RISK ASSESSMENT SUMMARY SHEET

Updated: October 2020

Wakame (*Undaria pinnatifida*)

- A large brown seaweed with corrugated appearance.
- Established with scattered populations in GB.
- Found on hard structures (including man-made).
- Most likely introduced as a contaminant of aquaculture stock and / or hull fouling.
- Spreads rapidly via hull fouling and other spread pathways.
- Outcompetes native seaweed species.

Photograph: David Fenwick

History in GB

Widely distributed outside of its native range. First recorded in Europe in Brittany in 1983 (probably as a result of contaminated pacific oyster imports). In GB, first report in 1994 in the Hamble Estuary, Solent. Has subsequently spread to many other sites.

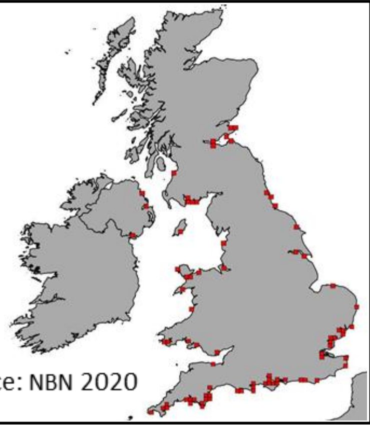
Native Distribution

North-western Pacific shores, i.e. coasts of Japan, Korea, northeast China and southeast Russia.

Map source: https://depts.washington.edu/oldenlab/wordpress/wp-content/uploads/2015/09/Unidaria_pinnatifida_Bloch_2014.pdf

GB Distribution

Scattered populations across GB



Source: NBN 2020

Impacts

Environmental (major, low confidence)

- A number of studies have shown that this species can displace native kelp; however, this is not always the case.

Economic (moderate, low confidence)

- Some potential cost / disruption as a result of biofouling submerged structures.

Social (minor, low confidence)

- Few, but nuisance caused by biofouling may be problematic for some.

Introduction pathway

Potential introduction pathways to GB include as a contaminant of aquaculture stock, hull fouling or natural dispersal from European populations.

Spread pathway

Natural (intermediate, low confidence), there is mixed evidence that suggests this species could spread long distances by natural means

Human (rapid, medium confidence), most likely spread around GB is via hull fouling

Summary

	Response	Confidence
Entry	VERY LIKELY	VERY HIGH
Establishment	VERY LIKELY	VERY HIGH
Spread	RAPID	MEDIUM
Impact	MAJOR	LOW
Overall risk	HIGH	LOW

Rapid Risk Assessment of: *Undaria pinnatifida*
Author: Hannah Tidbury (Cefas)
Draft: Draft 1 (Feb 2015), Draft 2 (April 2018), Draft 3 (June 2018)
Signed off by NNRAP: May 2018
Approved by Programme Board: September 2020
Placed on NNSS website: October 2020

GB Non-native species Rapid Risk Assessment (NRRA)

Introduction:
The rapid risk assessment is used to assess invasive non-native species more rapidly than the larger GB Non-native Risk Assessment. The principles remain the same, relying on scientific knowledge of the species, expert judgement and peer review. For some species the rapid assessment alone will be sufficient, others may go on to be assessed under the larger scheme if requested by the Non-native Species Programme Board.

1 - What is the principal reason for performing the Risk Assessment? (Include any other reasons as comments)

Response:

To rapidly assess the risk associated with *Undaria pinnatifida* (*U. pinnatifida*) in line with requirements under the UK Marine Strategy (UKMS). Specifically, the risk assessment was performed as part of a series of risk assessments conducted to identify high and moderate risk species, already present in the UK, which should be prioritised for monitoring.

2 - What is the Risk Assessment Area?

Response: GB

3 - What is the name of the organism (scientific and accepted common; include common synonyms and notes on taxonomic complexity if relevant)?

Response: *Undaria pinnatifida* (Harvey) Suringar 1873

Common name: Japanese Kelp; Wakame; precious sea grass; sea mustard

Synonyms:
Alaria pinnatifida Harvey, 1860
Alaria amplexicaulis Martens, 1866
Ulopteryx pinnatifida (Harvey), Kjellman, 1885

4 - Is the organism known to be invasive anywhere in the world?

Response: Yes. *U. pinnatifida* is on the 100 of the World's Worst Invasive Alien Species

(Lowe et al., 2000) and was also included in a set of 10 species representative of the worst invasive species in Europe (Gallardo, 2014).

5 - What is the current distribution status of the organism with respect to the Risk Assessment Area?

Response: *U. pinnatifida* is native to North-western Pacific shores, i.e. coasts of Japan, Korea, northeast China and southeast Russia.

However, this species is widely distributed outside its native range. The first record outside its native range was on the French Mediterranean coast following accidental introduction. It was then intentionally transferred to three sites in Brittany in 1983 for farming and has subsequently spread. Populations were also reported in northern Spain in 1990 and more recently along the North Spanish Atlantic coast down to the Portuguese border. In 1999 the species was reported in Zeebrugge, Belgium and in the Netherlands (near Yerseke and Strijenham). There are also sporadic records from the Mediterranean and Adriatic Sea (e.g. in the Venice lagoon). Introduced locations also include Argentina, Australia, Chile, Mexico, New Zealand, Sweden, Norway and California.

The first report in GB was in 1994 in the Hamble Estuary in the Solent. Since this initial report, this species has been reported elsewhere in a number of locations along the south coast of England, the east coast of England (Humber estuary), the west coast of England (Fleetwood), the west coast of Wales (Pembroke Dock and Holyhead Marina), in Scotland (Queensferry Marina). The species has also been reported on the east coast of Northern Ireland (Carrickfergus Marina, Kilmore Quay) and on the east coast of Republic of Ireland (Carlingford Marina) and on the Channel Islands (Jersey).

(Information sources include: Epstein and Smale, 2017; Gollasch, 2006; Guiry, 2014; Hewitt et al., 2005; Kraan,2017; Minchin and Nunn, 2014; Oakley, 2007; Ohno and Mizuta, 2011 and references therein).

6 - Are there conditions present in the Risk Assessment Area that would enable the organism to survive and reproduce? Comment on any special conditions required by the species?

Response: Yes.

U. pinnatifida grows on a wide range of substrates and tolerates a wide range of temperatures, salinities and wave exposures (Epstein and Smale, 2017; Farrell and Fletcher, 2006; James et al., 2015; Russell et al., 2008). The tolerance of this species to variation in environmental factors, taken together with the current presence of *U. pinnitifida* in multiple locations within the risk assessment area, indicates that the conditions present in the risk assessment are suitable for the survival and reproduction of *U. pinnatifida.*

7 - 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?

Response: Yes.

This species is already present in the risk assessment area and in countries within the same ecoclimatic zone, suggesting that conditions in the risk assessment area are compatible with the survival of this species.

8 - Has the organism established viable (reproducing) populations anywhere outside of its native range (do not answer this question if you have answered 'yes' to question 4)?

Response: NA

9 - Can the organism spread rapidly by natural means or by human assistance?

Response: Yes, though the rate of spread is likely to vary between sites.

Introduction of *U. pinnatifida* to the French Mediterranean coast from Japan was thought to be accidental with the import of Pacific Oysters (Gollasch, 2006) highlighting the potential role of contaminated aquaculture stock movements in the spread of this species.

Long range spread of *U. pinnatifida* is thought to be most likely via the shipping pathway (Farrell and Fletcher, 2004; Hay, 1990). The spread of the species along a 400 km stretch of the south coast of England in nine years is thought to be the result of inter-marina traffic (Farrell and Fletcher, 2006). Spread may also be possible via ballast water (though unlikely (Minchin and Nunn, 2014)), natural dispersal (Farrell and Fletcher, 2006; Forrest et al., 2000; Minchin and Nunn, 2014) and movement of contaminated fishing gear and aquaculture equipment (Farrell and Fletcher, 2006).

10 - Could the organism itself, or acting as a vector, cause economic, environmental or social harm in the Risk Assessment Area?

Response: Yes, though the extent to which *U. pinnatifida* impacts the environment remains uncertain and is likely to be highly context specific, depending on, for example, space, time and the taxa present in the introduced location (South et al., 2017).

Environmental impacts may include out-competition of native species (Farrell and Fletcher, 2006) and reductions in local biodiversity (Arnold et al., 2016; Suárez-Jiménez et al., 2017; Valentine and Johnson, 2003). However, environmental impacts may be transient (South et al., 2015) and are not always evidenced (Forrest and Taylor, 2002).

Though economic impacts are poorly understood and not well studied, *U. pinnatifida* may result in economic costs associated with cleaning and maintenance of fouled vessels and aquaculture equipment (Fletcher and Farrell, 1998; Hewitt et al., 2005; Minchin and Nunn, 2014). Economic costs and social costs may also be incurred where *U. pinnatifida* impacts biodiversity and reduces recreational and commercial fishing revenue (Irigoyen et al., 2011) and satisfaction.

Entry Summary

Estimate the overall likelihood of entry into the Risk Assessment Area for this organism (comment on key issues that lead to this conclusion).

Response: very *likely*
Confidence: *very high*

Comments (include list of entry pathways in your comments):

Introductions may be possible via the import of aquaculture stock contaminated with *U. pinnatifida*. Introduction of this species to the French Mediterranean coast from Japan was thought to be accidental with the import of Pacific Oysters (Gollasch, 2006). The zoospore lifestage of this species is microscopic, facilitating accidental introduction of this species attached to aquaculture stock. However, the fact that imports of aquaculture stock into GB are relatively infrequent indicates that other pathways may be more important for the introduction of *U. pinnatifida*.

Introductions may be most likely via the shipping pathway (Farrell and Fletcher, 2004; Hay, 1990). Its ability to foul ship's hulls and its presence in or near ports and marinas supports this hypothesis. Sporophytes have been found to survive on ships' hulls during voyages over distances greater than 4000km (Hay, 1990), emphasising the potential for successful introduction from landmasses large distances from the risk assessment area. Although transport in ballast has been suggested the ability of spores to survive conditions in the ballast tank has been subsequently questioned (Minchin and Nunn, 2014). Contamination of fishing gear, aquaculture equipment, buoys and ropes being transported between different locations may also lead to introduction of *U. pinnatifida* (Farrell and Fletcher, 2006), though perhaps may be more likely associated with the spread of this species within the risk assessment area following introduction. Introduction of this species may also occur through natural dispersal of spores, for example, on tidal currents from neighbouring landmasses. Though natural dispersal of *U. pinnatifida* has been suggested to be slow, step-wise and over small distances compared to dispersal on vessels, there is potential for the natural dispersal of *U. pinnatifida* over distances of tens to hundreds of meters or several of kilometers annually (Forrest et al., 2000; Minchin and Nunn, 2014 and references therein). Natural dispersal over greater distances is facilitated by drifting of entire sporophytes which remain viable for longer periods than individual spores (Forrest et al., 2000).

In addition to the aforementioned evidence with respect to entry risk, the fact that the species is already located in the risk assessment area provides support for the 'very likely' entry response score given with very high confidence.

Establishment Summary

Estimate the overall likelihood of establishment (comment on key issues that lead to this conclusion).

Response: *very likely*
Confidence: *very high*

Comments (state where in GB this species could establish in your comments, include map if possible):

The establishment potential will be influenced by a number of factors such as; time of year (and therefore water temperature) the introduction takes place, the specific environmental conditions (salinity, temperature, availability of substrate) and the ecosystem (presence of predators, competitors) of the introduction location.

U. pinnatifida grows on sublittoral rock and hard substrates, including artificial hard substrates, up to a depth of 18m, and though rare, has been found inhabiting sea grass beds and mixed sediment communities (Epstein and Smale, 2017; Farrell and Fletcher, 2006; James et al., 2015; Russell et al., 2008). Optimum growth of sporophytes is seen between 5°C and 20°C, though growth occurs between 0°C and 27°C. Zoospores are released when temperatures are between 11°C and 25°C. Gametophyte growth is optimum between 15°C and 20°C and gametogenesis and fertilisation is optimum between 10°C and 15°C. Microscopic gametophytes may survive temperatures between -1°C and 30 °C and dark conditions for up to 6 months, thereby aiding the persistence of this species (Epstein and Smale, 2017 and references therein). Predictions of global distributions of *U. pinnatifida* based on sea surface temperature indicate that the UK sea temperatures are suitable for *U. pinnatifida*, and in fact that they may promote more persistent populations with year-round (rather than annual, as in their native range) phenology (James et al., 2015). *U. pinnatifida* prefers saline conditions of above 27 PSU. However, zoospores may attach at salinities as low as 19 PSU (Epstein and Smale, 2017 and references therein). The species also tolerates a wide range of wave exposures and is found commonly in more sheltered locations such as marinas, but also in more open locations (Russell et al., 2008). Limitations to *U. pinnatfida* geographic distribution may be low salinity and excessive wave action (South et al., 2017).

The conditions required for the establishment of this species are found widely within the risk assessment area. More specifically, the temperature range within the risk assessment area is suitable (and in some months may be optimal) for the survival and reproduction of the species (e.g. James et al., 2015). In addition, there is wide availability of habitat preferred by this species, especially within locations this species is most likely to be introduced into (for example hard substrates within marinas (e.g. Farrell and Fletcher (2006)). In further support of the species' very likely establishment response score, the species is already established in a number of geographically spread locations within the risk assessment area.

Spread Summary

Estimate overall potential for spread (comment on key issues that lead to this conclusion).

Response: *rapid*
Confidence: *medium*

Sub scores:

Natural spread only:
Response: intermediate
Confidence: low

Human facilitated spread only:
Response: rapid
Confidence: medium

Comments (in your comments discuss how much of the total habitat that the species could occupy has already been occupied; also comment on how much of that currently unoccupied area is likely to be occupied within 5 years; also list all of the spread pathways):

Spread of *U. pinnatifida* through natural dispersal, for example, via tidal currents, has been suggested to be slow, step-wise and over small distances compared to human facilitated spread. For example, *U. pinnatifida* dispersed only 200m away from an established marina population in the UK in 7 years (Farrell and Fletcher, 2006). However, other sources indicate that there is potential for the natural dispersal of *U. pinnatifida* over distances of tens to hundreds of meters or several kilometers annually (Forrest et al., 2000; Minchin and Nunn, 2014 and references therein). It is thought that natural dispersal over longer distances is facilitated by drifting of entire sporophytes which remain viable for longer periods than individual spores (Forrest et al., 2000). It is likely that the rate of natural dispersal varies between sites.

Long range and rapid spread of *U. pinnatifida* is thought to be most likely via the shipping pathway (Farrell and Fletcher, 2004; Hay, 1990). Its ability to foul ship's hulls and its presence in or near ports and marinas supports this hypothesis. Nine years following initial reports in the Solent, populations of this species are now found in locations along a 400 km stretch of the south coast of GB. This rather extensive spread is thought to be the result of inter-marina traffic (Farrell and Fletcher, 2006). Contamination of fishing gear, aquaculture stock, equipment, buoys and ropes being transported between different locations may also lead to spread of this species (Farrell and Fletcher, 2006).

The extent to which the habitat may be occupied by the species will be variable and dependent on the presence of other species and the level of disruption (Thompson and Schiel, 2012) at the time of establishment and subsequently.

Estimation of rates of dispersal by different means (i.e. natural vs human mediated) is difficult, hence the high uncertainty, as the role the different pathways in population dispersal is not always clear (South et al., 2017).

Impact Summary

Estimate overall severity of impact (comment on key issues that lead to this conclusion)

Response: *major*
Confidence: *low*

Sub-scores

Environmental impacts:

Response: major
Confidence: low

Economic impacts:
Response: moderate
Confidence: low

Social impacts:
Response: minor
Confidence: low

Comments (include list of impacts in your comments):

There is evidence to suggest that *U. Pinnatifida* does negatively impact the environment into which it is introduced. Some studies conclude that this species may impact the ecosystem into which it is introduced by out-competing native species. For example, in Torquay Marina, *U. pinnatifida* has invaded and outcompeted two species of native kelp *Laminaria digitata* and *Saccharina latissima* and a sea squirt, *Styela clava* (Farrell and Fletcher, 2006). Another study highlighted that the cover of a native alga *Colpomenia sinusa* was also reduced where *U. pinnatifida* was present (South et al., 2015). In addition, other studies indicated *that U. pinnatifida*, in comparison to native kelp species, may support less diverse epibiotic assemblages so that the proliferation of *U. pinnatifida* may result in a reduction in local biodiversity (Arnold et al., 2016; Suárez-Jiménez et al., 2017; Valentine and Johnson, 2003). However, a before-after-control-impact (BACI) study suggested that the abundance of native kelp species was not significantly impacted by the introduction of *U. pinnatifida* three years previously (Forrest and Taylor, 2002). Other evidence indicates that while *U. pinnatifida* may have some small impact on community diversity, these impacts may be transient and not seen in subsequent years (South et al., 2015). Results from other studies indicate that *U. pinnatifida* occupies habitats, substrates and depths which native species may not be able to (e.g. Fletcher and Farrell, 1998; Russell et al., 2008), thereby eliminating direct competition with native species and providing additional and beneficial nursery habitat for small fish and shelter for macrofauna. So, while environmental impacts may occur, the absence of impacts in some instances means confidence in environmental impacts is low.

Economic impacts are poorly understood and not well studied. *U. pinnatifida* may foul and cause disruption to marine structures and aquaculture operations (Fletcher and Farrell, 1998; Hewitt et al., 2005; Minchin and Nunn, 2014) with costs incurred for cleaning and maintenance. Economic costs and social costs may also be incurred where *U. pinnatifida* impacts biodiversity and reduces recreational and commercial fishing revenue (Irigoyen et al., 2011) and satisfaction.

While there is clearly potential for high environmental, economic and social impacts, resulting from the presence of this species, the lack of impacts in some instances means that impacts are likely to vary and the confidence in the ‘major’ overall impact risk score given is low.

Climate Change

What is the likelihood that the risk posed by this species will increase as a result of climate change?

Response: *moderate*
Confidence: *medium*

Comments (include aspects of species biology likely to be effected by climate change (e.g. ability to establish, key impacts that might change and timescale over which significant change may occur):

Species with increased tolerances are generally more likely to persist under climate change (Bellard et al., 2012). *U. pinnatifida* exhibits wide tolerance to temperature, due to the gametophytes and sporophytes stages of its lifecycle, which can persist in temperatures ranging from -1 to 30°C (Morita et al., 2003). Climate change and associated increases in sea temperatures may facilitate successful germination (occurring at 20°C) at more northern locations (Cook et al., 2013), therefore increasing the ability of this species to establish and spread and cause impact. In addition, climate change may increase extreme weather events such as storms. These may act to increase the risk of this species being spread by natural dispersal via currents.

It is therefore concluded, with moderate confidence, that the risk of this species may be moderately likely to increase under climate change.

Conclusion

Estimate the overall risk (comment on the key issues that lead to this conclusion).

Response: *high*
Confidence: *low*

Comments:

The risk attributed to this species is high for a number of reasons. It is already present in GB with high risk of spread by two main pathways, natural dispersal and vessel movements. There is a high likelihood of further introductions by natural dispersal, vessel movements and import of contaminated aquaculture stock, and the environmental and economic impacts associated with the species may be substantial.

Confidence is low due to variation in the reported spread rates and level of impact evidenced by different studies.

Management options (brief summary):

1 - Has the species been managed elsewhere? If so, how effective has management been?

Response:

As with many marine NNS, the eradication of *U. pinnitifida* is likely to be very difficult.

Though many eradication attempts have failed (South et al., 2017), successful treatment of this species was achieved in New Zealand. The treatment involved heating the area where the species was present either with a flame torch or using heat elements contained within a plywood box (Wotton et al., 2004). The treatment was successful, however, treatment success was likely improved because the treatment area was discrete and isolated (the hull of a single ship), both stages of the organism's lifecycle were targeted and long-term monitoring was undertaken following treatment. This form of treatment may not be suitable for all invaded areas and is costly and time consuming to undertake.

While not resulting in eradication, manual removal was successful in controlling *U. pinnatifida* in a
Tasmanian marine reserve (Hewitt et al., 2005). In addition, sustained long term management which included hand removal of sporophytes from infected habitats and vessels and treatment of microscopic life stages over an 8 year period, reduced vessel infection incidences compared to no intervention and short term management (Forrest and Hopkins, 2013).

2 - List the available control / eradication options for this organism and indicate their efficacy.

Response:
There are a number of possible control/eradication options for *U. Pinnitifda*:

Heat treatment – treatment with high water temperature (>30°C) is required to destroy all life stages including the microscopic gametophytes (Wotton et al., 2004). However, this option is only really viable for the treatment of small and isolated areas.

Manual removal – this reduces numbers and can therefore control population sizes and lessen spread. However, this method will not enable removal of microscopic gametophytes (Hewitt et al., 2005).

Hull cleaning/ treatment – manual removal of sporophytes from ships hulls can be undertaken. However, like the general manual removal option, this option is unlikely to result in the removal of all life stages and smaller fragments which can easily survive in moist spaces in structures of the boat hull. While this option may lessen spread it is unlikely to result in the eradication of this species.

Biological control - Some natural predators of this species do exist. For example, the kelp crab *Pugettia producta* is known to graze upon *U. pinnatifida* (Thornber et al., 2004). The use of predators as biological control agents may present a possible control option. However, predators present in the assessment area will be need to be determined and their role as biological controls agents studied prior to their use.

While the aforementioned options are available, the numerous life stages, including a persistent microscopic stage, which may remain viable even when dormant for 2.5 years (Hewitt et al., 2005), present a big challenge for the eradication/control of the species.

3 - List the available pathway management options (to reduce spread) for this organism and indicate their efficacy.

Response:

Pathway management should include strict biosecurity and awareness raising. More specifically, inspection of boat hulls and hard substrate within and around high risk locations such as marinas and ports should be encouraged. Awareness raising of the species at marinas, ports and with boat owners and companies should be undertaken. Boats leaving contaminated areas should have their hulls checked and cleaned if necessary.

In the case of ballast water, ballast water discharge and treatment regulations should be adhered to. In addition, aquaculture stock movements should be monitored and imports/movements from contaminated areas restricted. Inspection of aquaculture stock imports and equipment being moved should also be undertaken.

4 - How quickly would management need to be implemented in order to work?

Response:

This species has the potential to become established and spread very quickly. Management would therefore need to be implemented rapidly following the detection of this species, especially in warmer temperatures when growth and reproduction is more likely. Given that this species has been present in the risk assessment area for many years, eradication from the assessment area is unlikely to be possible. However, rapid implementation of management on detection of the species in new locations will act to reduce the risk of spread within and from these new locations.

References

Provide here a list of the references cited in the course of completing assessment

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