Risk assessment template developed under the "Study on Invasive Alien Species – Development of risk assessments to tackle priority species and enhance prevention"
Contract No 07.0202/2018/788519/ETU/ENV.D.2[1]

Name of organism: *Channa argus* (Cantor, 1842)

Authors of the assessment:

- *Luke Aislabie, Cefas, Lowestoft, UK*
- *Hugo Verreycken, Research Institute for Nature and Forest (INBO), Brussels, Belgium*
- *Gordon H. Copp, Cefas, Lowestoft, UK*

Risk Assessment Area: The risk assessment area is the territory of the European Union, excluding the outermost regions.

Peer review 1: *John S. Odenkirk, Virginia Department of Game and Inland Fisheries, Fredericksburg, VA USA*

Peer review 2: *Jeffrey Hill, University of Florida, Ruskin, Florida, USA*

Date of completion: 23 October 2019

Date of revision: 26 August 2020

[1] This template is based on the Great Britain non-native species risk assessment scheme (GBNNRA). A number of amendments have been introduced to ensure compliance with Regulation (EU) 1143/2014 on IAS and relevant legislation, including the Delegated Regulation (EU) 2018/968 of 30 April 2018, supplementing Regulation (EU) No 1143/2014 of the European Parliament and of the Council with regard to risk assessments in relation to invasive alien species (see https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A32018R0968).

Contents

SECTION A – Organism Information and Screening

A1. Identify the organism. Is it clearly a single taxonomic entity and can it be adequately distinguished from other entities of the same rank?
including the following elements: • the taxonomic family, order and class to which the species belongs; • the scientific name and author of the species, as well as a list of the most common synonym names; • names used in commerce (if any) • a list of the most common subspecies, lower taxa, varieties, breeds or hybrids As a general rule, one risk assessment should be developed for a single species. However, there may be cases where it may be justified to develop one risk assessment covering more than one species (e.g. species belonging to the same genus with comparable or identical features and impact). It shall be clearly stated if the risk assessment covers more than one species, or if it excludes or only includes certain subspecies, lower taxa, hybrids, varieties or breeds (and if so, which subspecies, lower taxa, hybrids, varieties or breeds). Any such choice must be properly justified.

Response: *Channa argus* (Cantor, 1842) is clearly a single taxonomic entity and it can be adequately distinguished from other species of the same genus (Courtenay & Williams, 2004).

Kingdom: Animalia –animals

Subkingdom: Bilateria

Infrakingdom: Deuterostomia

Phylum: Chordata –chordates

Subphylum: Vertebrata –vertebrates

Infraphylum: Gnathostomata

Superclass: Osteichthyes – bony fishes,

Class: Actinopterygii – ray-finned fishes

Subclass: Neopterygii – neopterygians Infraclass: Teleostei

Superorder: Acanthopterygii

Order: Perciformes – perch-like fishes

Suborder: Channoidei

Family: Channidae – snakeheads

Genus: *Channa* Scopoli, 1777 – Asian snakeheads

Species: *Channa argus* (Cantor, 1842)

The preferred common name in English is northern snakehead. Other English names are Amur snakehead, eastern snakehead and snakehead (Froese & Pauly, 2019).

According to Froese & Pauly (2019) the valid scientific name is *Channa argus* Cantor, 1842. The previously described subspecies *Channa argus argus* Cantor, 1842 and *Channa argus warpachowskii* (Berg, 1909) are not considered valid anymore nor are the other synonyms and combinations.

Non-valid senior and junior synonyms are *Channa argus kimurai* Shih, 1936, *Ophicephalus argus* Cantor, 1842, *Ophicephalus nigricans* Cuvier, 1831, *Ophicephalus pekinensis* Basilewsky, 1855, *Ophiocephalus argus* Cantor, 1842, *Ophiocephalus argus warpachowskii* Berg, 1909.

In ornamental aquatic trade the common name "platinum snakehead" is used for *Channa argus kimurai*, sometimes also referred to as *C. argus* "platinum"[2] or *C. argus var* 'Kimnra'[3].

This risk assessment considers the species *C. argus* with all its non-valid senior and junior synonyms.

A2. Provide information on the existence of other species that look very similar [that may be detected in the risk assessment area, either in the environment, in confinement or associated with a pathway of introduction]

Include both native and non-native species that could be confused with the species being assessed, including the following elements:

- other alien species with similar invasive characteristics, to be avoided as substitute species (in this case preparing a risk assessment for more than one species together may be considered);
- other alien species without similar invasive characteristics, potential substitute species;
- native species, potential misidentification and mis-targeting

Response:

Other snakeheads (*Channa* spp,) are superficially similar to *C. argus.* These are all alien to and not established in the risk assessment area. Some species of genus *Channa* are traded and kept in aquaria within the risk assessment area. There are no similar native species in the risk assessment area. In the USA, beside *C. argus*, which is established in the Mid Atlantic region and in Arkansas, there are also two other snakehead species with established populations: bullseye snakehead *C. marulius* in Florida and blotched snakehead *C. maculata* in Hawaii. The giant snakehead *C. micropeltes* was recorded in six states, but there are no known established populations (Benson, 2019). It is unclear whether all the established *Channa* species in the USA are invasive. Nakai (2019) states there is little evidence suggesting ecological invasiveness in recent years of the three introduced snakeheads *C. argus*, *C. maculata* and small snakehead *C. asiatica* to Japan.

A3. Does a relevant earlier risk assessment exist? Give details of any previous risk assessment, including the final scores and its validity in relation to the risk assessment area.

[2] See https://www.ruinemans.com/en/product/09295-channa-argus-platinum-l
[3] See e.g. https://animalscene.ph/2018/02/26/searching-for-the-true-identity-of-the-platinum-snakehead/ and https://www.ncbi.nlm.nih.gov/Taxonomy/Browser/wwwtax.cgi?id=2518323

Response:

At least five RAs are available for North America and might be of interest and/or partly valid for the risk assessment area as conditions are similar in parts of N. America and the risk assessment area.

Courtenay & Williams (2004) included the biological and risk information used to list the family Channidae (snakeheads) as injurious in the United States (https://pubs.er.usgs.gov/publication/cir1251). They assessed the probability of establishment and the consequences of establishment and the organism risk potential and rated them all high with a moderate to high certainty. They conclude that Channidae are organisms of major concern to the USA and constitute an unacceptable risk that justifies mitigation.

Cudmore & Mandrak (2006) assessed northern snakehead for Canada (http://biblio.uqar.ca/archives/30163321.pdf) . They also assessed the probability of establishment and the consequences of establishment and rated the organisms risk potential to be high with a reasonable certainty. This Canadian risk assessment used information from Courtenay & Williams (2004).

In a trinational risk assessment for North America (CEC 2009; http://www3.cec.org/islandora/en/item/2379-trinational-risk-assessment-guidelines-aquatic-alien-invasive-species-en.pdf), the assessors rate northern snakehead as a high risk species with high probability of establishment (uncertainty: very certain) and high consequences of establishment (uncertainty: reasonably certain).

Northern snakehead was screened in an Ecological Risk Screening Summary for the United States (USFWS, 2017) (https://www.fws.gov/fisheries/ANS/erss/highrisk/Channa-argus-ERSS-FINAL-Sept-2017.pdf) and this resulted in categorizing it as a high overall risk species (with high climate match and a high history of invasiveness, with medium certainty).

In the Non-Native Animal Assessments (http://nyis.info/non-native-animal-assessments/) of the New York Invasive Species Information Clearinghouse, *C. argus* was assessed as a high risk species (with a score of 77/100) in the invasiveness ranking with respective scores of 20/30 for Ecological impact, 27/30 for Biological characteristic and dispersal ability, 24/30 for Ecological amplitude and distribution and 10 out of 10 for Difficulty of control[4].

In relation to the risk assessment area, *C. argus* has been ranked, using the Fish Invasiveness Screening Kit (FISK) decision-support tool (Copp et al., 2009), as posing a high risk of being invasive in the following part of the risk assessment area: England & Wales, the Iberian Peninsula and southern Finland (Vilizzi et al., 2019).

A4. Where is the organism native?

including the following elements:

- an indication of the continent or part of a continent, climatic zone and habitat where the species is naturally occurring
- if applicable, indicate whether the species could naturally spread into the risk assessment area

[4] http://nyis.info/wp-content/uploads/2017/10/3d104_Channa-argus.ecological.pdf

Response: The native range of the northern snakehead is in Asia in the Amur southward to Xi Jiang and Hainan Island, China (Bogutskaya et al., 2008). FishBase (Froese & Pauly, 2019) mentions China, (South) Korea and Russia as native countries.

Fig. 1: Distribution of *C. argus* in the Eastern Hemisphere (Native and introduced range) Source: Courtenay & Williams (2004).

Courtenay & Williams (2004) made a literature review and summarise the native range of *Channa argus* (Cantor, 1842) as: Middle and lower Heilong (Amur), Songhua (Sungari), Manchuria, Tunguska (at Khabarovsk, Russia) and Ussuri; Lake Khanka; throughout Korea except its north-eastern region; rivers of China southward and south-westward to upper tributaries of the Chang Jiang (Yangtze) River basin in north-eastern Yunnan Province. Reported from Guangdong Province, China, likely an introduction there. Widely distributed in Chinese reservoirs.

It is as good as impossible for the northern snakehead to naturally spread into the risk assessment area from its native range.

A5. What is the global non-native distribution of the organism outside the risk assessment area?

Response: The global non-native range of northern snakehead is not very clear and can differ between contacted sources. FishBase (Froese & Pauly, 2019) state Japan, Turkmenistan, Uzbekistan and the USA as non-native countries. Bogutskaya & Naseka (2002) mention *C. argus* to have been translocated within Russia to ranges where it is non-native but establishment there failed.

Northern snakehead was brought from Korea and intentionally released by culturists in Japan in the early 1900s (Okada, 1960). In Kazakhstan, Turkmenistan, and Uzbekistan release in ponds, rivers, and

reservoirs in the early 1960s may have been accidental via transport in contaminated shipments of Asian carps (Courtenay & Williams, 2004), northern snakehead subsequently became established in these waters.
The introduction into the USA is best documented, the first records of northern snakehead date from the late 1990s. The species is established in the Mid Atlantic region (Virginia tributaries of the Potomac River) and in Arkansas (Benson, 2019; Froese & Pauly, 2019; Odenkirk & Isel, 2016).

Within the risk assessment area, *C. argus* was introduced in Central Bohemia in the Czech Republic (former Czechoslovakia) in 1956 and 1960 (Hanel et al. 2012) but in the severe winter of 1962/63 they all died and acclimatization was thus unsuccessful (Frank, 1970). Later, Lusk et al. (2010) wrote that northern snakehead was probably not established there while Musil et al. (2010) state that *C. argus* is now extinct in the Czech Republic (see Q. A8).

A6. In which biogeographic region(s) or marine subregion(s) in the risk assessment area has the species been recorded and where is it established? The information needs be given separately for recorded and established occurrences.

A6a. Recorded: List regions

A6b. Established: List regions

Freshwater / terrestrial biogeographic regions:

- Alpine, Atlantic, Black Sea, Boreal, Continental, Mediterranean, Pannonian, Steppic

Marine regions:

- Baltic Sea, North-east Atlantic Ocean, Mediterranean Sea, Black Sea

Marine subregions:

- Greater North Sea, including the Kattegat and the English Channel, Celtic Seas, Bay of Biscay and the Iberian Coast, Western Mediterranean Sea, Adriatic Sea, Ionian Sea, Central Mediterranean Sea, Aegean-Levantine Sea.

Comment on the sources of information on which the response is based and discuss any uncertainty in the response.

For delimitation of EU biogeographical regions please refer to: www.eea.europa.eu/data-and-maps/figures/biogeographical-regions-in-europe-2 (see also Annex V).

For delimitation of EU marine regions and subregions consider the Marine Strategy Framework Directive areas; please refer to: http://www.eea.europa.eu/data-and-maps/data/msfd-regions-and-subregions/technical-document/pdf (see also Annex V).

Response (6a): Continental (Central Bohemia), see answer to Q.8(a)

Response (6b): The species is currently not established in any part of the risk assessment area.

A7. In which biogeographic region(s) or marine subregion(s) in the risk assessment area could the species establish in the future under current climate and under foreseeable climate change?

The information needs be given separately for current climate and under foreseeable climate change conditions.

A7a. Current climate: List regions

A7b. Future climate: List regions

With regard to EU biogeographic and marine (sub)regions, see above.

With regard to climate change, provide information on

- the applied timeframe (e.g. 2050/2070)
- the applied scenario (e.g. RCP 4.5)
- what aspects of climate change are most likely to affect the risk assessment (e.g. increase in average winter temperature, increase in drought periods)

The assessment does not have to include a full range of simulations on the basis of different climate change scenarios, as long as an assessment with a clear explanation of the assumptions is provided. However, if new, original models are executed for this risk assessment, the following RCP pathways shall be applied: RCP 2.6 (likely range of 0.4–1.6°C global warming increase by 2065) and RCP 4.5 (likely range of 0.9–2.0°C global warming increase by 2065). Otherwise, the choice of the assessed scenario has to be explained.

- Response (7a): Atlantic, Black Sea, Boreal, Continental, Mediterranean, Pannonian, Steppic
- Response (7b): Atlantic, Black Sea, Boreal, Continental, Mediterranean, Pannonian, Steppic

Northern snakehead has a wide temperature range (0°C–30°C, optimum 10–27°C) (Courtenay & Williams, 2004) and it exhibits a broad tolerance to a wide range of environmental conditions and is extremely hardy (Cudmore & Mandrak, 2006) so it can probably establish in most of the EU biogeographic regions. No climate change scenarios are available for northern snakehead for the RA area but it can be assumed that this species will not become wider established under climate warming because of this already broad environmental tolerance. This is supported by the assessment of Cudmore and & Mandrak (2006) of the possible distribution of *C. argus* in Canada using models based a.o. on temperature and suggest that the distribution of *C. argus* could be widespread in Canada even up to about 60°N.

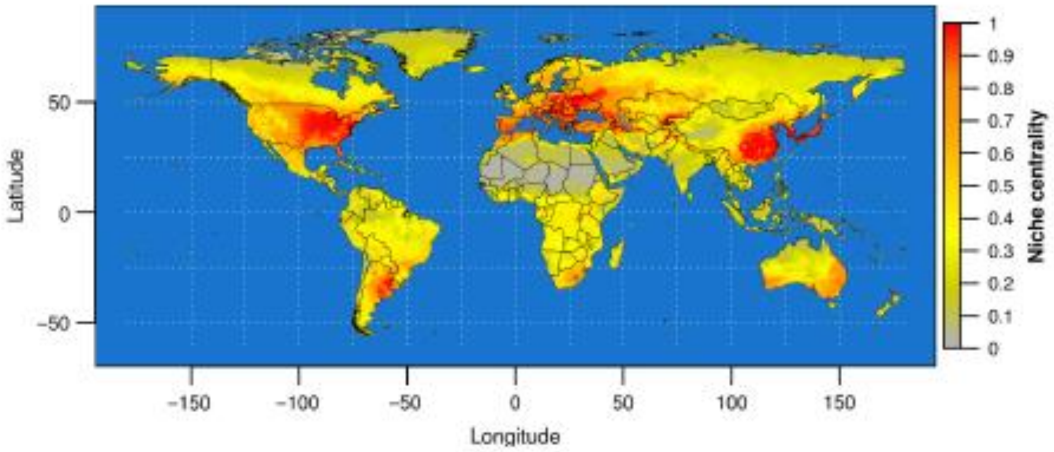


Fig. 7. Snakehead global niche. Map of niche centrality values with higher values indicating climate conditions falling within the modeled niche.

Kramer et al. (2017) published a world map with suitable areas for *C. argus*. The model predicted a large area of Europe (and part of South America) as equally suitable environments for this species as the Laurentian Great Lakes area of North America, where *C. argus* is established.

A8. In which EU Member States has the species been recorded and in which EU Member States has it established? List them with an indication of the timeline of observations. The information needs be given separately for recorded and established occurrences.

A8a. Recorded: List Member States

A8b. Established: List Member States

Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom

The description of the invasion history of the species shall include information on countries invaded and an indication of the timeline of the first observations, establishment and spread.

Response (8a): *C. argus* was introduced in Central Bohemia in the Czech Republic (former Czechoslovakia) in 1956 and 1960 as part of an experimental stocking programme (Hanel et al. 2012) but establishment failed (Frank, 1970, Lusk et al., 2010) Musil et al. (2010) state that *C. argus* is now extinct in the Czech Republic.

Response (8b): None

A9. In which EU Member States could the species establish in the future under current climate and under foreseeable climate change? The information needs be given separately for current climate and under foreseeable climate change conditions.

A9a. Current climate: List Member States

A9b. Future climate: List Member States

With regard to EU Member States, see above.

With regard to climate change, provide information on

- the applied timeframe (e.g. 2050/2070)
- the applied scenario (e.g. RCP 4.5)
- what aspects of climate change are most likely to affect the risk assessment (e.g. increase in average winter temperature, increase in drought periods)

The assessment does not have to include a full range of simulations on the basis of different climate change scenarios, as long as an assessment with a clear explanation of the assumptions is provided. However, if new, original models are executed for this risk assessment, the following RCP pathways shall be applied: RCP 2.6 (likely range of 0.4–1.6°C global warming increase by 2065) and RCP 4.5 (likely range of 0.9–2.0°C global warming increase by 2065). Otherwise, the choice of the assessed scenario has to be explained.

Response (9a): Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, France, Germany, Greece, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, United Kingdom.

Response (9b): Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom

Northern snakehead has a wide temperature range (0–30°C, optimum 10–27°C) (Courtenay & Williams, 2004) and it exhibits a broad tolerance to a wide range of environmental conditions and is extremely hardy (Cudmore & Mandrak, 2006) so it can probably establish in most of the risk assessment area countries. No climate change scenarios are available for northern snakehead for the risk assessment area but it can be assumed that this species under climate warming could also become established in colder parts of the RA area like Finland and Sweden . This is supported by the assessment of Cudmore and & Mandrak (2006) of the possible distribution of *C. argus* in Canada using models based a.o. on temperature and suggest that the distribution of *C. argus* could be widespread in Canada even up to about 60°N (60°N in Europe means an area north of Stockholm).

A10. Is the organism known to be invasive (i.e. to threaten or adversely impact upon biodiversity and related ecosystem services) anywhere outside the risk assessment area?

Response: Northern snakehead is considered invasive by many authors (e.g. Bressman et al. (2019) and Love & Genovese (2019) for the USA) but not by others (e.g. Nakai (2019) for Japan). Vilizzi et al. (2019) assessed northern snakehead to be of medium risk of becoming invasive for Australia and Japan and of high risk for Florida (USA).

The species' high fertility and tolerance of a wide range of conditions, as well as the reduced number of natural enemies in its introduced range, make it highly likely to be a formidable invasive if it was to become established (Global Invasive Species Database, 2020).

The family Channidae is included in Species Listed as Injurious Wildlife under the Lacey Act (18 U.S.C. 42a). Species listed as injurious may not be imported or transported between the continental United States, the District of Columbia, the Commonwealth of Puerto Rico, or any territory or possession of the USA by any means without a permit issued by the Service (Hill et al., 2018). Permits may be granted for the importation or transportation of live specimens of injurious wildlife and their offspring or eggs for bona fide scientific, medical, educational, or zoological purposes.

A11. In which biogeographic region(s) or marine subregion(s) in the risk assessment area has the species shown signs of invasiveness? Indicate the area endangered by the organism as detailed as possible.

Freshwater / terrestrial biogeographic regions:

- Alpine, Atlantic, Black Sea, Boreal, Continental, Mediterranean, Pannonian, Steppic

Marine regions:

- Baltic Sea, North-east Atlantic Ocean, Mediterranean Sea, Black Sea

Marine subregions:

Greater North Sea, incl. the Kattegat and the English Channel, Celtic Seas, Bay of Biscay and the Iberian Coast, Western Mediterranean Sea, Adriatic Sea, Ionian Sea, Central Mediterranean Sea, Aegean-Levantine Sea

Response: The species is not yet known to be present in the risk assessment area.

A12. In which EU Member States has the species shown signs of invasiveness? Indicate the area endangered by the organism as detailed as possible.

Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom

Response: The species is not yet known to be present in the risk assessment area.

Within the risk assessment area, although not established, the species is regulated as potentially invasive by some Member States e.g. import and sale is banned in England and Wales[5]. Furthermore,

[5] The Prohibition of Keeping or Release of Live Fish Order 2003 http://www.legislation.gov.uk/uksi/2003/25/article/2/made

the entire *Channa* genus is included in the Spanish[6] and Portuguese[7] national catalogues of invasive alien species. The inclusion of a species in these national catalogues entails the generic prohibition of its possession, transport, traffic and trade of live specimens, their remains or propagules, which could survive or reproduce, including foreign trade.

A13. Describe any known socio-economic benefits of the organism.

including the following elements:

- Description of known uses for the species, including a list and description of known uses in the Union and third countries, if relevant.
- Description of social and economic benefits deriving from those uses, including a description of the environmental, social and economic relevance of each of those uses and an indication of associated beneficiaries, quantitatively and/or qualitatively depending on what information is available.

If the information available is not sufficient to provide a description of those benefits for the entire risk assessment area, qualitative data or different case studies from across the Union or third countries shall be used, if available.

Response: Some snakehead species are used in the aquarium fish trade, especially small species and brightly coloured juveniles of several large snakeheads, e.g. giant snakehead *Channa micropeltes* (Zięba et al., 2010). However *C. argus* is not very popular with aquarists because they attain a large size and are difficult to feed (Cudmore & Mandrak, 2006). Snakeheads are moderately popular with hobbyists in Japan and Europe. There are no economic data available for northern snakehead in the aquarium trade, but the trade value is probably very low.

Channa species are important for aquaculture, for instance Halwart et al. (2009) report a production of 11525 tonnes of *C. micropeltis* in cages (all countries except China). They also mention that *Channa* species are mainly cultivated in Cambodia and Vietnam. On FishBase (Froese & Pauly, 2019) (https://www.fishbase.de/report/FAO/FAOAquacultureList.php?scientific=Channa+argus) the FAO statistics for the aquaculture production of *C. argus* in China and Korea can be found. Mean yearly production in China (2003–2007) is 230,000 tonnes and in the Republic of Korea (1976–2007) about 300 tonnes. According to the Food and Agriculture Organization of the United Nations (FAO, 2019), *C. argus* production in aquaculture (food fish purposes) was 483,415 tonnes in 2017 (EPO/OFI, pers. comm.). Zhuo et al. (2012) report that northern snakehead is renowned as a food fish in China due to its good taste, high protein content and few intramuscular bones. It is also regarded as a good tonic food fish used in traditional medicine for wound-healing.

Several species are marketed in Canada and have been sold in the USA, even in states where possession of live snakeheads has been illegal for decades (Courtenay & Williams, 2004). Hobbyists and importers can purchase snakeheads through a variety of sites on the Internet, also in Europe. Because of their highly predacious nature, however, snakeheads have not had a large following of interested hobbyists in the USA (Courtenay & Williams, 2004). The trade is generally illegal in most

[6] Real Decreto 630/2013, de 2 de agosto, por el que se regula el Catálogo español de especies exóticas invasoras.

[7] Decreto-Lei n.º 92/2019 de 10 de julho

of the USA (some states do not prohibit and there are a few remaining stocks perhaps) and the trade for aquarium hobbyists is tiny to non-existent now (J. Hill, pers. comm.).

Prior to Federal regulations restricting importation of the species, *C. argus* was the most widely available snakehead sold as a live-food fish in the USA accounting for the largest volume and greatest weight of live snakeheads imported into the USA until 2001 (Courtenay & Williams, 2004).

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."
- With regard to the scoring of the likelihood of events or the magnitude of impacts see Annexes I and II.
- With regard to the confidence levels, see Annex III.
- Highlight the selected response score and confidence level in **bold** but keep the other scores in normal text (so that the selected score is evident in the final document).

1 PROBABILITY OF INTRODUCTION

Important instructions:

- **Introduction** is the movement of the species into the risk assessment area (it may be either in captive conditions and/or in the environment, depending on the relevant pathways).
- **Entry** is the release/escape/arrival in the environment, i.e. occurrence in the wild and is treated in the next section (N.B. introduction and entry may coincide for species entering through pathways such as "corridor" or "unaided)".
- The classification of pathways developed by the Convention of Biological Diversity (CBD) should be used. For detailed explanations of the CBD pathway classification scheme consult the IUCN/CEH guidance document[8] and the provided key to pathways[9].
- For organisms that are already present in the risk assessment area, only complete this section for current active pathways and, if relevant, potential future pathways.

Q. 1.1. List relevant pathways through which the organism could be introduced. Where possible give details about the specific origins and end points of the pathways as well as a description of any associated commodities.

For each pathway answer questions 1.2 to 1.7 (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. 1.2a, 1.3a, etc. and then 1.2b, 1.3b etc. for the next pathway.

In this context, a pathway is the route or mechanism of introduction of the species.

[8] https://circabc.europa.eu/sd/a/738e82a8-f0a6-47c6-8f3b-aeddb535b83b/TSSR-2016-010%20CBD%20categories%20on%20pathways%20Final.pdf
[9] https://circabc.europa.eu/sd/a/0aeba7f1-c8c2-45a1-9ba3-bcb91a9f039d/TSSR-2016-010%20CBD%20pathways%20key%20full%20only.pdf

The description of commodities with which the introduction of the species is generally associated shall include a list and description of commodities with an indication of associated risks (e.g. the volume of trade; the likelihood of a commodity being contaminated or acting as vector).

If there are no active pathways or potential future pathways this should be stated explicitly here, and there is no need to answer the questions 1.2–1.9

Known pathways for introduction of *C. argus* are:

ESCAPE FROM CONFINEMENT – Pet/aquarium/terrarium species

ESCAPE FROM CONFINEMENT – Live food and live bait

RELEASE IN NATURE - Fishery in the wild (including game fishing)

RELEASE IN NATURE – Other intentional release (ceremonial release as a prayer species)

In other parts of the world, *C. argus* were intentionally introduced for aquaculture and aquarium trade and released for angling purposes and as prayer species (Cudmore & Mandrak, 2006). For the risk assessment area, however, there are no current active pathways of introduction of *C. argus* described.

Below we will discuss only the pathways assumed to be or become the most important (aquarium trade and live food) as the other pathways are estimated to be non-existing in the risk assessment area and not to become important in the near future. Currently, there seems to be no aquaculture or fishing interest for *C. argus* in Europe and very few *C. argus* (if any) would be available in the risk assessment area for prayer animal release.

Pathway name: ESCAPE FROM CONFINEMENT - Pet/aquarium/terrarium species

Q. 1.2a. Is introduction along this pathway intentional (e.g. the organism is imported for trade) or unintentional (e.g. the organism is a contaminant of imported goods)?

RESPONSE	**intentional** unintentional	**CONFIDENCE**	low medium **high**

Response: Aquarists in Japan, Europe, including the UK (e.g. *C. micropeltes*; Zięba et al., 2010), and to a lesser extent North America, have kept small, colourful snakehead species as pet fish (Courtenay & Williams, 2004). However, *C. argus* is not favoured for the aquarium or water garden trade as they are not very colourful and rapidly attain very large sizes (Courtenay & Williams, 2004; Orrell & Weigt, 2005). The same can be said of *C. micropeltes* in the UK, where a dead specimen was found on a river bank, presumably released live to the water by its owner when the pet aquarium fish became too large (Zięba et al., 2010).

Q. 1.3a. How likely is it that large numbers of the organism will be introduced through this pathway from the point(s) of origin over the course of one year? including the following elements: • discuss how likely the organism is to get onto the pathway in the first place. Also comment on the volume of movement along this pathway. • an indication of the propagule pressure (e.g. estimated volume or number of individuals / propagules, or frequency of passage through pathway), including the likelihood of reinvasion after eradication • if relevant, comment on the likelihood of introduction based on propagule pressure (i.e. for some species low propagule pressure (1-2 individuals) could result in introduction whereas for others high propagule pressure (many thousands of individuals) may not.

RESPONSE	unlikely	CONFIDENCE	medium

Response: There is online trade outside (*C. argus*, http://aquariumfishexporter.com/products/tropical-fish/snakehead/) and inside the risk assessment area (www.ruinemans.com/en-GB/7765/Channa-argus-platinum-l.html). However, *C. argus* is not favoured for the aquarium or water garden trade as they are not very colourful and rapidly attain very large sizes (Courtenay & Williams, 2004; Orrell & Weigt, 2005; Zięba et al., 2010); other *Channa* species are clearly introduced more frequently for the aquarium trade. No quantitative data on live shipments of *C. argus* were found for the risk assessment area.

Q. 1.4a. How likely is the organism to survive, reproduce, or increase during transport and storage along the pathway (excluding management practices that would kill the organism)?

RESPONSE	very likely	CONFIDENCE	high

Response: Survival is estimated to be high as the transport of live fish is normally well organised and the conditions for aquarium fish are normally very good. But even in bad conditions, *C. argus* would probably survive as *C. argus* exhibits a broad tolerance to a wide range of environmental conditions and is extremely hardy (Cudmore & Mandrak, 2006). According to Courtenay and Williams (2004) in a consignment of *C. argus*, the fish were even alive after being shipped from China without water to Canada. The potential for *C. argus* to survive in transit while being shipped overseas is high. Many snakehead species are obligate air breathers, others are facultative air breathers. Therefore, some snakehead species are capable of surviving hypoxic conditions and can even survive out of water for considerable periods of time as long as they remain moist (Mendoza et al., 2009). However, reproduction or an increase in numbers will not occur during transport.

Q. 1.5a. How likely is the organism to survive existing management practices during transport

and storage along the pathway?

RESPONSE	likely	CONFIDENCE	medium

Response: *Channa argus* is extremely hardy and exhibits considerable tolerance to a wide range of environmental conditions (Cudmore & Mandrak, 2006), so it is likely that they would survive existing management practices during transport and storage along the pathway. However, as the purpose of a live fish import is to have live fish for aquaria, so management practices during transport and storage can be assumed to be designed to ensure the fish arrive in a living state.

Q. 1.6a. How likely is the organism to be introduced into the risk assessment area undetected?

RESPONSE	moderately likely	CONFIDENCE	low

Response: As mentioned in Q.1.3a., an online trade exists outside and inside the risk assessment area. Despite the fact that *C. argus* is not favoured for the aquarium or water garden trade as they are not very colourful and rapidly attain very large sizes (Courtenay & Williams, 2004; Orrell & Weigt, 2005; Zięba et al., 2010), it seems moderately likely that they are traded and imported into the RA area undetected.

Q. 1.7a. Estimate the overall likelihood of introduction into the risk assessment area based on this pathway?

RESPONSE	unlikely	CONFIDENCE	medium

Response: *Channa argus* is of low importance in the aquarium fish trade, with the species not being favoured for aquaria or water gardens due to the fact that they are not very colourful, except as small juveniles, and they rapidly attain very large sizes (Courtenay & Williams, 2004; Orrell & Weigt, 2005). The number of imported specimens of this species through this pathway would thus be low.

End of pathway assessment, repeat Q. 1.3 to 1.7 as necessary using separate identifier.

Pathway name: ESCAPE FROM CONFINEMENT – Live food and live bait

Q. 1.2b. Is introduction along this pathway intentional (e.g. the organism is imported for trade)

or unintentional (e.g. the organism is a contaminant of imported goods)?

RESPONSE	**intentional**	**CONFIDENCE**	**high**

Response: The importation of *C. argus* to the USA was originally as live fish for the Oriental retail and restaurant trade (Courtenay & Williams, 2004), and in view of the existence of an Asian market in virtually all EU countries, this species could be of interest amongst importers for the wholesale or retail live fish trade.

Q. 1.3b. How likely is it that large numbers of the organism will be introduced through this pathway from the point(s) of origin over the course of one year?

including the following elements:

- discuss how likely the organism is to get onto the pathway in the first place. Also comment on the volume of movement along this pathway.
- an indication of the propagule pressure (e.g. estimated volume or number of individuals / propagules, or frequency of passage through pathway), including the likelihood of reinvasion after eradication
- if relevant, comment on the likelihood of introduction based on propagule pressure (i.e. for some species low propagule pressure (1–2 individuals) could result in introduction whereas for others high propagule pressure (many thousands of individuals) may not.

RESPONSE	**moderately likely**	**CONFIDENCE**	**medium**

Response: For the trade in an imported live fish to be commercially viable, the consignments would need to be relatively large.

Q. 1.4b. How likely is the organism to survive, reproduce, or increase during transport and storage along the pathway (excluding management practices that would kill the organism)?

RESPONSE	**very likely**	**CONFIDENCE**	**high**

Response: The purpose of a live fish import is to have live fish to sell, and the species is known to be very tolerant of low oxygen levels and other stressors, so the likelihood of survival is high but reproduction and an increase in numbers would not take place during transport.

Q. 1.5b. How likely is the organism to survive existing management practices during transport and storage along the pathway?

RESPONSE	**likely**	**CONFIDENCE**	**medium**

Response: As mentioned in the response to Q 1.4b, the purpose of a live fish import is to have live fish to sell, so management practices during transport and storage can be assumed to be designed to ensure the fish arrive in a living state.

Q. 1.6b. How likely is the organism to be introduced into the risk assessment area undetected?

RESPONSE	**unlikely**	**CONFIDENCE**	**medium**

Response: An online trade exists outside and inside the risk assessment area. *Channa argus* is important as live food for the oriental retail and restaurant trade (Courtenay & Williams, 2004), and in view of the existence of an Asian market in virtually all EU countries, this species could be of interest amongst importers for the wholesale or retail live fish trade. However, it is unlikely that these live food fish are traded and imported into the RA area undetected.

Q. 1.7b. Estimate the overall likelihood of introduction into the risk assessment area based on this pathway?

RESPONSE	**unlikely**	**CONFIDENCE**	**medium**

Response: Although the likelihood of survival, of high numbers etc. range from moderately likely to very likely, these depend upon the species actually being imported to the risk assessment area in a live form for commercial or other sale. At present, there is no known importation of *C. argus* in live form to the risk assessment area, and therefore, overall, the species' introduction into the risk assessment area via this pathway is unlikely.

Q. 1.8. Estimate the overall likelihood of introduction into the risk assessment area based on all pathways and specify if different in relevant biogeographical regions in current conditions.

Provide a thorough assessment of the risk of introduction in relevant biogeographical regions in current conditions: providing insight in to the risk of introduction into the Union.

RESPONSE	unlikely	CONFIDENCE	medium

Response: Although the likelihood of survival, of high numbers etc. range from moderately likely to very likely, these depend upon the species actually being imported to the EU in a live form for the aquarium fish trade or as live food. At present, there is no known importation of *C. argus* in live form to the risk assessment area, and therefore, overall, the species' introduction into the risk assessment area via this pathway is unlikely.

Q. 1.9. Estimate the overall likelihood of introduction into the risk assessment area based on all pathways in foreseeable climate change conditions?

Thorough assessment of the risk of introduction in relevant biogeographical regions in foreseeable climate change conditions: explaining how foreseeable climate change conditions will influence this risk.

With regard to climate change, provide information on

- the applied timeframe (e.g. 2050/2070)
- the applied scenario (e.g. RCP 4.5)
- what aspects of climate change are most likely to affect the likelihood of introduction (e.g. change in trade or user preferences)

The thorough assessment does not have to include a full range of simulations on the basis of different climate change scenarios, as long as an assessment of likely introduction within a medium timeframe scenario (e.g. 30–50 years) with a clear explanation of the assumptions is provided. However, if new, original models are executed for this risk assessment, the following RCP pathways shall be applied: RCP 2.6 (likely range of 0.4–1.6°C global warming increase by 2065) and RCP 4.5 (likely range of 0.9–2.0°C global warming increase by 2065). Otherwise, the choice of the assessed scenario has to be explained.

RESPONSE	unlikely	CONFIDENCE	medium

Response: Because the aquarium/pet fish trade is not normally influenced by climate, and there does not appear to be any particular commercial pressure for the importation of live *C. argus* to the risk assessment area for consumption, it is unlikely that there would be any difference in the introduction of this species in the future.

2 PROBABILITY OF ENTRY

Important instructions:

- Entry is the release/escape/arrival in the environment, i.e. occurrence in the wild. Entry is not to be confused with spread, the movement of an organism within the risk assessment area.
- The classification of pathways developed by the Convention of Biological Diversity (CBD) should be used. For detailed explanations of the CBD pathway classification scheme consult the IUCN/CEH guidance document[10] and the provided key to pathways[11].
- For organisms which are already present in the risk assessment area, 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 entry.

Q. 2.1. List relevant pathways through which the organism could enter into the environment.

For each pathway answer questions 2.2 to 2.7 (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. 2.2a, 2.3a, etc. and then 2.2b, 2.3b etc. for the next pathway.

In this context a pathway is the route or mechanism of entry of the species into the environment.

If there are no active pathways or potential future pathways this should be stated explicitly here, and there is no need to answer the questions 2.2–2.8

ESCAPE FROM CONFINEMENT - Pet/aquarium/terrarium species

RELEASE IN NATURE – Other intentional release

Pathway name: ESCAPE FROM CONFINEMENT - Pet/aquarium/terrarium species

Q. 2.2a. Is entry into the environment intentional (e.g. the organism is released for a specific purpose) or unintentional (e.g. the organism escapes from a confinement)?

RESPONSE	**intentional** unintentional	**CONFIDENCE**	low medium **high**

Response: Some snakeheads living in natural waters of the USA may have been released by aquarium hobbyists (USGS, 2004). As such, if the trade of *C. argus* for aquarium purposes into the risk

[10] https://circabc.europa.eu/sd/a/738e82a8-f0a6-47c6-8f3b-aeddb535b83b/TSSR-2016-010%20CBD%20categories%20on%20pathways%20Final.pdf
[11] https://circabc.europa.eu/sd/a/0aeba7f1-c8c2-45a1-9ba3-bcb91a9f039d/TSSR-2016-010%20CBD%20pathways%20key%20full%20only.pdf

assessment area were to become important, then deliberate release from aquaria would be likely. The likelihood of release is further increased due to the highly-predacious nature and the significant costs associated with feeding and housing of this species (Cudmore & Mandrak, 2006). Long-living, large-bodied species have a higher chance of being released into the environment from aquaria and garden ponds (Magalhães et al., 2017). This is a.o. documented for *C. micropeltes* in the UK, where a dead specimen was found on a river bank, presumably released live to the water by its owner when the pet aquarium fish became too large (Zięba et al., 2010).

Q. 2.3a. How likely is it that large numbers of the organism will enter into the environment along this pathway from the point(s) of origin over the course of one year?

including the following elements:

- discuss how likely the organism is to get onto the pathway in the first place. Also comment on the volume of movement along this pathway.
- an indication of the propagule pressure (e.g. estimated volume or number of individuals / propagules, or frequency of passage through pathway), including the likelihood of reinvasion after eradication
- if relevant, comment on the likelihood of entry into the environment based on propagule pressure (i.e. for some species low propagule pressure (1-2 individuals) could result in entry whereas for others high propagule pressure (many thousands of individuals) may not).

RESPONSE	**unlikely**	**CONFIDENCE**	**medium**

Response: Because snakeheads, in particular *C. argus*, represent only a very minor component of aquarium fish trade, the illegal release or dumping of this species in the environment will never encompass large numbers of individuals, especially since *C. argus* specimens are mostly kept alone or in very small groups in an aquarium.

Q. 2.4a. How likely is the organism to enter into the environment within the risk assessment area undetected?

RESPONSE	**very likely**	**CONFIDENCE**	**high**

Response: Illegal disposal of fishes is probably not going to be reported.

Q. 2.5a. How likely is the organism to enter into the environment during the months of the year most appropriate for establishment?

RESPONSE	very likely	CONFIDENCE	high

Response: Disposal of unwanted fish (e.g. too big for aquarium) is very likely to happen any time of year. Since *C. argus* is a warm to cold water species (Froese & Pauly, 2019) it could thrive the whole year round in most of the risk assessment area. This is supported by the assessment of Cudmore and Mandrak (2006) of the possible distribution of *C. argus* in Canada using models based a.o. on temperature and suggest that the distribution of *C. argus* could be widespread in Canada even up to about 60°N.

Q. 2.6a. How likely is the organism to be able to transfer from the pathway to a suitable habitat or host in the environment?

RESPONSE	very likely	CONFIDENCE	high

Response: Disposed fish are very likely to end up in waters in close proximity of the aquarium. The aquarium trade has been identified as an important pathway of aquatic invasive species (Maceda-Veiga et al., 2013).

Q. 2.7a. Estimate the overall likelihood of entry into the environment within the risk assessment area based on this pathway?

RESPONSE	likely	CONFIDENCE	medium

Response: Although the illegal release or dumping of this species in the environment will never encompass large numbers of individuals, it is likely that *C. argus* will enter into the environment via this pathway. This species is difficult to hold in aquaria because of their highly predacious nature and the significant costs associated with feeding and housing this species (Courtenay & Williams 2004). Snakeheads are therefore likely to end up in the environment after, or as a consequence of, illegal release (Copp et al., 2005b).

End of pathway assessment, repeat Q. 2.2 to 2.7. as necessary using separate identifier.

Pathway name: RELEASE IN NATURE – Other intentional release

Q. 2.2b. Is entry into the environment intentional (e.g. the organism is released for a specific

purpose) or unintentional (e.g. the organism escapes from a confinement)?

RESPONSE	**intentional**	**CONFIDENCE**	**high**

Response: Although escape from live fish holdings remains a distant possibility, the fact that such fish are normally held in quarantine-type locations, is not considered here. However, there have been cases of releases of live animals, imported live for consumption, such as the American lobster *Homarus americanus*, which were released at various locations around Great Britain but with large numbers at two locations along the southern coast of England (Stebbing et al., 2012). There are various reasons for the live release of animals, including consumption, animal rights and religious beliefs (Copp et al., 2005b; Stebbing et al., 2012).

Q. 2.3b. How likely is it that large numbers of the organism will enter into the environment along this pathway from the point(s) of origin over the course of one year?

including the following elements:

- discuss how likely the organism is to get onto the pathway in the first place. Also comment on the volume of movement along this pathway.
- an indication of the propagule pressure (e.g. estimated volume or number of individuals / propagules, or frequency of passage through pathway), including the likelihood of reinvasion after eradication
- if relevant, comment on the likelihood of entry into the environment based on propagule pressure (i.e. for some species low propagule pressure (1-2 individuals) could result in entry whereas for others high propagule pressure (many thousands of individuals) may not).

RESPONSE	**moderately likely**	**CONFIDENCE**	**medium**

Response: The intentional release of live animals that have been purchased for that purpose is most likely to be as part of a religious ceremony or to make an animal-rights political statement (Crossman & Cudmore, 1999; Copp et al., 2005b). In either case, it can be assumed that the release of a large number of animals would make a bigger impact (religious or political) than a single individual or a few specimens. So, it is moderately likely that a relatively large number of fish would be released into the environment. Additionally, restaurant holders can release their surplus livestock as has happened e.g. with the narrow-clawed crayfish *Pontastacus leptodactylus* in Flemish waters in the 1980s (H. Verreycken, pers. comm.).

Q. 2.4b. How likely is the organism to enter into the environment within the risk assessment area undetected?

RESPONSE	likely	CONFIDENCE	medium

Response: Illegal disposal of fishes is not going to be reported, so the sole detection would be by those persons releasing the fish.

Q. 2.5b. How likely is the organism to enter into the environment during the months of the year most appropriate for establishment?

RESPONSE	likely	CONFIDENCE	medium

Response: It would seem counter-productive for the release of live animals (as a religious or political statement) to take place at a time of year when the fish are likely to die due to thermal shock.

Q. 2.6b. How likely is the organism to be able to transfer from the pathway to a suitable habitat or host in the environment?

RESPONSE	likely	CONFIDENCE	medium

Response: Again, it would seem counter-productive for the release of live animals (as a religious or political statement) to be into a habitat that is not suitable for that species. That said, if the persons undertaking the release are not familiar with *C. argus* and release the fish into a marine environment, then the fish would die. Note that there is conflicting information as regards to the salinity tolerance of *C. argus*. Courtenay & Williams (2004) reported it to be 1–10 ppm, whereas Fuller et al. (2019) have reported the upper limits to be 15–18 ppt. Bunch et al. (2019) state that the upper lethal limit is 18 ppt, they can disperse through 5–18 ppt, but probably persist mostly below 10 ppt.

Q. 2.7b. Estimate the overall likelihood of entry into the environment within the risk assessment area based on this pathway?

RESPONSE	moderately likely	CONFIDENCE	medium

Response: Assuming that the species is in fact introduced to the risk assessment area alive, then releases to the environment are moderately likely, based on past events with *C. argus* (Courtenay & Williams 2004) and other non-native aquatic animals (Copp et al., 2005b; Stebbing et al., 2012).

Q. 2.8. Estimate the overall likelihood of entry into the environment within the risk assessment area based on all pathways in current conditions and specify if different in relevant biogeographical regions. Provide a thorough assessment of the risk of entry into the environment in relevant biogeographical regions in current conditions.

RESPONSE	**moderately likely**	**CONFIDENCE**	**low**

Response: If *C. argus* is actually imported to the risk assessment area for the aquarium fish trade or as live food or for other reasons e.g. religious practices, then it is moderately likely that it will be released, or will escape, into the environment at some point. The likelihood of entry into the environment in current conditions is estimated to be equal in all biogeographical regions of the RA area.

Q. 2.9. Estimate the overall likelihood of entry into the environment within the risk assessment area based on all pathways in foreseeable climate change conditions and specify if different in relevant biogeographical regions. Thorough assessment of the risk of entry in relevant biogeographical regions in foreseeable climate change conditions: explaining how foreseeable climate change conditions will influence this risk, specifically if likelihood of entry is likely to increase or decrease for specific pathways.

RESPONSE	**moderately likely**	**CONFIDENCE**	**medium**

Response:

Climate change conditions will not affect the likelihood of *C. argus* being released, or escape, into the environment. The likelihood of entry into the environment in future conditions is estimated to be equal in all biogeographical regions of the RA area.

3 PROBABILITY OF ESTABLISHMENT

Important instructions:

- For organisms which are already established in parts of the risk assessment area, answer the questions with regard to those areas, where the species is not yet established.

Q. 3.1. How likely is it that the organism will be able to establish in the risk assessment area based on the history of invasion by this organism elsewhere in the world (including similarity between other abiotic conditions within it and the organism's current distribution)?

RESPONSE	**very likely**	**CONFIDENCE**	**medium**

Response: *Channa argus* has a broad range of environmental tolerances and is extremely resilient; it inhabits fresh waters within a temperature range of 0 to 30°C (Courtenay & Williams, 2004), preferring stagnant shallow ponds or swamps with mud substratum and vegetation; they can also be found in slow muddy streams and in canals, reservoirs, lakes, and rivers (Cudmore & Mandrak, 2006; Dukravets & Machulin, 1978). As an obligate airbreather it can survive out of water for up to four days by breathing oxygen; cold temperatures reduce metabolism rates and oxygen demand, allowing them to survive under ice (Global Invasive Species Database (2020). In the USA, *C. argus* has reported in Massachusetts (Courtenay & Williams, 2004) and Maine (Fish and Wildlife Service, 2002), as well as California, Florida, North Carolina, Rhode Island, and Wisconsin (CABI, 2012), with established populations reported for Maryland (Landis et al., 2011) and Arkansas (Rypel, 2014). The species has also been found in British Columbia, Canada (Scott et al., 2013). A prediction map for the USA (Poulos et al., 2012) indicates that suitable habitat for *C. argus* exists from Mexico to Hudson Bay, New York State (Herborg et al., 2007). Therefore, *C. argus* could spread to warmer parts of the southeastern United States and Florida, and because most (if not all) of the climate types in that geographical span match those of the risk assessment area (Peel et al., 2007), most of the risk assessment area is at risk of *C. argus* establishment. Female *C. argus* in the Potomac River began spawning at the end of April and continued through August, with a peak spawning at the beginning of June, when mean temperatures were 26ºC. *Channa argus* in the Potomac River demonstrated plasticity in timing of reproduction, which may be bi-modal, and rapid larval growth rates (Landis et al., 2011), attributes that are likely to contribute to the species establishment success in new environments.

Q. 3.2. How widespread are habitats or species necessary for the survival, development and multiplication of the organism in the risk assessment area?

RESPONSE	**widespread**	**CONFIDENCE**	**high**

Response: There is an abundance of suitable habitats for *C. argus* throughout the risk assessment area, where lentic habitats and regulated rivers are very common in central and southern regions. This is also backed up with Peel et al (2007) climate classification which shows that habitat conditions are present in the risk assessment area in relation to their native range.

Q. 3.3. 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?

RESPONSE	**N/A**	**CONFIDENCE**	**high**

Response: No evidence of a dependency on any other species.

Q. 3.4. How likely is it that establishment will occur despite competition from existing species in the risk assessment area?

RESPONSE	**very likely**	**CONFIDENCE**	**high**

Response: *Channa argus* is known to be 'highly predatory' (Courteney & Williams, 2004), with fish representing up to 33% of their diet (Okada, 1960; R/C Modeler Corporation, 2010), spanning 17 species of prey fish, including loaches, breams, common carp *Cyprinus carpio*, and Eurasian perch *Perca fluviatilis* (Dukravets & Machulin, 1978). Other than fishes, the species' diet includes crayfishes, dragonfly larvae, beetles, and frogs, all of which are present throughout the risk assessment area. Combined with the species' ability to make short overland movements (Scott et al., 2013), this suggests that the species is likely either to devour or to out-compete native species, especially after entering an enclosed water body – a similar phenomenon has been reported in England for small ponds following the release of northern pike *Esox lucius*, a native piscivorous fish species (Copp et al., 2005b). Also, as *C. argus* can attain large sizes, the adult specimens may be too big for native predators and thus are more likely to survive and have a higher chance to establish.

In the USA, a study to quantify *C. argus* diet relative to those of non-native largemouth bass *Micropterus salmoides*, and native American eel *Anguilla rostrata* and yellow perch *Perca flavescens* in tidal freshwaters of Virginia and Maryland (Saylor et al., 2012), found that >97% of *C. argus* gut contents were fishes, with fundulid and centrarchid species consumed most frequently. Dietary overlap was biologically significant only between *C. argus* and non-native *M. salmoides*. Aquatic invertebrates were >10× more common in native predator diets, reducing dietary overlap with *C. argus*.

Q. 3.5. How likely is it that establishment will occur despite predators, parasites or pathogens already present in the risk assessment area?

RESPONSE	**likely**	**CONFIDENCE**	**medium**

Response: Unlike highly predatory native fishes in the USA, snakeheads are very protective of their young, thus enhancing survival beyond early life history stages and suggesting the possibility of eventual dominance in suitable waters (Courtenay & Williams, 2004). Native piscivorous fishes in the risk assessment area that could prey on *C. argus* include northern pike *Esox lucius* and Eurasian perch *Perca fluviatilis*, with piscivorous birds such as cormorants and herons, but there is no evidence to suggest that these species would hinder *C. argus* establishment.

We are not aware of any studies that examined whether pathogens and parasites already present in the non-native range could prevent or minimise snakehead establishment.

However, snakehead mortality in intensive culture, such as *C. argus*, but particularly chevron snakehead *Channa striata* and spotted snakehead *Channa punctata*, has been known to occur from epizootic ulcerative syndrome (EUS), a disease which involves several pathogens. This disease is the only that Courtenay & Williams (2004) drew attention to as a serious threat to *C. argus*, albeit in aquaculture only. There are no known studies of whether EUS is observed in wild populations or whether it could become a limiting factor for the establishment of the species in the risk assessment area.

Q. 3.6. How likely is the organism to establish despite existing management practices in the risk assessment area?

RESPONSE	likely	CONFIDENCE	medium

Response: As with virtually all fishes, it would be virtually impossible to eradicate *C. argus* once it was established in a water course. However, in small, closed waters (e.g. small lakes or ponds), eradication may be possible by chemical means (e.g. rotenone) or drain down of the water body (Britton et al., 2008, 2010), especially if undertaken immediately prior to spawning (Jiao et al., 2009).

Q. 3.7. How likely are existing management practices in the risk assessment area to facilitate establishment?

RESPONSE	moderately likely	CONFIDENCE	low

Response: Monitoring and detection approaches currently being used at the national level are unlikely to detect the species, if introduced to the risk assessment area and released to the environment, and therefore establishment of *C. argus* is likely to happen before detection and management measures can be arranged to extirpate the species. Thus, existing management practices are moderately likely to facilitate establishment. However, emerging and future approaches, e.g. e-DNA sampling, may be able to detect the presence of *C. argus* sooner, which will allow a faster response to possibly prevent establishment.

Q. 3.8. How likely is it that biological properties of the organism would allow it to survive eradication campaigns in the risk assessment area?

RESPONSE	likely	CONFIDENCE	medium

Response: If the species is released to a large water course, then eradication is very unlikely to be successful. However, in small water bodies, use of rotenone is likely to extirpate the species due to its high sensitivity to that chemical piscicide (Lazur et al., 2006). Other stressors, such as low oxygen concentration are unlikely to have any effect due to the species ability to survive extended periods of ice cover (Courtenay & Williams, 2004).

Q. 3.9. How likely are the biological characteristics of the organism to facilitate its establishment in the risk assessment area?

including the following elements:

- a list and description of the reproduction mechanisms of the species in relation to the environmental conditions in the Union
- an indication of the propagule pressure of the species (e.g. number of gametes, seeds, eggs or propagules, number of reproductive cycles per year) of each of those reproduction mechanisms in relation to the environmental conditions in the Union.

If relevant, comment on the likelihood of establishment based on propagule pressure (i.e. for some species low propagule pressure (1-2 individuals) could result in establishment whereas for others high propagule pressure (many thousands of individuals) may not.

RESPONSE	**likely**	**CONFIDENCE**	**medium**

Response: A mature *C. argus* female can carry as many as 115 000 eggs (Dukravets & Machulin, 1978), with spawning taking place in somewhat dense aquatic vegetation where they feed and reproduce (Courtenay & Williams, 2004). Depending on water temperature, eggs can hatch in about 24–48 hours. When the young-of-the-year *C. argus* hatch, they remain clustered near the nest for 3–4 weeks, protected by their parents, until their fins develop. At that time, early juveniles begin swimming by diving down into the centre of the nest, then rising back to the surface. All species of snakeheads guard their eggs and young, a behaviour that is rare in native fishes of the risk assessment area. Juvenile *C. argus* cluster at the surface of their "nest," a column of water cleared from vegetation in 0.5–0.75 m of water(FWS, 2004)

Channa argus reaches sexual maturity at 2–3 years of age, i.e. 30 to 35 cm total length (TL). Females are iteroparous (repeated reproductive events) and are capable of spawning one to five times per year (Courtenay & Williams, 2004). Fecundity is variable and ranges from 1300–15 000 eggs (mean number of eggs = 7300) per spawning event. Fecundity of individuals ranges from 21 000 to 51 000 per event, often exceeding 100 000 eggs produced annually (Frank, 1970). This high fecundity facilitates the species' rapid establishment in novel environments. *Channa argus* is a long-lived fish species, with one specimen recorded as attaining eight years of age and a length of 76 cm TL which indicates multiple spawning occasions (Courtenay & Williams, 2004; Froese & Pauly, 2019).

Q. 3.10. How likely is the adaptability of the organism to facilitate its establishment?

RESPONSE	very likely	CONFIDENCE	high

Response: Cudmore & Mandrak (2006) report that *C. argus* has a greater temperature tolerance than most other fish species, is highly adaptable to a wide range of environments (evidenced by its establishment in waters all over Asia), reproduces at a high rate (one female can produce over 100 000 eggs a year), and feeds on a wide variety of fish of all sizes, shrimps, prawns, crabs, and insect larvae (Hilton, 2002).

Q. 3.11. How likely is it that the organism could establish despite low genetic diversity in the founder population?

RESPONSE	moderately likely	CONFIDENCE	low

Response: This has already happened in the USA, where in April 2004, several fish were found from the Potomac River in Maryland and Virginia (USGS, 2004). It has been determined that these populations were the result of several independent introductions and that the populations are reproducing naturally (Odenkirk & Owens, 2005; Orrell & Weigt, 2005). Wegleitner et al. (2016) suggest that two genetic populations of *C. argus* exist in the eastern United States, possibly as a result of two unique introductions from a source population in its native range or from some other undiscovered and unsampled population not included in their dataset. Successful establishment by two separate founder releases in the USA does suggest that initial establishment is possible based on low genetic diversity. However, these results are insufficient to answer with certainty that low genetic diversity would not impede establishment over the longer term, given that true establishment refers to continued persistence of the new population.

Q. 3.12. If the organism does not establish, then how likely is it that casual populations will continue to occur?

Consider, for example, a species which cannot reproduce in the risk assessment area, because of unsuitable climatic conditions or host plants, but is present because of recurring introduction, entry and release events. This may also apply for long-living organisms.

RESPONSE	likely	CONFIDENCE	medium

Response: The species ability to breath air, and its high tolerance to many other environmental conditions indicates that even if establishment is unsuccessful, then the extant *C. argus* will persist as casuals until their death (Courtenay & Williams 2004).

Q. 3.13. Estimate the overall likelihood of establishment in the risk assessment area based on the similarity between climatic conditions within it and the organism's current distribution under current climatic conditions. In addition, details of the likelihood of establishment in

relevant biogeographical regions under current climatic conditions should be provided. Thorough assessment of the risk of establishment in relevant biogeographical regions in current conditions: providing insight in the risk of establishment in (new areas in) the Union.

RESPONSE	very likely	CONFIDENCE	medium

Response: Comparison of the habitats and climates of the risk assessment area and where *C. argus* has established outside its native range (Peel et al., 2007), e.g. the USA (Courtenay & Williams 2004), it is very likely the species would be able to establish itself if imported live to the risk assessment area and released to the environment under current climate conditions. Northern snakehead is the only temperate snakehead species, and tolerance for a wide range of environmental conditions could allow this species to survive in most regions of North America, from northern Florida to Hudson Bay and Alaska and likely in other temperate regions such as western Europe (Lapointe et al., 2013).

Q. 3.14 Estimate the overall likelihood of establishment in the risk assessment area under foreseeable climate change conditions. In addition, details of the likelihood of establishment in relevant biogeographical regions under foreseeable climate change conditions should be provided. Thorough assessment of the risk of establishment in relevant biogeographical regions in foreseeable climate change conditions: explaining how foreseeable climate change conditions will influence this risk. With regard to climate change, provide information on • the applied timeframe (e.g. 2050/2070) • the applied scenario (e.g. RCP 4.5) • what aspects of climate change are most likely to affect the likelihood of establishment (e.g. increase in average winter temperature, increase in drought periods) The thorough assessment does not have to include a full range of simulations on the basis of different climate change scenarios, as long as an assessment of likely establishment within a medium timeframe scenario (e.g. 30–50 years) with a clear explanation of the assumptions is provided. However, if new, original models are executed for this risk assessment, the following RCP pathways shall be applied: RCP 2.6 (likely range of 0.4–1.6°C global warming increase by 2065) and RCP 4.5 (likely range of 0.9–2.0°C global warming increase by 2065). Otherwise, the choice of the assessed scenario has to be explained.

RESPONSE	likely	CONFIDENCE	low

Response: No data could be found on the effect of climate change on the future establishment of *C. argus* in the RA area. However, given its broad tolerance to both low and high temperatures it is likely that *C. argus* will be able to establish in the RA area, probably even in a larger area (including parts of Scandinavia) than in current conditions.

4 PROBABILITY OF SPREAD

Important instructions:

- Spread is defined as the expansion of the geographical distribution of an alien species within the risk assessment area.
- Repeated releases at separate locations do not represent continuous spread and should be considered in the probability of entry section. In other words, intentional anthropogenic "spread" via release or escape ("jump-dispersal"), should be dealt within the entry section. However, as repeated releases contribute to the spread of the target organism in the risk assessment area, the relevant pathway(s) should be briefly discussed here too, with an explicit reference to the entry section for additional details.

Q. 4.1. How important is the expected spread of this organism within the risk assessment area by natural means? (List and comment on each of the mechanisms for natural spread.)

including the following elements:

- a list and description of the natural spread mechanisms of the species in relation to the environmental conditions in the risk assessment area.
- an indication of the rate of each of those spread mechanisms in relation to the environmental conditions in the Union.

The description of spread patterns should include elements of the species life history and behavioural traits able to explain its ability to spread, including: reproduction or growth strategy, dispersal capacity, longevity, dietary requirements, environmental and climatic requirements, specialist or generalist characteristics.

RESPONSE	**major**	**CONFIDENCE**	**medium**

Response: *Channa argus* is capable of short overland migration (Cudmore & Mandrak, 2006; Scott et al., 2013), although it has not been observed in introduced populations in the United States (J. Hill, pers. comm.), and downstream migrations have also been reported in non-native populations (Courtenay & Williams 2004). Lapointe et al. (2013) demonstrated that in the Potomac River in the invaded range in the USA *C. argus* remain in restricted home ranges throughout the year, but that a considerable portion of the population can disperse over considerable distances to establish a new home range. If introduced to the risk assessment area and escaped or was released to open waters, then *C. argus* is expected to similarly be able to spread via natural means, both from still waters to water courses and within water courses as also in Europe most rivers are interconnected by man-made waterways.

Q. 4.2. How important is the expected spread of this organism within the risk assessment area by human assistance? (List and comment on each of the mechanisms for human-assisted spread and provide a description of the associated commodities.)

including the following elements:

- a list and description of the anthropogenic spread mechanisms of the species in relation to the

	environmental conditions in the Union.
•	an indication of the rate of each of those spread mechanisms in relation to the environmental conditions in the Union.

RESPONSE	**minor**	**CONFIDENCE**	**medium**

Response: Although anglers were considered responsible for the spread of *C. argus* in several locations within their native and introduced ranges (Courtenay & Williams, 2004), there seems to be very little interest in snakehead fishery in the risk assessment area, therefore the risk of spread through this pathway seems to be minor in the risk assessment area.

The release of captive larger-sized *Channa* species to open waters has already been demonstrated in one EU country, i.e. *C. micropeltes* in the UK (Zięba et al., 2010), so disposal of unwanted fish from aquaria is probably also a possible cause for spread. However, *C. argus* seems to be currently of little interest for aquaria in the risk assessment area.

Overall, angler and aquarist releases of the species are anticipated to be of minor importance relative to the species' natural dispersal ability, which is both overland and via water ways (Courtenay & Williams, 2004).

Q. 4.2a. 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 4.3 to 4.9 (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. 4.3a, 4.4a, etc. and then 4.3b, 4.4b etc. for the next pathway.

including the following elements:

- a list and description of pathways with an indication of their importance and associated risks (e.g. the likelihood of spread in the Union, based on these pathways; likelihood of survival, or reproduction, or increase during transport and storage; ability and likelihood of transfer from the pathway to a suitable habitat or host). Where possible details about the specific origins and end points of the pathways shall be included.
- an indication of the propagule pressure (e.g. estimated volume or number of specimens, or frequency of passage through pathway), including the likelihood of reinvasion after eradication.
- All relevant pathways should be considered. The classification of pathways developed by the Convention of Biological Diversity shall be used.

Pathway name: RELEASE IN NATURE - Fishery in the wild (including game fishing)

(See also relevant sections under Introduction and Entry chapters)

Q. 4.3a. Is spread along this pathway intentional or unintentional (e.g. the organism is a contaminant of translocated goods within the risk assessment area)?

RESPONSE	intentional	CONFIDENCE	high

Response: Anglers are well known to release sport fish to 'enhance' their fishery (Copp et al., 2005a). In the USA, this was demonstrated for *Channa* species (Courtenay & Williams, 2004).

Q. 4.4a. How likely is it that a number of individuals sufficient to originate a viable population will spread along this pathway from the point(s) of origin over the course of one year?

including the following elements:

- an indication of the propagule pressure (e.g. estimated volume or number of specimens, or frequency of passage through pathway), including the likelihood of reinvasion after eradication
- if appropriate, indicate the rate of spread along this pathway
- if appropriate, include an explanation of the relevance of the number of individuals for spread with regard to the biology of species (e.g. some species may not necessarily rely on large numbers of individuals).

RESPONSE	moderately likely	CONFIDENCE	medium

Response: The movement of large fishes can range from a few specimens (Copp et al., 2003) to larger numbers (Copp et al., 2010), so such intentional releases will vary on a case-by-case basis.

Q. 4.5a. How likely is the organism to survive, reproduce, or increase during transport and storage along the pathway (excluding management practices that would kill the organism)?

RESPONSE	very likely	CONFIDENCE	high

Response: Survival is estimated to be high as the transport of live sport fish is normally well organized, but even in bad conditions, *C. argus* would probably survive due to its broad tolerance to a wide range of environmental conditions and is extremely hardy (Cudmore & Mandrak, 2006). Owing to the species' ability to air breathe, a consignment of *C. argus* was shipped from China to Canada without water and survived (Courtenay & Williams, 2004).

Q. 4.6a. How likely is the organism to survive existing management practices during spread?

RESPONSE	likely	CONFIDENCE	medium

Response: There are no management practices during the transport of live fish for stocking.

Q. 4.7a. How likely is the organism to spread in the risk assessment area undetected?

RESPONSE	**likely**	**CONFIDENCE**	**medium**

Response: Intentional release of non-native fishes is illegal but still takes place and therefore goes unreported.

Q. 4.8a. How likely is the organism to be able to transfer from the pathway to a suitable habitat or host during spread? (including, where possible, details about the specific origins and end points of the pathway)

RESPONSE	**very likely**	**CONFIDENCE**	**high**

Response: *Channa argus* is highly tolerant of poor environmental conditions, and it is capable of upstream and downstream but also overland migrations (Courtenay & Williams, 2004; Lapointe et al., 2013) although movement out of water is more likely through marshy areas and during flooding (J. Hill, pers. comm.), so whether released into a suitable or unsuitable environment, the species has the ability to move until it finds a suitable habitat.

Q. 4.9a. Estimate the overall potential rate of spread within the Union based on this pathway? (please provide quantitative data where possible).

RESPONSE	**moderate**	**CONFIDENCE**	**medium**

Response: Anglers are well known to release sport fish to 'enhance' their fishery (Copp et al., 2005a). The import of live fish can occur with long distance transport but the spread of this species to enhance the fisheries is likely to occur rather locally within the range of the anglers' fishing area. This human aided spread can be followed by natural dispersal as their functional terrestrial locomotor behaviours, combined with their emersion behaviour and efficient air-breathing capabilities, suggest that *C. argus* may be able to colonise new bodies of water via temporary overland movements (Bressman et al., 2019). But overland movement is very slow, and within-waterway migration apparently is seasonal and moderate (Lapointe et al., 2013). Overland migration is an ability to overcome local barriers to movement rather than a long-range migration ability (J. Hill, pers. comm.).

End of pathway assessment, repeat Q. 4.3 to 4.9. as necessary using separate identifiers.

Q. 4.10. Within the risk assessment area, how difficult would it be to contain the organism in relation to these pathways of spread?

RESPONSE	**very difficult**	**CONFIDENCE**	**medium**

Response: Once established in a river basin, whether in a still water or a water course, containment is likely to be difficult due to the species natural dispersal abilities and the many connections between basins in the risk assessment area.

Q. 4.11. Estimate the overall potential rate of spread in relevant biogeographical regions under current conditions for this organism in the risk assessment area (indicate any key issues and provide quantitative data where possible).

Thorough assessment of the risk of spread in relevant biogeographical regions in current conditions, providing insight in the risk of spread into (new areas in) the Union.

RESPONSE	**slow**	**CONFIDENCE**	**medium**

Response: *C. argus* can tolerate a range of climates and could be spread easily into many parts of the risk assessment area by e.g. anglers, However, the limited interest of anglers in this species and its natural dispersal ability and somewhat sedentary character suggest that the rate of spread would be slow under current climate conditions.

Q. 4.12. Estimate the overall potential rate of spread in relevant biogeographical regions in foreseeable climate change conditions (provide quantitative data where possible).

Thorough assessment of the risk of spread in relevant biogeographical regions in foreseeable climate change conditions: explaining how foreseeable climate change conditions will influence this risk, specifically if rates of spread are likely slowed down or accelerated.

RESPONSE	**slow**	**CONFIDENCE**	**medium**

Response: *C. argus* can tolerate a range of climates and could be spread easily into many parts of the risk assessment area by e.g. anglers, However, the limited interest of anglers in this species and its natural dispersal ability and somewhat sedentary character suggest that the rate of spread is unlikely to be affected by climate, so its spread would also be slow under future climate conditions.

5 MAGNITUDE OF IMPACT

Important instructions:

- Questions 5.1–5.5 relate to biodiversity and ecosystem impacts, 5.6–5.8 to impacts on ecosystem services, 5.9–5.13 to economic impact, 5.14–5.15 to social and human health impact, and 5.16–5.18 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 starts with the impact elsewhere in the world, then considers impacts in the risk assessment area (=EU excluding outermost regions) separating known impacts to date (i.e. past and current impacts) from potential future impacts (including foreseeable climate change).
- Only negative impacts are considered in this section (socio-economic benefits are considered in Q. A.7)

Biodiversity and ecosystem impacts

Q. 5.1. How important is the impact of the organism on biodiversity at all levels of organisation caused by the organism in its non-native range excluding the risk assessment area?

including the following elements:

- Biodiversity means the variability among living organisms from all sources, including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems
- impacted chemical, physical or structural characteristics and functioning of ecosystems

RESPONSE	**major**	**CONFIDENCE**	**medium**

Comment: Gascho Landis et al. (2011) state that the total impact of the introduction of northern snakehead in the USA is still unknown but the potential for negative effects on native aquatic communities is large. Adult northern snakehead are highly piscivorous (Ling, 1977). Introductions of predatory fish can alter aquatic community structure and food webs through top-down mechanisms (Madenjian et al., 2002). Northern snakehead have broad environmental tolerances, and have the potential to significantly impact aquatic resources throughout North America (Herborg et al., 2007).

Channa argus is known to be 'highly predatory' (Ling, 1977), with fish representing up to 33% of their diet (Courtenay & Williams 2004), spanning 17 species of prey fish, including loaches, breams, common carp *Cyprinus carpio*, and Eurasian perch *Perca fluviatilis* (Dukravets & Machulin, 1978). Investigations of *C. argus* diet in the USA have found that >97% of *C. argus* gut contents were fishes. In the Potomac River between 2004 and 2006 (Odenkirk & Owens, 2007) diet included banded killifish *Fundulus diaphanous*, white perch *Morone americana*, bluegill *Lepomis macrochirus*, pumpkinseed sunfish *Lepomis gibbosus*, which is also commonly consumed (Odenkirk & Owens, 2007). Other fish species in *C. argus* diet include goldfish *Carassius auratus*, gizzard shad *Dorosoma petenense*, American eel *Anguilla rostrata*, largemouth bass *Micropterus salmoides*, spottail shiner

Notropis hudsonias, eastern silvery minnow *Hybognathus regius*, mummichog *Fundulus heteroclitus*, channel catfish *Ictalurus punctatus*, green sunfish *Lepomis cyanellus*, and tessellated darter *Etheostoma olmstedi*.

Other than fishes, the species' diet includes crayfishes, dragonfly larvae, beetles, and frogs, amphibians and crustaceans (Courtenay & Williams 2004; Dolin 2003). *Channa argus* is considered to pose a threat through predation to threatened and endangered species, reduce biodiversity and to alter communities, especially those of naturally low species diversity (Courtenay & Williams, 2004).

Q. 5.2. How important is the current known impact of the organism on biodiversity at all levels of organisation (e.g. decline in native species, changes in native species communities, hybridisation) in the risk assessment area (include any past impact in your response)?

Discuss impacts that are currently occurring or are likely occurring or have occurred in the past in the risk assessment area. Where there is no direct evidence of impact in the risk assessment area (for example no studies have been conducted), evidence from outside of the risk assessment area can be used to infer impacts within the risk assessment area.

RESPONSE	N/A	**CONFIDENCE**	**-**

Comment: At present, *C. argus* is not known to exist within the risk assessment area.

Q. 5.3. How important is the potential future impact of the organism on biodiversity at all levels of organisation likely to be in the risk assessment area?

See comment above. The potential future impact shall be assessed only for the risk assessment area.

RESPONSE	**major**	**CONFIDENCE**	**medium**

Comment: If *C. argus* were to be introduced to the risk assessment area and released to the environment, then it is likely to exert adverse impact on biodiversity, especially in small water bodies of naturally-low species diversity (Courtenay & Williams, 2004). This is especially true of ponds, which are known to support disproportionately high aquatic biodiversity. Because no *Channa* species occurs naturally in Europe, there is no possibility of introduced snakeheads hybridising or interbreeding with native fishes.

Q. 5.4. How important is decline in conservation value with regard to European and national nature conservation legislation caused by the organism currently in the risk assessment area?

including the following elements:

- native species impacted, including red list species, endemic species and species listed in the Birds

and Habitats directives
- protected sites impacted, in particular Natura 2000
- habitats impacted, in particular habitats listed in the Habitats Directive, or red list habitats
- the ecological status of water bodies according to the Water Framework Directive and environmental status of the marine environment according to the Marine Strategy Framework Directive

RESPONSE	N/A	CONFIDENCE	-

Comment: At present, *C. argus* is not known to exist within the risk assessment area.

Q. 5.5. 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 the risk assessment area?

including the following elements:

- native species impacted, including red list species and species listed in the Birds and Habitats directives
- protected sites impacted, in particular Natura 2000
- habitats impacted, in particular habitats listed in the Habitats Directive, or red list habitats
- the ecological status of water bodies according to the Water Framework Directive and environmental status of the marine environment according to the Marine Strategy Framework Directive

RESPONSE	major	CONFIDENCE	medium

Comment: The presence of *C. argus* is likely to have a massive impact on the conservation status of both lakes and rivers, especially those with areas of dense aquatic vegetation and of naturally low species diversity and those containing endemic aquatic species (Courtenay & Williams, 2004). Such a top predator can negatively affect species (fish, crayfish, frogs) and habitats listed in the Habitat Directive, protected sites and the ecological status of water bodies according to the WFD.

The introduction of a small number (<5) of *C. argus* specimens into an isolated spring habitat could result in extinction through predation of endemic spring-adapted fishes or crustaceans (Courtenay & Williams, 2004), with competition for food resources also considered high.

Ecosystem Services impacts

Q. 5.6. How important is the impact of the organism on provisioning, regulating, and cultural services in its non-native range excluding the risk assessment area?

- For a list of relevant services use the CICES classification V5.1 provided as an annex.
- Impacts on ecosystem services build on the observed impacts on biodiversity (habitat, species, genetic, functional) but focus exclusively on reflecting these changes in relation to their links with socio-economic well-being.

- Quantitative data should be provided whenever available and references duly reported.
- In absence of specific studies or other direct evidences this should be clearly stated by using the standard answer "No information has been found on the issue". This is necessary to avoid confusion between "no information found" and "no impact found".

RESPONSE	moderate	CONFIDENCE	medium

Comment: Owing to the voracious predatory nature of *C. argus*, the species poses a potential threat to aquatic ecosystem services associated with fisheries and aquaculture (Courtenay & Williams, 2004) through the reduction of fish or crustacean stocks.

The Department of Environmental Conservation of New York State (USA) warns that northern snakeheads have the potential to reduce or even eliminate native fish populations and alter aquatic communities. Municipalities which rely on tourism from recreational fishing may suffer losses should northern snakeheads continue to invade their waters.[12]

Social consequences may exist should a population of northern snakehead become established, which negatively impacts commercial fisheries or other industries resulting in economic losses or reduction in quality of recreational usage of waterbodies (CABI, 2012).

Q. 5.7. How important is the impact of the organism on provisioning, regulating, and cultural services currently in the different biogeographic regions or marine sub-regions where the species has established in the risk assessment area (include any past impact in your response)?

- See guidance to Q. 5.6.

RESPONSE	N/A	CONFIDENCE	-

Comment: This species is not established within the RA area.

Q. 5.8. How important is the impact of the organism on provisioning, regulating, and cultural services likely to be in the different biogeographic regions or marine sub-regions where the species can establish in the risk assessment area in the future?

- See guidance to Q. 5.6.

RESPONSE	minimal	CONFIDENCE	low

Comment: No information has been found on this issue.

[12] https://www.dec.ny.gov/animals/45470.html

Economic impacts

Q. 5.9. How great is the overall economic cost caused by the organism within its current area of distribution (excluding the risk assessment area), including both costs of / loss due to damage and the cost of current management. • Where economic costs of / loss due to the organism have been quantified for a species anywhere in the world these should be reported here. The assessment of the potential costs of / loss due to damage shall describe those costs quantitatively and/or qualitatively depending on what information is available. Cost of / loss due to damage within different economic sectors can be a direct or indirect consequence of the earlier-noted impacts on ecosystem services. In such case, please provide an indication of the interlinkage.

RESPONSE	**moderate**	**CONFIDENCE**	**low**

Comment: An indication is provided by a modeling study that was conducted to determine if the expansion of invasive *C. argus* could negatively affect the population of a popular sport fish, the largemouth bass *Micropterus salmoides* in the Potomac River (Chesapeake Bay), USA (Love & Newhard, 2012). The distributions for both species were generated using catch records. *Channa argus* was not widely distributed during the study period and occurred mainly in upstream areas of tributaries. Many of these areas were moderately or highly suitable habitats for *M. salmoides*. Of sites where juvenile largemouth bass were collected, 10.6% were associated with *C. argus*. Using population modelling and measured predator–prey interactions, Love & Newhard (2012) determined that this level of co-occurrence would result in a 3.8% reduction in *M. salmoides* population size. This prediction is consistent with observations that indicate there has not been a negative trend in the *M. salmoides* fishery. As co-occurrence was increased in the model, however, the negative impact of *C. argus* on largemouth bass monotonically increased. The time required for such increases in *C. argus* distribution could not be determined, but if *C. argus* continued to expand its range in the absence of control measures, then the population model, with its assumptions, predicted a 35.5% reduction in the abundance of *M. salmoides*.

Q. 5.10. How great is the economic cost of / loss due to damage (excluding costs of management) of the organism currently in the risk assessment area (include any past costs in your response)? • Where economic costs of / loss due to the organism have been quantified for a species anywhere in the risk assessment area these should be reported here. Assessment of the potential costs of damage on human health, safety, and the economy, including the cost of non-action. A full economic assessment at EU scale might not be possible, but qualitative data or different case studies from across the EU (or third countries if relevant) may provide useful information to inform decision making. In absence of specific studies or other direct evidences this should be clearly stated by using the standard answer “No information has been found on the issue”. This is necessary to avoid confusion between “no information found” and “no impact found”. Cost of / loss due to damage within different economic sectors can be a direct or indirect consequence of the earlier-noted impacts on ecosystem services. In such case, please provide an indication of the interlinkage.

RESPONSE	N/A	CONFIDENCE	-

Comments: *Channa argus* is not currently present in the RA area.

Q. 5.11. How great is the economic cost of / loss due to damage (excluding costs of management) of the organism likely to be in the future in the risk assessment area?   • See guidance to Q. 5.10.

RESPONSE	moderate	CONFIDENCE	low

Comments: The potential economic cost/loss due to damage if *C. argus* were to establish in the risk assessment area would depend upon the extent of the species presence, the success or not of efforts to extirpate the species, and the locations where it invades (i.e. those of economic value, e.g. aquaculture facilities, being of particular concern).

Q. 5.12. How great are the economic costs / losses associated with managing this organism currently in the risk assessment area (include any past costs in your response)?   • In absence of specific studies or other direct evidences this should be clearly stated by using the standard answer "No information has been found on the issue". This is necessary to avoid confusion between "no information found" and "no impact found".

RESPONSE	N/A	CONFIDENCE	-

Comments: *Channa argus* is not currently present in the RA area.

Q. 5.13. How great are the economic costs / losses associated with managing this organism likely to be in the future in the risk assessment area?   • See guidance to Q. 5.12.

RESPONSE	moderate	CONFIDENCE	low

Comments: The economic costs of eradication of *C. argus* could be relatively modest or very high, depending upon the extent of the species' presence, the size of the water bodies it invades, etc. As mentioned above, the cost of *C. argus* eradication from a small pond in Crofton, Maryland (USA), was estimated to be $110k USD, encompassing personnel time for planning meetings, field application of the piscicide, and disposal of the dead fish (Courtenay & Williams, 2004). Costs of eradication would increase with increasing larger waterbody size (e.g. Britton et al., 2010, 2011), but on average £20k GBP per hectare (≈ €22k/ha) (Britton et al., 2008).

Social and human health impacts

Q. 5.14. How important is social, human health or other impact (not directly included in any earlier categories) caused by the organism for the risk assessment area and for third countries, if relevant (e.g. with similar eco-climatic conditions). The description of the known impact and the assessment of potential future impact on human health, safety and the economy, shall, if relevant, include information on • illnesses, allergies or other affections to humans that may derive directly or indirectly from a species; • damages provoked directly or indirectly by a species with consequences for the safety of people, property or infrastructure; • direct or indirect disruption of, or other consequences for, an economic or social activity due to the presence of a species. Social and human health impacts can be a direct or indirect consequence of the earlier-noted impacts on ecosystem services. In such case, please provide an indication of the interlinkage.

RESPONSE	**minor**	**CONFIDENCE**	**low**

Comments: As mentioned here above, if *C. argus* is introduced to the risk assessment area and released to the environment, then the potential risks to social/human health appear limited, based on current knowledge. There is one snakehead species, the chevron snakehead *Channa striata*, that has been found to be an intermediate host of the helminth parasite *Gnathostoma spinigerum*, which causes gnathostomiasis, a disease which may be transmitted to humans (Cudmore & Mandrak, 2006). The fact that one *Channa* species has been shown as a carrier indicates that there are other species that could present a similar threat to human health, though this has yet to be investigated (Courtenay & Williams, 2004). No other information on potential threats to social or human health were found.

Q. 5.15. 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 risk assessment area. • In absence of specific studies or other direct evidences this should be clearly stated by using the standard answer "No information has been found on the issue". This is necessary to avoid confusion between "no information found" and "no impact found".

RESPONSE	**minor**	**CONFIDENCE**	**low**

Comments: No information has been found on the issue

Other impacts

Q. 5.16. How important is the impact of the organism as food, a host, a symbiont or a vector for other damaging organisms (e.g. diseases)?

RESPONSE	**major**	**CONFIDENCE**	low

Comments: Potential to transfer pathogens (parasites, diseases) is largely unknown. A paper by Chiba et al. (1989) mentions that *C. argus* introduced in 1923/24 from Korea had parasites but provides no further detail.

Nevertheless, all snakehead species are hosts to at least several species of parasite. See table below from Courtenay & Williams (2004)

Table 2—Parasites of northern snakehead (*Channa argus*)

[Adapted from Bykhovskaya-Pavlovskaya and others, 1964]

Parasite	***Group***	***Host tissues***	***Other fishes affected***
Myxidium ophiocephali	Myxosporidia	gallbladder, liver ducts	
Zschokkella ophiocephalli	Myxosporidia	kidney tubules	
Neomyxobolus ophiocephalus	Myxosporidia	gill filaments	
Mysosoma acuta	Myxosporidia	gill filaments	crucian carp
Myxobolus cheisini	Myxosporidia	gill filaments	
Henneguya zschokkei ?	Myxosporidia	gills, subcutaneous, musculature	salmonids (tubercle disease of salmonids)
Henneguya ophiocephali	Myxosporidia	gill arches, supra-branchial chambers	
Henneguya vovki	Myxosporidia	body cavity	
Thelohanellus catlae	Myxosporidia	kidneys	
Gyrodactylus ophiocephali	Monogenoidea	fins	
Polyonchobothrium ophiocephalina	Cestoidea	intestine	
Cysticercus gryporhynchus cheilancristrotus	Cestoidea	gallbladder, intestine	cyprinids, perches
Azygia hwangtsiüi	Trematoda	intestine	
Clinostomum complanatum	Trematoda	body cavity	perches
Pingis sinensis	Nematoda	intestine	
Paracanthocephalus curtus	Acanthocephala	intestine	cyprinids, esocids, sleepers, bagrid catfishes
Paracanthocephalus tenuirostris	Acanthocephala	intestine	
Lamproglena chinensis	Copepoda	gills	

At least two snakehead species used in intense aquaculture, *C. punctata* and *C. striata*, are susceptible to epizootic ulcerative syndrome (EUS), a disease believed to be caused by several species of bacteria, a fungus, and perhaps a retrovirus. Li et al. (2019) also describe the effects of this disease on the hybrid snakehead (*Channa maculata*♀ × *Channa argus*♂) so it is very likely that EUS can also affect *C. argus* itself. The EUS causes high mortality in these fishes but it is not specific to snakeheads and has affected other fishes, such as clariid catfishes, bagrid catfishes, two cyprinid genera, mastacembalid eels, a nandid fish in India, and giant gourami and climbing perch in Thailand. The EUS involves several pathogens (Courtenay & Williams, 2004), including motile aeromonad bacteria (for example, *Aeromonas hydrophila, A. caviae, Pseudomonas fluorescens*), a fungus, *Aphanomyces* *invadans*, which is considered a primary pathogen, and perhaps a rhabdovirus. Another bacterium, *Aquaspirillum* sp. has also been implicated. There have been no studies undertaken to examine transfer of parasites or diseases to native North American fishes (Courtenay & Williams, 2004), and the same appears to be true for fishes native to the risk assessment area.

Q. 5.17. How important might other impacts not already covered by previous questions be resulting from introduction of the organism?

RESPONSE	**minimal**	**CONFIDENCE**	**low**

Comments: No other impacts have been recorded in the species' non-native range, which suggests if any exist, they are of minimal magnitude.

Q. 5.18. How important are the expected impacts of the organism despite any natural control by other organisms, such as predators, parasites or pathogens that may already be present in the risk assessment area?

RESPONSE	**major**	**CONFIDENCE**	**low**

Comments: In view of the previously described potential impacts, and the unlikely natural control on this voracious predator fish, the anticipated impacts would still be major.

Q. 5.19. Estimate the overall impact in the risk assessment area under current climate conditions. In addition, details of overall impact in relevant biogeographical regions should be provided.

Thorough assessment of the overall impact on biodiversity and ecosystem services, with impacts on economy as well as social and human health as aggravating factors, in current conditions.

RESPONSE	**major**	**CONFIDENCE**	**medium**

Although *C. argus* is not established in the RA area and the introduction of this species is considered unlikely, if this species was to find its way in the risk assessment area, then it is likely to spread and exert major biodiversity and ecosystem impacts. As a top predator it can negatively affect species (fish, crayfish, frogs) and protected habitats and the ecological status of water bodies according to the WFD. Also, endemic fishes or crustaceans can experience high competition e.g. for food resources (Courtenay & Williams, 2004).

Q. 5.20. Estimate the overall impact in the risk assessment area in foreseeable climate change conditions. In addition, details of overall impact in relevant biogeographical regions should be

provided.
Thorough assessment of the overall impact on biodiversity and ecosystem services, with impacts on economy as well as social and human health as aggravating factors, under future conditions.

RESPONSE	**major**	**CONFIDENCE**	**medium**

The overall impact of *C. argus* on other biota and habitats is not expected to change in future climate conditions. However, some colder areas of the RA area (parts of Scandinavia) may become at risk in the future because of more benign conditions for *C. argus* to establish.

RISK SUMMARIES			
	RESPONSE	**CONFIDENCE**	**COMMENT**
Summarise Introduction*	**unlikely**	**medium**	Currently, *C. argus* is not present in the risk assessment area and no active introduction pathways are known. *Channa argus* is available for sale on the internet and, although not very popular with aquarists or as live food, could still be imported. Other pathways (as described for the USA and Canada e.g. angling, prayer animal release) are not taken into account in this risk assessment as estimated to be non-existing in the risk assessment area.
Summarise Entry*	**moderately likely**	**medium**	Because snakeheads represent only a very minor component of aquarium fish trade in the risk assessment area, the illegal release or dumping of this species in the environment will never encompass large numbers of individuals. However, *C. argus* specimens would have a high chance of being dumped because of their highly predacious nature and the significant costs associated with feeding and housing this species. They also are not very colourful and rapidly attain very large sizes.
Summarise Establishment*	**very likely**	**high**	Appropriate habitats and climate are found throughout most of the risk assessment area and *C. argus* and its congeners have invasion histories characterised by successful establishment outside their native ranges, which is facilitated by their high tolerance of poor water quality conditions.
Summarise Spread*	**slow**	**medium**	*Channa argus* is tolerant of a wide range of environmental conditions, it is able to migrate overland and undertakes modest seasonal migrations, so its rate of spread in the risk assessment area is likely to be slow unless translocated by humans, which could be for sport fishing reasons, for example. However, there seems to be limited interest in *C.*

			argus for sports fishing.
Summarise Impact*	**major**	**medium**	The introduction of a small number (<5) of *C. argus* specimens into an isolated spring habitat could result in extinction through predation of endemic spring-adapted fishes or crustaceans (Courtenay & Williams, 2004), with competition for food resources also considered high. This species would present a potential economic threat to wild fish stocks and to fish culture interests, especially if this species enters culture facilities from adjacent waters (Courtenay & Williams, 2004). These impacts would have both ecosystem services and socio-economic consequences.
Conclusion of the risk assessment (overall risk)	**high**	**medium**	Although the introduction of this species is considered unlikely, if this species was to find its way in the risk assessment area, then it is likely to spread and exert major impacts.

*in current climate conditions and in foreseeable future climate conditions

REFERENCES

• Benson A., 2019 Snakehead Fishes (*Channa* spp.) in the USA. Proceedings of the first international snakehead symposium, 2018, American Fisheries Society Symposium 89, 3-21.

• Bogutskaya N.G., Naseka A. 2002. An overview of nonindigenous fishes in inland waters of Russia. Proc. Zool. Inst. Russ. Acad. Sci, 296,21-30.

• Bogutskaya N.G., Naseka A.M., Shedko S.V., Vasil'eva E.D. & Chereshnev I.A. 2008. The fishes of the Amur River: updated check-list and zoogeography. Ichthyological Exploration of Freshwaters 19, 301-366.

• Bressman N.B., Love J.W. King T., Horne C., Ashley-Ross M.A. 2019. Emersion and functional terrestrial locomotion by the invasive Northern Snakehead, *Channa argus*. Integrative And Comparative Biology 59 (Suppl.), E24-E24.

• Britton J.R., Brazier M., Davies G.D. & Chare S.I. 2008. Case studies on eradicating the Asiatic cyprinid topmouth gudgeon *Pseudorasbora parva* from fishing lakes in England to prevent their riverine dispersal. Aquatic Conservation 18, 867–876.

• Britton J.R., Copp G.H., Brazier M. & Davies G.D. 2011. A modular assessment tool for managing introduced fishes according to risks of species and their populations, and impacts of management actions. Biological Invasions 13, 2847–2860.

• Britton J.R., Davies G.D. & Brazier M. 2010. Towards the successful control of the invasive *Pseudorasbora parva* in the UK. Biological Invasions 12, 125–131.

• Bunch A.J., Odenkirk J.S., Isel M.W., Boyce R.C. 2019. Spatiotemporal patterns and dispersal mechanisms of Northern Snakehead in Virginian. Proceedings of the first international snakehead symposium, 2018, American Fisheries Society Symposium 89, 22-35.

• CABI 2012. Invasive Species Compendium: datasheet *Channa argus argus* (northern snakehead). https://www.cabi.org/isc/datasheet/89026#53034364-3CA0-4FD0-9283-112544C3DF24; last accessed Feb. 2020.

• Chiba K., Taki Y., Sakai K. and Oozeki Y. 1989. Present status of aquatic organisms introduced into Japan. p. 63–70 In: Exotic aquatic organisms in Asia. Proceedings of the Workshop on Introduction of Exotic Aquatic Organisms in Asia. S.S. De Silva editor. Asian Fisheries Society Special Publication 3. Asian Fisheries Society, Manila, Philippines. 154 pp.

• Copp G.H., Bianco P.G., Bogutskaya N., Erős T., Falka I., Ferreira M.T., Fox M.G., Freyhof J., Gozlan R.E., Grabowska J., Kováč V., Moreno-Amich R., Naseka A.M., Peňáz M., Povž M., Przybylski M., Robillard M., Russell I.C., Stakėnas S., Šumer S., Vila-Gispert A. and Wiesner C. 2005a. To be, or not to be, a non-native freshwater fish? Journal of Applied Ichthyology 21, 242–262.

• Copp G.H., Vilizzi L. & Gozlan R.E. 2010. Fish movements: the introduction pathway for topmouth gudgeon *Pseudorasbora parva* and other non-native fishes in the UK. Aquatic Conservation: Marine & Freshwater Ecosystems 20, 269–273.

• Copp G.H., Vilizzi L., Mumford J., Fenwick G.V., Godard M.J. & Gozlan R.E. 2009. Calibration of FISK, an invasiveness screening tool for nonnative freshwater fishes. Risk Analysis 29, 457–467.

• Copp G.H., Wesley K.J, Kováč V., Ives, M. & Carter, M.G. 2003. Introduction and establishment of the pikeperch *Stizostedion lucioperca* (L.) in Stanborough Lake (Hertfordshire) and its dispersal in the Thames catchment. The London Naturalist 82, 139–153.

• Copp G.H., Wesley K.J. & Vilizzi L. 2005b. Pathways of ornamental and aquarium fish introductions into urban ponds of Epping Forest (London, England): the human pathway. Journal of Applied Ichthyology 21, 263–274.

• Courtenay W.R. & Williams J.D. 2004. Snakeheads (Pisces, Channidae)—A Biological Synopsis and Risk Assessment. U.S. Geological Survey circular (volume 1251). ISBN.0-607-93720

• Crossman E.J. and Cudmore, B.C. 1999. Summary of North American introductions of fish through the aquaculture pathway and related human activities. pp. 297–303 In: R. Claudi & J. H. Leach (eds.) Nonindigenous Freshwater Organisms, Pathways, Biology and Impacts. Boca Raton, Florida: Lewis Publishers.

• Cudmore B; Mandrak NE, 2006. Risk Assessment for Northern Snakehead (*Channa argus*) in Canada. Canadian Science Advisory Secretariat, Fisheries and Oceans Canada, Ottawa, ON. CSAS Res. Doc, 2006/075. Ottawa, Ontario, Canada: Canadian Science Advisory Secretariat, Fisheries and Oceans Canada.

• Dolin E.J. 2003. Snakehead: A fish out of water. Smithsonian Institution, Washington, DC. (ISBN: 1588341542)

• Dukravets G.M. & Machulin A.I. 1978. The morphology and ecology of the Amur snakehead, *Ophiocephalus argus warpachowskii*, acclimatized in the Syr Dar'ya basin: Journal of Ichthyology 18, 203–208.

• Froese R. & Pauly D. (Eds) 2019. FishBase. World Wide Web electronic publication. www.fishbase.org, version (08/2019).

• Frank S. 1970. Acclimatization experiments with Amur snakehead, *Ophiocephalus argus* warpachowskii Berg, 1909. Věstník Československé společnosti zoologické 4, 277–283.

• Fuller P.L., Benson A.J., Nunez G., Fusaro A. & Neilson, M. 2019, Channa argus (Cantor, 1842): U.S. Geological Survey, Nonindigenous Aquatic Species Database, Gainesville, FL, https://nas.er.usgs.gov/queries/factsheet.aspx?speciesid=2265, Revision Date: 7/31/2019, Peer Review Date: 4/1/2016, Access Date: 19/08/2019

• Fish and Wildlife Service (FWS), 2002. Injurious wildlife species: snakeheads (family Channidae). US Environmental Protection Agency, Federal Register Environmental Documents, Vol. 67, No. 193, 255 pp.

• Fish and Wildlife Service (FWS), 2004. Invasive Species Program—Snakeheads, Aquatic Invaders. Retrieved from: www.fws.gov/fisheries/ans/pdf_files/Snakeheads.pdf.

• Gascho Landis A.M., Lapointe N.W.R., Angermeier P.L., 2011. Individual growth and reproductive behavior in a newly established population of northern snakehead (*Channa argus*), Potomac River, USA. Hydrobiologia 661, 123–131. DOI 10.1007/s10750-010-0509-z

• Global Invasive Species Database, 2020. Species profile: *Channa argus*. Downloaded from http://www.iucngisd.org/gisd/species.php?sc=380 on 16-01-2020

• Herborg L.M., Mandrak N.E., Cudmore B.C. & MacIsaac H.J. 2007. Comparative distribution and invasion risk of snakehead (Channidae) and Asian carp (Cyprinidae) species in North America. Canadian Journal of Fisheries and Aquatic Sciences 64, 1723–1735.

• Halwart M., Soto D., Arthur J.R. (éds) 2009. Aquaculture en cage – Études régionales et aperçu mondial. FAO Document technique sur les pêches. No. 498. Rome, FAO. 259p.

• Hanel L., Plesnik J., Andreska J., Lusk S, Novak J. & Plistil J. 2012. Alien fishes in European waters. Bulletin lampetra 7: 148 – 185

• Hill J.E., Tuckett Q.M. & Watson C.A. 2018. Court Ruling Creates Opportunity to Improve Management of Nonnative Fish and Wildlife in the United States. Fisheries 43: 225-230. https://doi.org/10.1002/fsh.10071

• Hilton R. 2002. The northern snakehead: an invasive fish species. Hot Topic Series, Cambridge Scientific Abstracts. www.csa.com/hottopics/snakehead. Accessed on 15 January 2004.

• Jiao Y., Lapointe N.W.R. & Angermeier P.L., Murphy B.R. 2009. Hierarchical demographic approaches for assessing invasion dynamics of non-indigenous species: An example using northern snakehead (*Channa argus*). Ecological Modelling 220, 1681–1689.

• Kramer A.M., Annis G., Wittmann, M.E., Chadderton W.L., Rutherford E.S., Lodge D.M., Mason L., Beletsky D., Riseng C. & Drake J.M. 2017. Suitability of Laurentian Great Lakes for invasive species based on global species distribution models and local habitat. Ecosphere, 8(7), e01883.

• Landis A.M.G., Lapointe N.W. & Angermeier P.L. 2011. Individual growth and reproductive behavior in a newly established population of northern snakehead *Channa argus*, Potomac River, USA. Hydrobiologia 661, 123–131.

• Lapointe N.W.R., Odenkirk J.S., Angermeier P.L. 2013. Seasonal movement, dispersal, and home range of northern snakehead *Channa argus* (Actinopterygii, Perciformes) in the Potomac River catchment. Hydrobiologia 709, 73–87.

• Lazur A., Early S. & Jacobs J.M. 2006. Acute toxicity of 5% rotenone to northern snakeheads. North American Journal of Fisheries Management 26, 628–630.

• Li Z., Wang G., Zhang K., Gong W., Yu E., Tian J., Xie J., Yu D. 2019. Epizootic ulcerative syndrome causes cutaneous dysbacteriosis in hybrid snakehead (*Channa maculata*♀ × *Channa argus*♂). PeerJ. 7:e6674. doi: 10.7717/peerj.6674.

• Ling S.W., 1977. Aquaculture in Southeast Asia: A Historical Overview. University of Washington Press, Seattle.

• Love J.W., Genovese P. 2019. Fishing for an Invasive: Maryland's Toolbox for Managing Northern Snakehead Fisheries. Proceedings of the first international snakehead symposium, 2018, American Fisheries Society Symposium 89, 139-152.

• Love J.W., Newhard J.J. 2012. Will the expansion of northern snakehead negatively affect the fishery for largemouth bass in the Potomac River (Chesapeake Bay)? North American Journal of Fisheries Management 32, 859–868.

• Lusk S., Lusková V. & Hanel L. 2010. Alien fish species in the Czech Republic and their impact on the native fish fauna. Folia Zoologica 59, 57–72.

• Maceda-Veiga A., Escribano-Alacid J., de Sostoa A. and García-Berthou E. 2013. The aquarium trade as a potential source of fish introductions in southwestern Europe. Biological Invasions 15: 2707–2716.

• Madenjian C.P., Fahnenstiel G.L., Johengen T.H., Nalepa T.F., Vanderploeg H.A., Fleischer G.W., Schneeberger P.J., Benjamin D.M., Smith E.B., Bence J.R., Rutherford E.S., Lavis D.S., Robertson D.M., Jude D.J. & Ebener M.P., 2002. Dynamics of the Lake Michigan food web, 1970–2000. Canadian Journal of Fisheries and Aquatic Sciences 59, 736–753.

• Magalhães A.L.B., Orsi M.L., Pelicice F.M., Azevedo-Santos V.M., Vitule J.R. S., Lima-Junior D. & Brito M.F.G. 2017. Small size today, aquarium dumping tomorrow: sales of juvenile non-native large fish as an important threat in Brazil. Neotropical Ichthyology 15, e170033. https://dx.doi.org/10.1590/1982-0224-20170033

• Mendoza R.E., Alfaro E., Cudmore B., Orr R., Fisher J.P., Contreras-Balderas S., Courtenay W.R., Koleff-Osorio P., Mandrak N., Álvarez-Torres P., Arroyo-Damián M., Escalera-Gallardo C., Güevara-Sanguinés A., Greene G., Lee D., Orbe-Mendoza A., Ramírez-Martínez C. & Stabridis-Arana O. 2009. Trinational risk assessment guidelines for aquatic alien invasive species. CEC Project Report. www.biodiversidad.gob.mx/especies/Invasoras/pdf/Directrices_estcaso_ingles.pdf

• Musil J., Jurajda P., Adámek Z., Horký P., Slavík O. 2010. Non-native fish introductions in the Czech Republic – species inventory, facts and future perspectives. Journal of Applied Ichthyology 26, 38–45.

• Nakai K. 2019. Historical Review of Introduced Snakeheads in Japan. Proceedings of the first international snakehead symposium, 2018, American Fisheries Society Symposium 89, 185-202.

• Odenkirk J.S. & Isel M.W. 2016. Trends in Abundance of Northern Snakeheads in Virginia Tributaries of the Potomac River, Transactions of the American Fisheries Society, 145, 687-692. DOI: 10.1080/00028487.2016.1149516

• Odenkirk J. & Owens S. 2005. Northern snakeheads in the tidal Potomac River system. Transactions of the American Fisheries Society 134, 1605–1609.

• Odenkirk J. & Owens S. 2007. Expansion of a northern snakehead population in the Potomac River system, Transactions of the American Fisheries Society 136, 1633–1639.

• Okada, Y. 1960, Studies of the freshwater fishes of Japan, II, Special part: Prefectural University of Mie. Journal of the Faculty of Fisheries 4 (3), p. 1–860, 61 plates.

• Orrell T.M. & Weigt L. 2005. The northern snakehead *Channa argus* (Anabantomorpha: Channidae), a non-indigenous fish species in the Potomac River, USA Proceedings of the Biological Society of Washington 118(2), 407–415.

• Peel M.C., Finlayson B. L., McMahon T. A. 2007. Updated world map of the Köppen-Geiger climate classification. Hydrol. Earth Syst. Sci., 11, 1633–1644. https://doi.org/10.5194/hess-11-1633-2007.

• Poulos H.M., Chernoff B., Fuller P.L. and Butman D. 2012. Ensemble forecasting of potential habitat for three invasive fishes. Aquatic Invasions 7, 59–72.

• R/C Modeler Corporation. 2010. Freshwater and Marine Aquarium. California.

• Rypel A.L. 2014. Do invasive freshwater fish species grow better when they are invasive?. Oikos 123, 279–289.

• Saylor R.K., Lapointe, N.W.R., Angermeier P.L. 2012. Diet of non-native northern snakehead (*Channa argus*) compared to three co-occurring predators in the lower Potomac River, USA. Ecology of Freshwater Fish 21, 443–452.

• Scott D., Moore J.W., Herborg L.-M., Murray C.C., Serrao N.R. 2013. A non-native snakehead fish in British Columbia, Canada: capture, genetics, isotopes, and policy consequences. Management of Biological Invasions 4:265-271.

• Stebbing, P., Johnson, P., Delahunty, A., Clark, P.F., McCollin, T., Hale, C. & Clark, S., 2012. Reports of American lobsters, *Homarus americanus* (H. Milne Edwards, 1837), in British waters. BioInvasions Records 1, 17–23.

• USGS. 2004. Non-indigenous aquatic species database – northern snakehead (*Channa argus*). United States Geological Survey (www.nas.er.usgs.gov.

• Vilizzi L., Copp G.H., Adamovich B., Almeida D., Chan J., Davison P.I., Dembski S., Ekmekçi F.G., Ferincz Á., Forneck S., Hill J.E., Kim J-E., Koutsikos N., Leuven R.S.E.W., Luna S., Magalhães F., Marr S., Mendoza R., Mourão C.F., Neal J.W., Onikura N., Perdikaris C., Piria M., Poulet N., Puntila R., Range I.L., Simonović P., Ribeiro F., Tarkan A.S., Troca D.F.A., Vardakas L., Verreycken H., Vintsek L., Weyl O.L.F., Yeo D.C.J. & Zeng Y. 2019. A global review and meta-analysis of applications of the Fish Invasiveness Screening Kit. Reviews in Fish Biology and Fisheries 29, 529–568.

• Wegleitner B.J., Tucker A., Chadderton W.L. & Mahon A.R. 2016. Identifying the genetic structure of introduced populations of northern snakehead (*Channa argus*) in Eastern USA. Aquatic Invasions 11, 199–208.

• Zhuo X., Liang R., Chen Y., Huang G., Yu D., Zou J. 2012. Genetic characterization of northern snakehead (*Channa argus*) populations in China using microsatellite markers. Biochemical Systematics and Ecology 43, 25–31

• Zięba G., Copp G.H., Davies G.D., Stebbing P.D., Wesley K.J. & Britton J.R. (2010) Recent releases and dispersal of non-native fishes in England and Wales, with emphasis on sunbleak *Leucaspius delineatus*. Aquatic Invasions 5, 155–161.

Distribution Summary

Please answer as follows:

Yes if recorded, established or invasive

– if not recorded, established or invasive

? Unknown; data deficient

The columns refer to the answers to Questions A5 to A12 under Section A.
For data on marine species at the Member State level, delete Member States that have no marine borders. In all other cases, provide answers for all columns.

Member States

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

Biogeographical regions of the risk assessment area

	Recorded	Established (currently)	Possible establishment (under current climate)	Possible establishment (under foreseeable climate)	Invasive (currently)
Alpine	-	-	-	-	-
Atlantic	-	-	Yes	Yes	-
Black Sea	-	-	Yes	Yes	-
Boreal	-	-	Yes	Yes	-
Continental	Yes	-	Yes	Yes	-
Mediterranean	-	-	Yes	Yes	-
Pannonian	-	-	Yes	Yes	-
Steppic	-	-	Yes	Yes	-

Marine regions and subregions of the risk assessment area

	Recorded	Established (currently)	Possible establishment (under current climate)	Possible establishment (under foreseeable climate)	Invasive (currently)
Baltic Sea					
Black Sea					
North-east Atlantic Ocean					
Bay of Biscay and the Iberian Coast				-	
Celtic Sea					
Greater North Sea					
Mediterranean Sea					
Adriatic Sea					
Aegean-Levantine Sea					
Ionian Sea and the Central Mediterranean Sea					
Western Mediterranean Sea					

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, and other impacts**
	Question 5.1-5	*Question 5.6-8*	*Question 5.9-13*	*Question 5.14-18*
Minimal	Local, short-term population loss, no significant ecosystem effect	No services affected[13]	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 reversible; 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.

[13] Not to be confused with “no impact”.

ANNEX III Scoring of Confidence Levels

(modified from Bacher et al. 2017)

Each answer provided in the risk assessment must include an assessment of the level of confidence attached to that answer, reflecting the possibility that information needed for the answer is not available or is insufficient or available but conflicting.

The responses in the risk assessment should clearly support the choice of the confidence level.

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.

ANNEX IV Ecosystem services classification (CICES V5.1, simplified) and examples

For the purposes of this risk assessment, please feel free to use what seems as the most appropriate category / level / combination of impact (Section – Division – Group), reflecting information available.

Section	Division	Group	Examples (i.e. relevant CICES "classes")
Provisioning	**Biomass**	**Cultivated *terrestrial* plants**	Cultivated terrestrial plants (including fungi, algae) grown for nutritional purposes; Fibres and other materials from cultivated plants, fungi, algae and bacteria for direct use or processing (excluding genetic materials); Cultivated plants (including fungi, algae) grown as a source of energy *Example: negative impacts of non-native organisms to crops, orchards, timber etc.*
		Cultivated *aquatic* plants	Plants cultivated by in- situ aquaculture grown for nutritional purposes; Fibres and other materials from in-situ aquaculture for direct use or processing (excluding genetic materials); Plants cultivated by in- situ aquaculture grown as an energy source. *Example: negative impacts of non-native organisms to aquatic plants cultivated for nutrition, gardening etc. purposes.*
		Reared animals	Animals reared for nutritional purposes; Fibres and other materials from reared animals for direct use or processing (excluding genetic materials); Animals reared to provide energy (including mechanical) *Example: negative impacts of non-native organisms to livestock*
		Reared *aquatic* animals	Animals reared by in-situ aquaculture for nutritional purposes; Fibres and other materials from animals grown by in-situ aquaculture for direct use or processing (excluding genetic materials); Animals reared by in-situ aquaculture as an energy source *Example: negative impacts of non-native organisms to fish farming*
		Wild plants (terrestrial and aquatic)	Wild plants (terrestrial and aquatic, including fungi, algae) used for nutrition; Fibres and other materials from wild plants for direct use or processing (excluding genetic materials); Wild plants (terrestrial and aquatic, including fungi, algae) used as a source of energy *Example: reduction in the availability of wild plants (e.g. wild berries, ornamentals) due to non-native organisms (competition, spread of disease etc.)*
		Wild animals (terrestrial and aquatic)	Wild animals (terrestrial and aquatic) used for nutritional purposes; Fibres and other materials from wild animals for direct use or processing (excluding genetic materials); Wild animals (terrestrial and aquatic) used as a source of energy *Example: reduction in the availability of wild animals (e.g. fish stocks, game) due to non-native organisms (competition,*

			predations, spread of disease etc.)
	Genetic material from all biota	**Genetic material** from plants, algae or fungi	Seeds, spores and other plant materials collected for maintaining or establishing a population; Higher and lower plants (whole organisms) used to breed new strains or varieties; Individual genes extracted from higher and lower plants for the design and construction of new biological entities *Example: negative impacts of non-native organisms due to interbreeding*
		Genetic material from animals	Animal material collected for the purposes of maintaining or establishing a population; Wild animals (whole organisms) used to breed new strains or varieties; Individual genes extracted from organisms for the design and construction of new biological entities *Example: negative impacts of non-native organisms due to interbreeding*
	Water[14]	**Surface water** used for nutrition, materials or energy	Surface water for drinking; Surface water used as a material (non-drinking purposes); Freshwater surface water, coastal and marine water used as an energy source *Example: loss of access to surface water due to spread of non-native organisms*
		Ground water for used for nutrition, materials or energy	Ground (and subsurface) water for drinking; Ground water (and subsurface) used as a material (non-drinking purposes); Ground water (and subsurface) used as an energy source *Example: reduced availability of ground water due to spread of non-native organisms and associated increase of ground water consumption by vegetation.*
Regulation & Maintenance	**Transformation** of biochemical or physical inputs to ecosystems	**Mediation of wastes or toxic substances** of anthropogenic origin by living processes	Bio-remediation by micro-organisms, algae, plants, and animals; Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals *Example: changes caused by non-native organisms to ecosystem functioning and ability to filtrate etc. waste or toxics*
		Mediation of nuisances of anthropogenic origin	Smell reduction; noise attenuation; visual screening (e.g. by means of green infrastructure) *Example: changes caused by non-native organisms to ecosystem structure, leading to reduced ability to mediate nuisances.*
	Regulation of physical, chemical, biological conditions	**Baseline flows and extreme event** regulation	Control of erosion rates; Buffering and attenuation of mass movement; Hydrological cycle and water flow regulation (Including flood control, and coastal protection); Wind protection; Fire protection *Example: changes caused by non-native organisms to ecosystem functioning or structure leading to, for example, destabilisation of soil, increased risk or intensity of wild fires etc.*

[14] Note: in the CICES classification provisioning of water is considered as an abiotic service whereas the rest of ecosystem services listed here are considered biotic.

		Lifecycle maintenance, habitat and gene pool protection	Pollination (or 'gamete' dispersal in a marine context); Seed dispersal; Maintaining nursery populations and habitats (Including gene pool protection) *Example: changes caused by non-native organisms to the abundance and/or distribution of wild pollinators; changes to the availability / quality of nursery habitats for fisheries*
		Pest and disease control	Pest control; Disease control *Example: changes caused by non-native organisms to the abundance and/or distribution of pests*
		Soil quality regulation	Weathering processes and their effect on soil quality; Decomposition and fixing processes and their effect on soil quality *Example: changes caused by non-native organisms to vegetation structure and/or soil fauna leading to reduced soil quality*
		Water conditions	Regulation of the chemical condition of freshwaters by living processes; Regulation of the chemical condition of salt waters by living processes *Example: changes caused by non-native organisms to buffer strips along water courses that remove nutrients in runoff and/or fish communities that regulate the resilience and resistance of water bodies to eutrophication*
		Atmospheric composition and conditions	Regulation of chemical composition of atmosphere and oceans; Regulation of temperature and humidity, including ventilation and transpiration *Example: changes caused by non-native organisms to ecosystems' ability to sequester carbon and/or evaporative cooling (e.g. by urban trees)*
Cultural	**Direct, in-situ and outdoor interactions** with living systems that depend on presence in the environmental setting	**Physical and experiential** interactions with natural environment	Characteristics of living systems that that enable activities promoting health, recuperation or enjoyment through active or immersive interactions; Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions *Example: changes caused by non-native organisms to the qualities of ecosystems (structure, species composition etc.) that make it attractive for recreation, wild life watching etc.*
		Intellectual and representative interactions with natural environment	Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge; Characteristics of living systems that enable education and training; Characteristics of living systems that are resonant in terms of culture or heritage; Characteristics of living systems that enable aesthetic experiences *Example: changes caused by non-native organisms to the qualities of ecosystems (structure, species composition etc.) that have cultural importance*

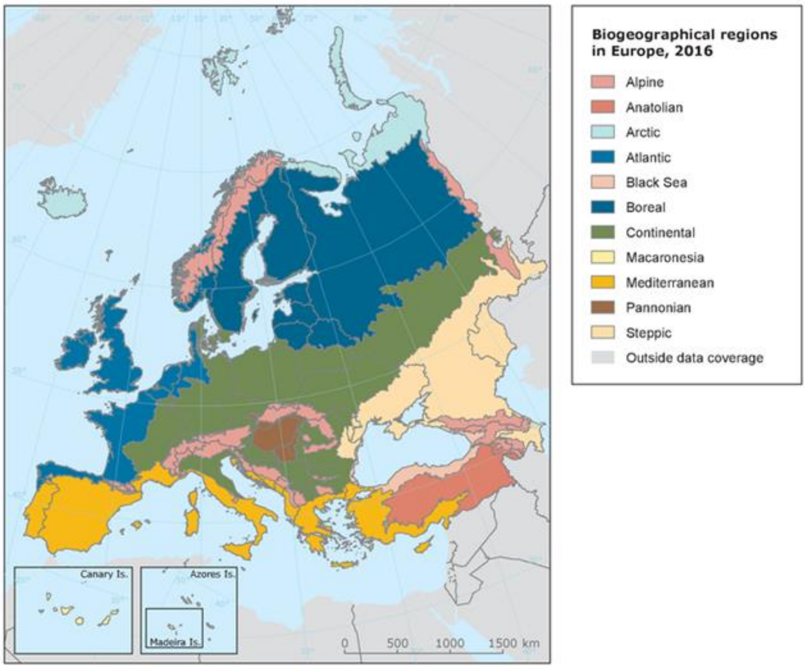
	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	**Spiritual, symbolic** and other interactions with natural environment	Elements of living systems that have symbolic meaning; Elements of living systems that have sacred or religious meaning; Elements of living systems used for entertainment or representation *Example: changes caused by non-native organisms to the qualities of ecosystems (structure, species composition etc.) that have sacred or religious meaning*
		Other biotic characteristics that have a **non-use value**	Characteristics or features of living systems that have an existence value; Characteristics or features of living systems that have an option or bequest value *Example: changes caused by non-native organisms to ecosystems designated as wilderness areas, habitats of endangered species etc.*

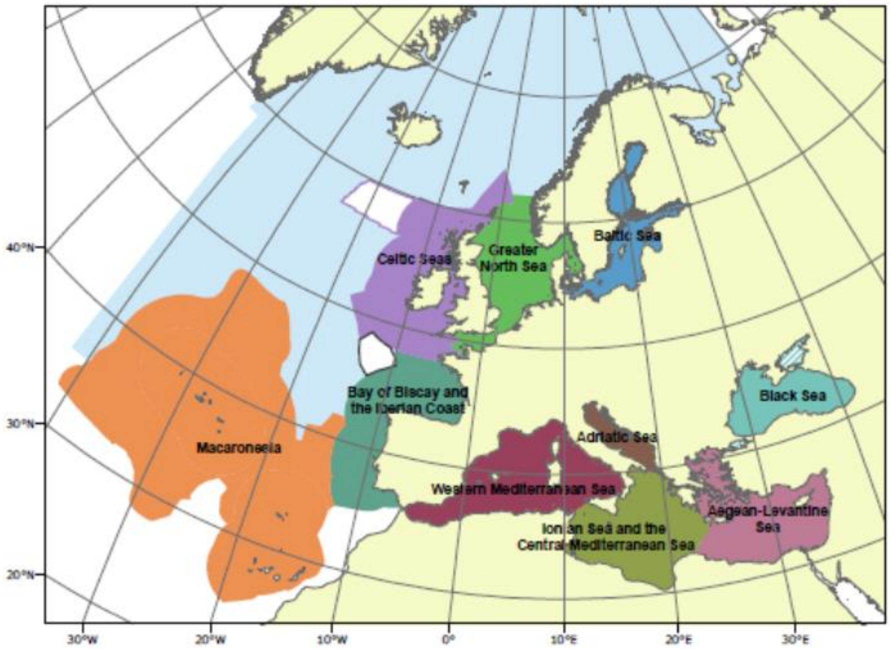
ANNEX V EU Biogeographic Regions and MSFD Subregions

See https://www.eea.europa.eu/data-and-maps/figures/biogeographical-regions-in-europe-2 , http://ec.europa.eu/environment/nature/natura2000/biogeog_regions/

and

https://www.eea.europa.eu/data-and-maps/data/msfd-regions-and-subregions-1/technical-document/pdf





ANNEX VI Delegated Regulation (EU) 2018/968 of 30 April 2018

see https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A32018R0968