likely	high	Other crayfish species have spread throughout Europe partly as a result of anthropogenic activities described here (Kouba et al. 2014). Without intervention, there is no reason for this not also be the case for this species.
End of pathway assessment, repeat as necessary.			
2.10. Within Europe, how difficult would it be to contain the organism?	difficult	high	If the species becomes widespread, it will be difficult to contain *F. rusticus* as already occurred for *Faxonius limosus*, *Pacifastacus leniusculus* and *Procambarus clarkii* (Kouba et al. 2014). If action is taken before the species spreads, the species could be contained with some difficulty, especially in closed systems.
2.11. Based on the answers to questions on the potential for establishment and spread in Europe, define the area endangered by the organism.	Many of the EU rivers, streams, lakes and ponds.	high	As the species is a generalist, with broad environmental tolerances (Hamr 2002), it is likely that the species could establish throughout much of the EU. Limiting factors could be the distribution of other crayfish species (e.g. *Pacifastacus leniusculus* and *Procambarus clarkii*) that may outcompete the species for resources, although this interaction has never been tested.
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?	0-10	very high	The species is not present in Europe in the wild (only reported for the ornamental trade).

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	medium	There are numerous factors that would potentially affect the rate of establishment, such as the connectivity of water courses, and the amount of anthropogenic translocation. As the species has been reported to spread at a rate of 3.7 km per annum in US, then rapid spread would be expected (Souty-Grosset et al. 2006). Anthropogenic translocation would increase the rate of spread and extend the species distribution further (Conard et al. 2015). A limiting factor in the rate of spread may be the interaction between the species and other invasive alien crayfish that are known to be highly aggressive (e.g. *Pacifastacus leniusculus* and *Procambarus clarkii*).
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	high	The species is likely to spread further in a relatively short time frame, dependent on variables as discussed in Q 2.13 above (Souty-Grosset et al. 2006). Compared to *F. virilis*, the species is considered a higher invasive species, capable of quickly colonizing new areas. In Wisconsin lakes and streams, *F. rusticus* has increased from 3% in the 1970s to approximately 50% in 2007 (Olden et al. 2006), so in 10 years it could reach an increased distribution of approximately 11%., and this has been considered a good period to assess the spread of the species.
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	medium	Considering the high invasiveness of the species and the variables involved (see Q 2.13 above) in relation to establishment of this species into endangered areas/habitats, this is the best estimation that can be provided. Moreover, as stated in the previous answer, the species has increased from 3% in the 1970s to approximately 50% in 2007 (Olden et al. 2006), meaning approximately 11% per 10 years. The likely spread is therefore towards the bottom end of this bracket.

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	Depending on many variables, such as the degree of human involvement, the connectivity of currently invaded water courses and interaction with other species, and considering its invasion history in North America, the species can rapidly spread.
2.17. Estimate the overall potential for spread in relevant biogeographical regions in foreseeable climate change conditions	likely	high	It is likely that the species will be able to spread also in the future, only suitability of habitats will change (less in the Southern Europe).

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	very high	The species can reach high densities (up to 113 crayfish m^{-2}; Hamr 2002). It is considered one of the most invasive crayfish where introduced (Lodge et al. 2012). It feeds on macrophytes, fish eggs and invertebrates decreasing biodiversity. It outcompetes congenerics and hybridizes with *F. propinquus*, resulting in fertile hybrids (Lodge et al. 2012). As reported in U.S. Fish and Wildlife Service RA on the species (2015): *"Orconectes rusticus* has a range of ecological impacts on introduced environments that include competition and displacement of native crayfish, increased predation on snails, native and threatened bivalves, reduction of macrophyte abundance, reduction of sport-fish abundance, reduction of macroinvertebrate abundance, increases in periphyton activity, and other cascading trophic interactions." *"F. rusticus* aggressive nature, greater fitness, and large chelae and body size allow it to displace native crayfish from food and habitat (Byron & Wilson 2001; Garvey

			et al. 2003; Garvey & Stein 1993; Hill & Lodge 1999; Klocker & Strayer 2004). Displacement from food causes reduced fitness to its congeners and displacement from habitat increases predation pressure (Hill & Lodge 1994). *O. rusticus* displaces native crayfish, *O. virilis*, and previous invader, *O. propinquus*, from lakes throughout northern Wisconsin (Byron & Wilson 2001; Garvey & Stein 1993; Hill & Lodge 1994). Along with direct competition and displacement, research indicates that fish and other predators avoid *O. rusticus* because of its larger chelae and body size and this selective predation pressure is likely an important driver in the replacement of crayfish species by rusty crayfish (Roth & Kitchell 2005; DiDonato & Lodge 1993). *O. rusticus* is known to hybridize with native crayfish *O. propinquus* in Lake Michigan (Jonas et al. 2005). In northeastern United States, *O. rusticus* may pose a threat to native crayfish *O. limosus*, which it was found to dominate in shelter competition and aggression trials (Klocker & Strayer 2004).” As *F. limosus* is already present in Europe, this interaction could also occur if *F. rusticus* would be introduced. “Rusty crayfish prey on threatened, native bivalves in northeastern United States. Although native crayfish also prey on these bivalves, *O. rusticus* can live at very high densities so the threat of increased predator populations can harm already threatened unionid populations (Klocker & Strayer 2004; Kuhlmann & Hazelton 2007). *O. rusticus* also preys on snails and in Trout Lake, Wisconsin, snails declined from >10,000 to <5 snails/m2 in one of the initially invaded areas (Wilson et al. 2004). Relative to control treatments, rusty crayfish were found to reduce the biomass of northeastern US native *Lymnaea* and *Physa* snails by

			>90% (Johnson et al. 2009). Furthermore, *O. rusticus* has been found to co-occur with *Bellamya chinensis*, an invasive snail with a thick shell that prevents predation by *O. rusticus*, in northern temperate lakes throughout the United States. The predation pressure of *O. rusticus* on native snail communities combined with competition and displacement by the *B. chinensis* has resulted in the reduction of native snail biomass (Johnson et al. 2009).” It is noteworthy to mention that *B. chinensis* has also established populations in the Netherlands and Belgium (e.g. Collas et al. 2017) and could indirectly be facilitated by the presence *F. rusticus*. “The reduction of macrophyte abundance is another important impact of *O. rusticus*. Small-scale, comparative, and multi-lake studies confirm that macrophyte species richness and abundance decline significantly in lakes invaded by *O. rusticus* (Alexander et al. 2008; Rosenthal et al. 2006; Roth et al. 2007; Wilson et al. 2004). In northern Wisconsin, studies found the proportion of sites with no macrohpyte cover to increase from 40-73% (Roth et al. 2007), and submerged macrophyte species richness to decline by as much as 80% with the invasion of *O. rusticus* (Wilson et al. 2004).” “*O. rusticus* introduction is also believed to reduced sport fish populations especially pan-fish *Lepomis macrochirus* and *L. gibbossus* by either egg predation or competition with juveniles. Researchers have calculated fisheries damages of *O. rusticus* in Vilas County, Wisconsin, to be about $ 1.5 million annually (Keller et al. 2008).” “Additional cascading ecological impacts have been associated with *O. rusticus*. Decreasing macroinvertebrate densities and increasing periphyton productivity have been found to correlate with

			increasing *O. rusticus* densities (Charlebois & Lamberti 1996). In Trout Lake, Wisconsin, mean abundance of Odonata, Amphipoda, and Trichoptera decreased significantly lake-wide with the invasion of *O. rusticus* (Wilson et al. 2004).”
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)?	minimal	very high	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	high	Being an aggressive and omnivorous species, it can cause a decrease in macrophyte cover, macroinvertebrates abundance and diversity, altering the ecosystem function, and most likely nutrient cycling. Its feeding habit can change trophic interaction. Burrowing activity is scarce in US, but it can change in Europe as already happened for other alien crayfish (Tricarico & Aquiloni 2016).
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?	minimal	very high	The species is not yet established in Europe.
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	very high	Impact on native species, such as the white-clawed crayfish, *Austropotamobius pallipes*, or the noble crayfish *Astacus astacus*, could be significant through disease (i.e. crayfish plague), competition, predation, and trophic interactions. All invaded habitats are likely to be affected as a result of the species consumption of macrophytes and key stone species, in addition to burrowing and sediment mobilisation.
Ecosystem Services impacts			
2.23 How important is the impact of the organism on	moderate	high	In US, the rusty crayfish is more likely to compete with

provisioning, regulating, and cultural services in its non-native range excluding the Union?			juvenile gamefish for benthic invertebrate prey than are native species of crayfish. It has been shown to significantly reduce benthic invertebrate densities that serve as an important food source to young fish. It has also been seen to prey on fish eggs of various species, specifically those of trout. While an official study has not yet been conducted, personal observations of fisheries managers in US have suggested frequent decline of bluegill *Lepomis macrochirus*, northern pike *Esox lucius*, and bass *Micropterus* spp. populations following the introduction of rusty crayfish. Due to its conspicuousness during daylight hours relative to native crayfish species, *O. rusticus* has resulted in a decline in recreational swimming in areas where present, as swimmers fear stepping on it and being pinched by its large claws (Conard et al. 2015).
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)?	minimal	very high	The species is not yet established in Europe.
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	high	The species could have a major impact on all water ways in a diverse range of ways. For example, destabilising of banks, causing access issues, and impacting flood defences. Mobilisation of sediment could affect water extraction and navigation, while predation on fish would impact on recreational and commercial freshwater fisheries. Furthermore, bathers may be deterred from using waters invaded by the species. Impacted ecosystems could attract less visitors (impacts on cultural services) (Gunderson 1995)
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	major	medium	The species is not currently present within Europe and the authors could not find any direct information in relation to the economic impact of the species from

management			elsewhere (i.e. the USA). However, given the recognised impacts on the ecosystems, on bank and dike stability and their functions within the USA (Gunderson 1995) it is estimated that the economic impact is major.
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	minimal	very high	The species has not yet established in the EU.
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	high	Given the species ability to change ecosystem function, and its potential to establish over much of the EU, it may have a major economic cost. However, it is unclear how this species will interact with other invasive alien crayfish and if their impact would be greater than those already present. We can only hypothesise that *F. rusticus* could outcompete *F. limosus*, as already reported in North America (please see Q. 2.18). In Williams et al. (2010), the direct costs caused by signal crayfish (*Pacifastacus leniusculus*) was estimated at £2m (approximately 2.2m Euro) in the UK. Given the further spread of the species, the fact this report only covered direct costs and that this is likely to be a conservative estimation, then it is likely that the costs are now much higher for this species. In Italy, only in the Latium region, damages due to alien crayfish, particularly the red swamp crayfish *Procambarus clarkii*, are estimated for a maximum of 1.17 million Euro/year, including costs to fisheries, aquaculture and agriculture (Gherardi et al. 2014). Rusty crayfish are considered to be more invasive than signal crayfish and similar to the red swamp crayfish, therefore the likely costs could be potentially much higher or similar, after a similar period of invasion with the same lack of action to reduce it.
2.29. How great are the economic costs associated with	minimal	very high	The species has not yet established in the EU.

managing this organism currently in the Union (include any past costs in your response)?			
2.30. How great are the economic costs associated with managing this organism likely to be in the future in the Union?	moderate	low	This very much depends on when action is taken to control the species if it is introduced. If action is taken immediately, then costs could be relatively low depending on the extent of the introduction, but if left to spread the costs would potentially be major. The response and confidence provided is in relation to an immediate response to a single isolated population.
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).	minimal	very high	The species has not yet established in the EU.
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	Other than potentially causing minor physical damage to unlucky bathers the species does not present a human health risk. It could, however, potentially have social impact through damage to fisheries (both recreational and commercial). Risk of flooding might increase if dikes are destabilized by crayfish burrowing.
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)?	major	very high	The organism would most likely have a significant impact on crayfish species native to Europe, as all of these species are susceptible to crayfish plague (*Aphanomyces astaci*) (Souty-Grosset et al. 2006) which the rusty crayfish is mostly likely a vector for.
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)	NA	medium	No other known impacts.
2.35. How important are the expected impacts of the	major	high	Even if fish and birds could predate the species, they

organism despite any natural control by other organisms, such as predators, parasites or pathogens that may already be present in Europe?			maintain the population at low level of density and do not cause extinction. Although other invasive crayfish may slow the potential spread of 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).	All locations as previously indicated likely to be invaded	high	

RISK SUMMARIES

	RESPONSE	CONFIDENCE	COMMENT
Summarise Entry	likely	high	The species is already in the ornamental trade in Europe (Chucoll 2013; Mrugala et al. 2015) but has not yet been found in the wild. Specimens could be introduced by people into the wild.
Summarise Establishment	likely	high	The species is highly adaptable and can establish in a variety of habitats as already showed by its invasion history in North America (Philips 2010; Conard et al. 2015).
Summarise Spread	rapidly	high	The species has a high dispersal capability and, when introduced, can spread both unaided and facilitated by humans (Conard et al. 2015).
Summarise Impact	major	high	The species is considered one of the most invasive crayfish where introduced (Lodge et al. 2012). Its negative impact can be highly relevant in Europe.
Conclusion of the risk assessment	high	high	Based on the evidence from the literature and the presence of congeneric in Europe, the species could pose a high risk to the European ecosystems.

ADDITIONAL QUESTIONS - CLIMATE CHANGE			
3.1. What aspects of climate change, if any, are most likely to affect the risk assessment for this organism?	Changes in water temperature	high	Higher temperatures could decrease the suitable areas for the species and thus restrict its invasiveness in Europe.
3.2. What is the likely timeframe for such changes?	20 years	medium	
3.3. What aspects of the risk assessment are most likely to change as a result of climate change?	potential distribution of the species, possibly rate of spread and impacts	medium	
ADDITIONAL QUESTIONS – RESEARCH			
4.1. If there is any research that would significantly strengthen confidence in the risk assessment please summarise this here.	Interactions with other alien crayfish in Europe Physiological tolerances Impact on ecosystem services Indirect effects on decline in vegetation and burrowing behaviour	very high	

	(e.g., bank stability, damage dikes) Socio-economic impacts Extent of the species use in current trade Development of management techniques		

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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.

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[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.

ANNEX IV - Species Distribution Model

Data for modelling

Climate data were taken from freshwater-specific versions of the 'Bioclim' variables (Domisch *et al.*, 2015), aggregated to a 0.25 x 0.25 degree grid for use in the model. Based on the biology of *F. rusticus*, the following climate variables were used in the modelling:

- Mean upstream temperature of the warmest quarter (Bio10 °C) reflecting the summer thermal regime. As an ectotherm, it is reported to prefer water temperatures of 20-25°C, with maximum juvenile growth rates at 26-28 °C and maximum juvenile survival at 20-22 °C (Conard *et al.*, 2017). Above 30 °C, it is reported to dig burrows to escape the heat (Mundahl, 1989).
- Mean upstream annual precipitation (Bio12 mm) was used as an indicator of the availability of aquatic habitats.
- Upstream precipitation of the driest quarter (Bio17 mm) was used as an indicator of low flows, which might be detrimental for the species.
- Precipitation of driest month (Bio14 mm, ln+1 transformed) reflecting maximum stress in accessible water. In its native North American range, *O. rusticus* rarely occurs in the most arid regions.

Winter temperatures were not used as the species is still expanding northwards into Canada, and experiencing harsher winter temperatures than occur in Europe.

Climate model projections of climate change scenarios for these freshwater-specific variables are currently unavailable so no climate change projections could be made.

In the models we also included the following habitat variables, all ln+1 transformed for modelling:

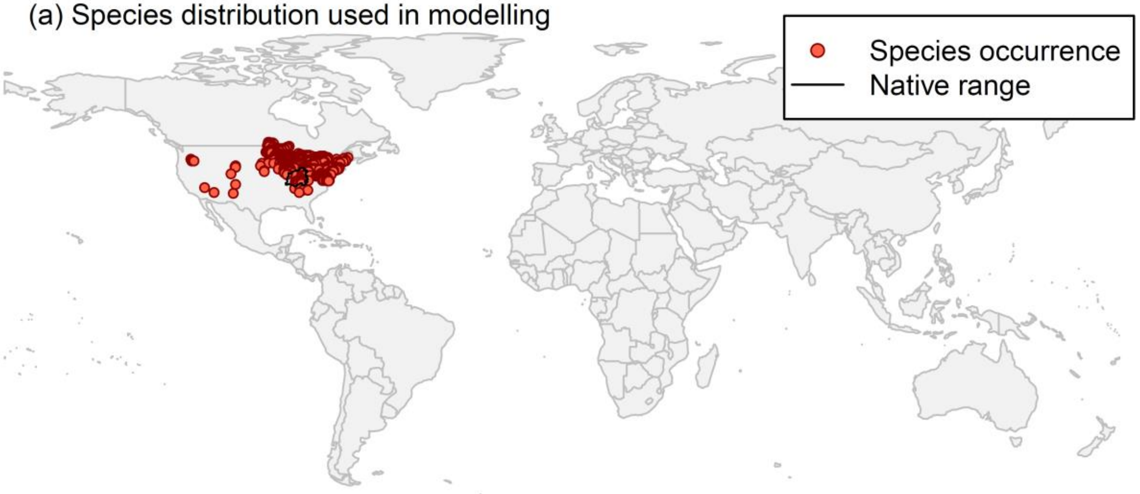
- Density of permanent rivers was estimated from the Vector Map (VMAP0; http://gis-lab.info/qa/vmap0-eng.html). River vectors were rasterised at 0.02 x 0.02 degree resolution. Then, the percentage of these grid cells containing rivers within each of the 0.25 x 0.25 degree cells used in the model was calculated.
- % Cover of lakes and wetlands from the Global Lakes and Wetlands Database (Lehner & Döll, 2004) processed similarly to the above.
- Average slope derived from the Hydrosheds database (Lehner *et al.*, 2006) and available with the freshwater-specific climate data (Domisch *et al.*, 2015). *F. rusticus* may avoid very steep areas.
- Soil pH in water derived from the SoilGrids database (Hengl *et al.*, 2014) and available with the freshwater-specific climate data (Domisch *et al.*, 2015). *F. rusticus* juvenile mortality is high at low pH (5.4–6.1) (Berrill *et al.*, 1985).

Species occurrence data were obtained from the Global Biodiversity Information Facility (GBIF), iNaturalist and USGS Non-Native Aquatic Species databases. The records were scrutinised to remove unreliable occurrences and then gridded at a 0.25 x 0.25 degree resolution for modelling (Figure 1a). In total 573 grid cells containing records of *F. rusticus* were used in the modelling (Figure 1a).

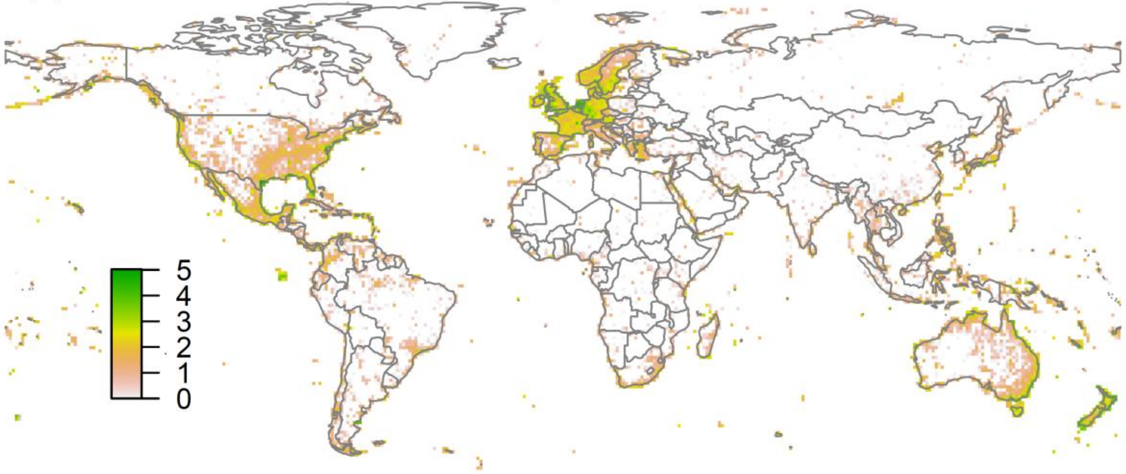
Additionally, the recording density of Malacostraca on GBIF was obtained as a proxy for spatial recording effort bias (Figure 1b).

Figure 1. (a) Occurrence records obtained for *Faxonius rusticus* and used in the modelling, showing the native range and (b) a proxy for recording effort – the number of Malacostraca records held by the Global Biodiversity Information Facility, displayed on a $\log_{10}$ scale.

(a) Species distribution used in modelling



(b) Estimated recording effort (log−scaled)



Species distribution model

A presence-background (presence-only) ensemble modelling strategy was employed using the BIOMOD2 R package v3.3-7 (Thuiller *et al.*, 2014, Thuiller *et al.*, 2009). These models contrast the environment at the species' occurrence locations against a random sample of background environmental conditions (often termed 'pseudo-absences') in order to characterise and project suitability for occurrence. This approach has been developed for distributions that are in equilibrium with the environment. Because invasive species' distributions are not at equilibrium and subject to dispersal constraints at a global scale, we took care to minimise the inclusion of locations suitable for the species but where it has not been able to disperse to. Therefore, the background sampling region included:

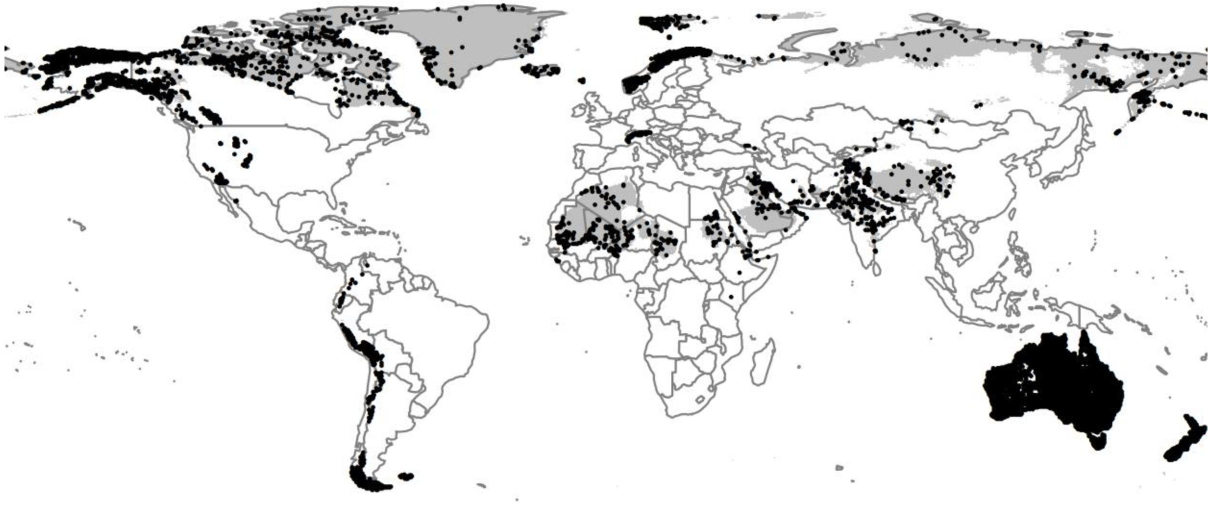
- The area accessible by native *F. rusticus* populations, in which the species is likely to have had sufficient time to disperse to all locations. The native range was defined from level 4 USGS Hydrological Units (HUC 4 polygons) overlapping the native range map in Conard *et al.* (2017). As can be seen in Figure 1a, the native range is very small compared to its full North American distribution and in fact only a small number of the occurrence grid cells were inside the native range (28 of 573); AND
- A relatively small 30 km buffer around all non-native occurrences, encompassing regions likely to have had high propagule pressure for introduction by humans and/or dispersal of the species; AND
- Regions where we have an *a priori* expectation of high unsuitability for the species (see Figure 2). Absence from these regions is considered to be irrespective of dispersal constraints. Ecophysiological information about *F. rusticus* suggested water temperature was likely to be a key distribution constraint, with restriction by cold and hot conditions (Conard *et al.*, 2017, Mundahl, 1989, Phillips, 2010). Based on the distribution data, the following rules for unsuitability were applied:
    - Mean upstream temperature of the warmest quarter (Bio10) < 15 °C. Only 0.3% of occurrence records had Bio10 < 15 °C.
    - Mean upstream temperature of the warmest quarter (Bio10) > 25 °C. Only 0.2% of occurrence records had Bio10 > 25 °C.

Soil pH was not used here, even though the literature suggests effects of low pH on mortality (Berrill *et al.*, 1985). Despite this, 20% of records have pH < 5, so we did not wish to specify these environments as unsuitable.

Winter temperature was not used in the modelling, as we were not sure that the distribution data contained a significant winter cold-limited range margin. The coldest occurrence has mean minimum temperature of the coldest month (Bio6) = -5.2 °C, but *F. rusticus* may be able to tolerate colder conditions than this.

To sample as much of the background environment as possible, without overloading the models with too many pseudo-absences, ten background samples of 5,000 randomly chosen grid cells were obtained (Figure 2). To account for recording effort bias, sampling of background grid cells was weighted in proportion to the reptile recording density (Figure 1b).

Figure 2. Randomly selected background grid cells used in the modelling of *Faxonius rusticus*, mapped as points. Points are sampled from the native range, a small buffer around non-native occurrences and from areas expected to be highly unsuitable for the species (grey background region), and weighted by a proxy for recording effort (Figure 1b).



Each dataset (i.e. combination of the presences and the individual background samples) was randomly split into 80% for model training and 20% for model evaluation. With each training dataset, ten statistical algorithms were fitted with the default BIOMOD2 settings (except where specified below) and rescaled using logistic regression:

- Generalised linear model (GLM)
- Generalised boosting model (GBM)
- Generalised additive model (GAM) with a maximum of four degrees of freedom per effect.
- Classification tree algorithm (CTA)
- Artificial neural network (ANN)
- Flexible discriminant analysis (FDA)
- Multivariate adaptive regression splines (MARS)
- Random forest (RF)

- Maxent
- Maximum entropy multinomial logistic regression (MEMLR)

Since the background sample was much larger than the number of occurrences, prevalence fitting weights were applied to give equal overall importance to the occurrences and the background. Normalised variable importance was assessed, and variable response functions were produced using BIOMOD2's default procedure. Model predictive performance was assessed by calculating the Area Under the Receiver-Operator Curve (AUC) for model predictions on the evaluation data, which were reserved from model fitting. AUC can be interpreted as the probability that a randomly selected presence has a higher model-predicted suitability than a randomly selected absence.

An ensemble model was created by first rejecting poorly performing algorithms with relatively extreme low AUC values and then averaging the predictions of the remaining algorithms, weighted by their AUC. To identify poorly performing algorithms, AUC values were converted into modified z-scores based on their difference to the median and the median absolute deviation across all algorithms (Iglewicz & Hoaglin, 1993). Algorithms with $z < -2$ were rejected. In this way, ensemble projections were made for each dataset and then averaged to give an overall suitability.

Global model projections were made for the current climate, avoiding model extrapolation beyond the ranges of the input variables. The optimal threshold for partitioning the ensemble predictions into suitable and unsuitable regions was determined using the 'minimum ROC distance' method. This finds the threshold where the Receiver-Operator Curve (ROC) is closest to its top left corner, i.e. the point where the false positive rate (one minus specificity) is zero and true positive rate (sensitivity) is one.

Limiting factor maps were produced following Elith et al. (2010). For this, projections were made separately with each individual variable fixed at a near-optimal value. These were chosen as the median values at the occurrence grid cells. Then, the most strongly limiting factors were identified as the one resulting in the highest increase in suitability in each grid cell. Partial response plots were also produced by predicting suitability across the range of each predictor, with other variables held at near-optimal values.

Results

The ensemble model suggested that suitability for *F. rusticus* at this scale was most strongly determined by the proxy for summer water temperature (Table 1). The influence of the unsuitability rules on the modelling was clear, with sharp delineation of suitable regions with Bio10 from 15-25 °C (Figure 3). The model also fitted weaker and less consistent reductions in suitability with low precipitation of the driest quarter, very high upstream annual precipitation and low soil pH (Figure 3). However, at this scale the habitat variables did not appear to have a strong effect on the species' occurrence.

Global projection of the model in current climatic conditions (Figure 4) indicates that further range expansion in North America will be possible and that many other parts of the world have a thermal regime apparently suitable for the species. This includes most of Europe, except the northwest and high mountains were temperatures are considered too cold (Figure 5) and some small regions of the Mediterranean that are considered too hot (Figure 5). The potential range margin in Northeastern Europe appears to be beyond the northern edge of the freshwater-specific climate data, meaning the model cannot predict potential establishment in Finland and northern Sweden. Uncertainty in this projection, in terms of disagreement among algorithms, was greatest around its predicted warm and cold-limited margins in both North America and Europe (Figure 4).

Most Biogeographical Regions of Europe (Bundesamt fur Naturschutz (BfN), 2003) are predicted to have suitability for *F. rusticus* currently (Figure 7). Those predicted to be most suitable are the Pannonian, Steppic, Atlantic, Black Sea, and Continental.

Table 1. Summary of the cross-validation predictive performance (AUC) and variable importance of the fitted model algorithms and the ensemble (AUC-weighted average of the best performing algorithms). Results are the average from models fitted to ten different background samples of the data.

Algorithm	**AUC**	**In the ensemble**	**Variable importance**					
			Minimum temperature of coldest month	**Mean temperature of warmest quarter**	**Precipitation of driest month**	**Climatic moisture index**	**Human Influence Index**	**Tree cover**
GLM	0.8598	yes	27%	25%	25%	19%	0%	4%
GBM	0.8736	yes	2%	52%	34%	9%	1%	2%
GAM	0.8680	yes	25%	23%	16%	30%	0%	5%
CTA	0.8448	no	5%	46%	28%	13%	3%	6%
ANN	0.8724	yes	25%	24%	20%	24%	4%	2%
FDA	0.8612	yes	18%	3%	59%	20%	1%	0%
MARS	0.8698	yes	0%	55%	20%	24%	0%	0%
RF	0.7556	no	7%	34%	31%	11%	9%	9%
Maxent	0.8692	yes	17%	48%	12%	21%	1%	1%
MEMLR	0.8346	no	31%	29%	27%	7%	0%	5%
Ensemble	0.8720		16%	33%	27%	21%	1%	2%

Figure 3. Partial response plots from the fitted models, ordered from most to least important. Thin coloured lines show responses from the algorithms in the ensemble, while the thick black line is their ensemble. In each plot, other model variables are held at their median value in the training data. Some of the divergence among algorithms is because of their different treatment of interactions among variables.

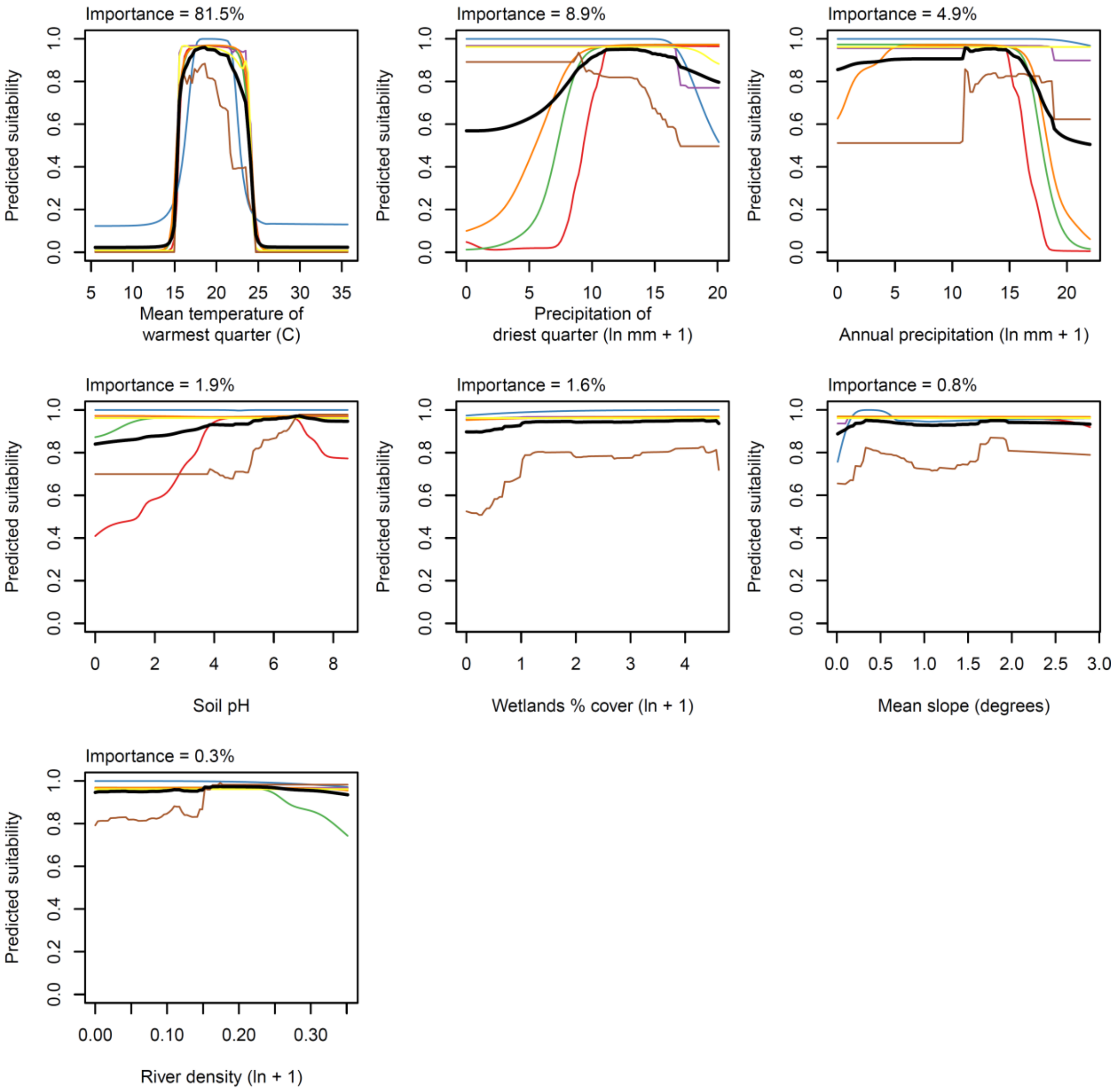
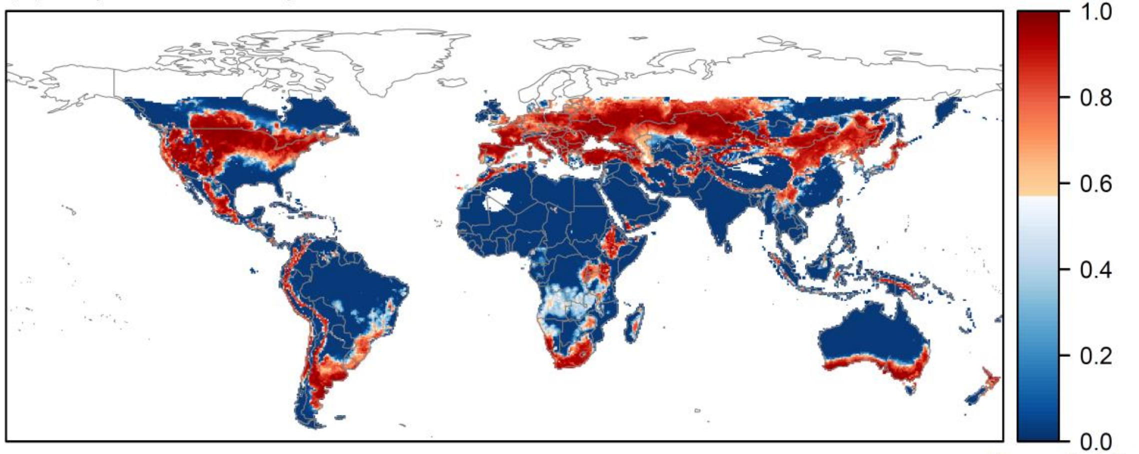

Importance = 81.5%
Predicted suitability
0.0
0.2
0.4
0.6
0.8
1.0
5
10
15
20
25
30
35
Mean temperature of warmest quarter (C)
Importance = 8.9%
0
5
10
15
20
Precipitation of driest quarter (ln mm + 1)
Importance = 4.9%
Annual precipitation (ln mm + 1)
Importance = 1.9%
0
2
4
6
8
Soil pH
Importance = 1.6%
0
1
2
3
4
Wetlands % cover (ln + 1)
Importance = 0.8%
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Mean slope (degrees)
Importance = 0.3%
0.00
0.10
0.20
0.30
River density (ln + 1)

Figure 4. (a) Projected global suitability for *Faxonius rusticus* establishment in the current climate. For visualisation, the projection has been aggregated to a 0.5 x 0.5 degree resolution, by taking the maximum suitability of constituent higher resolution grid cells. Red shading indicates suitability. White areas have climatic conditions outside the range of the training data so were excluded from the projection. (b) Uncertainty in the suitability projections, expressed as the standard deviation of projections from different algorithms in the ensemble model.

(a) Projected suitability



(b) Standard deviation in projected suitability

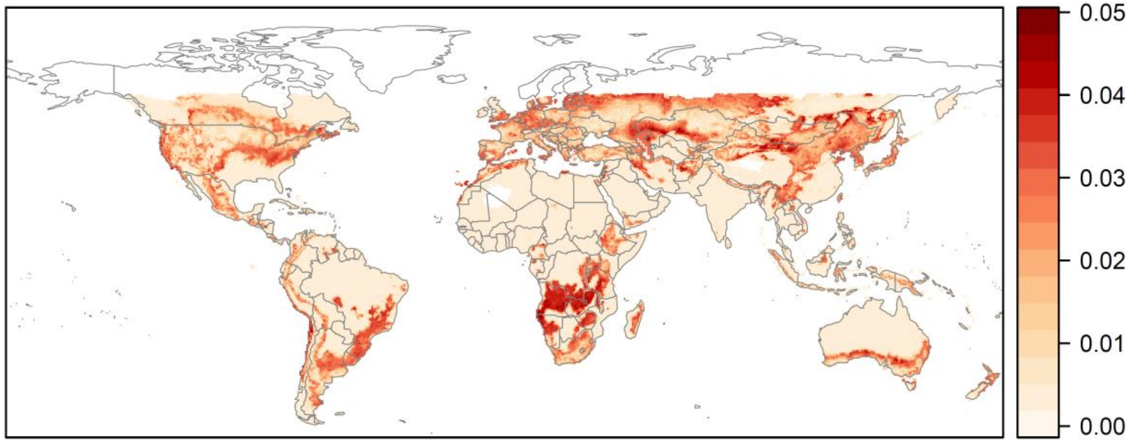


Figure 5. Projected current suitability for *Faxonius rusticus* establishment in Europe and the Mediterranean region. The white areas have climatic conditions outside the range of the training data so were excluded from the projection.

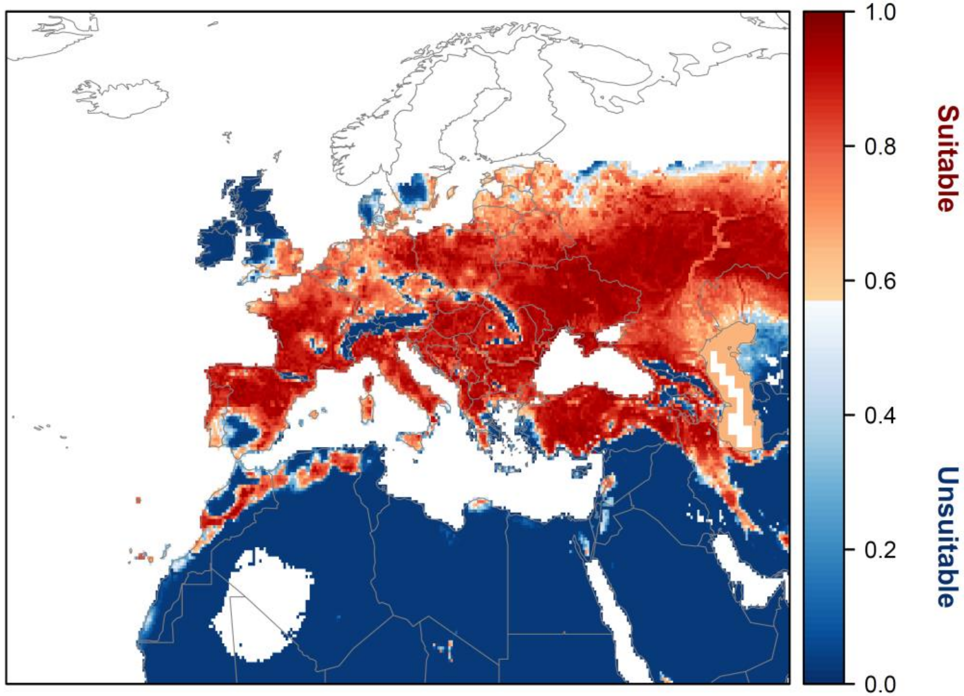


Figure 6. Limiting factor map for *Faxonius rusticus* establishment in Europe and the Mediterranean region in the current climate. Shading shows the predictor variable most strongly limiting projected suitability.

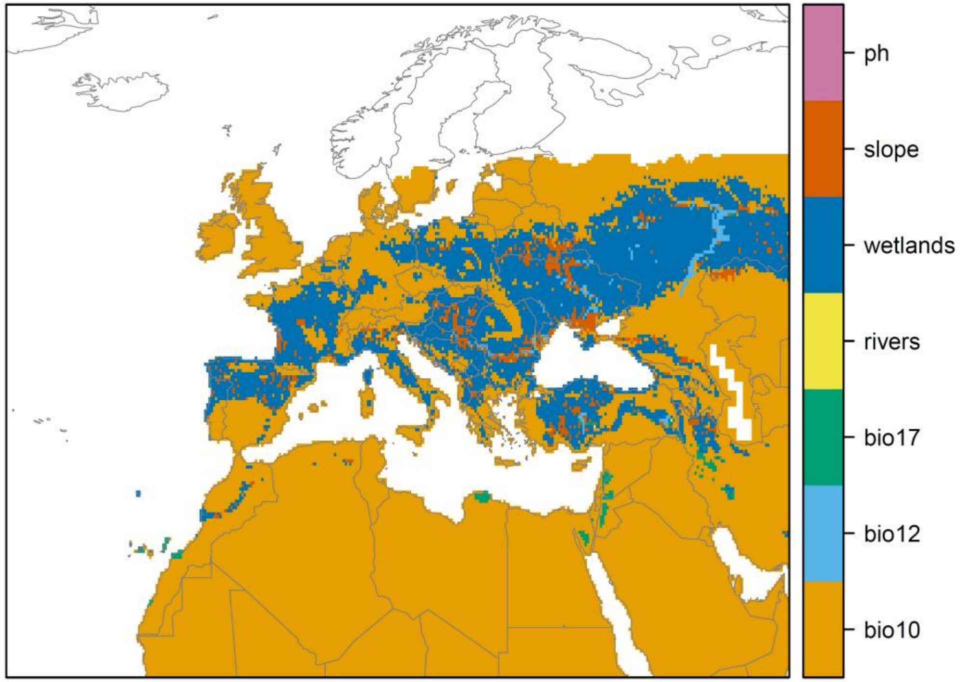
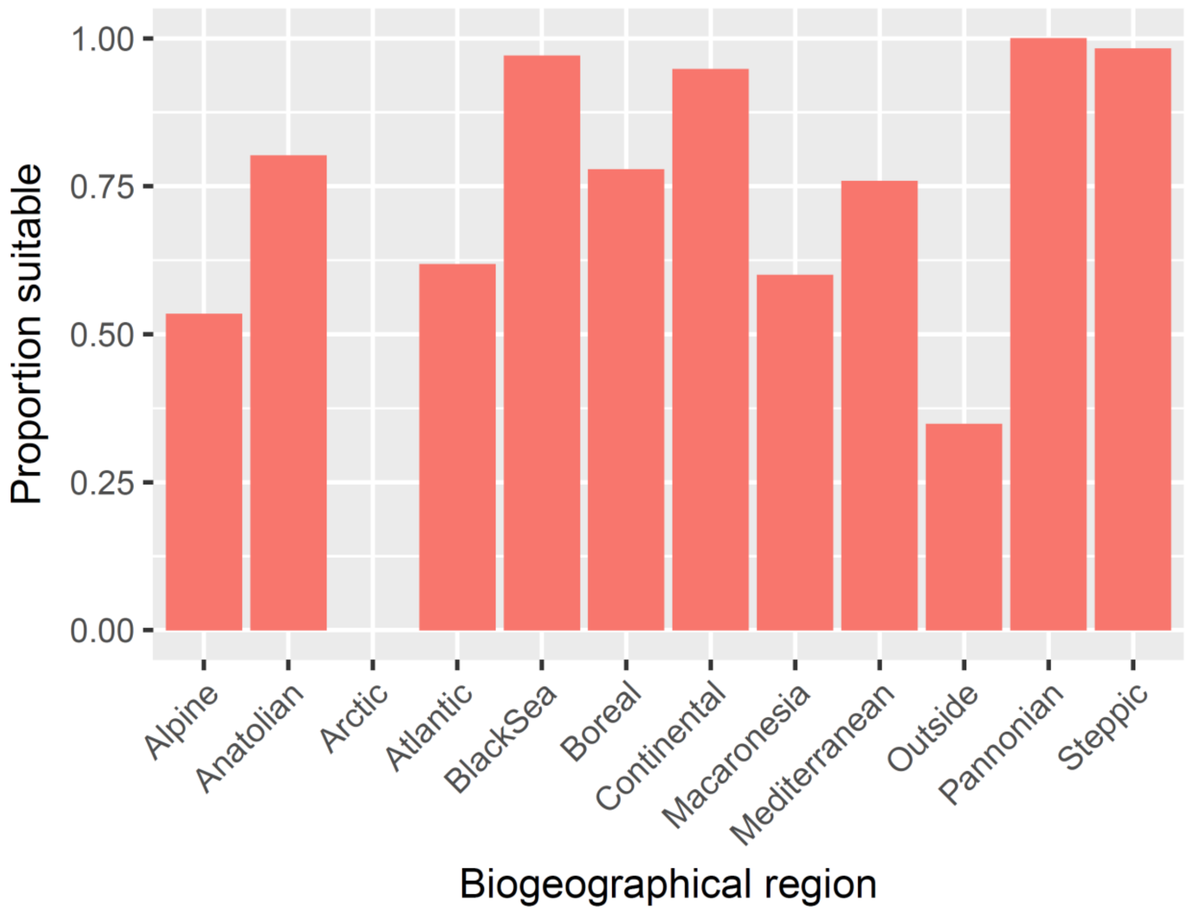
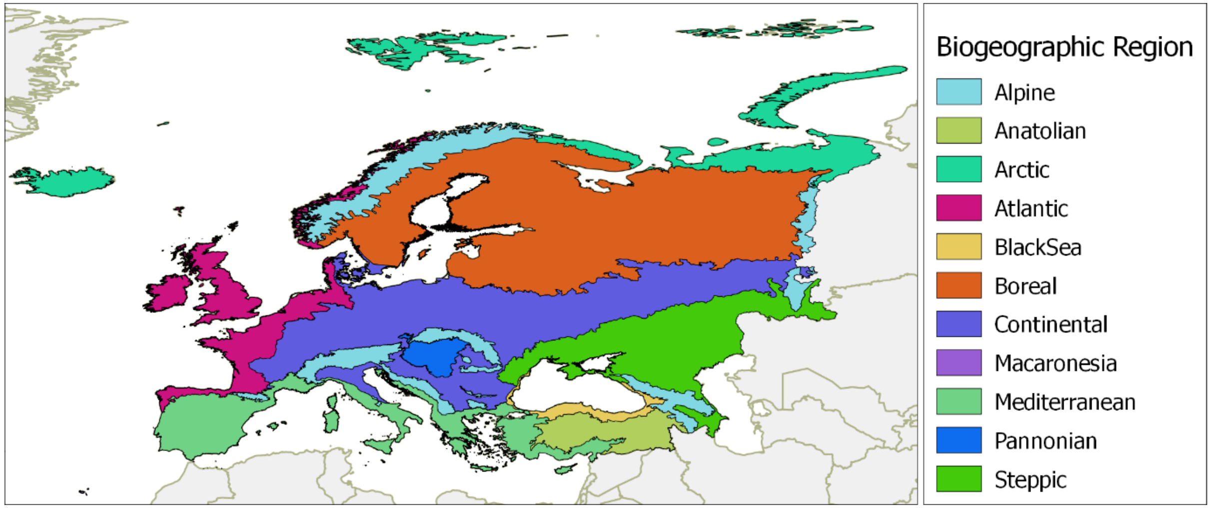


Figure 7. Variation in projected suitability among Biogeographical regions of Europe (Bundesamt fur Naturschutz (BfN), 2003). The bar plots show the proportion of grid cells in each region classified as suitable in the current climate. The coverage of each region is shown in the map below.


Proportion suitable
1.00
0.75
0.50
0.25
0.00
Alpine
Anatolian
Arctic
Atlantic
BlackSea
Boreal
Continental
Macaronesia
Mediterranean
Outside
Pannonian
Steppic
Biogeographical region



Caveats to the modelling

Modelling the potential global distributions of range-expanding species is always difficult and uncertain.

Faxonius rusticus represents an interesting case where it exhibits invasive (adventive) behaviour in its native continent, but so far has not been introduced outside its native continent. Adventiveness in the native continent implies strong natural dispersal constraints are important for its North American distribution. Even though the modelling techniques used here are designed to account for dispersal constraints, the native range was so restricted and contained so few occurrence records that it is likely that the model ability to characterise climatic or environmental responses was severely impeded. Instead, the model was forced to strongly follow the rules for thermal tolerance used to define the unsuitable back ground region. While this was biologically-plausible, it has the effect that the model was only able to resolve effects of summer water temperature. In effect it projects suitability for anywhere with Bio10 of 15-25 °C, the temperature range in which nearly all occurrence records are found.

As such, the projection should be regarded as generous – within the projected suitable region it is likely that other limiting factors could restrict establishment. This includes potentially important variables not included in the model such as dissolved oxygen content.

To remove spatial recording biases, the selection of the background sample was weighted by the density of Malacostraca records on the Global Biodiversity Information Facility (GBIF). While this is preferable to not accounting for recording bias at all, it may not be the perfect null model for species since additional data sources to GBIF were used.

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ANNEX V - Evidence on measures and their implementation cost and cost-effectiveness

Species (common name)	*Orconectes rusticus*
Species (scientific name)	Rusty crayfish
Date Completed	09/10/2017
Authors	Paul Stebbing, Elena Tricarico, revised by Peter Robertson
Version	V5

	Description of measures[1]	**Assessment of implementation cost and cost-effectiveness (per measure)**[2]	**Level of confidence**[3]
Methods to achieve prevention [4]	**Managing the pathways**: The Rusty crayfish was spread within North America through a variety of pathways. Here we have identified two possible pathways of introduction relevant to Europe: i) as live baits/live food and ii) as an ornamental species (Hamr 2002; Mrugala et al. 2015). The adoption and enforcement of appropriate legislation and codes of best practice could reduce the likelihood of introduction.	Legislation can be a very effective method of limiting the risk of introduction but requires sufficient sustained enforcement effort (Scott 2000). In addition, this should be coupled with a good education programme to increase public awareness (Stebbing 2016). A ban of live sale would be an effective means of limiting the risk of introduction of the species through the pathways identified. As there are other crayfish species that pose no or little risk available to the aquarium and live food trades (e.g. some *Cherax* and *Cambarellus* species; Chucholl & Wendler 2017), the ban of live sale of rusty crayfish as well as other invasive alien crayfish would have little or no economic impact. While there may be limited opposition to such legislation it would be considered very minor. Costs of	MEDIUM

		implementation could be kept to a minimum by utilising existing enforcement processes, for example those in place for the management of aquatic animal diseases required under EU Directive 2006/88.	
	Increasing public awareness: the species is already in the ornamental internet trade in Europe (Mrugala et al. 2015).	Intentional dumping from citizens can cause the introduction of this species as already recorded for other crayfish sold for ornamental purposes (e.g. the marbled crayfish; Kouba et al. 2014). Campaigns to educate and increase awareness on IAS are an effective way to curb illegal introductions, especially those targeted at specific sectors. Public awareness campaigns, however, do need to be maintained so they do not drop out of the collective consciousness, but also renewed periodically to avoid fatigue.	MEDIUM
	Effective surveillance and reporting: *Faxonius rusticus* can be misidentified with other congeneric as has happened in the past (Chucholl & Daudey 2008). A simple and clear identification sheet could be drafted and distributed to different stakeholders (e.g. anglers, aquarists) to increase the probability of an early detection and rapid response (e.g. some examples on other crayfish: http://www.life-rarity.eu/images/pdf/download/mazzoni_2004.pdf; http://www.nonnativespecies.org/factsheet/factsheet.cfm?speciesId=2498; https://nas.er.usgs.gov/queries/FactSheet.asp	Traps can be used for surveillance and monitoring in the EU, even if not always effective when the species is at low density. In North America, eDNA has been used to successfully detect the species at low density (Dougherty et al. 2016), even in large lakes (Larson et al. 2017). This tool can be considered also for the EU. Citizen science could be promoted to monitor the possible introduction and spread of the species.	MEDIUM

	x?speciesID=214; http://invaznidruhy.nature.cz/res/archive/327/040255.pdf?seek=1478683286)		
Methods to achieve eradication [5]	**Eradication of aquatic species is very challenging.** Prevention remains the best way to deal with the species. Management practices can be more effective at the early stage of invasion in a closed system (e.g. a pond), but not in an open system. An **integrated approach** is recommended (Gherardi et al. 2011; Stebbing 2016; Stebbing et al. 2014).	The suggested methods are coming from European experience on other invasive alien crayfish and from studies on rusty crayfish in US.	
	Mechanical removal: the use of baited traps of various designs (Swedish traps, Evo-traps, collapsible traps, fyke nets, seine nets, etc.) or by electrofishing can reduce the density of the populations.	Traps are very simple and user friendly, and their use is generally accepted by the public. Traps should be set to avoid the capture or harm of non-target organisms (such as amphibians, grass snakes, turtles). Recent work has suggested that trapping during periods where females carrying eggs are most abundant has the greatest impact on the population (Stebbing 2016). Frequent emptying of traps can increase capture rates since previously captured crayfish prevent other crayfish from entering the trap (Gherardi et al. 2011; Stebbing 2016). However, juveniles and ovigerous females can be trap shy and thus less trapped; moreover, long-term trapping programmes are necessary to be effective and this leads to a cost of manpower (it depends by the type of	HIGH

		water body: e.g. 2 people on a boat in 3 hours can cover a lake of 1 ha with 120 traps). Electrofishing is less used and limited in its application to certain habitats (e.g. shallow, clear water; small water systems; Stebbing 2016). Usually mechanical removal (e.g. trapping) is coupled with another technique to achieve the eradication (or near an eradication). Autocidal methods such as sterilisation have been suggested to be an effective means of enhancing the effectiveness of physical removal (Stebbing et al. 2014).	
	Physical methods: drainage of ponds may be used in the case of confined populations.	Very little is known about the efficacy of these methods. In cases where a single pond has been invaded, it may be possible to drain the pond, effectively destroying the population, but also the habitat. However, drought cannot be effective at eradication of some species, especially those that burrow (Gherardi et al. 2011). Even if burrowing activity of the rusty crayfish is uncommon in the US, it can change in Europe as already observed with other alien crayfish post-introduction (Tricarico & Aquiloni 2016).	LOW
	Biocides: chemicals can be used in certain cases. Many effective maintenance management projects employ chemicals, alone or in concert with mechanical or physical methods.	The synthetic pyrethroid BETAMAX VET was used in Europe to successfully eradicate the signal crayfish from some ponds (five small ponds, the largest measuring approximately 2000 m^2 surface area; Sandodden & Johnsen 2010). Similarly, the natural pyrethroid Pyblast was used with	HIGH

		different success to eradicate from some areas the signal crayfish and the red swamp crayfish in Europe (Gherardi et al. 2011). For example, in Scotland for signal crayfish sites treated were an isolated gravel-pit, c. 9,000 m^3; three dammed ponds, c. 5,000 m^3 and a leaking, offline pond, c. 6,000 m^3 (Peay et al. 2006), while in Italy for the red swamp crayfish a small part of a ditch (c 700 m^2) was treated (Cecchinelli et al. 2011). Laboratory tests have shown that the synthetic pyrethroid Baythroid kills rusty crayfish and that concentrations as high as 25 µl l-1 were necessary to kill rusty crayfish in the field (Bills & Marking 1988). Other chemicals have been tested and suggested to control alien invasive crayfish (Gherardi et al. 2011). However, these chemicals are not aquatic species selective and can be expensive. Moreover, they can cause environmental damage and problems with public opinion; they are not approved for use in all the Member States and can only be applied in very particular situations. Alternative means of deploying chemicals, such as via “attract and kill” feeding stations may be a means of reducing environmental damage (El-Sayed et al. 2009; see the autocidal methods).	
	Autocidal methods: they include the sterile male release technique (SMRT) and the use of sex pheromones. SMRT is based on capturing or rearing, sterilizing, and	In a pond (7 ha) located in North Italy, a two-year SMRT programme using males sterilised with X-rays coupled with intensive trapping has been proved to cause a reduction of 87%	MEDIUM

	releasing large numbers of males into the wild to mate females, who will then produce non-viable eggs. It has been successful in the control of some insect pests and aquatic vertebrates, such as sea lamprey *Petromyzon marinus*. Sex pheromones are widely used to control insect pests.	in the abundance red swamp crayfish (Aquiloni & Zanetti 2014). In UK, manual removal of gonopods has been successfully used to sterilise males of signal crayfish (Stebbing et al. 2014; Stebbing 2016), even if studies on the field are ongoing to assess its efficacy on long-term removal programmes. These methods have never been applied on rusty crayfish, but there is no apparent reason why they would not be successful. SMRT techniques are species-specific, not harmful to the environment and not problematic for public opinion. Costs depend on the quantity of animals to be sterilized but are usually low. Its use is more effective in closed systems. The presence of sex pheromones has been proved in crayfish (Gherardi et al. 2011; Stebbing 2016). However, their purification and identification have not yet been achieved, even if their use in managing invasive alien crayfish could be very successful. Sex pheromones can be used in the traps to attract and kill the reproductive specimens (El-Sayed et al. 2009).	
Methods to achieve management [6]	All the methods described above for eradication plus the methods below can be used also to manage established populations of rusty crayfish. Integrated approach is always recommended.	See above	See above
	Physical methods: diversion of rivers, and construction of barriers may be used in the	In some cases, exclusion barriers have been effective to contain invasive crayfish	MEDIUM

	case of confined populations.	populations (e.g. preventing them from spreading into headwater reaches; Dana et al. 2011; Frings et al. 2013). However, they can also impede the dispersal of native species.	
	Biological control methods: several studies have revealed that fish predation has an impact on crayfish populations. Fish usually predate juveniles and small sized crayfish, being complementary to trapping.	In Europe, native fish as the eel *Anguilla anguilla*, the pike *Esox lucius*, the perch *Perca fluviatilis* and the pikeperch *Stizostedion lucioperca* have been observed to prey on invasive alien crayfish (Gherardi et al. 2011; Stebbing 2016). In US, in an isolated lake of Wisconsin, Sparkling Lake (1 km^2), a long-term management action (8 years) involving the combination of intensive trapping and the protection of local smallmouth bass from fishing pressure led to the collapse of rusty crayfish (99% of decrease in abundance: Hein et al. 2006, 2007; Hansen et al. 2013). This method is generally acceptable to the public or does not cause environmental damage, even if moving fish would also require certification of fish health and biosecurity protocols. The cost is related mainly to traps and manpower. Native European fish should be used to control crayfish. They can be reintroduced or restocked (after having assessed the feasibility).	HIGH

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