NNSS GB non-native species secretariat

RISK ASSESSMENT SUMMARY

Updated: September 2015

Red King Crab (*Paralithodes camtschaticus*)

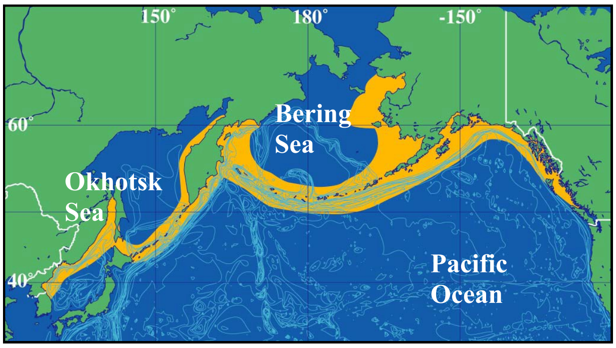
- Large crab with a span from leg to leg of up to 1.4m
- Introduced to the east Barents Sea (Russia) in the 1960s for food
- Usually found on sandy / muddy substrate in marine water around 300m deep
- Omnivorous opportunistic feeder, could have significant effects on native benthic fauna
- May impact of fishing and aquaculture as a predator of commercial shellfish and a nuisance to fisherman

History in GB

Not currently known in GB. It was introduced from the Okhotsk Sea to the east Barents Sea (Russia) for food, but has since spread east along the Kola Peninsula, and west into northern Norway. Entry to GB through natural range expansion is possible, but uncertain.

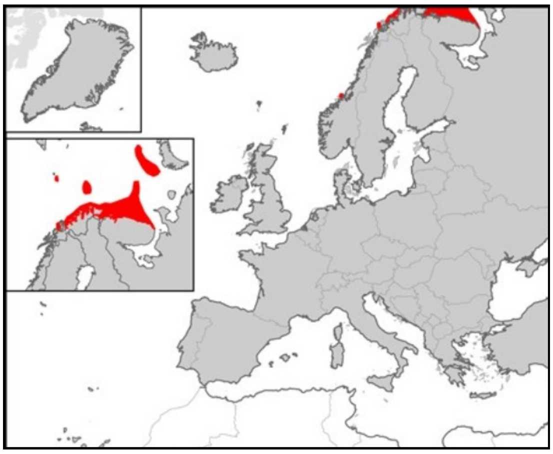
Native distribution

Native to the Okhotsk and Japan Sea, the Bering Sea and the North Pacific Ocean. (Native range in yellow)



Source: NOBANIS, 2014

Distribution in EU



Source: DAISIE, 2014

Impacts

<u>Environmental</u> (major)

- Opportunistic, generalist predator of benthic fauna.
- *P. camtschaticus* has impacted on biodiversity in the Barents Sea through predation and competition, resulting in anoxic sediments in some areas due to the loss of sedimentary organisms.

<u>Economic</u> (moderate)

- In Norway *P. camtschaticus* preys on commercial scallops, mussels and other shellfish, and on the eggs of commercial fish species.
- Impact on fishing and aquaculture by damaging fishing gear and filling nets after becoming entangled, and eating the catch.

<u>Social</u> (minor)

- Nuisance to fisherman (see economic impacts). Potential for injury when detangling crabs from nets.

Introduction pathways

<u>Ballast water</u> (likely) - large volumes transported worldwide regularly which could carry larvae. It is suspected that an individual found in the central Mediterranean Sea was introduced this way.

<u>Natural moderate</u> (moderate) - spread from the Barents Sea to Finnmark is thought to be due to pelagic larval transport and adult migration.

<u>Fishing operations</u> (moderate) - Bycatch is a serious problem in the Barents Sea with crabs becoming entangled in fishing gear. This may be a possible pathway for spread in future.

<u>Intentional planting</u> (moderate) - as a fishery resource

Spread pathways

<u>Natural</u> (intermediate) - Adult crabs are highly mobile. Tagging studies have reported movement of up to 425 km in a year.

<u>Human</u> (rapid) - may be spread in ballast water or intentionally by fisheries

Summary

	Risk	Confidence
Entry	LIKELY	MEDIUM
Establishment	MODERATELY LIKELY	MEDIUM
Spread	INTERMEDIATE	LOW
Impacts	MAJOR	HIGH
Conclusion	MEDIUM	MEDIUM

Information about GB Non-native Species Risk Assessments

The Convention on Biological Diversity (CBD) emphasises the need for a precautionary approach towards non-native species where there is often a lack of firm scientific evidence. It also strongly promotes the use of good quality risk assessment to help underpin this approach. The GB risk analysis mechanism has been developed to help facilitate such an approach in Great Britain. It complies with the CBD and reflects standards used by other schemes such as the Intergovernmental Panel on Climate Change, European Plant Protection Organisation and European Food Safety Authority to ensure good practice.

Risk assessments, along with other information, are used to help support decision making in Great Britain. They do not in themselves determine government policy.

The Non-native Species Secretariat (NNSS) manages the risk analysis process on behalf of the GB Programme Board for Non-native Species. Risk assessments are carried out by independent experts from a range of organisations. As part of the risk analysis process risk assessments are:

- Completed using a consistent risk assessment template to ensure that the full range of issues recognised in international standards are addressed.
- Drafted by an independent expert on the species and peer reviewed by a different expert.
- Approved by an independent risk analysis panel (known as the Non-native Species Risk Analysis Panel or NNRAP) only when they are satisfied the assessment is fit-for-purpose.
- Approved for publication by the GB Programme Board for Non-native Species.
- Placed on the GB Non-native Species Secretariat (NNSS) website for a three month period of public comment.
- Finalised by the risk assessor to the satisfaction of the NNRAP.

To find out more about the risk analysis mechanism go to: www.nonnativespecies.org

Common misconceptions about risk assessments

To address a number of common misconceptions about non-native species risk assessments, the following points should be noted:

- Risk assessments consider only the risks posed by a species. They do not consider the practicalities, impacts or other issues relating to the management of the species. They therefore cannot on their own be used to determine what, if any, management response should be undertaken.
- Risk assessments are about negative impacts and are not meant to consider positive impacts that may also occur. The positive impacts would be considered as part of an overall policy decision.
- Risk assessments are advisory and therefore part of the suite of information on which policy decisions are based.
- Completed risk assessments are not final and absolute. Substantive new scientific evidence may prompt a re-evaluation of the risks and/or a change of policy.

Period for comment

Draft risk assessments are available for a period of three months from the date of posting on the NNSS website*. During this time stakeholders are invited to comment on the scientific evidence which underpins the assessments or provide information on other relevant evidence or research that may be available. Relevant comments are collated by the NNSS and sent to the risk assessor. The assessor reviews the comments and, if necessary, amends the risk assessment. The final risk assessment is then checked and approved by the NNRAP.

*risk assessments are posted online at:
https://secure.fera.defra.gov.uk/nonnativespecies/index.cfm?sectionid=51
comments should be emailed to nnss@apha.gsi.gov.uk

GB NON-NATIVE ORGANISM RISK ASSESSMENT SCHEME

For more information visit: www.nonnativespecies.org

N	QUESTION	RESPONSE	COMMENT
	Name of Organism		***Paralithodes camtschaticus* - Red King Crab**
	Objectives:		Assess the risks associated with this species in GB
	Version:		Final (April 2016) - Original draft January 2012; signed off by NNRAP February 2012; approved by GB Programme Board March 2015; published on NNSS website September 2015.
	Author:		N. Sweet and J. Sewell (MBA)
N	**QUESTION**	**RESPONSE**	**COMMENT**
1	What is the reason for performing the Risk Assessment?		Request by GB Programme Board
2	What is the Risk Assessment area?	Great Britain	
3	Does a relevant earlier Risk Assessment exist?	YES (Go to 4)	Included in a 2009 horizon scanning report published by Natural England (Parrott *et al.* , 2009).
4	If there is an earlier Risk Assessment is it still entirely valid, or only partly valid?	PARTLY VALID OR NOT VALID (Go to 5)	The Natural England report is valid but offers limited information; this risk assessment will provide further, more detailed and more recent information.
	Stage 2: Organism Risk Assessment **SECTION A: Organism Screening**		
5	Identify the Organism. Is the organism clearly a single taxonomic entity and can it be adequately distinguished from other entities of the same rank?	YES (Give the full name & Go to 7)	Phyla: Arthropoda; Class: Crustacea; Subclass: Malacostraca; Order: Decapoda; Family: Lithodidae; Genus/species: *Paralithodes camtschaticus* Might be misidentified with: Phyla: Arthropoda; Class: Crustacea; Subclass: Malacostraca; Order: Decapoda; Family: Lithodidae; Genus/species: *Lithodes maja* (anonymous peer reviewer, pers. comm.)
6	If not a single taxonomic entity, can it be redefined?		
7	Is the organism in its present range known to be invasive, i.e. to threaten species, habitats or ecosystems?	YES (Go to 9)	*P. camtschaticus* is invasive in the Barents Sea. As a large, highly mobile generalist predator, *P. camtschaticus* can significantly impact native benthic communities through predation and competition, particularly during the post-mating/molting spring period when crabs feed most intensively (Jørgensen, 2005; Falk-Petersen *et al* ., 2011). In Norway, local divers report that scallop (*Chlamys islandica*) beds are being reduced due to predation by *P. camtschaticus* (ICES, 2002) and predation on the eggs of commercial fish may have population-level consequences (Falk-Petersen *et al* ., 2011). Conspicuous epibenthic species such as *C. islandica* are especially vulnerable to excessive predation by *P. camtschaticus* (Jørgensen & Primicerio, 2007). Reduced species diversity and biomass have been reported following red king crab invasion in the Barents Sea (Falk-Petersen *et al* ., 2011). Oug *et al* . (2010) reported that sediment habitat quality was degraded due to hypoxic conditions and low biological activity below surface layers. It is suggested that the crab has removed species performing important functions such as bio-irrigation and sediment reworking (Falk-Petersen *et al* . 2011; Oug *et al* ., 2011). Adult crabs spend a large part of the year in deep waters where they prey on soft bottom fauna. Reduction in large epibenthic prey organisms have been reported in areas invaded by the crab. Large mussels and echinoderms have disappeared from some areas and the soft-bottom communities are dominated by small individuals. In some hard-bottom communities predation by juvenile crabs could explain the observed reduction in benthic biomass and diversity (Falk-Petersen *et al.,* 2011).
8	Does the organism have intrinsic attributes that indicate that it could be invasive, i.e. threaten species, habitats or ecosystems?		N/A
9	Does the organism occur outside effective containment in the Risk Assessment area?	NO (Go to 11)	
10	Is the organism widely distributed in the Risk Assessment area?	NO (Go to 11)	
11	Does at least one species (for herbivores, predators and parasites) or suitable habitat vital for the survival, development and multiplication of the organism occur in the Risk Assessment area, in the open, in protected conditions or both?	YES (Go to 12)	Yes. *P. camtschaticus* glaucothoe settle on complex substrates which are coarse or hard and have abundant epifaunal cover, for example pebbles, boulders or shell debris covered with branched hydroids or bryozoans, or mussel colonies (Stevens & Kittaka, 1998). Adult crabs tend to be found on sandy/muddy substrate in deeper water (~300 m) but a shoreward migration to shallow waters occurs for mating and breeding in late winter and early spring (ICES, 2005). Thus, rocky reef habitat and large shallow inlets and bays with coarse substrate and epifaunal cover in UK waters would provide suitable habitat for settlement of glaucothoe. Pelagic larvae consume phytoplankton and zooplankton, and once settled feed on hydroids. Small crabs feed on a variety of prey including sea stars, kelp, egg masses, barnacles and mussels. Mature crabs are opportunistic, omnivorous feeders and known to feed on whatever is readily available in the benthos, including molluscs, echinoderms and polychaetes (ICES, 2005; Jørgensen, 2006; Falk-Petersen *et al* ., 2011); a wide variety of potential prey species occur in the risk assessment area.

12	Does the organism require another species for critical stages in its life cycle such as growth (e.g. root symbionts), reproduction (e.g. pollinators; egg incubators), spread (e.g. seed dispersers) and transmission, (e.g. vectors)?	NO (Go to 14)	
13	Is the other critical species identified in question 12 (or a similar species that may provide a similar function) present in the Risk Assessment area or likely to be introduced? If in doubt, then a separate assessment of the probability of introduction of this species may be needed.		
14	Does the known geographical distribution of the organism include ecoclimatic zones comparable with those of the Risk Assessment area or sufficiently similar for the organism to survive and thrive?	YES (Go to 16)	*P. camtschaticus* is native to the Okhotsk and Japan Sea, the Bering Sea, and the north Pacific Ocean. The crab occurs as far south as Korea. Since the intentional release into the Kolafjord in the east Barents Sea (Russia) the crab has spread both east along the Kola Peninsula, and westwards into the Norwegian zone (ICES, 2005). Literature suggests that water temperature may be an important physical feature structuring distribution. Nakanishi (1987; cited in Loher & Armstrong, 2005) reported that embryo development was optimized at 3–8 °C, and observed very slow development at lower temperatures. Temperature tolerance was recorded to range from -1.7 to +18 ºC with an optimum of +2 to +7 ºC (Falk-Petersen, 2004). This temperature range is comparable with that of the risk assessment area. In a 2002 report of the Benthos Ecology Working Group, it was suggested that *P. camtschaticus* migration could proceed as far south as Spain (ICES, 2002), however there appears to be insufficient information to confirm this.
15	Could the organism establish under protected conditions (e.g. glasshouses, aquaculture facilities, terraria, zoological gardens) in the Risk Assessment area?	YES (Go to 16)	Theoretically, *P. camtschaticus* larvae could settle in areas of aquaculture.
16	Has the organism entered and established viable (reproducing) populations in new areas outside its original range, either as a direct or indirect result of man's activities?	YES (Go to 17)	*P. camtschaticus* was introduced from the Okhotsk Sea to the Barents Sea by Russian scientists during the 1960s. Larvae, juveniles and adult crabs were intentionally released in the east Barents Sea (Russia) with the aim of creating a valuable fishing resource. Since then, successful breeding populations have become established and distribution has spread further east into Russian waters and west into Norwegian waters (ICES, 2005).
17	Can the organism spread rapidly by natural means or by human assistance?	YES (Go to 18)	*P. camtschaticus* has become well established in the Barents Sea over a period of 40 years, and its range has extended east and west since the initial introduction. Migration by mature crabs (including gravid females), which can reach 20 years of age, and the pelagic period of the zoea larvae make it likely that a continuing geographical expansion will be observed (Pederson *et al*., 2006). Larval spread within ballast water must be considered as a potential vector, and associations with fishing operations may also transport adult crabs (*P. camtschaticus* was reported to be a nuisance in traditional fisheries, getting entangled in fishing gear (Falk-Petersen, 2004; Furevik *et al*., 2008)). If crabs become entangled with fishing gear they may be transported considerable distance before being discarded/freed.
18	Could the organism as such, or acting as a vector, cause economic, environmental or social harm in the Risk Assessment area?	YES OR UNCERTAIN (Go to 19)	As a top benthic predator *P. camtschaticus* could have a significant negative impact upon benthic community structure. This species is an opportunistic omnivore which will prey upon a wide variety of the available benthos. Thus the crab could have an impact on substrates that represent important habitat, feeding areas and nursery areas for commercial and non-commercial species (Falk-Petersen *et al*., 2011). In the Bering Sea reduced numbers of clams and sea stars have been reported in areas of high *P. camtschaticus* abundance (Falk-Petersen, 2004). In Norway, local divers report that commercial scallop-beds (*Chlamys islandica*) and flatfish populations are being reduced due to predation by *P. camtschaticus* (ICES, 2002). In the Barents Sea, bycatch of *P. camtschaticus* causes problems for fishermen through damage to gear and catches (Furevik *et al*., 2008). *P. camtschaticus* may be a direct competitor of demersal fish, including commercial species. Fish species with a coastal distribution would be most affected (Gerasimova, 1997). Fish populations could be affected through indirect mechanisms such as competition for food and habitat and predation on eggs and larvae (Falk-Petersen *et al*., 2011). The crab could be a food competitor of benthic-feeding fish (e.g. place, haddock, wolfish, cod) and feed on eggs and roe (capelin and particular Arctic lumpsucker may be vulnerable). The king crab is also a vector for a cod parasite (*Johanssonia arctica*) that could increase mortality in cod populations. This has not been verified for the Norwegian cod stocks in areas invaded by the crab (see Hemmingsen *et al*., 2005, referred to in Falk-Petersen, 2011).
19	This organism could present a risk to the Risk Assessment area and a detailed risk assessment is appropriate.	Detailed Risk Assessment Appropriate GO TO SECTION B	
20	This organism is not likely to be a harmful non-native organism in the Risk Assessment area and the assessment can stop.		

B	SECTION B: Detailed assessment of an organism's probability of entry, establishment and spread and the magnitude of the economic, environmental and social consequences			
	Probability of Entry	**RESPONSE**	**UNCERTAINTY**	**COMMENT**
1.1	List the pathways that the organism could be carried on. How many relevant pathways can the organism be carried on?	moderate number - 2	MEDIUM -1	(1) Natural spread: Following introduction into the Barents Sea, successful breeding populations have established and spread along the coasts of Finnmark, north Norway. This spread is thought to have resulted from a combination of both pelagic larval transport and adult migration (Pedersen *et al*., 2006; Loher & Armstrong, 2005). (2) Larval transport in ballast water: *P. camtschaticus* larvae hatch in early winter and pass through four zoeal stages before settlement in July/August. It is assumed that this prolonged larval phase would enable transport via ballast water but no information was found to verify this. The Norwegian Ministry of Fisheries is performing a detailed risk assessment into the potential for spreading of *P. camtschaticus* via ballast water. This study began in 2003 and is planned to run for 10 years (ICES, 2005). In 2008 an individual estimated to be ten years old was found in the central Mediterranean Sea (Faccia *et al*., 2009). The authors suggest that ballast water was the most likely means of introduction, although this is speculative. (3) Movement associated with fishing operations: *P. camtschaticus* bycatch has been a serious problem in the Barents Sea, with crabs becoming entangled in fishing gear (Furevik *et al*., 2008). Although currently not likely to be an issue due to landing practices in its existing range, unintentional translocation of crabs during fishing operations may be a possible pathway for spread in the future. (4) Intentional planting of *P. camtschaticus* as a fishery resource.
1.2	Choose one pathway from the list of pathways selected in 1.1 to begin the pathway assessments.	Larval transport via ballast water		Transport via ballast water is a potential pathway for pelagic larvae of *P. camtschaticus*. Large volumes of ballast water are transported and exchanged regularly around the globe. Should the Northwest Passage become a viable shipping route, larvae from the north Pacific *P. camtschaticus* populations may also be unintentionally introduced.
1.3	How likely is the organism to be associated with the pathway at origin?	likely - 3	MEDIUM -1	*P. camtschaticus* larvae develop in the surface waters of the coastal zone and pass through four pelagic stages in about two months (Marukawa, 1933, cited in Pedersen *et al.*, 2006). Development from hatching to settlement takes approximately 460◦-days (Kurata, 1960, cited in Pedersen *et al.*, 2006). During this period there is potential for inclusion in ballast water uptake.
1.4	Is the concentration of the organism on the pathway at origin likely to be high?	moderately likely - 2	MEDIUM -1	No information was available regarding the concentration of larvae at origin, but as regular shipping operations occur in the regions of current *P. camtschaticus* distribution it is assumed that larvae will be taken up with ballast water. Fecundity varies between 15 000 - 500 000 eggs per female (Jorgensen, 2005).
1.5	How likely is the organism to survive existing cultivation or commercial practices?	very likely - 4	MEDIUM -1	*P. camtschaticus* supports an important fishery in both its native and introduced range. Despite fluctuations in abundance, stocks appear to be stable (NOAA, 2009). The king crab is well established in the Barents Sea and is managed as a commercial species to be harvested to give maximum sustainable yield in Russia and the eastern part of Norway (east of 26 ºE). There are no indications that this management strategy will change. An open access fishery partly subsidised by the Norwegian government is believed to slow down, but not stop, further spread of the king crab west of 26 ºE.
1.6	How likely is the organism to survive or remain undetected by existing measures?	very likely - 4	LOW - 0	Planktonic larvae are unlikely to be detected in ballast water without stringent sampling procedures, but may be found in plankton tow nets.
1.7	How likely is the organism to survive during transport /storage?	likely - 3	MEDIUM -1	Salinity, temperature and oxygen depletion tolerances will affect survival during transport. Laboratory studies revealed that the optimal salinity for larvae, under various temperatures, is 26.8-40.2 ppt. (Nakanishi, 1985, cited in Jewett & Onuf, 1988). Larvae may tolerate water-column temperatures of -1.8 to 18 °C, survival appears to be best at 5-10 °C (Jewett & Onuf, 1988). Larvae and juveniles appear to be more tolerant of reduced salinities than adult crabs. Larvae were found to tolerate salinities as low as 12 ppt. (Thomas & Rice, 1992).
1.8	How likely is the organism to multiply/increase in prevalence during transport /storage?	very unlikely - 0	LOW - 0	Larvae would not multiply/increase in prevalence during transport/storage.
1.9	What is the volume of movement along the pathway?	major - 3	LOW - 0	The lowest estimates of the volumes of ballast water taken up, transferred and discharged into world oceans each year are around 3 billion tonnes (GloBallast, 2004). About 17 million tonnes of ballast water is discharged at just under half of the 129 ports in England and Wales (MAFF, 1999), and the total for Scotland is almost 26 million tonnes annually (Macdonald, 1994). Should the Northwest Passage become a viable shipping route then volume of movement and potential for introduction from the north Pacific would increase significantly.
1.10	How frequent is movement along the pathway?	very often - 4	LOW - 0	Shipping operations occur regularly between British ports and those in regions with established *P. Camtschaticus* populations. Should the Northwest Passage become a viable shipping route then movement and potential for introduction from the north Pacific may increase.
1.11	How widely could the organism be distributed throughout the Risk Assessment area?	widely - 3	LOW - 0	Suitable habitat occurs throughout British waters, as do prey species. The species' ability to spread through larval transport and its highly mobile, migratory nature would facilitate widespread distribution.

1.12	How likely is the organism to arrive during the months of the year most appropriate for establishment ?	likely - 3	MEDIUM -1	*P. camtschaticus* larvae can tolerate water temperatures of -1.8 to 18 °C, and juveniles can tolerate temperatures of least 0-15 °C (Jewett & Onuf, 1988). These temperatures fall within the annual range expected for water column temperatures in British waters. Therefore arrival at any point during the year would be suitable for establishment.
1.13	How likely is the intended use of the commodity (e.g. processing, consumption, planting, disposal of waste, by-products) or other material with which the organism is associated to aid transfer to a suitable habitat?	likely - 3	LOW - 0	If larvae survive transport via ballast water then release would aid transfer to a suitable habitat.
1.14	How likely is the organism to be able to transfer from the pathway to a suitable habitat?	likely - 3	LOW - 0	If ballast water exchange occurs in open seas rather than in coastal areas, transfer of planktonic larvae to suitable substrate will be hampered. However, if ballast water is released in ports, estuaries or other coastal areas then establishment will be dependant on availability of suitable habitat. *P. camtschaticus* glaucothoe display the ability of prolonged swimming when searching for suitable substrate on which to settle (Stevens, 2003).

	Probability of Establishment	RESPONSE	UNCERTAINTY	COMMENT
1.15	How similar are the climatic conditions that would affect establishment in the Risk Assessment area and in the area of current distribution?	similar - 3	MEDIUM -1	Based on laboratory and field data, different life stages of *P. camtschaticus* have specific temperature tolerances and optima (Jewett & Onuf, 1988). Optimal temperatures for eggs are 3-8 °C. Larvae may tolerate water-column temperatures of -1.8 to 18 °C, however survival appears to be best at 5-10 °C. Juveniles can tolerate temperatures of at least 0-15 °C, but their optimal temperatures are thought to be 5-10 °C. An optimum water temperature range for adults is thought to be 2-7 °C. The authors also suggest that no successful development of larvae occurs at temperatures of 20 °C. If sea temperatures in the risk assessment area rise in the future, it is assumed that the potential for establishment may be reduced. The discovery of a mature individual in the central Mediterranean Sea in 2008 poses questions as to the ability of this species to survive in warm temperate seas. It is currently unknown how the specimen arrived in the Mediterranean Sea, or whether there are other crabs present in the cooler, deeper waters below the summer thermocline (Faccia *et al.* , 2009).
1.16	How similar are other abiotic factors that would affect establishment in the Risk Assessment area and in the area of present distribution?	similar - 3	LOW - 0	Water temperature, salinity and availability of suitable habitat are similar in the risk assessment area. Water temperatures are higher but are still within the tolerated range.
1.17	How many species (for herbivores, predators and parasites) or suitable habitats vital for the survival, development and multiplication of the organism species are present in the Risk Assessment area? Specify the species or habitats and indicate the number.	very many - 4	LOW - 0	Complex habitats (with a well developed sessile community structure of, for example, sponges, hydroids and bryozoans or mussel beds), required for settlement of *P. camtschaticus* glaucothoe and the protection of juveniles and moulting/spawning adults, occur extensively within the risk assessment area. Soft sediment substrates preferred by adults are also widespread. *P. camtschaticus* diet varies with life stage. Pelagic larvae consume phytoplankton and zooplankton, and once settled feed on hydroids. Small crabs feed on a variety of prey including sea stars, kelp, egg masses, barnacles and mussels. Mature crabs are opportunistic, omnivorous feeders and are known to feed on whatever is readily available in the benthos, including molluscs, echinoderms and polychaetes (ICES, 2005; Jørgensen, 2006). Prey species are also widespread within the risk assessment area.
1.18	How widespread are the species (for herbivores, predators and parasites) or suitable habitats vital for the survival, development and multiplication of the organism in the Risk Assessment area?	widespread - 4	LOW - 0	Species and habitats vital for survival, development and multiplication of *P. camtschaticus* are widespread in the risk assessment area.
1.19	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 the risk assessment area?	N/A		No one species is critical to the life cycle of *P. camtschaticus* .
1.20	How likely is it that establishment will not be prevented by competition from existing species in the Risk Assessment area?	likely - 3	LOW - 0	*P. camtschaticus* is a large, highly mobile, top benthic predator. The success of *P. camtschaticus* in Norwegian waters suggests that competition from native species would be unlikely to prevent establishment (ICES, 2005).
1.21	How likely is it that establishment will not be prevented by natural enemies already present in the Risk Assessment area?	likely - 3	LOW - 0	There are few natural predators of the adult *P. camtschaticus* in the risk assessment area although some predation may occur from seals and larger fish. Predation by planktivorous fish (flatfish, Pollock, salmon) could determine larval supply, post-larvae could be predated by a number of fish and sea stars, i.e. juvenile crabs < 3 years (Falk-Petersen *et al* ., 2011). Predators of earlier life stages of *P. camtschaticus* also include octopuses, other king crabs (they are cannibalistic), and several new species of nemertean worms, which have been found to eat *P. camtschaticus* embryos (NOAA, 2009). There is no conclusive evidence that predation controls the population in its native area of distribution, and no evidence that predation controls the population in the Barents Sea, although it has not been looked into (Falk-Petersen *et al.* , 2011).
1.22	If there are differences in man's management of the environment/habitat in the Risk Assessment area from that in the area of present distribution, are they likely to aid establishment? (specify)	unlikely - 1	MEDIUM -1	More stringent controls on ballast water exchange may hinder establishment (for example the requirement for offshore exchange of ballast water). Otherwise management of environment/habitat is likely to be similar. The king crab is managed as a commercial species in the eastern part of Norway and the Russian management zone, with restrictions on harvest of females. This management strategy is likely to aid further spread of pelagic larvae since it promotes a relatively large king crab population.
1.23	How likely is it that existing control or husbandry measures will fail to prevent establishment of the organism?	likely - 3	LOW - 0	Ballast water is recognised as a major vector for the unintentional transfer of non-native organisms, and existing controls have long been deemed inadequate to prevent such introduction (Olenin *et al* ., 2000). The International Convention for the Control and Management of Ships' Ballast Water and Sediments was adopted in 2004 (IMO, 2009). However all of the recommended approaches are subject to limitations.
1.24	How often has the organism been recorded in protected conditions, e.g. glasshouses, elsewhere?	very rare - 0	HIGH -2	The species may be kept in public aquaria (e.g. in Tromsø and Bergen, Norway).

1.25	How likely is the reproductive strategy of the organism and duration of its life cycle to aid establishment?	likely - 3	LOW - 0	The two to three month pelagic larval period, and the migratory capabilities of the mature crab (coupled with a long lifespan of 20 + years) make successful range expansions more likely (Jørgensen, 2005). Females brood eggs underneath their tail for approximately 11 months, during which time migrations are undertaken. Fecundity varies between 15 000 to nearly 500 000 eggs (Jewett & Onuf, 1988).
1.26	How likely is it that the organism's capacity to spread will aid establishment?	likely - 3	LOW - 0	Pelagic larvae are passive and may be transported considerable distances by currents (Pedersen *et al.* , 2006). Adult males are known to migrate from wintering grounds to mating areas. Tagging studies in Bristol Bay, Alaska, indicated movement at rates of up to 0.67 km per day, with a single year movement of as much as 425 km (Loher & Armstrong, 2005). Following the intentional release of *P. camtschaticus* into the Barents Sea during the 1960s, its presence was reported in fjords in northern Norway, 150 km away from the point of release, within 10 years (Orlov & Ivanov, 1978).
1.27	How adaptable is the organism?	moderately adaptable - 2	MEDIUM -1	*P. camtschaticus* is an opportunistic feeder usually feeding on the most abundant benthic organisms; hence it adapts its diet to include whatever prey is available. Data concerning this species' ability to adapt to warmer water temperatures is lacking but the crab does occur as far south as Korea in its native range. It has been suggested that migration from Norwegian waters as far south as Spain is possible (ICES, 2002). In 2008 an individual estimated to be ten years old was found in the central Mediterranean Sea (Faccia *et al* ., 2009). The authors suggest that ballast water was the most likely means of introduction, and if true, *P. camtschaticus* must be capable of surviving and growing to maturity in warm temperate seas.
1.28	How likely is it that low genetic diversity in the founder population of the organism will not prevent establishment?	likely - 3	LOW - 0	Jørstad *et al.* (2007) compared *P. camtschaticus* samples from the Barents Sea (northern Norway) with samples from the Bering Sea and Kamchatka regions in the Pacific Ocean. The authors identified no reduction in genetic variation. Therefore, low genetic diversity is unlikely to prevent further spread or establishment.
1.29	How often has the organism entered and established in new areas outside its original range as a result of man's activities?	few - 1	LOW - 0	The only record of successful establishment outside of the native range is that of the Barents Sea population, introduced in the 1960s and now successfully established and spreading along the Norwegian coast. One mature individual was found in the Mediterranean Sea in 2008; however it is unknown when/how it arrived or whether other crabs are present in cooler, deeper waters below the thermocline (Faccia *et al* ., 2009).
1.30	How likely is it that the organism could survive eradication campaigns in the Risk Assessment area?	likely - 3	LOW - 0	It has been suggested that the species could be maintained at minimal population densities, and further spread prevented, by allowing and promoting open fisheries for the species (Falk-Petersen, 2004). This is more a preventative and restrictive measure than one of eradication. Eradication campaigns would be very difficult to implement due to the migratory nature of the crab and planktonic larval stage. Should the species become more widespread, the commercial value of the species (the incentive to fish) may be reduced.
1.31	Even if permanent establishment of the organism is unlikely, how likely is it that transient populations will be maintained in the Risk Assessment area through natural migration or entry through man's activities (including intentional release into the outdoor environment)?	moderately likely - 2	MEDIUM -1	If accidental introduction via ballast water occurs, it seems reasonable to assume that re-introduction could occur. This will be less likely if more stringent controls on ballast water exchange are implemented. Prevention of introduction into the risk assessment area would require significant effort into the sampling and treatment of ballast water to identify planktonic larvae. Alternatively, ballast water exchange could be performed at considerable distance from shore. In response to this issue, The International Convention for the Control and Management of Ships' Ballast Water and Sediments was adopted in 2004 (IMO, 2009). The crab has been found at depths down to 510 m (Falk-Petersen *et al.* , 2011); it is therefore conceivable that migration to GB waters may occur over time.

	Spread	RESPONSE	UNCERTAINTY	COMMENT
2.1	How rapidly is the organism liable to spread in the Risk Assessment area by natural means?	intermediate - 2	LOW - 0	Pelagic larvae are passive and may be transported considerable distances by currents (Pedersen *et al*., 2006). Adult males are known to migrate from wintering grounds to mating areas. Tagging studies in Bristol Bay, Alaska, indicated movement at rates of up to 0.67 km per day, with a single year movement of as much as 425 km (Loher & Armstrong, 2005). Jørgensen *et al*. (2007) report crabs walking a distance of 270 m in one hour. Following the intentional release of *P. camtschaticus* into the Barents Sea during the 1960s, its presence was reported in northern Norwegian fjords 150 km away from the point of release within 10 years (Orlov & Ivanov, 1978)
2.2	How rapidly is the organism liable to spread in the Risk Assessment area by human assistance?	rapid - 3	LOW - 0	Accidental transport via ballast water could accelerate spread of *P. camtschaticus* larvae once established within the risk assessment area. Furthermore, intentional introduction and relocation by fisheries may lead to spread.
2.3	How difficult would it be to contain the organism within the Risk Assessment area?	very difficult - 4	LOW - 0	*P. camtschaticus* has successfully established and spread following its initial introduction into the Barents Sea. It would be impossible to prevent the spread of planktonic larvae in currents once establishment had occurred. It has been suggested that the population could be controlled with active unrestricted fisheries (WWF-Norge, 2002; Falk-Petersen, 2004). The Norwegian government has established a boundary (west of 26°E) where the management goal is to stop, or as far as possible limit, the expansion of *P. camtschaticus*. In this area an open access fishery for *P. camtschaticus* has been implemented (Fisheries. no, 2009).
2.4	Based on the answers to questions on the potential for establishment and spread define the area endangered by the organism.		LOW - 0	Areas with suitable habitat (adults: sediment- sand/muddy substrate; settlement of glaucothoe: complex substrate (boulders, pebbles, shell fragment etc. with associated sessile community e.g. bryozoans, sponges, hydroids, mussels)) and prey species are widespread. This may include protected areas (e.g. Special Areas of Conservation) and areas of aquaculture/mariculture. SAC habitats potentially at risk are shallow bays and inlets (764 560 ha), reefs (5 723 600 ha) and sandbanks (733 106 ha) (JNCC, 2009).

	Impacts	RESPONSE	UNCERTAINTY	COMMENT
2.5	How important is economic loss caused by the organism within its existing geographic range?	moderate - 2	HIGH -2	In the risk assessment area, economic impacts may arise through predation on commercial scallops, mussels and other shellfish, and also on the eggs of commercial fish species. However these would be difficult to quantify and have not been effectively recorded in areas of current distribution. Although *P. camtschaticus* is a valuable fishery resource in both its native range and in the Barents Sea (following its intentional introduction), bycatch problems are commonly reported with crabs becoming entangled in and damaging fishing gear, filling nets or eating the catch. In an attempt to ameliorate these issues, licences to catch *P. camtschaticus* are issued to those fishers encountering bycatch issues (Fisheries. no, 2009). Negative impacts have largely been resolved by lifting fishing gear off the seabed (Falk-Petersen, pers. comm.).
2.6	Considering the ecological conditions in the Risk Assessment area, how serious is the direct negative economic effect of the organism, e.g. on crop yield and/or quality, livestock health and production, likely to be? (describe) in the Risk Assessment area, how serious is the direct negative economic effect of the organism, e.g. on crop yield and/or quality, likely to be?	moderate - 2	HIGH -2	The figures are based on (a) - shallow bays and inlets (764 560 ha), reefs (5 723 600 ha) and sandbanks (733 106 ha) in UK waters (JNCC, 2009). These habitats are potentially suitable sites for establishment of *P. camtschaticus*. However *P. camtschaticus* occurs in different habitats during different life stages. Young crabs establish in shallow waters, and adults generally reside at depths of up to 300 m. Adults migrate to shallow waters (10-30 m) in late winter and early spring to breed (Jorgensen, 2005). Therefore, the figure is a very conservative estimate based only on JNCC marine habitat figures. (b) - Due to the successful establishment of *P. camtschaticus* in the Barents Sea, all suitable areas are considered 'at risk' for the purposes of this assessment although uncertainty is high. (C-) *P. camtschaticus* has not yet become established in UK waters. (d) Total value of UK mussel, oyster, clam, cockle and scallop production in 2006 was £35.77 million (FAO, 2009). Negative economic impacts to traditional fisheries (related to bycatch) have not been included due to difficulties in quantifying speculative costs. (e) Estimated final proportion of the resource value at risk is based on the possibility of *P. camtschaticus* becoming widely established . Again, there is very high uncertainty with such an estimation. (f) *P. camtschaticus* had established a reproductive population within 10 years following introduction into the Barents Sea (Jorgensen, 2005). (g) The Norwegian government has set a boundary (west of 26°E) and implemented an open access fishery aiming to limit the spread of *P. camtschaticus*, but the costs and success of this incentive have not been reported (Fisheries. no, 2009). In a comprehensive modelling exercise of the economic impacts of *P. camtschaticus* in the Barents Sea, Falk-Petersen (pers. comm.) concludes that a lack of knowledge on ecosystem impact makes a full assessment impossible. Also important to note that *P. camtschaticus* provides a valuable fishery resource.
2.7	How great a loss in producer profits is the organism likely to cause due to changes in production costs, yields, etc., in the Risk Assessment area?	moderate - 2	HIGH -2	Estimating the potential economic loss to fishers/aquaculture is difficult. Costs associated with damaged gear from entanglement of the crabs would be reported but time spent detangling, reduction in catch due to predation of the crab on bait/catch are less obvious. The costs of altering fishing gear such as gill nets to lift off from the seabed are unknown. Reports that commercial scallop beds in Norway are being reduced by *P. camtschaticus* predation (ICES, 2002), and the susceptibility of epibenthic fauna to predation by *P. camtschaticus* would suggest that mollusc fisheries in the risk assessment area could be affected if *P. camtschaticus* establishment were successful. Total value of UK mussel, oyster, clam, cockle, arkshell, scallop and pecten production in 2006 was £35.77 million (FAO, 2009). *P. camtschaticus* may also compete directly with demersal groundfish, including commercial species (Gerasimova, 1997). In the species' current range, losses through gear damage have been ameliorated by altering fishing behaviour.
2.8	How great a reduction in consumer demand is the organism likely to cause in the Risk Assessment area?	moderate - 2	HIGH -2	If native shellfish stocks/seafish landings were affected by the establishment of *P. camtschaticus* then market prices could be expected to rise, reducing consumer demand.
2.9	How likely is the presence of the organism in the Risk Assessment area to cause losses in export markets?	unlikely - 1	HIGH -2	Whilst export markets in native shellfish could be affected negatively due to production losses, the *P. camtschaticus* is a valuable commercial species and where fisheries exist for this species, considerable export trade occurs (Orlov & Ivanov, 1978; Furevik *et al.*, 2008).
2.10	How important would other economic costs resulting from introduction be? (specify)	minimal - 0	HIGH -2	No further economic costs were reported.

2.11	How important is environmental harm caused by the organism within its existing geographic range?	major - 3	MEDIUM -1	Reduced species diversity and biomass have been reported following red king crab invasion in the Barents Sea (Falk-Petersen *et al*., 2011). As a large, highly mobile generalist predator, *P. camtschaticus* can significantly impact native benthic communities through predation and competition, particularly during the post-mating/molting spring period when crabs feed most intensively (Jørgensen, 2005; Falk-Petersen *et al*., 2011). However, Britayev *et al*. (2010) suggest that impacts on benthic communities in the Barents Sea are less dramatic than may be expected due to the wide range of prey species utilised and the crab's omnivory. The authors suggest that this will reduce the likelihood of species elimination or drastic decrease in food resource for commercially important species. In Norway, local divers report that scallop (*Chlamys islandica*) beds are being reduced due to predation by *P. camtschaticus* (ICES, 2002) and predation on the eggs of commercial fish may have population-level consequences (Falk-Petersen *et al*., 2011). It has also been hypothesised that predation of capelin eggs by *P. camtschaticus* could cause recruitment failure of capelin, a key species transporting energy up the food chain in the Barents Sea (Falk-Petersen, 2004). Oug *et al.* (2010) reported that sediment habitat quality was degraded due to hypoxic conditions and low biological activity below surface layers. It is suggested that the crab has removed species performing important functions such as bio-irrigation and sediment reworking (anonymous peer reviewer, pers. comm.).
2.12	How important is environmental harm likely to be in the Risk Assessment area?	major - 3	MEDIUM -1	Should *P. camtschaticus* become established, there is potential for significant impacts to native benthic fauna including reduced biodiversity and creation of anoxic sediments (Falk-Petersen, 2004; ICES, 2005; Jørgensen, 2005; Falk-Petersen *et al*., 2011; Oug *et al*., 2010) .
2.13	How important is social and other harm caused by the organism within its existing geographic range?	minor - 1	MEDIUM -1	*P. camtschaticus* has been reported as a nuisance to fishers through entanglement in gear and predation on bait/catch; there is thus a potential for fishers' livelihoods to be affected. However this problem is addressed in Norway through the award of licences to affected fishers to catch *P. camtschaticus* commercially, and has largely been resolved through lifting gear off from the seabed. A change in fishing methods used and alterations to gear may have some socio-economic costs but these are unknown. There is a potential danger to fishermen of injury when detangling crabs from fishing nets.
2.14	How important is the social harm likely to be in the Risk Assessment area?	minor - 1	MEDIUM -1	Potential for fishers' livelihoods to be affected; however this may be addressed through the award of licences to catch *P. camtschaticus* commercially.
2.15	How likely is it that genetic traits can be carried to native species, modifying their genetic nature and making their economic, environmental or social effects more serious?	very unlikely - 0	LOW - 0	No native congeners are present.
2.16	How probable is it that natural enemies, already present in the Risk Assessment area, will have no affect on populations of the organism if introduced?	very likely - 4	LOW - 0	Few natural predators on adult *P. camtschaticus* occur within the risk assessment area (see 1.21). Larvae and juveniles are preyed upon by a variety of fish and other crabs (Falk-Petersen, 2004).
2.17	How easily can the organism be controlled?	difficult - 3	MEDIUM -1	It has been suggested that the population could be controlled with active unrestricted fisheries (WWF-Norge, 2002; Falk-Petersen, 2004). During 2004, Norway and Russia agreed to limit the spread of the crab westwards by establishing a border at 26°E in the Norwegian zone. West of this longitude Norway was given free rein to apply all necessary management methods with a view to limiting the spread of the crab. The joint Norwegian and Russian management ended in 2007. Since then, management has been continued by each country within their respective fishery zones in the Barents Sea. At present two management regimes are implemented in Norwegian waters and located at two different geographical areas/regions. One commercial eastern area from the Russian border at 31°E to North Cape at 26°E is controlled by the governmental management plan for a king crab fishery, where the population of king crabs are managed in order to give the best possible biological and economical output. The second area is the western area, south and west of 26° E, with unrestricted fishing of the red king crab in order to reduce the rate of spreading south along the Norwegian coastline (St. meld. 40, 2006-2007; Øseth, 2008; Information and references supplied by anonymous peer reviewer, pers. comm.).
2.18	How likely are control measures to disrupt existing biological or integrated systems for control of other organisms?	unlikely - 1	LOW - 0	A specific *P. camtschaticus* pot fishery aimed at reducing population numbers would be unlikely to disrupt existing systems for control of other organisms.

2.19	How likely is the organism to act as food, a host, a symbiont or a vector for other damaging organisms?	likely - 3	LOW - 0	The carapace of *P. camtschaticus* serves as a host for the leech *Johanssonia arctica,* which is itself a vector for *Trypanosoma murmanensis* , a blood parasite of marine fish. *T. murmanensis* is capable of killing juvenile cod and causing sub-lethal effects on adult cod and other fish hosts (Hemmingsen *et al.* , 2005). Hemmingsen *et al.* (2005) found that trypanosome infections in cod in the area of Finnmark where *P. camtschaticus* were most abundant, were significantly higher than in adjacent areas.
2.20	Highlight those parts of the endangered area where economic, environmental and social impacts are most likely to occur		LOW - 0	Large shallow inlets and bays, sandbanks which are slightly covered by seawater all the time and reefs, including protected areas. Commercial fishing areas (and possibly aquaculture sites).

Summarise Entry	likely - 3	MEDIUM -1	*P. camtschaticus* larvae develop in the coastal zone with a pelagic phase of 2-3 months (Pedersen *et al*., 2006) which may facilitate transport via ships' ballast water. Survival during transport would depend on water temperature, salinity and oxygen content. Entry through natural range expansion is also a possibility, although opinions appear divided on the matter. Suggestions that *P. camtschaticus* could migrate as far south as Spain have been made but no evidence was found to support or refute this (ICES, 2002). The discovery of a mature individual in the central Mediterranean Sea in 2008 poses further questions as to the ability of this species to survive in warm temperate seas.
Summarise Establishment	moderately likely - 2	MEDIUM -1	Suitable habitat and prey species for *P. camtschaticus* occur throughout the risk assessment area. Climatic and other abiotic conditions are similar; although water temperatures in the risk assessment area are greater than those in much of the native and current distribution, *P. camtschaticus* is successful as far south as Korea - a similar latitude to some southern European countries (ICES, 2005). No native predators on adult *P. camtschaticus* occur within the risk assessment area as a barrier to establishment.
Summarise Spread	intermediate - 2	LOW - 0	Following the intentional introduction of *P. camtschaticus* into the Barents Sea during the 1960s, spread has occurred to the north and west in the Barents Sea and southwest along the coast of northern Norway. The individuals caught in Lofoten are believed to be intentionally released in the area. The crab is believed to have spread without human aid as far as northern Troms (the county west of Finnmark). Pelagic larvae may be transported considerable distances by currents (Pedersen *et al.*, 2006). Adults are known to migrate from wintering grounds to mating areas. Tagging studies in Bristol Bay, Alaska, indicated movement at rates of up to 0.67 km per day, with a single year movement of as much as 425 km (Loher & Armstrong, 2005). If *P. camtschaticus* were to establish successfully within the risk assessment area it is assumed that spread would occur at a similar rate to that of *P. camtschaticus* in Norwegian waters - from introduction into the Kolafjord in the east Barents Sea during the 1960s, to the Lofoten Islands (about 1/3 of the Norwegian coast) by 2006.
Summarise Impacts	major - 3	HIGH -2	Impacts to native benthic fauna may be significant, as *P. camtschaticus* is an omnivorous, opportunistic feeder (Jørgensen, 2005), usually feeding on the most abundant and readily available benthic fauna (ICES, 2005). No native predators of the adult crab occur within the risk assessment area. Reductions in benthic species diversity and biomass have been reported following red king crab invasion in the Barents Sea (Falk-Petersen *et al*., 2011). However, Britayev *et al*. (2010) suggest that impacts on benthic communities in the Barents Sea are less dramatic than may be expected and species elimination and loss of prey species for commercially important species is unlikely. Impacts increase with crab numbers and may be particularly significant where aggregations of juveniles occur in shallow waters, and when crabs display podding behaviour. Where crabs have removed species performing important functions such as bio-irrigation and sediment reworking, sediment quality has been affected (Oug *et al*. 2010) and sediments in areas of high king crab abundance have been found to be anoxic due to a lack of sedimentary organisms (Oug *et al*. 2011). Negative economic impacts are very difficult to quantify. In Norway these are related to predation on *Chlamys islandica* and bycatch in traditional fisheries but speculation exceeds knowledge (Falk-Petersen, pers. comm.). Commercial shellfish production may be impacted through predation.
For pathway/policy risk assessment Assess the potential for establishment and economic/environmental/social impacts of another organism or stop			
Conclusion of the risk assessment	MEDIUM -1	MEDIUM -1	Climatic and abiotic conditions within the risk assessment area are similar and suitable habitats occur throughout UK waters. As a cold water species which has successfully established and spread within the Barents Sea since its initial introduction in the 1960s, it seems likely that *P. camtschaticus* could become established within the risk assessment area. Entry may occur via ballast water in the short term, or through natural spread over a greater timescale. If establishment occurs, significant impacts to native benthic fauna may be expected. Population control may be possible through an open access fishery as in Norway (Fisheries. no, 2009), but conclusions on the success of such a scheme are not yet available.
Conclusions on Uncertainty		MEDIUM -1	Scientific opinion appears to be divided on the issue of potential further spread and establishment of *P. camtschaticus.* The literature review provided numerous insights into the biology, physiology, range and commercial potential of *P. camtschaticus* but suggestions concerning the invasive potential and possible impacts are largely speculative.
Should risk management options be considered?			

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