

**Risk assessment template developed under the "Study on Invasive Alien Species – Development of risk assessments to tackle priority species and enhance prevention"**  
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**Name of organism:** North American Beaver (*Castor canadensis*)

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**Risk Assessment Area:** The risk assessment area is the territory of the European Union 27, excluding the EU-outermost regions.

**Note:** The present document is a revision and update of the risk assessment of Hollander et al. (2017) following the current template. Answers to some of the questions may be taken from the latter document largely unmodified, permission for which was granted by the copyright holders.

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<sup>1</sup> 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> ).

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## 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.

This risk assessment covers one species, the North American Beaver, *Castor canadensis* Kuhl, 1820 (class: Mammalia, order: Rodentia, family: Castoridae). English synonyms are American beaver, and Canadian beaver.

Two former synonyms, *Castor subauratus* Taylor, 1912, and *Castor caecator* Bangs, 1913, have been relegated to the subspecific rank (Jenkins & Busher 1979). These authors also list 24 subspecies, as recognized in earlier work, but also mention that boundaries between the distributions of subspecies are uncertain partly because of large-scale transplanting and restocking operations.

The subspecies mentioned by Jenkins & Busher (1979) are *C. c. acadicus* V. Bailey and Douth, 1942:87; *C. c. baileyi* Nelson, 1927:125; *C. c. belugae* Taylor, 1916:429; *C. c. caecator* Bangs (1913:513); *C. c. canadensis* Kuhl, 1820:64; *C. c. carolinensis* Rhoads, 1898:420; *C. c. concisor* Warren and Hall, 1939:358; *C. c. duchesnei* Durrant and Crane, 1948:413; *C. c. frondator* Mearns, 1897:502; *C. c. idoneus* Jewett and Hall, 1940:87; *C. c. labradorensis* V. Bailey and Douth, 1942:86; *C. c. leucodontus* Gray, 1869:293; *C. c. mexicanus* V. Bailey, 1913:191; *C. c. michiganensis* V. Bailey, 1913:192; *C. c. missouriensis* V. Bailey, 1919:32; *C. c. pallidus* Durrant and Crane, 1948:409; *C. c. phaeus* Heller, 1909:250; *C. c. repentinus* Goldman, 1932:266; *C. c. rostralis* Durrant and Crane, 1948:411; *C. c. sagittatus* Benson, 1933:320; *C. c. shastensis* Taylor (1916:433); *C. c. subauratus* Taylor (1912:167); *C. c. taylori* Davis, 1939:273; *C. c. texensis* V. Bailey, 1905:122.

The only other extant species in the genus *Castor* is the Eurasian beaver, or European beaver, *Castor fiber* Linnaeus, 1758. Importantly, many zoologists recognised only one beaver species until the first half of the twentieth century, and it was not until the 1970s that the distinction between the two species became well established on the basis of their different numbers of chromosomes (*C.f.*: 2N = 48, *C.c.*: 2N = 40; Lavrov & Orlov 1973, in Parker et al. 2012). As is clarified below, this mistaken identity has had important consequences for the introduction history of North American beaver in the risk assessment area.

This chromosome difference also prevents interbreeding between the two species. Despite experimentation and observed copulation, no live-born *canadensis-fiber* hybrids have ever been confirmed (Parker et al. 2012). There is thus no need for this assessment to consider hybrids.

**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

From a distance, *C. canadensis* might be confused with other large-sized, semiaquatic rodents, such as capybara (*Hydrochoerus hydrochaeris*) or *Myocastor coypu* (nutria). The latter species is widely present in the risk assessment area, and listed as invasive alien species of Union concern (Implementing Regulations 2016/1141).

From up close, however, the only species that *C. canadensis* might (and is likely to) be confused with, is the Eurasian beaver *C. fiber*. Indeed, both species are very similar in a morphological, behavioural, and ecological sense. *C. fiber* is native to the risk assessment area and widely distributed (see A7 and A9 for more details).

Both species are similar in size, with reported weights of adult *C. canadensis* ranging from 11 to 26 kg (up to 39 kg; Jenkins & Busher 1979). The species' total length ranges from 100 to 120 cm, including a tail of 26 to 33 cm length. The guard hairs are long and coarse. The species may range from yellowish-brown to black in colour, with reddish-brown being most common. The tail is flattened dorso-ventrally, scaled and relatively hairless. Young animals have black tails that become lighter with age (Jenkins & Busher 1979).

Beavers are semiaquatic, with many traits suited to this lifestyle. They have large, flat, paddle-shaped tails and large, webbed hind feet. The unwebbed front feet are smaller than the rear, and clawed. The eyes are covered by a nictitating membrane which allows beavers to see underwater. The nostrils and ears are sealed while submerged. A thick layer of fat under the skin insulates beavers from the cold water environment (Jenkins & Busher 1979). The beaver's fur consists of long, coarse outer hairs and short, fine inner hairs. The fur is waterproofed most likely through the skin lipid squalene (Rosell 2002). Scent glands near the genitals secrete an oily substance known as castoreum, which is used for territorial marking.

Beavers are renowned as ecosystem engineers, as they modify their environment to their needs in very profound ways. They fell trees, and construct burrows and lodges (for shelter and, to a lesser extent, food storage), canals (to extend feeding areas), and dams (to raise water levels). These activities may

significantly change the geomorphology, and consequently the hydrological characteristics and biotic properties of the landscape (Rosell et al. 2005). Beaver lodges have at least one underwater entrance, and an interior chamber above water level. Fluctuations in ambient temperature are strongly buffered within a lodge.

Despite all the similarities among *C. canadensis* and *C. fiber*, there are several differences. The guard hairs of the North American beaver have a shorter hollow medulla at their tips. North American beavers tend to be slightly smaller, with smaller, more rounded heads; shorter, wider muzzles; thicker, longer and darker underfur; wider, more oval-shaped tails and longer shin bones, possibly allowing them a greater range of bipedal locomotion than the Eurasian species. The North American beaver has shorter nasal bones than the Eurasian beaver, with the widest point being at the middle of the snout for the former, and in the tip for the latter. The nasal opening for the North American species is square, unlike that of its Eurasian counterpart, where it is triangular. The foramen magnum is triangular in the North American beaver, and rounded in the European. These morphometrical differences, especially those of the skull, may thus provide a way of identifying dead specimens.

The anal glands of the North American beaver are smaller and thick-walled with a small internal volume compared to that of the European species. There is a consistent difference among species and sexes in the secretion from the anal glands: a thick paste of a greyish colour in *C. fiber* females; an oily, whitish or pale straw-coloured fluid in *C. fiber* males; runny, whitish or light yellow in *C. canadensis* females; and viscous and brown in *C. canadensis* males. The colour and viscosity of the secretion can be an effective and reliable tool for identification (Rosell & Sun 1999).

The two species have a different numbers of chromosomes: *C. fiber* has 48 chromosomes, whereas *C. canadensis* has 40 (Lavrov & Orlov 1973, in Parker et al. 2012; see A1). This prevents the species from interbreeding, and no live-born hybrids have been confirmed from captivity (despite experimentation) or from the wild (Dewas et al. 2012, Parker et al. 2012). Karyotypic studies can thus be used to tell the species apart, as can older and modern barcoding techniques (e.g. Kuehn et al. 2000). One interesting, non-invasive method is to sample for DNA in wood chips at foraging sites (Iso-Touru et al. 2021).

In summary, there is no means for local actors to reliably distinguish the two species *in situ*. Identification depends on expertise, especially based on (skull) morphometry, anal gland secretion, or genetic analysis.

It has also been previously stated that *C. canadensis* shows higher building activity than *C. fiber* (Rosell et al. 2005). However, a comparative study of both beaver species in the western Russian population concluded that building activity is a response of animals to specific features of the environment, rather than a species-specific manifestation of instinct. Under similar geographical and hydrological conditions, both species built their lodges and dams with equal frequencies (Danilov & Fyodorov 2015).

Other ecological differences between the two species (e.g. reproduction) are discussed under Qu. 2.3, in light of their mutual competition.

**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.**

*C. canadensis* has been considered in several risk assessments. Table 1 presents an overview.

Table 1: overview of risk assessments involving *Castor canadensis* (chronologically ordered). RA = risk assessment.

Country/area	Scope	Method	Risk classification	Source	Validity
Belgium	Impact assessment of alien species	ISEIA	Medium risk (score 10/12), isolated populations (category B1)	Branquart et al. (2009)	Valid: relevant RA area and RA protocol
Luxembourg	Impact assessment of invasive alien vertebrates	ISEIA	Medium risk (score 9/12), isolated populations (category B1)	Ries et al. (2014)	Valid: relevant RA area and RA protocol
The Netherlands	Rapid risk assessment	Questionnaire for the selection of potential IAS	Impact on biodiversity: high; ecosystems: absent; ecosystem services: low	Verbrugge et al. (2015)	Valid: relevant RA area, no protocol
Germany	Invasiveness assessments for alien vertebrates	GABLIS	Potentially invasive (action list)	Nehring et al. (2015)	Valid: relevant RA area and RA protocol
European Union	Risk assessment of alien North American beaver for the European Union	Harmonia <sup>+</sup>	Introduction risk: high; establishment risk: high; spread risk: high; impact score: high; overall risk: high	Hollander et al. (2017)	Valid: relevant RA area and RA protocol
European Union	Risk assessment of alien North American beaver for the European Union	ISEIA	<i>C. fiber</i> present: medium risk (score 9/12), isolated populations (category B1); <i>C. fiber</i> absent: high risk (12/12), isolated populations (A1)	Hollander et al. (2017)	Valid: relevant RA area and RA protocol
The Netherlands	Risk assessment of alien North American beaver in The Netherlands	ISEIA	<i>C. fiber</i> present: medium risk (score 9/12), absent (category B0); <i>C. fiber</i> absent: high risk (12/12), absent (A0)	Hollander et al. (2017)	Valid: relevant RA area and use of RA protocol
Poland	Risk assessment of alien North American beaver for Poland	Harmonia <sup>+PL</sup>	Category of invasiveness: moderately invasive	Czech et al. (2018)	Valid: relevant RA area and use of RA protocol

In all cases, it should be taken into account that risk assessments consider the situation of *C. canadensis* at the time of assessment. E.g. the species was known to be present at four sites in Luxembourg at the time of the assessment of Ries et al. (2014). This no longer is the case (see under A8).

Experts from Belgium performed an impact assessment of *C. canadensis* for **Belgium** by means of the ISEIA protocol (Branquart et al. 2009, Vanderhoeven et al. 2015). The goal of this assessment was a classification of species according to the national black, watch and alert lists. The dispersion potential (invasiveness) and colonization of high conservation value habitats were scored high. The risk of adverse impact on native species, and risk of alteration of ecosystem functions were scored medium. The total score was a 10 (out of 12), which is categorized as a medium risk. Given that the species was then present in isolated populations, *C. canadensis* was added to the watch list (B1 category).

Ries et al. (2014) performed an impact assessment of *C. canadensis* for **Luxembourg**, also using the ISEIA protocol (Vanderhoeven et al. 2015). The dispersion potential (invasiveness) and colonization of high conservation value habitats were scored high. The risks of adverse impacts on native species was scored medium, and risk of alteration of ecosystem functions was scored low. The total score was a 9 (out of 12), which classifies as a medium risk. Given that the species was then present in isolated populations here as well, this added *C. canadensis* to the watch list (B1 category).

A Dutch panel of experts performed a rapid risk assessment for the **Netherlands** using a standardized questionnaire for the selection of potentially invasive species (Verbrugge et al. 2015). These experts used a semi-quantitative score system with four risk classes (0: absent; 1: low; 2 medium; 3: high). The risk of impacts on biodiversity, on ecosystems, and on ecosystem services were assessed as high, absent, and low, respectively. The latter two scores reflect the additional effects of *C. canadensis* to those of native beaver *C. fiber*.

The risk of *C. canadensis* has been assessed for **Germany** by Nehring et al. (2015), using the GABLIS method (Essl et al. 2011). The assessment is much in line with the other Member State assessments. As a result of the assessment, the species is included in the black list for Germany, and more specifically, the action list for the country, which means that eradication is considered feasible and recommended (Nehring et al. 2015).

Hollander et al. (2017) provided the first risk assessment for the **European Union** (then including the United Kingdom). The authors used the ISEIA protocol (Vanderhoeven et al. 2015) and the more extensive *Harmonia*<sup>+</sup> protocol (D'hondt et al. 2015), for scenarios with or without *C. fiber*, and under current or future conditions. The *Harmonia*<sup>+</sup> assessment, undertaken only for the scenario without *C. fiber*, yielded a high risk score under current conditions (1.0 out of 1.0). Under current conditions, the ISEIA protocol had an end score of 9 for the case with *C. fiber* (out of 12, i.e. medium), and an end score of 12 for the case without *C. fiber* (high). Considering future instead of current conditions did not change the scores in any of these assessments.

Since the above-mentioned publication, the situation of *C. canadensis* at Member State level has changed substantially, and a significant amount of new scientific information has since emerged. **The present document therefore is a revision and update of the risk assessment of Hollander et al. (2017) following the current template. Answers to some of the questions may be taken from Hollander et al. (2017) largely unmodified, permission for which was granted by the copyright holders.**

As an appendix, Hollander et al. (2017) have then also applied the ISEIA protocol specifically for the **Netherlands**. The end scores were the same as assessed for the European territory (9, or medium, for the case with *C. fiber*; 12, or high, for the case without *C. fiber*).

In 2018, Czech et al. (2018) performed a risk assessment for *C. canadensis* for the territory of **Poland** by means of the *Harmonia*<sup>+PL</sup> protocol (a modified version of the *Harmonia*<sup>+</sup> protocol, see above). The exposure (invasion) score and impact score were assessed as 0.50 and 0.63, respectively. In summary, the species was assessed as ‘moderately invasive’ by the authors.

In addition, *C. canadensis* was identified as an invasive alien species in **Finland**’s National Strategy on Invasive Alien Species, based on expert opinion regarding the potential harm using information available at the time (Ministry of Agriculture and Forestry in Finland 2012). The National Strategy did not provide details on the specific risks of *C. canadensis*, and it is therefore excluded from Table 1.

Although no risk assessments, it is worthy to note the inclusion of *C. canadensis* in the database of the European Network on Invasive Alien Species (NOBANIS). The factsheet briefly describes affected habitats and indigenous organisms, and potential effects on human health, economy and society (Nummi 2010). Similarly, the Global Invasive Species Database (GISD) is an online source of information about alien and invasive species that negatively impact biodiversity, and also includes a profile on *C. canadensis* (GISD 2009). The same is true for the CABI Invasive Species Compendium (Aldridge 2009).

#### **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

*C. canadensis* occupies most of the North American continent, from northern Canada to northern Mexico (Jenkins & Busher 1979, Gallo-Reynoso et al. 2002). In the United States, its range includes peninsular Florida and California (Lanman et al. 2013). Trapping and hunting had reduced the species to low numbers throughout much of the continent by 1900, but it has now become re-established in most of its former range.

The species’ habitat range stretches from the Arctic tundra to the deserts of the American Southwest, including taiga, mixed and deciduous forests, riparian habitats (also in desert areas), and swamps. The elevational range extends from sea level to above 3400 m (Jenkins & Busher 1979, Baker & Hill 2003).

The ability of *C. canadensis* to modify its environment to its needs also greatly expands the range of potentially suitable sites. This allows the species to also make a habitat from man-made watercourses (e.g. canals, ditches), and in anthropogenic landscapes (e.g. agricultural areas).



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

North American beavers were intentionally introduced to **Tierra del Fuego** (southernmost South America), specifically near Fagnano Lake on the Isla Grande de Tierra del Fuego (Argentina), for fur farming purposes in 1946. Here, the species has considerably expanded its range (Lizarralde 1993, Anderson et al. 2006, Merino et al. 2009). This introduction was also part of a government effort to economically “enhance” the species-poor Fuegian landscape by introducing exotic furbearers, including beavers, muskrats (*Ondatra zibethicus*) and minks (*Neogale vison*). While only 25 mating pairs were released initially, by the 1950s the expanding population had spread to the Chilean portion of the island. By the 1960s the species had successfully crossed channels to the adjacent Chilean archipelago, including Navarino and Hoste Islands (Anderson et al. 2006). The species also crossed the Strait of Magellan, which is two kilometres wide at its narrowest point, to the mainland of Chile on the eastern shore of the Brunswick Peninsula near the San Pedro River (Graells et al. 2015). Beaver densities rapidly increased to levels of 0,2 to 5,8 colonies/km<sup>2</sup>. Today, beavers inhabit nearly every available watershed on most of the islands, except for a few uncolonized refuges in the far southern and western portions of the archipelago (Anderson et al. 2006). Occupied rivers and streams are surrounded by Magellanic forest (dominated by *Nothofagus* spp.), steppe, or cool semi-desert (Graells et al. 2015). Further information on the Tierra del Fuego population is provided under A10 (invasiveness) and chapter 4 of section B (impacts).

*C. canadensis* was also successfully introduced, around the 1970s, into the **Russian Far East** (Russian Federation) (Nolet & Rosell 1998). The species here occurs in the Primorsky region, the Khabarovsk Krai, and the Kamchatka peninsula (Nummi 2010, Khlyap et al. 2021). Halley et al. (2021) mention a population figure of less than 200 for this region.

The species also occurs in the Republic of Karelia of **European Russia** (Russian Federation), which borders Finland. The species’ presence here is due to natural spread from the Finnish population (see A8, Khlyap et al. 2021), but was also boosted by the release of some *C. canadensis* near Lake Onega in 1964 (Nolet & Rosell 1998). For this region, Halley et al. (2021) mention a population of less than 20,000. A map with observations within the Russian Federation is provided at <https://rusmam.ru/atlas/map> (Lissovsky et al. 2018). Additional details are provided under Qu. 1.2b-1.8b.

*C. canadensis* has also been released in **Ukraine** in 1933 and 1934, but this population became extinct by the 1960s (Parker et al. 2012, Halley et al. 2021).

**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 (including casual or transient occurrences) and established**

occurrences. “Established” means the process of an alien species successfully producing viable offspring with the likelihood of continued survival<sup>2</sup>.

**A6a. Recorded: List regions**

**A6b. Established: List regions**

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 <https://www.eea.europa.eu/data-and-maps/figures/biogeographical-regions-in-europe-2> (see also Annex VI).

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

Response (6a):

Occurrences of *C. canadensis* are better documented at Member State level than at biogeographical level. Qu. A8 provides a detailed overview of Member States where the species has been recorded. The following biogeographic regions correspond with these records: Atlantic (records from France), Boreal (Finland), Continental (Austria, Belgium, France, Germany, Luxembourg, Poland) and Pannonian (Hungary). An overview is provided in Table 2.

Table 2: Summary of the status of *C. canadensis* in biogeographical regions of the European Union.

Biogeographical region	Recorded	Currently established	Potential establishment	Currently invasive
Alpine	No	No	Yes	No
Atlantic	Yes	No	Yes	No
Black Sea	No	No	Yes	No
Boreal	Yes	Yes	Yes	Yes
Continental	Yes	Yes	Yes	Yes
Mediterranean	No	No	Yes	No
Pannonian	Yes	No	Yes	No
Steppic	No	No	Yes	No

Response (6b):

The species is currently established in the Boreal (Finland) and Continental (Germany) regions (Table 2, Qu. A8). It was formerly established in the Atlantic region (France).

**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**

<sup>2</sup> Convention on Biological Diversity, Decision VI/23

**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 or SSP 2-4.5)
- 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 or SSP scenarios 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); SSP 1-2.6 (estimated warming 1.8°C by 2081-2100), SSP 2-4.5 (estimated warming 2.7°C by 2081-2100) and SSP 5-8.5 (estimated warming 4.4°C by 2081-2100). Otherwise, the choice of the assessed scenario has to be explained.

Response (7a):

A first approach to substantiate the potential establishment of *C. canadensis* is to project the species' worldwide distribution to the risk assessment area. The native range in particular is very informative, because this is where the species has exploited its potential niches most widely (A4).

Annex VIII provides a species distribution model (SDM) based on the accessible data for the species (GBIF 2023). The model suggests that all biogeographic regions from the risk assessment area are highly suitable (Alpine, Atlantic, Black Sea, Boreal, Continental, Mediterranean, Pannonian, Steppic; see Table 2). For the Mediterranean region, there is a modest uncertainty linked to that estimate (0.81-1.00). (Note that Annex VIII also considers the Anatolian, Arctic and Macaronesian regions, which fall outside the scope of this question.)

A second approach would be to infer potential establishment for *C. canadensis* in Europe from *C. fiber*, given the species' ecological similarities (A2). The range of Eurasian beavers is currently still expanding following its near-extinction, but its historic (potential) range is relatively well documented (Wróbel 2020). In their overview, Halley et al. (2021) provided evidence from all but three member states (all of which are islands, see A9), and these span all of the biogeographic regions. This thus aligns with the results from the SDM (Table 2).

Response (7b):

As derived from the SDM, climate change is expected to have no effect on the risk of establishment of *C. canadensis* within the different biogeographic regions from the risk assessment area (Annex VIII, Shared Socioeconomic Pathways SSP2.6, 4.5 and 8.5). It is notable that the suitability also remains high

for the Mediterranean region, although the uncertainty for that estimate increases according to the scenarios in their respective order.

Indeed, beavers are known to be able to establish in relatively dry and arid areas (provided that suitable watercourses are available). *C. canadensis* also occurs in Mediterranean climate in its native range, i.e. California (A4, Lanman et al. 2013), whereas *C. fiber* is native to Mediterranean Europe (above).

**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**

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):

Table 3 lists the status of *C. canadensis* for each of the Member States. The species has been recorded in eight of them, details for which are provided below.

Table 3: Summary of the status of *C. canadensis* in Member States of the European Union.

Member State	Recorded	Currently established	Potential establishment	Currently invasive
Austria	Yes	No	Yes	No
Belgium	Yes	No	Yes	No
Bulgaria	No	No	Yes	No
Croatia	No	No	Yes	No
Cyprus	No	No	No	No
Czech Republic	No	No	Yes	No
Denmark	No	No	Yes	No
Estonia	No	No	Yes	No
Finland	Yes	Yes	Yes	Yes
France	Yes	No	Yes	No
Germany	Yes	Yes	Yes	Yes
Greece	No	No	Yes	No
Hungary	Yes	No	Yes	No
Ireland	No	No	Yes	No
Italy	No	No	Yes	No
Latvia	No	No	Yes	No
Lithuania	No	No	Yes	No
Luxembourg	Yes	No	Yes	No
Malta	No	No	No	No
Netherlands	No	No	Yes	No
Poland	Yes	No	Yes	No
Portugal	No	No	Yes	No

Romania	No	No	Yes	No
Slovakia	No	No	Yes	No
Slovenia	No	No	Yes	No
Spain	No	No	Yes	No
Sweden	No	No	Yes	No

**FINLAND** – As both species were not yet known to be distinct (see A1), North American beavers were unintentionally introduced to Finland in 1937 as part of the program to reintroduce the exterminated Eurasian beaver *C. fiber*. From seven specimens acquired from New York state, two pairs that had been introduced in southeastern Finland established and multiplied rapidly (Parker et al. 2012, Alakoski et al. 2021). Live-trapped individuals from this population were later translocated to northern, north-eastern and central parts of Finland. During the late 1940s and early 1950s, North American beavers also spread to the Russian side of Karelia (Nummi 2010). No observations of *C. canadensis* near the Swedish border have recently been made; it rather seems that *C. fiber* is spreading from Sweden into Finland (Alakoski et al. 2020, Herrero & Iso-Touru 2024).

The Finnish population of *C. canadensis* was considered to comprise about 6,000 family groups in 2013 (Brommer et al. 2017). The population is clearly viable and has generally spread westward. The latest monitoring count from 2023 estimates the population of North American beaver in Finland to be between 9,500 and 17,700, which is slightly less than in the previous inventory in 2020 (LUKE 2021, Alakoski et al. 2021, Herrero & Iso-Touru 2024). The population of Eurasian beaver is estimated at 3,200-4,400 (Herrero & Iso-Touru 2024).

Recently, expanding populations of *C. canadensis* and *C. fiber* have converged on three fronts in Finland, i.e. within the regions of Pirkanmaa, Etelä-Pohjanmaa and Lapland (Alakoski et al. 2019, Alakoski et al. 2020). In a studied Finnish river system where both species occur sympatrically, the outcome of competition is not yet clear (Alakoski et al. 2019).

Alakoski et al. (2020) and Halley et al. (2021) provide recent maps for the known distribution of both species in Finland. The latest information (also based on DNA monitoring) can be consulted at <https://luonnonvaratieto.luke.fi/kartat?panel=pienriista&lang=en>.

Note, however, that a Management Plan is in place, and that the distribution of both species is affected by planned hunting, among other measures. Details on this management are provided under Qu. 2.5.

**POLAND** – North American beavers have been introduced to Poland (1930s), where the Popielno beaver breeding farm is known to have supplied game reserves and zoos in Germany, France (1975) and Austria (1976-1990) (Nolet & Rosell 1998, Lejeune 2021). *C. canadensis* was last observed in Poland in 1979 (Parker et al. 2012). Currently this species does not occur in Poland (Czech et al. 2018).

**AUSTRIA** – In Austria, *C. canadensis* was first released in Lower Austria in 1953, but a population failed to establish. Animals were again released along the floodplains of the Danube, along with *C. fiber*, during the 1980s (Halley et al. 2021). Furthermore, also in the 1980s, a few *C. canadensis* individuals escaped from a zoo in Styria and were present in the wild for some years (Englisch 2005). However, *C. canadensis* was last observed in nature in 1986 (Parker et al. 2012). Currently the fate of escaped and deliberately released individuals is unknown, but it is assumed that *C. canadensis* has become extinct in Austria (Halley & Rosell 2002, Halley et al. 2021).

**FRANCE** – In France, three North American beavers escaped from a private park (Boutissaint) at the end of the 1970s, and formed an established population in watercourses and lakes of the La Puisaye region (spanning the departments Yonne, Loiret and Nièvre; Dewas et al. 2012, Bressan & Hurel 2018).

Because native *C. fiber* was also present near the same area (in the Loire river), a decision was made to eradicate the *C. canadensis* population (in and around the tributary to the Loire). Twenty-four *C. canadensis* individuals were captured and removed from 1984 to 1985 (Bressan & Hurel 2018). Following this, no *C. canadensis* populations have been recorded in France (Dewas et al. 2012). Moreover, hundreds of beaver samples have been genetically checked since, but all proved to be *C. fiber*. Such analyses are continued within the operation of France's 'beaver network' (Réseau Castor; Bressan & Hurel 2018). The status as 'eradicated' thus holds to date.

**HUNGARY** – In Hungary, *C. canadensis* was recorded in the early 1990s (Parker et al. 2012). However, there are no available records since then.

**GERMANY** – *C. canadensis* may have escaped from a breeding farm in the state of Bavaria in 1966. However, no sites of establishment originating from these escapees have ever been confirmed (Parker et al. 2012). Furthermore, three individuals were observed in the 1990s, although two of them were found near enclosures (Zahner 1997). These specimens may have originated from *C. canadensis* introduced in Austria.

In 2006, a beaver that was killed by road traffic was found on the border with Luxembourg, along the River Our, in the state of Rhineland-Palatinate. The animal was identified as belonging to *C. canadensis* on the basis of the colour of its anal gland secretion (Dewas et al. 2012). Based on a subsequent large-scale genetic study in the greater region, it was found very likely that the presence of *C. canadensis* in Rhineland-Palatinate and adjacent regions is linked to the Eifel-Zoo (Lünebach), since all specimens analyzed were of the same haplotype as animals kept at that zoo at that time (Dewas et al. 2012, Schley 2019).

*C. canadensis* was also reportedly observed in the state of North Rhine-Westphalia since 1981 (Dewas et al. 2012, Parker et al. 2012). Here, beavers originating from the Popielno animal farm in Poland, where both *C. canadensis* and *C. fiber* were bred, were released between 1981 and 1989. However, there is no proof that specimens of *C. canadensis* were actually involved in the releases (Schley 2019). This conclusion is supported by genetic investigations (C. Frosch, Senckenberg Museum, Frankfurt, unpublished results). The only times *C. canadensis* was detected in North Rhine-Westphalia was in 2012 and 2014 on the southern border with Rhineland-Palatinate (see above). The specimens from 2012 disappeared without a trace, the 2014 specimen was caught (Schley 2019).

In summary, *C. canadensis* is understood to be currently present only in Rhineland-Palatinate, although exact information on the local population is lacking.

**LUXEMBOURG** – The presence of *C. canadensis* was confirmed at multiple sites in Luxembourg by DNA analyses of collected hair samples (Herr & Schley 2009, Dewas et al. 2012). As was concluded from a large-scale genetic study, the presence of the species here was due to natural dispersal from the bordering state of Rhineland-Palatinate (Germany).

The first observation dates from 2006. As is detailed under Qu. 2.5, coordinated initiatives were taken to manage the species following this discovery. Thirty-two individuals were caught from 12 sites within

a decade (Schley 2019). With the last capture in 2019, the country is now considered free of *C. canadensis* (L. Schley, pers. comm., September 2023).

**BELGIUM** – The first North American beaver in Belgium was recorded in 2001, along the river Our in eastern Wallonia (Lejeune 2021). By 2009, multiple sites had been confirmed over a larger territory, all of which were close to the border with Germany or Luxembourg. It is therefore likely that they too spread from the bordering state of Rhineland-Palatinate (Germany). Following control actions, which removed tens of specimens (see Qu. 2.5) and coincided with a natural expansion of *C. fiber*, the presence of *C. canadensis* has drastically declined up to the point that it is now probably extinct.

Response (8b):

*C. canadensis* is currently established in Finland and Germany.

**A9. In which EU Member States could the species establish in the future under current climate and under foreseeable climate change? The information needs to 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 or SSP 2-4.5)
- 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 or SSP scenarios 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); SSP 1-2.6 (estimated warming 1.8°C by 2081-2100), SSP 2-4.5 (estimated warming 2.7°C by 2081-2100) and SSP 5-8.5 (estimated warming 4.4°C by 2081-2100). Otherwise, the choice of the assessed scenario has to be explained.

Response (9a):

As explained under A7, the potential range of *C. canadensis* in the risk assessment area can firstly be inferred by projecting the species' worldwide distribution to the risk assessment area. This is provided in Annex VIII (species distribution model, SDM).

The model attains maximum suitability (1.00) for all Member States, but four. Spain (0.99) and Greece (0.98) still attain a very high suitability. The estimates are lower for Cyprus and Malta (0.88 and 0.00,

respectively), but both values come with a very high uncertainty (0.00-1.00). In summary, only some Mediterranean countries are thus considered somewhat less suitable to *C. canadensis* (in accordance with the results under A7).

Secondly, the range of *C. fiber* could be used as a proxy, given the species' ecological similarities (A7). In their review of the range of Eurasian beaver, Halley et al. (2021) provide evidence of past or current presence from all but three Member States, i.e. Ireland, Malta and Cyprus. No details were provided for Greece, but the species also occurred here (Galanaki et al. 2022). Obviously, the absence of Eurasian beaver from these Member States is linked to their island geography, but for Malta and Cyprus, probably also to a mismatch in climate and suitable habitat.

Taking these two lines of evidence together, we mark all Member States as potentially suitable, except for the Mediterranean island states Malta and Cyprus (Table 3). The actual range of *C. canadensis* in the risk assessment area is thus still very limited compared to its potential range.

Response (9b):

As derived from the SDM, climate change is expected to have no effect on the risk of establishment of *C. canadensis* within the different Member States from the risk assessment area (Annex VIII, climate change scenarios SSP2.6, 4.5 and 8.5). For the Mediterranean Member States (Italy, Portugal, Spain, Greece, Cyprus), there only is a discernable increase in the uncertainty for these estimates (according to the scenarios in the respective order).

**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?**

In 2008, the number of beavers in the **Tierra del Fuego** archipelago (see A5) increased to an estimated 100,000. They have invaded roughly 16 million hectares of indigenous forest, leaving a swath of destruction (through impacts explained in Section B). In November 2016, the authorities of Argentina and Chile signed an agreement to try and exterminate the North American beavers in the Patagonia region that spans the border of the two countries, owing to the devastating impacts on southern woodlands. This cull is backed by the United Nations and environmental groups. Local experts expect that it could take 10 to 15 years to cull all the beavers (Choi 2008, MercoPress 2016).

**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.**

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

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



As can be read from A8, the population of *C. canadensis* in Finland has established firmly, increased in number, and spread geographically. The same is true in Germany (the state of Rhineland-Palatinate), but to a much lesser degree, nonetheless affecting Luxembourg and Belgium. The species' former presence in France was also considered worrying as it could spread further, motivating the control actions taken.

Signs of invasiveness are thus observed for the Boreal, Continental and Atlantic regions (Table 2).

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

See the question above: signs of invasiveness are observed for Finland, Germany, Luxembourg, Belgium and France (Table 3).

**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 risk assessment area 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 risk assessment area or third countries shall be used, if available.

Beavers are among the few species besides humans that can significantly change the geomorphology, and consequently the hydrological, abiotic and biotic properties, of the landscape (Rosell et al. 2005, Sommer et al. 2019, Brazier et al. 2021). Where beavers are native (*C. fiber* in Eurasia, *C. canadensis* in northern America), these impacts are generally considered positive for the society at large, as they translate into intact, biodiverse and functionally rich landscapes (Stringer & Gaywood 2016, Thompson et al. 2021).

However, these same impacts may also be negative, often at stakeholder level (e.g. forestry, agriculture), and since these impacts are closely interlinked with the impacts on biodiversity and ecosystems (Qu. 4.1-4.5), ecosystems (Qu. 4.6-4.8), and the economy (Qu. 4.9-4.13), we opted to describe these landscape-wide impacts in detail under Section B, Qu. 4.1, instead of here.

The exploitation of beavers for their fur (beaver pelts) has existed since prehistoric times. It did probably not result in over-exploitation in Europe until the nineteenth century (*C. fiber*), or in systematic exploitation in the New World until the sixteenth century (*C. canadensis*) (Tapper & Reynolds 1996).

Nowadays, the general demand for beaver furs on international markets has decreased sharply (Safonov 2016). Beaver pelts may hold limited commercial value in countries where beaver is hunted, although no qualitative information was found. In Finland, where *C. canadensis* is hunted (see Qu. 2.5 and 4.12), there is no commercial market apart from local hunters who value fur hats and mittens made of beaver pelt.

Castoreum is an oily secretion that is used for territorial marking, and probably arises as a mixture of secondary metabolites from urine (A2, Rosell & Schulte 2004). It has been used extensively in perfumery, and has been added to food as a flavor ingredient for at least 80 years (Burdock 2007). In perfumery, it is used as a fragrance in cosmetics, or as a fixative in soaps, creams, lotions, and perfumes. As a flavor component, it can be used in most major categories of foods (particularly vanilla flavored), including alcoholic and nonalcoholic beverages, frozen dairy desserts, candy, baked goods, gelatins and puddings, and meat and meat products. Castoreum is prepared through hot extraction from the dried and macerated castor sac scent glands, from both male and female animals. Worldwide, less than 150 kg of castoreum is harvested annually, mostly of *C. canadensis* (Bloudoff-Indelicato 2013), but no further qualitative information was found.

## 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.” In this case, no score and confidence should be given and the standardized “score” is N/A (not applicable).
- 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 AND ENTRY

### 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
- Introduction and entry may coincide for species entering through pathways such as “corridor” or “unaided”, but it also may differ. If different, please consider all relevant pathways, both for the introduction into the risk assessment area and the entry in the environment.
- For each described pathway, in each of the questions below, ensure that there are separate comments explicitly addressing both the “introduction” and “entry” where applicable and as appropriate. The classification of pathways developed by the Convention of Biological Diversity (CBD) should be used (see Annex IV). For detailed explanations of the CBD pathway classification scheme consult the IUCN/CEH guidance document<sup>3</sup> and the provided key to pathways<sup>4</sup>.
- For organisms which are already present (recorded or established) in the risk assessment area, the likelihood of introduction and entry should be scored as “very likely” by default.
- Repeated (independent) introductions and entries at separate locations in the risk assessment area should be considered here (see Qu. 1.7).

**Qu. 1.1. List relevant pathways through which the organism could be introduced into the risk assessment area and/or enter into the environment. Where possible give details about the specific origins and end points of the pathways as well as a description of any associated commodities.**

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<sup>3</sup> <https://op.europa.eu/en/publication-detail/-/publication/f8627bbc-1f15-11eb-b57e-01aa75ed71a1>

<sup>4</sup> <https://circabc.europa.eu/sd/a/0aeba7f1-c8c2-45a1-9ba3-bcb91a9f039d/TSSR-2016-010%20CBD%20pathways%20key%20full%20only.pdf>

For each pathway answer questions 1.2 to 1.8 (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 and/or entry of the species.

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.

At present, two pathways are considered relevant for the potential introduction and entry into the risk assessment area's environment: (1) *ESCAPE from confinement: Botanical garden/zoo/aquaria*, and (2) *UNAIDED: Natural dispersal*. These pathways are detailed under questions 1.2a-1.8a, and 1.2b-1.8b, respectively.

A historic pathway has been the deliberate release of beavers in nature (*RELEASE in nature*). Such releases could take place for a combination of different reasons: to support the species itself, to stimulate the ecological quality on a landscape scale, or for hunting and trapping purposes. (The corresponding CBD categories being: (1) *Introduction for conservation purposes*, (2) *Landscape/flora/fauna "improvement" in the wild*, and (3) *Hunting in the wild*.) Since it was not until the 1970s that the distinction between *C. canadensis* and *C. fiber* became well established (the two species previously being regarded as the same species; see A1), such actions partly involved *C. canadensis*. Indeed, the species has entered the environment in Finland and Poland via this pathway (see A8).

Given the increased knowledge on the species' distinction, in combination with a decreased demand for beaver (re)introductions, and easier access to specimens of Eurasian than North American beaver, we consider it very unlikely that *C. canadensis* would become newly introduced for any of these purposes (initiatives of beaver release now often being referred to as 'rewilding'). These pathways of intentional release are therefore not elaborated further.

Hollander et al. (2017) also mention fur farming as a potential pathway into the risk assessment area, albeit without specific details (*ESCAPE from confinement: fur farms*). Although we cannot rule out that beaver fur farming has historically contributed, we assess the current and future risk of introduction via this route as negligible. The beaver is not an established species in fur farming, and we have no indications of current beaver farming within the risk assessment area. Moreover, the general demand for beaver furs on international markets has decreased sharply (Safonov 2016), and the fur industry is strictly controlled, if not nationally banned.

**(a) ESCAPE from confinement: Botanical garden/zoo/aquaria**

**Qu. 1.2a. Is introduction and/or entry 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	<b>intentional</b> unintentional	CONFIDENCE	low medium <b>high</b>
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North American beaver may be kept in zoological gardens (zoos, including minizoo, hobby zoo...), wildlife parks and similar captive facilities for ornamental or educational purposes.

While the initial introduction of the species into captivity (and thus, into the risk assessment area) is clearly intentional, their subsequent entry into the wild from this source may be either intentional (cf. release) or unintentional (cf. escape).

**Qu. 1.3a. How likely is it that large numbers of the organism will be introduced and/or enter into the environment 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 and/or entry based on propagule pressure (i.e. for some species low propagule pressure (1-2 individuals) could result in subsequent establishment whereas for others high propagule pressure (many thousands of individuals) may not.

RESPONSE	very unlikely unlikely moderately likely <b>likely</b> very likely	CONFIDENCE	low <b>medium</b> high
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The beaver is an iconic species, and may thus be of interest to collection owners. Whether the species is *C. fiber* or *C. canadensis*, probably is of secondary importance.

The Zoological Information Management System (ZIMS), the world's most comprehensive database on animal holdings, lists the following Member States of the European Union to have *C. canadensis* (ZIMS Species Holdings 2023): Belgium (1 institution, 2 specimens), the Czech Republic (1 inst., 2 spec.),

Germany (2 inst., 5 spec.), France (1 inst., 1 spec.), the Netherlands (2 inst., 12 spec.) and Slovenia (1 inst., 6 spec.). In, Finland, there currently only is 1 institution with the species (2 specimens), and a replacement by *C. fiber* is already planned (pers. comm., Prof. H. Henttonen (LUKE) and H. Niinimäki (Ranua)).

This database is limited to members of Species360, which number over 1.300 worldwide, and include all members of the European Association of Zoos and Aquaria (EAZA). Taking non-member collections into account, which are numerous but tend to be smaller in size and may have a different focus (e.g. on domesticated species), the true number of holdings and specimens of *C. canadensis* in European collections remains unknown. However, it seems reasonable to conclude that the overall number of captive *C. canadensis* is probably low.

Zoological collections on public display are set within tight legal frameworks, with the reduction of escape risks being of prime importance (Council Directive 1999/22/EC of 29 March 1999 on the keeping of wild animals in zoos). As that risk is generally well-monitored by holding owners and public authorities, the likelihood for entry into the environment through escape from such collections is greatly reduced. Nonetheless, the risk of escapes can never be fully excluded (Cassey & Hogg 2015), and may be particularly high with (smaller) collections that have limited staff or resources.

Indeed, escape of captive *C. canadensis* from small-scale animal parks into the environment has already occurred, as detailed under A8 (e.g. Austria, France, Germany). As another example, three North American beavers have escaped their pond at a zoo in Finland in 2019 by digging a tunnel under the fence, though these individuals were quickly re-captured (LUKE, pers. comm.).

Following the Annex I guidelines, the likelihood is therefore scored as ‘likely’.

**Qu. 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)?**

<b>RESPONSE</b>	very unlikely unlikely moderately likely likely <b>very likely</b>	<b>CONFIDENCE</b>	low medium <b>high</b>
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When animals are put on display in living collections, care is taken by holding owners to keep specimens in good condition during transport and display. Holding might include a possibility for reproduction. Indeed, *C. canadensis* births have been reported in the ZIMS data from the aforementioned collections in the European Union (Qu. 1.3a; ZIMS Species Holdings 2023).

**Qu. 1.5a. How likely is the organism to survive existing management practices before and during transport and storage along the pathway?**

<b>RESPONSE</b>	very unlikely unlikely moderately likely likely <b>very likely</b>	<b>CONFIDENCE</b>	low medium <b>high</b>
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The management of animals in zoological collections is all about keeping the animals alive, with respect for their health and well-being.

**Qu. 1.6a. How likely is the organism to be introduced into the risk assessment area or entry into the environment undetected?**

Please note that “detection” here is considered as any system or event that may actively contribute to record the presence of a species in a way that appropriate management measures could be potentially undertaken by relevant authorities.

<b>RESPONSE</b>	very unlikely unlikely moderately likely <b>likely</b> very likely	<b>CONFIDENCE</b>	low <b>medium</b> high
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With regards to the introduction into the risk assessment area (i.e., import into the Union), *C. canadensis* is unlikely to enter undetected. The only conceivable route for this would be through a mistaken entity as *C. fiber* – an event that is still considered rather unlikely, given current knowledge.

With regards to the entry into the environment (i.e., escape or release), the presence of beavers may become apparent through visual observations, dam building, tree damage, roadkill, etc. In the event, such discovery is likely to occur. However, the actual challenge lies in recognizing specimens as *C. canadensis*, not *C. fiber*. Given the expertise needed in the techniques that allow distinction (genetic analysis, anal gland secretion, skull morphometry; see A2), it is rather unlikely that the former species will be correctly identified, unless the findings can be linked to a reported escape of *C. canadensis*.

Indeed, zoos are expected to report on escapes and initiate recapture efforts (Council Directive 1999/22/EC on the keeping of wild animals in zoos), but these requirements may not be adhered to by mini zoos or hobby zoos that have limited staff or resources. Among birds, reptiles and mammals, the highest retrieval for zoo escapes was found for mammals (Cassey & Hogg 2015).

**Qu. 1.7a. How isolated or widespread are possible points of introduction and/or entry into the environment in the risk assessment area?**

<b>RESPONSE</b>	isolated <b>widespread</b> ubiquitous	<b>CONFIDENCE</b>	low <b>medium</b> high
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As included under Qu. 1.3a, known *C. canadensis* holdings are few, but distributed over various Member States. The true number of holdings is essentially unknown, but probably low; their distribution is probably widespread.

**Qu. 1.8a. Estimate the overall likelihood of introduction into the risk assessment area and/or entry into the environment based on this pathway?**

<b>RESPONSE</b>	very unlikely unlikely moderately likely <b>likely</b> very likely	<b>CONFIDENCE</b>	low <b>medium</b> high
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Although holdings of *C. canadensis* in the Union are rare, and risks of escape are generally well-controlled, such holdings are a cause of concern since escapes can never be fully prevented. Indeed, such escapes have already taken place. The problematic identification of the species increases the likelihood for a successful (undetected) entry into the environment.

**(b) UNAIDED: Natural dispersal**

**Qu. 1.2b. Is introduction and/or entry along this pathway intentional (e.g. the organism is imported for trade) or unintentional (e.g. the organism is a contaminant of imported goods)?**

<b>RESPONSE</b>	intentional <b>unintentional</b>	<b>CONFIDENCE</b>	low medium <b>high</b>
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As introduced under A4, this pathway specifically refers to the presence of North American beaver in European Russia (the Republic of Karelia, Russian Federation). Since the origin of this population lies in bordering Finland, and given that the population now is of considerable size (“not exceed[ing] 20,000”, Halley et al. 2021), there is a possibility for this population to spill back into the risk assessment area.

As this pathway refers to animals spreading to new regions without assistance by humans, it is unintentional by definition.



**Qu. 1.3b. How likely is it that large numbers of the organism will be introduced and/or enter into the environment 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 and/or entry based on propagule pressure (i.e. for some species low propagule pressure (1-2 individuals) could result in subsequent establishment whereas for others high propagule pressure (many thousands of individuals) may not.

RESPONSE	very unlikely unlikely moderately likely likely <b>very likely</b>	CONFIDENCE	low <b>medium</b> high
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The most likely Member State to be confronted with immigrating *C. canadensis* from European Russia is Finland, which shares a population. If the species were to increase its distribution in European Russia south of the Gulf of Finland, Estonia and Latvia would be the first other Member States facing the same risk (see with Qu. 1.7b).

Given, however, a lack of precise understanding of the Russian population's exact size (but see Halley et al. 2021, above), distribution (but see Lissovsky et al. 2018, Khlyap et al. 2021), trend, and management (if any), the confidence on the frequency of such entry is somewhat lowered.

This likelihood is also largely dependent on the outcome of the interaction with Eurasian beaver. This is not clear-cut (see Qu. 2.3). Halley et al. (2021) noted that *C. fiber* is slowly losing ground to *C. canadensis* on the line of contact between the White Sea and Lake Onega (Arkhangelsk region), but that *C. canadensis* has lost ground to *C. fiber* on the Karelian isthmus north of St. Petersburg, Leningrad Province.

**Qu. 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 unlikely unlikely moderately likely <b>likely</b> very likely	CONFIDENCE	Low <b>medium</b> high
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Dispersing North American beavers at the range front would be exposed to natural dynamics, the local conditions of which vary with the availability and connectivity of suitable habitat. Overall, there is little reason to assume any crucial bottlenecks that would prevent survival, reproduction and increase during range expansion, apart from the potential interaction with Eurasian beaver (see Qu. 1.3b, Qu. 2.3) or human interventions (which is excluded from consideration in this question).

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

RESPONSE		CONFIDENCE	
	very unlikely		low
	unlikely		medium
	<b>moderately likely</b>		high
	likely		
	very likely		

Beavers are relatively easy to manage (i.e., trap or shoot), when compared with other mammals, but management of North American beaver is seriously hampered in cases where confusion can arise with Eurasian beaver. In such cases, genetic analysis is needed to confirm the species' identity before actions are taken.

Beavers are harvested in the Russian Federation (the annual bag exceeding 100,000; Safonov 2016). We have no information on whether *C. canadensis* is harvested disproportionately more than *C. fiber*. Assuming this is not the case, current hunting is considered not to prevent *C. canadensis* from spreading.

**Qu. 1.6b. How likely is the organism to be introduced into the risk assessment area or entry into the environment undetected?**

Please note that "detection" here is considered as any system or event that may actively contribute to record the presence of a species in a way that appropriate management measures could be potentially undertaken by relevant authorities.

RESPONSE		CONFIDENCE	
	very unlikely		low
	unlikely		<b>medium</b>
	<b>moderately likely</b>		high
	likely		
	very likely		

As with Qu. 1.6a, the presence of newly establishing beavers is likely to become apparent (e.g. visual observations, dam building, tree damage, roadkill), but the challenge lies in recognizing specimens as

North American beaver instead of Eurasian beaver. This challenge would be particularly complex in regions where Eurasian beaver is well established. This distinction requires expert techniques (genetic analysis, anal gland secretion, skull morphometry; see A2). Only if partners have been warned that the establishment of beaver may actually involve North American species, is it likely that such steps will be undertaken.

In our response, we consider that the expansion and state of beaver populations raises sufficient interest with Member State authorities to monitor the species fairly closely, including sporadic or systematic (environmental) DNA sampling (e.g. Iso-Touru et al. 2021). This is illustrated by various Member State initiatives under A8.

**Qu. 1.7b. How isolated or widespread are possible points of introduction and/or entry into the environment in the risk assessment area?**

<b>RESPONSE</b>	<b>isolated</b> widespread ubiquitous	<b>CONFIDENCE</b>	low medium <b>high</b>
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The Finnish-Russian distribution of *C. canadensis* is large and continuous (see A5). Regardless of developments in Finland, new animals can thus enter from across the border along its full length.

For the species to reach eastern Estonia, the species would have to cross the Karelian isthmus, including the Saint Petersburg urban district. The closest record to Estonia is less than 200 km away from its border (<https://rusmam.ru/atlas/map>, consulted 14 September 2023; Lisovsky et al. 2018).

Although large in geographic extent, we consider this an isolated point of introduction within the wider scope of the European Union.

**Qu. 1.8b. Estimate the overall likelihood of introduction into the risk assessment area and/or entry into the environment based on this pathway?**

<b>RESPONSE</b>	very unlikely unlikely moderately likely likely <b>very likely</b>	<b>CONFIDENCE</b>	low <b>medium</b> high
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Since the *C. canadensis* population is known to cross the border of Finland and the Russian Federation, it is certain that the species is entering the risk assessment area through this pathway (Qu. 1.2b-1.7b). The confidence on that response is somewhat lowered by a lack of understanding on the Russian population and on the interaction with *C. fiber* (Qu. 1.3b).

**Qu. 1.9. Estimate the overall likelihood of introduction into the risk assessment area or entry into the environment 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 risk assessment area.

<b>RESPONSE</b>	very unlikely unlikely moderately likely likely <b>very likely</b>	<b>CONFIDENCE</b>	low <b>medium</b> high
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The cross-border population of *C. canadensis* in Finland and the Russian Federation ensures that the species enters the risk assessment area on a regular base. In the long term, there is a real risk for this population to enter Estonia or Latvia. This risk of entry through natural dispersal is currently unique to the boreal region (Qu. 1.2b-1.8b).

A lower but widespread risk exists for *C. canadensis* to enter the environment from captivity. Reported holdings are few, and include few individuals, but are geographically dispersed. Yet, the true number of specimens in the risk assessment area remains unknown. Although beavers in such holdings are generally well-contained, the risk of escape can never be completely excluded, as exemplified by a few reported cases (Qu. 1.2a-1.8a).

**Qu. 1.10. Estimate the overall likelihood of introduction into the risk assessment area or entry into the environment 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 or SSP 2-4.5)
- 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 or SSP scenarios 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); SSP 1-2.6 (estimated

warming 1.8°C by 2081-2100), SSP 2-4.5 (estimated warming 2.7°C by 2081-2100) and SSP 5-8.5 (estimated warming 4.4°C by 2081-2100). Otherwise, the choice of the assessed scenario has to be explained.

<b>RESPONSE</b>	very unlikely unlikely moderately likely likely <b>very likely</b>	<b>CONFIDENCE</b>	low <b>medium</b> high
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Under foreseeable climate change conditions, the risk of entry of *C. canadensis* from captive populations (Qu. 1.2a-1.8a) is not expected to change. The likelihood for entry through natural dispersal (Qu. 1.2b-1.8b) might theoretically be increased since the severity of winter weather is considered a factor influencing litter size (Jenkins & Busher 1979). That likelihood was already assessed as maximal.

## 2 PROBABILITY OF ESTABLISHMENT

### Important instructions:

- For organisms which are already established in parts of the risk assessment area or have previously been eradicated, the likelihood of establishment should be scored as “very likely” by default.
- Discuss the risk also for those parts of the risk assessment area, where the species is not yet established.

**Qu. 2.1. How likely is it that the organism will be able to establish in the risk assessment area based on similarity of climatic and abiotic conditions in its distribution elsewhere in the world?**

RESPONSE		CONFIDENCE	
	very unlikely		low
	unlikely		medium
	moderately likely		<b>high</b>
	likely		
	<b>very likely</b>		

The climatic suitability of the risk assessment area to *C. canadensis* was introduced under question A7. Considering the projected species’ distribution (SDM, Annex VIII), or the range of *C. fiber* as a substitute, it is clear that the risk assessment area’s climate conditions are very suitable.

The species’ physical habitat (streams, ponds, margins of large lakes...; Jenkins & Busher 1979) is also widely available throughout the risk assessment area. Landscape types considered suitable from the native range (e.g. tundra, taiga, mixed and deciduous forests, swamps...; see A4), all have a European counterpart.

Some abiotic parameters related to *C. canadensis*’ physiological range were listed by Hollander et al. (2017): water pH 5.5-8.3, water temperature 0-20 °C (Baker & Hill 2003), stream gradient preferably less than 3 to 6%, valley width preferably over 25 to 45m (Allen 1982, Suzuki & McComb 1998).

Small annual fluctuations of the water level are preferred. Indeed, heavy rainfall, sudden snowmelts or violent spring ice breakups may lead to floods that destroy lodges, and may cause newborn beavers to drown in the dens, or trap beavers under the ice (Hoffmann 1967, Baker & Hill 2003).

Alakoski et al. (2020) have constructed a species distribution model (SDM) for *C. canadensis* (and *C. fiber*) in Finland, exploring the roles of the aquatic habitat type, climate, anthropogenic disturbance, and food resources. Their work includes several response curves of the species to these variables, with the aquatic habitat type (i.e. streams and rivers), autumn temperature and mean winter temperature being of prime importance. The response to the winter temperature was not linear, suggesting an optimum mean temperature for the North American beaver at approximately −6 °C. As the authors note, these models

have difficulty filtering out the invasion history, and should thus be interpreted with care (and in this case, for Finland only).

**Qu. 2.2. How widespread are habitats or species necessary for the survival, development and multiplication of the organism in the risk assessment area? Consider if the organism specifically requires another species to complete its life cycle.**

<b>RESPONSE</b>	very isolated isolated moderately widespread <b>widespread</b> ubiquitous	<b>CONFIDENCE</b>	low medium <b>high</b>
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Apart from the plant species that supply food, and trees that provide building material for dams and lodges, *C. canadensis* is not dependent on other species to complete its life cycle. The species is a strict, but generalist herbivore: they eat the leaves, twigs and bark of most woody plant species that grow near water, and many species of herbaceous (mostly aquatic) plants (e.g. roots, rhizomes, and runners of *Nuphar* and *Nymphaea*). Despite this generalistic behaviour, beavers are usually quite selective. For example, 16 of 17 tree genera present at a beaver pond in Massachusetts were cut in a two year period, but only 6 of the genera accounted for more than 90% of all trees cut (Jenkins & Busher 1979). Willow (*Salix* spp.) and aspen (*Populus* spp.) are among the favoured genera. In a Californian creek, Hall (1960) found aspen to be preferred over willow, but the latter resprouts more successfully, and so is more of a renewable resource for beavers. When one site becomes exhausted, beavers may shift gradually up- or downstream to better stands, permitting the original area to recuperate.

In the species distribution model for *C. canadensis* in Finland (see previous question), Alakoski et al. (2020) found the most important variables in term of food resources to be the volume of aspen (*Populus tremula*) and grey alder (*Alnus incana*). For *C. fiber*, a relatively larger importance was attributed to the volume of birch (*Betula* spp.), here.

Mortality due to starvation can occur especially when food cannot be stored in large enough quantities to sustain beavers through the winter. This is likely to be reflected in the climatic constraints rather than biotic constraints in itself. Generally speaking, the biotic requirements for *C. canadensis* are largely met in the risk assessment area, as suitable habitat and plant species are widespread.

**Qu. 2.3. How likely is it that establishment will occur despite competition from existing species in the risk assessment area?**

<b>RESPONSE</b>	very unlikely unlikely moderately likely	<b>CONFIDENCE</b>	low medium <b>high</b>
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	<b>likely</b> very likely		
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The species which *C. canadensis* can compete most emphatically with, clearly is the Eurasian beaver *C. fiber*. This is because, according to ecological theory (e.g. Gause's competitive exclusion principle; Hardin 1960), two species with identical niches cannot coexist indefinitely. At least some niche differentiation would be needed in order for the two species to co-exist.

Comparative studies have generally found that *C. canadensis* matures earlier, and has larger litters (Rosell et al. 2005, Parker et al. 2012). E.g., the latter authors found a mean colony size of 5.2 ( $\pm$  1.4 s.d.) for *C. canadensis*, and 3.8 ( $\pm$  1.0) for *C. fiber*. Reported litter sizes in these references are 3.2 - 4.0 for *C. canadensis* and 1.9 - 2.2 for *C. fiber*. This higher reproductive rate may give *C. canadensis* a competitive advantage. However, from the few zones where both species have come into contact, the actual outcome of competition is unclear so far.

In locations where the original Finnish introductions introduced both species, only *C. canadensis* has survived (Alakoski et al. 2020). The expanding populations of both species now converge in three regions in Finland, i.e. Pirkanmaa, Etelä-Pohjanmaa and western Lapland. Alakoski et al. (2019) have studied their sympatry in the first of these regions, where the species live in the same river systems (and have anecdotally even been observed near the same lodge). By studying their habitat use, the authors concluded that the most apparent difference between the species' activity was related to the distance from agriculture: Eurasian beaver were more active closer to agricultural areas, whereas North American beaver appear to avoid settling close to agriculture. This may give *C. fiber* an edge in partly agricultural landscapes. Apart from that, the species' habitat use is overlapping and quite flexible in both cases. The authors therefore point out that landscape features alone cannot be relied upon if the spread of *C. canadensis* were to be prevented.

In the western Russian population, *C. fiber* is slowly losing ground to *C. canadensis* on the line of contact between the White Sea and Lake Onega (Arkhangelsk region), but *C. canadensis* has lost ground to *C. fiber* on the isthmus north of St. Petersburg, Leningrad Province (Danilov & Fyodorov 2015, Halley et al. 2021).

Thus, North American beaver appears to sometimes, but not always, displace Eurasian beaver. The factors that can tip the balance are likely to be complex, including local biotic conditions and the genetic diversity of founder populations. The results of interspecific competition are also likely to be influenced by the relative sizes of each population, and so by the number of dispersers, once beavers have spread throughout a river system and begin to compete for space (Parker et al. 2012, Danilov & Fyodorov 2015, Halley et al. 2021). This is related to the 'priority effect', in which the species that colonizes a habitat first negatively affects a species that arrives later (De Meester et al. 2002).

The competition with *C. fiber* admittedly is a decisive factor in the assessment of *C. canadensis*' risks. Given that the species are virtually interchangeable, a negative effect on the native beaver species might constitute the North American beavers' main impact of concern (see Qu. 4.1-4.20).

At the same time, the outcome of competition is an important element for the management of *C. canadensis*. If *C. fiber* populations prove difficult for *C. canadensis* to infiltrate, management may prove simpler. If the latter species mixes in with *C. fiber* populations, the opposite is true (Parker et al. 2012).



Current knowledge suggests that the outcome of this competition cannot be reliably predicted at a local scale, and that either species may emerge as the winner. Being unpredictable rather than uncertain, we put forward a high confidence that the species will establish despite competition in at least some cases.

**Qu. 2.4. How likely is it that establishment will occur despite predators, parasites or pathogens already present in the risk assessment area?**

<b>RESPONSE</b>	N/A very unlikely unlikely moderately likely likely <b>very likely</b>	<b>CONFIDENCE</b>	low medium <b>high</b>
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### Predators

Natural enemies of (young) North American beaver in its native range are wolf (*Canis lupus*), coyotes (*Canis latrans*) and mountain lions (*Puma concolor*). Some other mammalian predators are of generally minor importance, such as bears (*Ursus* spp.), wolverines (*Gulo gulo*), river otters (*Lontra canadensis*), Canadian lynx (*Lynx canadensis*), bobcat (*Lynx rufus*) and American mink (*Neogale vison*) (Jenkins & Busher 1979, Baker & Hill 2003). Predation is best understood for wolf, for which beaver is a secondary or tertiary prey item in many areas. In some systems, under high beaver densities and low ungulate densities, beavers can actually be the primary summer prey of wolves (Gable et al. 2016). From a Canadian study site, researchers calculated that wolves could extract up to 90% of the annual growth of the beaver population (Potvin et al. 1992, in Baskin 2011; also see Nitsche 2016). In the case of American mink, these frequently visit beaver lodges (Errington 1943), but are understood to predate on beaver kits only (Swank 1949, in Jenkins & Busher 1979).

Baskin (2011) provided an overview of predation of *C. fiber* from Russian literature, noting that many observations are anecdotal or indirect (e.g. scat analysis, observations of digging out dens), and so do not actually prove predation of live beavers. Species listed are: wolf, brown bear (*Ursus arctos*), dog (*Canis familiaris*), fox (*Vulpes vulpes*), otter (*Lutra lutra*), eagle owl (*Bubo bubo*), viper (*Vipera berus*) and pike (*Esox lucius*). In many of these cases, the only reported victims were beaver kits (e.g. with eagle owl, viper and pike). Other species that may also play a role, but for which there is even less evidence, are mentioned: American mink, European mink (*Mustela lutreola*), white-tailed eagle (*Haliaeetus albicilla*), Eurasian goshawk (*Accipiter gentilis*), greater spotted eagle (*Clanga clanga*), common buzzard (*Buteo buteo*), black kite (*Milvus migrans*), osprey (*Pandion haliaetus*), western marsh harrier (*Circus aeruginosus*), great grey owl (*Strix nebulosa*) and Ural owl (*Strix uralensis*) (references in Baskin 2011). Hollander et al. (2017) also suggested Eurasian lynx (*Lynx lynx*) as a predator, probably from analogy with North America (above). Eurasian lynx are known to opportunistically predate on beavers in Finland, but no written reports exist (Holmala, K. & Herrero, A., unpublished).

The risk of predation is a major determining factor in the behavior of beavers, who therefore stay close to the water (Voelker & Dooley 2008). Nonetheless, we consider it very unlikely that predation would

prevent establishment and spread of *C. canadensis* in the risk assessment area. This is most clear from analogy with *C. fiber*, the comeback of which has not been hampered by the presence of predators in its range (Halley et al. 2021). This consideration also takes into account the current expansion of the range of wolves in Europe (Mysłajek et al. 2019).

Parasites and pathogens

Jenkins & Busher (1979) refer to some ectoparasites from the native range: the beaver beetle *Platypsyllus castoris*, the beaver nest beetle *Leptinillus validus* (Coleoptera); *Prolabidocarpus canadensis*, *Schizocarpus mingaudi*, *Ixodes banksi* (Arachnida); *Stichorchis subtriquetrus* (Trematoda); *Travassosius americanus*, *Castorstrongylus castoris* (Nematoda); and two species of coccidians. *C. canadensis* is also known to be involved in the epidemics of tularemia (rabbit fever), giardiasis (beaver fever), and even rabies (see Qu. 4.14).

Tularemia (rabbit fever) in beaver sometimes can be traced to infections in terrestrial rodents that deposit urine or faeces in water, or die in water, which then harbours *Francisella tularensis* bacteria. For example, an outbreak of tularemia in Montana between 1939 and 1940 caused widespread mortality of *C. canadensis* (several hundred carcasses were found) and coincided with an infection and mortality in meadow voles (*Microtus pennsylvanicus*) that inhabited the grassy streambanks.

Relevant parasites and pathogens of *C. canadensis* are likely to be shared with *C. fiber* (e.g. Girling et al. 2019, Åhlen et al. 2021). We therefore consider it very unlikely that these parasites and pathogens will prevent establishment and spread of North American beaver, given that the comeback of the Eurasian beaver was also not hampered by them.

**Qu. 2.5. How likely is the organism to establish despite existing management practices in the risk assessment area? Explain if existing management practices could facilitate establishment.**

<b>RESPONSE</b>	very unlikely unlikely moderately likely <b>likely</b> very likely	<b>CONFIDENCE</b>	low medium <b>high</b>
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*C. canadensis* is being managed (Finland, Germany) or has been managed (Luxembourg, Belgium, France) by Member States. In the latter cases, management has succeeded in eradicating populations. See A8 for the background of the species’ invasion history and status per country.

**Finland**

A national management plan for both beaver species in Finland was published by the Finnish Wildlife Agency (Riistakeskus; Anonymous 2024). The main goal of the plan is to strengthen the population of *C. fiber* in Finland by, among others, (1) enhancing the spread of *C. fiber* (naturally or by translocation), and (2) controlling the spread of *C. canadensis*. Such control is realized by hunting, by removing *C. canadensis* from western Lapland (as to prevent the species spreading into Sweden), and by creating

buffer zones free of *C. canadensis* next to *C. fiber* populations. In support of this, (e-)DNA analyses are carried out to map the national distribution of both beaver species (Iso-Touru et al. 2021).

The hunting season runs from August to April for both *Castor* species. A permit from the Finnish Wildlife Agency (Riistakeskus) is needed to hunt *C. fiber* (with quota applying), but not to hunt *C. canadensis* (Alakoski et al. 2021). Hunting is by shooting rather than trapping (Parker & Rosell 2003, Campbell-Palmer et al. 2015). About 4,000 - 5,000 *C. canadensis* are culled annually in Finland (Anonymous 2024). See Qu. 4.12 for more details.

An analysis of census data over the period 1995-2013 suggested that *C. fiber* has numerically increased in Finland, while *C. canadensis* has declined in numbers over that period. It is likely that hunting has contributed to these trends (Brommer et al. 2017). Alakoski et al. (2021), too, concluded that the North American beaver's distribution has not grown in recent decades, probably in part because of selective hunting.

## **Sweden**

In Sweden, *C. fiber* is hunted (Parker & Rosell 2003). Hunting privileges belong to the landowner, who can kill their proportion of a quota set by the government either themselves or by leasing hunting rights to others. Hunting in most regions is permitted from October to May (Busher & Dzieciolowski 1999).

## **Luxembourg, Belgium and Germany**

Following the discovery of the presence of *C. canadensis* in its border region, Luxembourg took the initiative to set up a group to deal with the issue. This group included representatives from Luxembourg; the Walloon Region (Belgium); the states of Rhineland-Palatinate, North Rhine-Westphalia and Saarland (Germany); the Lorraine Region (France); and the Netherlands. This group launched a large-scale genetic survey to delimit the geographic area colonized by *C. canadensis* and to investigate its origin, and decided on coherent management actions aimed at its eradication.

In Luxembourg, the eradication programme started in 2009. Up to 2014, 25 individuals were removed. From 2015 to 2017, 6 were removed. From 2018 to 2019, 1 was removed. In total, 12 sites were involved. Noteworthy, all individuals removed after 2014 were solitary at their site (Schley 2019). The programme thus succeeded in eradicating *C. canadensis* from the country (L. Schley, pers. comm., September 2023). The *C. fiber* population is growing rapidly, and every new site is tested genetically to confirm the species' identification.

In Wallonia (Belgium), an eradication programme was launched in 2010, which initially consisted of trapping and euthanizing specimens. Since this method was very time consuming, it was decided to hunt the beavers instead. As of May 2019, a total of 43 North American beavers have been removed from 16 sites, all of which are situated on the watershed of the river Our along the country border (Schley 2019). The presence of *C. canadensis* has drastically declined up to the point that it is now probably extinct.

In Rhineland-Palatinate (Germany), where the cross-border population stemmed from, the strategy is to capture and sterilize specimens, and release them again at the site of capture (Dewas et al. 2012). This particular strategy does not follow the recommendation of the aforementioned beaver group, and was also criticized by the Scientific Committee of the International Beaver Symposium of 2012. Although exact information on the current, local population is lacking, *C. canadensis* is considered to be still present.

In North Rhine-Westphalia (Germany), on the border with Rhineland-Palatinate, *C. canadensis* was detected by genetic testing in 2012 and again at another location in 2014. The beavers from 2012 disappeared without a trace, the single specimen from 2014 was caught. Other samples of beaver in the state, including more recent ones, turned out to be *C. fiber*, or were inconclusive so far.

**France**

The eradication campaign from central France in the 1980s is detailed under A8. Genetic testing of beaver samples for *C. canadensis* is continued within the operation of the ‘beaver network’ (Réseau Castor; Bressan & Hurel 2018). As of October 2023, no *C. canadensis* in France has been detected through genetic analysis from 301 samples collected between 2010 and ’22 (Y. Bressan, French Biodiversity Agency, pers. comm.).

**Overall**

The eradication campaigns from the latter Member States under Qu. 2.5 prove that *C. canadensis* can be prevented from establishing and spreading in an early invasion stage if *dedicated* measures are taken. Given *existing* measures only (hunting, if allowed), however, we reckon that establishment is likely. If the presence of *C. canadensis* goes undetected, the legal protection of *C. fiber* will also protect *C. canadensis*.

**Qu. 2.6. How likely is it that biological properties of the organism would allow it to survive eradication campaigns in the risk assessment area?**

<b>RESPONSE</b>	very unlikely <b>unlikely</b> moderately likely likely very likely	<b>CONFIDENCE</b>	low <b>medium</b> high
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Beaver is relatively easy to manage (i.e., trap or shoot), when compared with other mammals. Nonetheless, the total cost of mammal eradication campaigns increases very rapidly with an increase in range, so the feasibility of campaigns is disproportionately greater very early in the invasion (Robertson et al. 2016).

Indeed, the eradication campaigns from the latter Member States under Qu. 2.5 prove that *C. canadensis* can be prevented from establishing and spreading in an early invasion stage if dedicated measures are taken.

Even more, that beaver can be eradicated even when being widespread, is proven by its historic extirpation (which was replicated twice, considering the case of *C. fiber* in Eurasia). Of course, this extirpation was largely driven by commercial motivations. On the other hand, *C. canadensis* has not (yet) been successfully eradicated from South America. This may be due to the vastness and remoteness of the occupied territory (Choi 2008).

Where *C. canadensis* and *C. fiber* occur sympatrically, field campaigns would be challenged by the identification of specimens, as this requires expertise (genetic analysis, anal gland secretion, skull morphometry; see A2).

**Qu. 2.7. 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 risk assessment area
- 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 risk assessment area.
- 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.
- If relevant, comment on the adaptability of the organism to facilitate its establishment and if low genetic diversity in the founder population would have an influence on establishment.

<b>RESPONSE</b>	very unlikely unlikely moderately likely likely <b>very likely</b>	<b>CONFIDENCE</b>	low medium <b>high</b>
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Morphological and behavioral traits of North American beaver have been introduced under A2, many of which show the species' adaptive behaviour and ability to modify its environment. Here, we add more information on reproduction in particular.

North American beavers reach sexual maturity at 1.5 to 3 years (defined as age at which the first litter is produced), although puberty may be reached several months before breeding first occurs. Beavers are monogamous, typically breed in winter and give birth in late spring, producing only 1 litter per year. The potential breeding season is very long, with conception reported to have occurred between November and March, and parturition between February and November. Latitude and climate can affect the breeding season, which is generally shorter in colder climates and longer in warmer climates. Breeding takes place in open water, bank dens, or lodges. *C. fiber* remains in oestrus for 10 to 12 hours and has a second oestrus after 14 days if fertilization does not occur. A typical gestation period for *C. canadensis* is 100 days with a range of 98 to 111 days (Baker & Hill 2003, Jenkins & Busher 1979).

*C. canadensis* litter size typically ranges from two to four, although local averages may be as high as six, and total number can vary from one to nine. Large litters may be associated with better quality habitats and heavier mothers. Litter size can be reduced by lack of food (e.g., as a result of inaccessibility due to ice on ponds) or quality of food (e.g., limited supply of preferred plants). Because fewer yearlings breed in relatively dense populations and litter size may be inversely related to the number of beavers

in the family, reproduction in beaver may be density dependent (Jenkins & Busher 1979, Baker & Hill 2003). According to Jenkins & Busher (1979), the most important proximate factors that influence litter size are quantity and quality of available food and the severity of winter weather. Young beavers are weaned from about six weeks to two months. Lactation continues for at least three months.

Few animals live beyond 10 years, but the longevity record for wild beaver ranges up to 21 years (Jenkins & Busher 1979).

The fundamental unit of a beaver population is the colony, consisting of 4 to 8 related individuals, more or less exclusively occupying a pond or section of stream. The mean colony size ( $\pm$  standard deviation) of the North American beaver is 5.2 ( $\pm$  1.4 s.d.) (Rosell et al. 2005, Parker et al. 2012). Adult females seem to be more sedentary than adult males. The average density of *C. canadensis* colonies in 7200 ha of southern Finland over the period 1980 to 1998 was 0.08 colonies per km<sup>2</sup>. This is below the density of colonies found in North America which was measured at 0.2 to 4.6 colonies per km<sup>2</sup> (Jenkins & Busher 1979, Parker et al. 2002, Hyvönen & Nummi 2008).

The establishment in Finland has occurred despite low genetic diversity in the founder population, given only seven specimens been acquired from New York state (see A8, Parker et al. 2012).

**Qu. 2.8. 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		CONFIDENCE	
	very unlikely		low
	<b>unlikely</b>		<b>medium</b>
	moderately likely		high
	likely		
	very likely		

Given our understanding that the overall number of captive *C. canadensis* is probably low (Qu. 1.3a), and this is the only relevant pathway by which casual (non-establishing) populations could form, this risk is considered unlikely. Rather, escapes from captivity are likely to lead to self-sustaining populations, as has been the case for, e.g., France and Germany (see A8).

**Qu. 2.9. Estimate the overall likelihood of establishment in the risk assessment area 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 risk assessment area.

<b>RESPONSE</b>	very unlikely unlikely moderately likely likely <b>very likely</b>	<b>CONFIDENCE</b>	low medium <b>high</b>
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The species is already established in the risk assessment area. Taking the elements from the above questions into consideration (notable, Qu. 2.1-2.5 and 2.7), it is also very likely that this will continue to be the case in current climatic conditions.

**Qu. 2.10. 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 or SSP 2-4.5)
- 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 or SSP scenarios 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); SSP 1-2.6 (estimated warming 1.8°C by 2081-2100), SSP 2-4.5 (estimated warming 2.7°C by 2081-2100) and SSP 5-8.5 (estimated warming 4.4°C by 2081-2100). Otherwise, the choice of the assessed scenario has to be explained.

<b>RESPONSE</b>	very unlikely unlikely moderately likely likely <b>very likely</b>	<b>CONFIDENCE</b>	low medium <b>high</b>
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Notes on the climatic niche of *C. canadensis*, or *C. fiber* as a substitute, are included under A7. Climate change in the next fifty to hundred years will probably have little impact on the potential distribution range of *C. canadensis* in the risk assessment area. A good indication that *C. canadensis* can establish under warmer conditions is found in the fact that *C. canadensis* occurs in Mediterranean climate in its

native range (California), and that *C. fiber* widely occurred in Mediterranean Europe. At the other extreme, regions that are currently too cold for establishment are likely to open up for the species. Indeed, the severity of winter weather is considered an important factor influencing litter size (Jenkins & Busher 1979).



### 3 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 introduction and entry section (Qu. 1.7).

#### Qu. 3.1. 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 spread discussed in relation to the species biology and the environmental conditions in the risk assessment area.

The description of spread patterns here refers to the CBD pathway category “Unaided (Natural Spread)”. It 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	minimal minor <b>moderate</b> major massive	CONFIDENCE	low <b>medium</b> high
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Some details on natural dispersal have already been provided under Qu. 1.2b-1.8b, since such dispersal also provides a pathway for *C. canadensis* to enter the risk assessment area. Here, we add some more ecological knowledge.

Beavers produce one litter per year. Animals disperse when they are a yearling (13 to 24 months old) or a subadult (25 to 36 months old). The average natural dispersal rate of male and female *C. canadensis* individuals from their natal site to settlement was 24 km/year in Southern Illinois (USA), with a range of 2 and 115 km/year (McNew & Woolf 2005). The maximum movement distance ever reported for a trapped and relocated individual was 238 km in North Dakota, USA (Petro et al. 2015). In Illinois (USA), beavers with free-flowing water access dispersed further from natal colonies than landlocked beavers (mean distance 5.9 and 1.7 km, respectively; McNew & Woolf 2005). According to Knudsen & Hale (1965), the mean movement distance of beavers transplanted into streams in Wisconsin (USA) was more than twice that of beavers transplanted into landlocked waters (7.4 versus 3.2 km, respectively). In Chile, the species was able to disperse from the Isla Grande de Tierra del Fuego to the mainland via the Strait of Magellan, which is two kilometres wide at its narrowest point (Graells et al. 2015).

Since their introduction in Finland, *C. canadensis* appears to have spread along an estimated 6.9 km shoreline per year (compared to 2.8 km for *C. fiber*; Alakoski et al. 2021). Alakoski et al. (2019) found that distance to agricultural areas was the most apparent difference in habitat use between *C. canadensis* and *C. fiber* in a river system where the species occur sympatrically (see Qu. 2.3.). They suggest that, to some extent, this may help inhibiting the spread of *C. canadensis* into the Eurasian beaver's current range in Finland.

Given the widespread availability of suitable habitat, the species' intrinsic capacity to spread along large rivers, canals and interconnected lakes in the risk assessment area is thus considerable. Since this capacity is lower than what is plausible for, for example, birds or flying insects, we opt for a moderate score. Our confidence on this response is lowered as the presence of *C. fiber* may affect spread (see Qu. 2.3).

**Qu. 3.2a. List and describe relevant pathways of spread other than "unaided". For each pathway answer questions 3.3 to 3.9 (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. 3.3a, 3.4a, etc. and then 3.3b, 3.4b etc. for the next pathway.**

including the following elements:

- a list and description of pathways of spread with an indication of their importance and associated risks (e.g. the likelihood of spread in the risk assessment area, 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) in relation to the environmental conditions in the risk assessment area.
- an indication of the rate of spread for each pathway discussed in relation to the species biology and the environmental conditions in the risk assessment area.
- All relevant pathways of spread (except "Unaided (Natural Spread)", which is assessed in Qu. 3.1) should be considered. The classification of pathways developed by the Convention of Biological Diversity shall be used (see Annex IV).

Besides natural dispersal, only 'ESCAPE from confinement: Botanical garden/zoo/aquaria' is considered a relevant pathway for *C. canadensis* (Qu. 1.2a-1.8a). This pathway only concerns entry into the environment, and not post-release dispersal, and is therefore not discussed further here.

As argued under Qu. 1.1., we consider pathways that involve *RELEASE in nature* (for conservation purposes, landscape improvement, rewilding, or hunting) now very unlikely for the combination of following reasons: (1) knowledge on the species' distinction has drastically increased, (2) the demand for beaver (re)introductions has generally decreased, (3) there now is easier access to specimens of Eurasian than North American beaver (both in the wild and in captivity). (The latter may not be true only for Finland. However, there is no need, nor an indication, for intentional *C. canadensis* translocations here.)

**Qu. 3.3a. Is spread along this pathway intentional (e.g. the organism is deliberately transported from one place to another) or unintentional (e.g. the organism is a contaminant of translocated goods within the risk assessment area)?**

<b>RESPONSE</b>	intentional unintentional	<b>CONFIDENCE</b>	low medium high
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Response: N/A.

**Qu. 3.4a. 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).

<b>RESPONSE</b>	very unlikely unlikely moderately likely likely very likely	<b>CONFIDENCE</b>	low medium high
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Response: N/A.

**Qu. 3.5a. 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)?**

<b>RESPONSE</b>	very unlikely unlikely moderately likely likely very likely	<b>CONFIDENCE</b>	low medium high
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Response: N/A.

**Qu. 3.6a. How likely is the organism to survive existing management practices during spread?**

RESPONSE	very unlikely	CONFIDENCE	low
	unlikely		medium
	moderately likely		high
	likely		
	very likely		

Response: N/A.

**Qu. 3.7a. How likely is the organism to spread in the risk assessment area undetected?**

Please note that “detection” here is considered as any system or event that may actively contribute to record the presence of a species in a way that appropriate management measures could be potentially undertaken by relevant authorities.

RESPONSE	very unlikely	CONFIDENCE	low
	unlikely		medium
	moderately likely		high
	likely		
	very likely		

Response: N/A.

**Qu. 3.8a. How likely is the organism to be able to transfer from the pathway to a suitable habitat or host during spread?**

RESPONSE	very unlikely	CONFIDENCE	low
	unlikely		medium
	moderately likely		high
	likely		
	very likely		

Response: N/A.

**Qu. 3.9a. Estimate the overall potential rate of spread based on this pathway in relation to the environmental conditions in the risk assessment area. (please provide quantitative data where possible).**

<b>RESPONSE</b>	very slowly slowly moderately rapidly very rapidly	<b>CONFIDENCE</b>	low medium high
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Response: N/A.

**Qu. 3.10. Within the risk assessment area, how difficult would it be to contain the organism in relation to these pathways of spread?**

<b>RESPONSE</b>	very easy easy with some difficulty <b>difficult</b> very difficult	<b>CONFIDENCE</b>	low <b>medium</b> high
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The containment of spreading *C. canadensis* would be facilitated by the relative ease of detecting beaver presence (e.g. observations, dam building, tree damage) and the effectiveness of intervention measures (e.g. trapping, shooting). On the other hand, containment would be strongly complicated by challenges regarding species identification (requiring expertise, cf. A2) or long-distance dispersal events (cf. Qu. 3.1). Containment campaigns can therefore only be successful if they are well-coordinated, region-wide and long-lasting.

**Qu. 3.11. 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 risk assessment area.

<b>RESPONSE</b>	very slowly slowly <b>moderately</b> rapidly	<b>CONFIDENCE</b>	low <b>medium</b> high
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	very rapidly		
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As motivated under Qu. 3.1, *C. canadensis* has a moderate capacity to disperse naturally throughout the risk assessment area, along large rivers, canals and interconnected lakes. As the presence of *C. fiber* may inhibit spread (see Qu. 2.3), a medium confidence is provided.

Following entry into the environment, the species would be able to colonize large parts of the risk assessment area in a matter of decades, unless spread becomes inhibited by natural or human processes. Biogeographic regions and countries considered suitable for establishment are mentioned under questions A7 and A9, respectively.

**Qu. 3.12. 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.

<b>RESPONSE</b>		<b>CONFIDENCE</b>	
	very slowly		low
	slowly		<b>medium</b>
	<b>moderately</b>		high
	rapidly		
	very rapidly		

Beavers produce one litter per year, irrespective of latitude or climate, but the severity of winter weather is considered an important factor influencing litter size (Jenkins & Busher 1979). However, we do not expect that future changes in winter weather will shift the spread capacity of *C. canadensis* to a higher order of magnitude for that reason, since litter sizes may already be large, and litter size is only diffusely correlated to spread rate.

## 4 MAGNITUDE OF IMPACT

### Important instructions:

- Questions 4.1-4.5 relate to biodiversity and ecosystem impacts, 4.6-4.8 to impacts on ecosystem services, 4.9-4.13 to economic impact, 4.14-4.15 to social and human health impact, and 4.16-4.18 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 Qu. A.13)
- 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”. In this case, no score and confidence should be given and the standardized “score” is N/A (not applicable). Note that in principle, even if no information is available for the risk assessment area, this does not apply to Qu. 4.2 and 4.3, because the information on impact can be inferred from regions outside the risk assessment area. If no information is available from regions outside the risk assessment area either, then this should be discussed explicitly.

## Biodiversity and ecosystem impacts

**Qu. 4.1. 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		CONFIDENCE	
	minimal		low
	minor		medium
	moderate		<b>high</b>
	major		
	<b>massive</b>		

Beavers are among the few species besides humans that can significantly change the geomorphology, and consequently the hydrological, abiotic and biotic properties, of the landscape. Biotically, these changes generally involve an increase in habitat heterogeneity and species diversity, and a change in the course of succession (Rosell et al. 2005, Sommer et al. 2019, Brazier et al. 2021). Besides being ecosystem engineers, beavers are thus also keystone species. Where beavers are native (*C. fiber* in Eurasia, *C. canadensis* in northern America), these impacts are generally considered positive, as they translate into integer, biodiverse and functionally resilient landscapes (Stringer & Gaywood 2016). Strictly speaking, these effects thus fall outside the scope of this section, which considers negative impacts only.

However, these same effects may be considered negative, when (1) they occur in ecosystems where beavers are not naturally present (this question); or when (2) they conflict with other activities (e.g. agriculture; Qu. 4. 9).

**Therefore, we consider it useful to first provide an overview of (a) abiotic and (b) biotic effects caused by beaver, as an introduction to various parts under chapter 4.** (Findings in this overview stem from North American beaver in the native range, or apply to beaver in general. Findings specifically from within the risk assessment area are transferred to Qu. 4.2., and should thus be considered in addition.) **The question about the effects in the non-native area outside the risk assessment area will then be answered under (c).**

#### **(a) Abiotic effects**

The strength of beaver impact varies from site to site, depending on the geographical location, relief and impounded habitat type. Consequently, they may not act as system changers in all parts of their distribution, but have strong interactions only under certain circumstances (Naiman et al. 1988). It is widely recognized that there are strong and continuous interactions between hydrology, geomorphology, water chemistry and temperature (Naiman et al. 2000). These are all significant factors that influence aquatic organisms, and they can all be modified by beaver activity (Rosell et al. 2005).

##### Geomorphology

Beavers are known for changing landscapes through dam building and the creation of ponds. In addition, they tend to overexploit the trees, and subsequently abandon the overexploited site creating so called “beaver meadows” (Wright et al. 2002). Beaver dams play a significant role in shaping the morphology of river channels (Gibson & Olden 2014). For example, a 1.25 ha beaver pond in a Maryland waterbody (USA) reduced the annual discharge of total organic carbon by 28% and the total suspended solids by 27%. In Glacier National Park, Montana (USA), the depth of sediment ranged from an average of 24.6 cm in younger ponds (< 6 years old) to 45 cm in an older pond (> 10 years old). Accordingly, the sedimentation volume ranged from 9.4 m<sup>3</sup> in a young pond (area 38 m<sup>2</sup>) to 267 m<sup>3</sup> in an older pond (area 588 m<sup>2</sup>) (Meentemeyer & Butler 1999).

##### Hydrology

Increases in groundwater surface elevation (i.e., water table), groundwater storage potential and aquifer recharge surrounding a beaver dam have been recorded in Oregon (USA). In the San Pedro River in Arizona (USA), dams caused an increase in stream flow during dry seasons, potentially converting the downstream hydrological regime from an intermittent to a perennial type. Beaver dams may also reduce stream velocity and erosive power during peak flows (Gibson & Olden 2014). Due to large initial



differences in velocity, beaver dams that flood upland areas reduce the kinetic energy of the stream more than those that flood wetlands.

It has been observed that older beaver dams reduced stream velocity and discharge more efficiently than young dams in low-order streams in Montana (USA). In a second order stream in Maryland (USA), the creation of a 1.25 ha beaver pond reduced the annual water discharge of 8%. Although a single beaver dam may have little influence on stream flow, a series of dams can have a significant effect by moderating the peaks and troughs of the annual discharge patterns.

During dry periods, up to 30% of water in an Oregon catchment could be held in beaver ponds (Duncan 1984). By increasing storage capacity, it has been suggested that large numbers of beaver dams will lead to higher flows during late summer, which may result in continual flows in previously intermittent streams (Rutherford 1955, Yeager & Hill 1954, Parker 1986, Rosell et al. 2005).

#### Water quality and chemistry

Beaver dams affect water temperatures as a result of changes in water surface area (increase), water depth (increase), water residence time (increase), or shading by trees (increase or decrease) (Rosell et al. 2005, Gibson & Olden 2014). A large-scale, long-term study highlighted that the effect on temperature is complex, but found that increased dam and pond creation generally contributes to the moderation of daily temperature cycles (i.e., increasing minimum temperatures and decreasing maximum temperatures) (Weber et al. 2017).

Furthermore, the input and retention of organic matter and nutrients in both dryland and temperate streams increases. It seems probable that beaver ponds increase the net ecosystem retention of nitrogen and, thus, overall productivity of ponds and downstream waters (Rosell et al. 2005, Gibson & Olden 2014). Beaver altered sites have higher levels of organic and (in)organic N, suggesting that seasonal hydrological changes could be affecting nitrification and denitrification, also resulting in accumulated organic C and P in the stream channel. Beaver ponds may be considered sources of essential nutrients (P and N) and C (Lizarralde et al. 2004).

#### **(b) Biotic effects**

Stringer & Gaywood (2016) performed a meta-analysis of evidence investigating the impacts of beavers (both species) on biodiversity, and found 73% of the studies to report a positive effect, 17% a neutral effect, and 10% a negative effect (63 studies). The biotic effects of beaver are therefore considered generally positive.

#### Effects on vegetation

Beaver activity alters the riparian community both directly through herbivory and indirectly through dam construction. Beavers are unique in their ability to fell mature trees and thus alter the riparian canopy cover (Baker & Hill 2003). In addition, beaver foraging activity is concentrated along the water's edge (Gibson & Olden 2014). There is a close association between beaver presence and the distribution of willow (*Salix*), but there is little evidence for a negative population level response of willow to beaver foraging. However, unlike willow, substantial negative population level effects of beaver herbivory on cottonwood (*Populus*) have been documented (Gibson & Olden 2014). There is some evidence that beaver herbivory can promote the spread of alien plants such as salt cedar (*Tamarix* spp.) and Russian olive (*Elaeagnus angustifolia*) at the expense of native communities (Gibson & Olden 2014). Beaver herbivory can also negatively affect aquatic vegetation. Plant biomass was reduced by 60% in beaver

wetlands near Atlanta, Georgia (USA). Here, both native (e.g., *Saururus cernuus*) and alien (e.g., *Myriophyllum aquaticum*) plant species were grazed (Parker et al. 2007).

Beavers also have indirect effects on the aquatic as well as riparian vegetation. Beaver dams locally raise the water level and cause flooding of bank vegetation along dammed rivers and ponds (Nummi & Kuuluvainen 2013). Flooding of riparian vegetation will gradually lead to mortality of the least water tolerant wetland plants, and to the colonization of the pond by aquatic plants such as *Lemna* and *Utricularia*, as was found in Finland (Hyvönen & Nummi 2011, Nummi & Kuuluvainen 2013). Beaver dams also raise and stabilize the surrounding water table, which creates ideal conditions for some riparian plant species. The strong interdependence between beaver dams, groundwater elevation, and willow has been extensively studied in temperate Yellowstone National Park, where the restoration of tall riparian willow communities was dependent on the restoration of the hydrological conditions that had been affected by beaver dams (Gibson & Olden 2014).

In a meta-analysis from 53 studies across both *Castor* species, Sommer et al. (2019) found 79 % of the studies to report an increase in plant species diversity at landscape level. For animal species diversity, 83 % of the studies reported an increase.

#### Effects on mammals

Dryland beaver activity can enhance habitat for aquatic and riparian associated mammals, including some species of conservation concern. River otter (*Lontra canadensis*), which have suffered particularly steep population declines in the south-west, are known to make use of beaver ponds and dens. Beaver ponds are likely to provide ideal riparian habitat for the rare meadow jumping mouse (*Zapus hudsonius luteus*) in New Mexico. Observations of a semi-arid Idaho beaver pond revealed that a greater abundance and a different assemblage of riparian small mammals was supported than in an adjacent un-impounded stream (Gibson & Olden 2014).

#### Effects on birds

Dryland *Populus-Salix* riparian forests support a high richness and density of breeding songbirds, which highlights the conservation importance of beaver impacts on these forests. Density, biomass, and species richness of riparian birds were all higher surrounding a beaver pond than along an un-impounded reach of a semi-arid Wyoming stream (USA) (Gibson & Olden 2014).

#### Effects on fish

In dryland streams, most research addressing beaver–fish relationships has focused on trout species. These studies generally conclude that, consistent with temperate stream findings, trout populations benefit from beaver ponds (Jakober et al. 1998, Talabere 2002). Construction of beaver ponds may enhance the success of alien fishes, to the detriment of native fish communities (Rosell et al. 2005, Gibson & Olden 2014). However, a study of two northern Utah streams in the USA showed that beaver dams were acting as movement barriers for the alien brown trout (*Salmo trutta*), but not for native Bonneville cutthroat trout (*Oncorhynchus clarkia*) or alien brook trout (*Salvelinus fontinalis*) (Lokteff et al. 2013). According to Gibson & Olden (2014), little information is available to describe associations between beaver activity and non-salmonid fishes in dryland streams.

#### Effects on amphibians

Beaver dam building activity may provide valuable habitat for dryland amphibians (Gibson & Olden 2014, Nummi & Kuuluvainen 2013). Observations of a valley in the Eifel (Germany) show that the altered landscapes of the native beaver *C. fiber* offer high quality habitats for amphibians. All anuran species typical of the region occupied beaver ponds, including species that were absent or rare in natural waters (Dalbeck et al. 2007).

#### Effects on reptiles

Turtles and water snakes (e.g., *Natrix* spp. and *Nerodia* spp.) may utilize beaver ponds (Hilfiker 1991). Reptiles were observed to be more abundant in beaver ponds than in un-impounded streams in western South Carolina, USA (Metts et al. 2001). This was associated with the preference of reptiles for shallow, standing or slow flowing water, abundant aquatic vegetation and soft organic substrates. The degree of community reptile overlap was relatively low between old and new beaver ponds and un-impounded streams, with significant differences in diversity between all three habitat types (Russel et al. 1999, Rosell et al. 2005).

#### Effects on invertebrates

Pond habitat created by beavers will favour lentic species rather than the original lotic animals (Rosell et al. 2005). For example, the typical low order stream invertebrate community of a small stream in Quebec (Canada) was replaced by assemblages that were functionally more similar to large order systems (McDowell & Naiman 1986). Beavers are also capable of influencing the invertebrate fauna of lakes (Rosell et al. 2005). Many boreal headwater lakes in Ontario (Canada) have limited littoral invertebrate habitat features, and beaver lodges can provide suitable habitat structures in such environments. For example, the richness and abundance of ten benthic macroinvertebrate taxa in the Canadian Shield lakes were higher near beaver lodges compared with other littoral zone sites which consisted of sand and rock (France 1997). Beavers also influenced the conservation of endangered invertebrate species in North America (Rosell et al. 2005). For example, the Hungerford crawling water beetle (*Brychius hungerfordi*) is associated with the area downstream of beaver dams (US Fish and Wildlife Service 1994). By contrast, the inundation resulting from beaver dams and accumulations of silt caused by dam construction presented a significant danger to the Louisiana pearlshell mussel (*Margaritifera hembeli*) (US Fish and Wildlife Service 1993, Johnson & Brown 1998).

### **(c) Negative impacts in the non-native range excluding the risk assessment area**

#### Tierra del Fuego

The effect of *C. canadensis* on ecosystems has been documented for its introduced range in South America. Impacts relating to beaver's status as ecosystem engineers on sub-Antarctic vegetation have been quantified for tree canopy cover, seedling abundance and composition, as well as herbaceous species richness, abundance and composition on Navarino Island, Cape Horn County (Chile). Beavers significantly reduced the forest canopy to a distance of 30 m away from streams, essentially eliminating riparian forests. The tree seedling bank was greatly reduced and seedling species composition was altered as a result of suppression of *Nothofagus betuloides* and *Nothofagus pumilio*, and allowance of *Nothofagus antarctica*. Herbaceous richness and abundance almost doubled in meadows. However, unlike the effects of beaver on North American herbaceous plant communities, much of this increased species richness was due to invasion by exotic plants, and beaver modifications of the meadow

vegetation assemblage did not result in a significantly different community, in contrast to forests. Overall, 42% of plant species were shared between both habitat types. Beaver engineering in sub-Antarctic landscapes has increased local herbaceous richness, but in contrast to their native range, a unique plant community was not created. The elimination of *Nothofagus* forests and their seed bank, and the creation of invasion pathways for exotic plants together threaten one of the world's most pristine temperate forest ecosystems (Anderson et al. 2006, Wallem et al. 2007). Beavers have mainly altered upland stream valleys in mountainous areas and wetlands in Argentina and Chile, converting large areas from closed *Nothofagus* forest to grass and sedge dominated meadows. These forests are strongly dominated by three species of *Nothofagus*, which did not evolve with beaver and have no chemical defenses against them, in contrast to some northern hemisphere trees like conifers and quaking aspen that do. Moreover, *Nothofagus* do not regenerate well when damaged by beavers. When beavers abandon sites, even though there is some recolonization by typical forest understory plants, some species have not returned in 20 years, and at best only small tree seedlings are present at such sites. In the beaver's native range, grass- and sedge-dominated meadows often persist long after beavers have abandoned sites, with succession differing greatly from that occurring in openings created by other disturbances, perhaps because of differences in nutrient accumulation and changes in soil structure (Wallem et al. 2007, Simberloff 2009).

Beavers on Isla Grande de Tierra del Fuego appear to be generating an invasional meltdown. Beaver-affected sites on Isla Grande and Navarino Island feature several introduced plant species that are otherwise scarce in the *Nothofagus* forest, perhaps due to the higher levels of organic and inorganic nitrogen in sediments of beaver sites. Beavers on the islands of Tierra del Fuego have also wrought hydrological changes as a result of impacts on the local geomorphology, and some of these can have great consequences for the entire ecological community. Nitrate and nitrite concentrations were many times higher in beaver pond water than in water of other ponds. The mean surface area of ponds on Isla Grande has increased enormously, and stream morphology has also been modified. There is also the prospect of an invasional meltdown in aquatic as well as terrestrial systems. Beaver ponds have disproportional amounts of habitat suitable for brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus mykiss*), and brook trout (*Salvelinus fontinalis*), all of which have been introduced and are non-native to Tierra del Fuego (Simberloff 2009). Thus, beavers have enormous impacts on entire ecosystems when they are introduced to islands due to profound changes relating to their status as ecological engineers and by virtue of potential invasional meltdowns where altered habitats become suitable for other introduced species (Simberloff 2009). In this way beavers change the entire nature of large areas.

Anderson & Rosemond (2007) observed that beaver engineering in ponds created taxonomically simplified, but more productive, benthic macroinvertebrate assemblages in the Cape Horn Biosphere Reserve, Chile. Specifically, macroinvertebrate richness, diversity and number of functional feeding groups were reduced by half, while abundance, biomass and secondary production increased three- to fivefold in beaver ponds compared to forested sites. Beaver ponds were also characterized by the enhancement of higher trophic levels as a result of increased organic matter flows to invertebrate predators. However, the four studied streams were naturally dependent on allochthonous resources (particularly amorphous detritus), meaning that changes wrought by beavers to the streams in the forested portion of the archipelago may have less impact on benthic ecosystem processes in this landscape than they would have in other ecosystem types. In contrast to the sub-Antarctic forested ecoregion, beavers have been invading grassland ecosystems farther north which are likely to be more dependent on primary production and may be more affected by beaver impacts than the forested sites studied in Cape Horn, Chile (Anderson & Rosemond 2010).

### Russian Federation

Given that *C. fiber* is historically native to both western Russia (European Russia) and the Russian Far East (Halley et al. 2021), the effects brought about by *C. canadensis* on biodiversity would generally not be considered negative (though local conflicts may be possible).

Studies on interspecific comparison of beaver building activity in European Russia from the 1970s suggested that *C. canadensis* expressed a stronger building instinct than *C. fiber*. However, when incorporating more recent information, the same authors corrected their findings, concluding that both species build lodges and dams with equal frequencies (Danilov & Fyodorov 2015).

**Qu. 4.2. 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	minimal minor moderate <b>major</b> massive	CONFIDENCE	low <b>medium</b> high
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### Abiotic and biotic effects

The abiotic and biotic effects of beaver described under the previous question equally apply to (1) *C. canadensis* in its native range, (2) *C. canadensis* in its Eurasian alien range, and (3) *C. fiber* in its native range. Since these effects are generally considered positive for biodiversity at all levels of organisation (Stringer & Gaywood 2016), there are no negative impacts to report, be it with noting that local conflicts may always arise. This may be the case when conservation targets in the riparian environment conflict with beaver-induced changes; e.g. the loss of trees, or mismatches in the hydrological regimes for some types of grassland.

Effects that have been described specifically from the *C. canadensis* populations in Finland, include the following.

By studying flood dynamics caused by *C. canadensis* in southern Finland from 1970–2018, Kivinen et al. (2020) showed that beaver has created a dynamic mosaic of flood-inundated and post-flood patches. These networks with diverse abiotic and biotic conditions increase environmental heterogeneity in space and time. Beaver-induced changes can thereby influence ecosystems for decades, or even longer, especially if sites are repeatedly flooded.

Using camera traps and snow track surveys, Nummi et al. (2019) found mammalian species richness (+83%) and occurrence (+12%) to be significantly higher in *C. canadensis* patches than in controls. Moose (*Alces alces*) used such patches more during the ice-free season as well as winter. Eurasian otter (*Lutra lutra*), pine marten (*Martes martes*) and least weasel (*Mustela nivalis*) made more use of beaver sites during the winter.

Similarly, Nummi et al. (2011) found two bat species (*Eptesicus nilssoni* and *Myotis daubentoni*) to use *C. canadensis* flowages more than non-beaver ponds. Bats also seemed to forage in larger groups while above beaver ponds compared to controls. A plausible reason for this could be the high number of insects emerging from beaver ponds.

Nummi & Holopainen (2014) also found *C. canadensis* to act as a community facilitator for water birds. The number of water bird species observed per pond per year was significantly higher during beaver inundation than before beaver activity, as was the water bird abundance per survey. The numbers of seven species of waders and ducks increased during flooding. Common teal (*Anas crecca*) and green sandpiper (*Tringa ochropus*) showed the most positive response to flooding. Mallard (*Anas platyrhynchos*) and wigeon (*Anas penelope*) were new species that entered the duck guild in the flooded wetlands.

Finally, positive effects were also found for the moor frog (*Rana arvalis*), which benefitted from pond construction and removal of trees by North American beavers (Vehkaoja & Nummi 2015).

In our answer we only consider negative impacts that are not already caused by the native *C. fiber* (as this species is an integral part of Europe's natural landscapes). In this regard, the impact of *C. canadensis* is thus considered minimal.

#### Competition with *C. fiber*

A clear, potentially negative impact, however, is the competition of *C. canadensis* with *C. fiber*. This is described in detail under Qu. 2.3. Larger litter and colony sizes are reported for the former species than for *C. fiber* (Rosell et al. 2005, Parker et al. 2012). However, the actual outcome of competition, as derived from the limited number of areas where both species come into contact, is unclear so far. In summary, North American beaver sometimes, but not always, displaces Eurasian beaver (see Qu. 2.3). The factors that can tip the balance are likely to be complex, including local biotic conditions and population parameters (size, genetic diversity...; Parker et al. 2012, Danilov & Fyodorov 2015, Halley et al. 2021).

Our answer therefore reflects the possible loss of *C. fiber* populations due to *C. canadensis*. This translates into a 'major' impact according to the guidelines of Annex II. Given limited information available, this response comes with a medium confidence.

As explained under A2, there is no risk for hybridization among *C. canadensis* and *C. fiber*. Parasites and pathogens carried by *C. canadensis* are included under Qu. 2.4 and 4.14.

<b>Qu. 4.3. 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?</b>
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See comment above. The potential future impact shall be assessed only for the risk assessment area. A potential increase in the distribution range due to climate change does not *per se* justify a higher impact score.

<b>RESPONSE</b>	minimal minor moderate <b>major</b> massive	<b>CONFIDENCE</b>	low <b>medium</b> high
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The low predictability of the outcome of competition among the two beaver species (see previous question) suggests that, if *C. canadensis* was to spread significantly across its potential range in the risk assessment area, the native *C. fiber* would considerably lose grounds. This would, tragically, set back one of the most spectacular recoveries of a formerly threatened vertebrate in Europe (Ledger et al. 2022). In a pessimistic scenario, which is nevertheless best considered -taking the precautionary principle into account-, *C. fiber* could again become endangered (locally, regionally, nationally or EU-wide).

The replacement of a native species by a non-native, but functionally near-identical counterpart, has some analogy with the demise of European mink (*Mustela lutreola*) in favor of American mink (*Neogale vison*) (Vada et al. 2023). The former, now critically endangered species can only be found in restricted parts of its former range (although the reasons for its decrease are complex and not only attributable to *N. vison*) (Maran et al. 2016).

There is no reason to assume that the predicted changes in climate would significantly alter the presumed impacts (abiotic or biotic impacts, generally considered positive; competition with *C. fiber*, complex, both of general concern).

**Qu. 4.4. 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

<b>RESPONSE</b>	minimal minor moderate <b>major</b> massive	<b>CONFIDENCE</b>	low <b>medium</b> high
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### Protected habitats and sites

The area exposed to wild *C. canadensis* (Finland, Germany) comprises various habitat types of undisturbed rivers, streams and lakes in a forested landscape; e.g. within the 31 series (standing water), such as 3160 (dystrophic lakes and ponds); 32 series (running water), such as 3210 (Fennoscandian natural rivers); 90 series (forests of boreal Europe), such as 9080 (Fennoscandian deciduous swamp woods); 91 series (forests of temperate Europe), such as 91E0 (alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior*).

The abiotic and biotic effects of beaver introduced under Qu. 4.1. in these habitats are generally considered positive for nature conservation (Stringer & Gaywood 2016). These effects equally apply to *C. canadensis* and *C. fiber*. In fact, Törnblom et al. (2011) point out that landscapes modified by beavers are prime references for the good ecological status of small to medium sized streams as requested by the Water Framework Directive.

Local conflicts in terms of conservation may arise, e.g. when beaver-induced changes lead to losses of trees, or mismatches in the hydrological regimes for some types of grassland. Although detailed accounts are lacking, beaver damage in Finland amounts to about 900 ha per year (LUKE, pers. comm.; see Härkönen 1999 for damage to commercial forest types).

In our answer we only consider negative impacts that are not already caused by the native *C. fiber* (as this species is an integral part of Europe's natural landscapes). In this regard, the impact of *C. canadensis* is thus considered minimal.

### Protected species

Competition with *C. fiber* has been introduced in detail under Qu. 2.3 and further developed under Qu. 4.2. In accordance with the latter question, our answers reflect the possible loss of *C. fiber* populations due to *C. canadensis*.

**Qu. 4.5. 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?**

- See guidance to Qu. 4.3. and 4.4.

RESPONSE	minimal minor moderate <b>major</b> massive	CONFIDENCE	low <b>medium</b> high
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### Protected habitats and sites

If *C. canadensis* was to spread significantly across its potential range in the risk assessment area, more habitat types within the 31 series (standing water), 32 series (running water), 90 series (forests of boreal Europe) and 91 series (forests of temperate Europe) will become exposed to the species (see with



previous question). Eventually, also habitat types within the 92 series (Mediterranean deciduous forests) might become affected, such as 92A0 (*Salix alba* and *Populus alba* galleries). Insofar as these habitats benefit from the presence of beaver (*C. fiber*), no negative effect of *C. canadensis* is expected.

The outcome might be different for semi-natural meadows in river valleys that have largely taken the place of natural forests (64 series). Here, the rise in water level because of damming might exceed the ground level for the grasslands, or might lead to contaminated river water penetrating grasslands (indications exist for 6410, *Molinion caeruleae* meadows, in Belgium; Huysentruyt et al. 2019).

#### Protected species

Competition with *C. fiber* has been introduced in detail under Qu. 2.3 and further developed under Qu. 4.2. A range expansion of *C. canadensis* would expectedly come at the expense of a loss in *C. fiber*'s range. This would tragically set back one of the most spectacular recoveries of a formerly threatened vertebrate in Europe (Ledger et al. 2022). As a precaution, we assume that this could contribute to *C. fiber* becoming endangered again (locally, regionally, nationally or EU-wide).

## Ecosystem Services impacts

### **Qu. 4.6. 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 services use the CICES classification V5.1 provided in Annex V.
- 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.

<b>RESPONSE</b>	minimal minor moderate major <b>massive</b>	<b>CONFIDENCE</b>	low <b>medium</b> high
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The processes by which beavers affect ecosystems are introduced under Qu. 4.1, and the impact of *C. canadensis* on the Fuegian ecosystems (South American population) has been described under Qu. 4.1(c).

Although the effects on the services associated with these ecosystems are generally the same as these described under the next questions (for the risk assessment area), the effects in South America are more profound and negative. E.g. having evolved in the absence of beaver, the dominant tree species (*Nothofagus* spp.) have not developed strategies to cope with beaver herbivory, leading to a relatively stronger decrease in wild plant biomass (provisioning services). Similarly, beavers more fundamentally transform biochemical cycles (e.g. nitrogen flow) here than is the case for the Northern hemisphere (regulation and maintenance services).

The impact on services of *C. canadensis* in the Russian Federation is similar to that in the risk assessment area (hereafter).

**Qu. 4.7. 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 Qu. 4.6.

RESPONSE	minimal minor moderate major massive	CONFIDENCE	low medium high
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The processes by which beavers affect ecosystems are introduced under Qu. 4.1. The changes induced in these systems are profound and thus affect a range of associated services. Thompson et al. (2021) evaluated the ecosystem services provided by beavers (both *Castor* spp.) in the Northern Hemisphere. Their activity provides ecosystem services and disservices, often dependent on the scale considered (e.g. beaver-induced forest flooding might be a disservice at stakeholder level, but a service to the society at large). Services produced by beaver activity include moderation of extreme events, greenhouse gas sequestration, water purification (*regulating services*); water supply, recreational hunting and fishing (*provisioning services*); habitat and biodiversity provision, nutrient cycling (*supporting services*); non-consumptive recreation, historical value (*cultural services*).

Habitat and biodiversity provision (133 million USD), along with greenhouse gas sequestration (75 million USD), were evaluated as particularly valuable services in absolute terms, while non-consumptive recreation (167 USD ha<sup>-1</sup>) and habitat and biodiversity provision (133 USD ha<sup>-1</sup>) had the largest annual per-hectare values. The process of greenhouse gas sequestration through beaver activity is particularly challenging to evaluate. The increase in surface area of standing water led to increased emissions of methane (CH<sub>4</sub>), estimated to have increased 200-fold over the course of the 20th century (Whitfield et al., 2015). On the other hand, carbon is stored in pond sediments and influences peat formation (Thompson et al. 2021).

An alternative overview of *C. canadensis*' impact on ecosystem services was provided by Hollander et al. (2017), mainly based on professional judgement (Table 4).

Table 4: potential effects of *C. canadensis* on ecosystem services (taken from Hollander et al. 2017).

Categories and subclasses of ecosystem services	Effects
<i>Provisioning services</i>	
Food	Damage to agricultural fields by flooding due to beaver dams (negative)
Fibre	Damage to timber production (negative)
Genetic resources	None

Biochemicals, natural medicines and pharmaceuticals	None
Fresh water	Dam building contributes to water retention and flooding (negative)
<b>Regulating services</b>	
Air quality regulation	None
Climate regulation	None
Water regulation	Dams have impacts on water retention and affect discharge regimes (may be positive or negative)
Erosion regulation	Lower discharge of suspended solids and total organic carbon (may be valued as positive or negative)
Water purification and waste treatment	None
Disease regulation	None
Pest regulation	None
Pollination	None
Natural hazard regulation	Increase of water retention in headwaters (may be positive at a regional scale and negative or positive at a local scale)
<b>Cultural services</b>	
Cultural diversity	None
Spiritual and religious values	May be valued as positive or negative <sup>1</sup>
Knowledge systems	None
Educational values	None
Inspiration	May be valued as positive or negative <sup>1</sup>
Aesthetic values	May be valued as positive or negative <sup>1</sup>
Social relations	None
Sense of place	May be valued as positive or negative <sup>1</sup>
Cultural heritage values	None
Recreation and ecotourism	May attract tourists (positive)
<b>Supporting services</b>	
Soil formation	Increase in sedimentation upstream of beaver dams and decrease in sediment load downstream (positive or negative)
Photosynthesis	Not relevant
Primary production	Water retention and inundation due to dams will increase primary production in lacustrine parts of rivers upstream of beaver dams (positive or negative)
Nutrient cycling	Slight increase in nutrient retention in beaver ponds (positive)
Water cycling	Water retention and inundation as a result of dam building (positive and negative)
<sup>1</sup> Valuation of impacts strongly depends on the subjective perceptions of assessors	

In summary, the effect of *C. canadensis* on provisioning services is expected to be moderately negative for the production of food products (crops), fibre (timber) and fresh water supply, due to the contribution of beaver dams to water retention and flooding. *C. canadensis* may have positive and negative effects on different subclasses of regulating services: water regulation, erosion regulation, and natural hazard regulation, mainly due to the construction of dams. Effects of the species on supporting services are valued as neutral overall. Beaver dams result in a higher water retention and changes to nutrient and water cycling that may be valued positively or negatively depending on the reference condition and location (e.g., upstream and downstream of the dam, in a beaver pond or in the riparian area). The effect

of *C. canadensis* on cultural services may be valued positively or negatively, depending on the perception of the assessor. The overall effect score may therefore be considered neutral for this category.

In our answer we only consider negative impacts that are not already caused by the native *C. fiber* (as this species is an integral part of Europe's natural landscapes). In this regard, the impact of *C. canadensis* is thus considered minimal.

**Qu. 4.8. 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 Qu. 4.6.

<b>RESPONSE</b>	<b>minimal</b> minor moderate major massive	<b>CONFIDENCE</b>	low <b>medium</b> high
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If *C. canadensis* was to spread significantly across its potential range in the risk assessment area, the impact of this particular species on ecosystem services would become widespread (although we do not consider it likely that the effects would significantly change under changed climate conditions, however).

In our answer we only consider negative impacts that are not already caused by the native *C. fiber* (as this species is an integral part of Europe's natural landscapes). In this regard, the impact of *C. canadensis* thus remains minimal.

## Economic impacts

**Qu. 4.9. 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. As far as possible, it would be useful to separate costs of / loss due to the organism from costs of current management.

<b>RESPONSE</b>	minimal minor	<b>CONFIDENCE</b>	<b>low</b> medium
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	moderate <b>major</b> massive		high
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The processes by which beavers affect ecosystems are introduced under Qu. 4.1. Although generally considered positive from an ecological perspective, to the society at large, the same processes may be considered negative if they conflict with other activities, generally at stakeholder level (Thompson et al. 2021).

Economic impact on a land and water may arise from the alteration of water levels (e.g. leading to productivity loss), burrowing (e.g. leading to infrastructure damage) and foraging activity (e.g. leading to loss of crops or trees) (Campbell-Palmer et al. 2015). Quantitative information is however scarce.

#### Economic loss and costs: native range (North America)

Damage can generally be categorized into dyke and impoundment damage, tree damage, and flooding. According to Loven (1985), these damages totaled \$9,326,541 for the fiscal years 1983 to 1985 in Texas (USA).

Soybean and corn have found to be attractive food items. But Dieter & McCabe (1988) found damaged areas of corn in South Dakotan fields to be minor, averaging less than 0,1 acres in area, and less than \$10 loss per field (at prices at the time).

#### Economic loss and costs: introduced range (South America)

Quantitative information on economic loss and costs relating to *C. canadensis* in its introduced range is scarce. The contingent valuation technique has been applied to estimate the economic value of native forest affected by *C. canadensis* in Tierra del Fuego. In total the opinions of 396 economically active persons in Punta Arenas and Porvenir were recorded. This resulted in a total valuation of 4,864,508 Chilean pesos, or 6,522 euros, (2011 exchange rate) per year (Simeone & Soza-Amigo 2014).

Given that local costs of damage in North and South America are limited, but considering the wide distribution of the species, we assume that the total cost would nonetheless be major.

#### **Qu. 4.10. 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 EU 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”. In this case, no score and confidence should be given and the standardized “score” is N/A (not applicable). 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.

<b>RESPONSE</b>	<b>minimal</b> minor moderate major massive	<b>CONFIDENCE</b>	<b>low</b> medium high
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Härkönen (1999) estimated the damage to trees by *C. canadensis* in Finland. He found the size of damaged areas to average 2.2 ha in 1998. The total damage area annually is about 900 – 1,000 ha. Flood damage resulting from damming was the most important negative impact type (50%).

In our answer we only consider negative impacts that are not already (or would not be) caused by the native *C. fiber* (as this species is an integer part of Europe's natural landscapes). In this regard, the impact of *C. canadensis* is considered minimal.

**Qu. 4.11. 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 Qu. 4.10.

<b>RESPONSE</b>	<b>minimal</b> minor moderate major massive	<b>CONFIDENCE</b>	<b>low</b> medium high
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If *C. canadensis* was to spread significantly across its potential range in the risk assessment area, the total cost linked to this particular species would considerably increase. Where *C. canadensis* would replace *C. fiber*, no changes would be expected whatsoever, given that the species are near to identical in their effects (Stringer & Gaywood 2016).

**Qu. 4.12. 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”. In this case, no score and confidence should be given and the standardized “score” is N/A (not applicable).

<b>RESPONSE</b>	minimal	<b>CONFIDENCE</b>	low
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	<b>minor</b> moderate major massive		<b>medium</b> high
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Details on management of *C. canadensis* for Finland and Germany have been given under Qu. 2.5.

The Finnish Wildlife Agency (Riistakeskus) is responsible for beaver management in Finland, with the Natural Resources Institute Finland (LUKE) undertaking the monitoring of beavers in the country. Hunting volunteers assist this process by counting the number of active beaver lodges in their area, from which whole country populations are estimated every three years. Hunting of *C. canadensis* is quite straightforward under a general hunting license and with land owner permission. There are no specific beaver trappers or hunters, with any culls undertaken by normal hunters. For *C. fiber* a special permit is required, and this is only given for real problem animals. No figures are available for management costs, though these are expected to be low (Campbell-Palmer et al. 2015).

No further information has been found on the costs associated with managing *C. canadensis* in Germany, nor on the current monitoring of beaver in France, Luxembourg or Belgium (collection of samples and genetic analysis, as to exclude *C. canadensis*).

**Qu. 4.13. 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 Qu. 4.12.

<b>RESPONSE</b>	minimal minor moderate <b>major</b> massive	<b>CONFIDENCE</b>	<b>low</b> medium high
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If *C. canadensis* was to spread significantly across its potential range in the risk assessment area, the cost associated with managing this organism would strongly increase (assuming that management is opted for, or becomes mandatory). Campbell-Palmer et al. (2015) provide an overview of techniques to manage *C. fiber* impacts, also including details on how this is organized in five regions in Europe. Generally, techniques are well-developed, ranging from non-lethal methods (such as tree guards, dam mitigation and bank protection) to lethal control. Also, repellents can be used to keep beavers away from particular areas (Hollander et al. 2017).

Efforts that should be taken in case of further *C. canadensis* spread include (1) surveying watercourses in regions where *C. canadensis* may be present (visual observations; eDNA, e.g. Iso-Touru et al. 2021)); (2) confirming species identification (see with A2); and (3) removing *C. canadensis* wherever possible (Dewas et al. 2012). In fact, Parker et al. (2012) have already outlined a strategy for the eradication of *C. canadensis* in Eurasia, which is in accordance with the IUCN Invasive Species Specialist Group's

recommendations for eradications (Veitch et al. 2011). Methods other than hunting, trapping, reintroduction and population monitoring are likely to be unnecessary. The strategy includes steps such as (1) the immediate removal of small populations; (2) conducting research on competitive exclusion; and (3) establishing an eradication strategy. A particular complication lies in areas where *C. canadensis* and *C. fiber* might form mixed populations, as challenges in terms of species distinction and stakeholder communication arise in such situations. For that reason, a ‘beaver free zone’ might be considered between the populations of both species (Parker et al. 2012).

Estimations of the total cost of such management efforts for the risk assessment area are not available. In comparison, the large scale eradication of all beavers (around 100,000) from southern Chile and Argentina was estimated to have cost US \$33 million, which includes wages and facilities for hunters, traps, the blowing up of dams, helicopter support, transportation, several support staff and governance costs over a period of five years (Parkes et al. 2008).

## Social and human health impacts

**Qu. 4.14. 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	minimal	CONFIDENCE	low
	minor		medium
	moderate		high
	major		
	massive		

Parasites and pathogens carried by *C. canadensis* have been introduced under Qu. 2.4. . The following pathogens are also of human health concern.

Waterborne tularemia (rabbit fever) is a zoonotic disease caused by the bacterium *Francisella tularensis holarctica* (type B), which commonly occurs in semiaquatic mammals such as beaver and muskrat (*O. zibethicus*), and occasionally becomes epizootic. Type B tularemia is responsible for 5-10% of human tularemia infections in North America but is not fatal to humans. Tularemia infections in beaver are typically subclinical without noticeable effects on the individual or the population, but they can be fatal



to beaver and cause mass mortality from local or regional epizootics (Baker & Hill 2003). *F. tularensis* has only been reported sporadically in Eurasian beavers (Girling et al. 2019). In boreal Fennoscandia, human tularemia is typically mosquito-borne, as larvae get the bacteria from water which is contaminated by rodents carrying the pathogens.

Beavers have long been recognized as reservoirs of the protist parasite *Giardia duodenalis* (beaver fever; Heyworth 2016, Tsui et al. 2018). In eastern Texas, 30 out of 100 examined beavers tested positive for *Giardia*. No relationship was found between *Giardia* in beaver and host age, sex, river system, habitat, county, or season. However, a relationship was found when season and habitat were considered together. This relationship seemed to be based on annual precipitation and ambient temperatures. The highest number of infected beavers was collected from marshes during spring and summer, from ponds during fall and winter, and from creeks during summer and fall. *Giardia* is infectious to humans and pets (Dunlap & Thies 2002). In humans, an intestinal infection causes intestinal cramps, a bloated stomach, nausea and attacks of aqueous diarrhoea. Heyworth (2016) reports on two outbreaks of giardiasis in humans where beavers were thought to be involved, but where current knowledge now casts doubt on the actual direction of transmission, thereby cautioning to oversimplify disease dynamics. *Giardia* is known to be present in Eurasian beavers (Girling et al. 2019).

Rabies has also been documented in beaver, but little is known about its pathogenesis or epizootiology (Baker & Hill 2003). It is not reported in Eurasian beavers (Girling et al. 2019).

In 2007, a dead beaver (*C. canadensis*) infected with the bacterium *Yersinia pseudotuberculosis* was found near a fresh water pond in Washington (USA). Based on the pathology and acute mortality described in this case, as well as historical reports of *Y. pseudotuberculosis* related mortality in other beavers, this species could serve as a public health sentinel for localized occurrences of this bacterium (Gaydos et al. 2009). Humans could, for instance, be exposed to *Y. pseudotuberculosis* through ingestion of contaminated drinking water (Fukushima et al. 1988), or exposure to infected animals or contaminated soils (Gasper & Watson 2001). Infection by this bacterium causes the Far East scarlet-like fever (FESLF) which is a severe inflammatory disease (Amphlett 2016).

Apart from *F. tularensis*, *Giardia* spp., terrestrial rabies and *Yersinia* spp. (above), Girling et al. (2019) identified the following high-risk pathogens associated with *Castor*: the parasites *Cryptosporidium parvum*, *Echinococcus multilocularis*, *Eimeria* spp., *Fasciola hepatica*, *Trichinella britovi*; the bacteria *Escherichia coli*, *Mycobacterium avium*, *Salmonella* spp.; the fungus *Chrysosporium parvum* (*Emmonsia parva*).

In our answer we only consider negative impacts that are not already (or would not be) caused by the native *C. fiber* (as this species is an integral part of Europe's natural landscapes). In this regard, the impact of *C. canadensis* is considered minimal.

**Qu. 4.15. 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”. In this case, no score and confidence should be given and the standardized “score” is N/A (not applicable).

<b>RESPONSE</b>	<b>minimal</b> minor moderate major massive	<b>CONFIDENCE</b>	low <b>medium</b> high
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If *C. canadensis* was to spread significantly across its potential range in the risk assessment area, its risk as a vector or reservoir species would increase. However, whether that would be the case in occasions where *C. canadensis* replaces *C. fiber* is unclear, since the concerned pathogens are probably shared among the species.

## Other impacts

**Qu. 4.16. How important is the organism in facilitating other damaging organisms (e.g. diseases) as food source, a host, a symbiont or a vector etc.?**

<b>RESPONSE</b>	<b>minimal</b> minor moderate major massive	<b>CONFIDENCE</b>	low <b>medium</b> high
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Some of the pathogens and parasites discussed under Qu. 2.4 and 4.14 can also affect domesticated animals. E.g., Heyworth (2016) lists a wide range of species that have been confirmed to host *Giardia*. This list includes pets (dog, cat, rabbit, guinea pig), livestock (cattle, sheep, goat, chicken, pig) and other domesticated animals (horse, alpaca, ferret, chinchilla, kangaroo). However, we found no cases in which infection was clearly a case of beaver-to-other transmission.

**Qu. 4.17. How important might other impacts not already covered by previous questions be resulting from introduction of the organism?**

<b>RESPONSE</b>	<b>minimal</b> minor moderate major massive	<b>CONFIDENCE</b>	low medium high
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No information has been found on the issue.

**Qu. 4.18. 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?**

<b>RESPONSE</b>	minimal minor moderate <b>major</b> massive	<b>CONFIDENCE</b>	low <b>medium</b> high
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The role of predators, parasites and pathogens in the establishment of *C. canadensis* in the risk assessment area has been discussed under Qu. 2.4. Just as we consider it very unlikely that these would prevent establishment (and spread), we also see no reason why these species would significantly change the impact of *C. canadensis*.

**Qu. 4.19. 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.

<b>RESPONSE</b>	minimal minor moderate <b>major</b> massive	<b>CONFIDENCE</b>	low <b>medium</b> high
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Since the environmental effects of *C. canadensis* to the risk assessment area are virtually the same as those of the native *C. fiber*, which are generally considered positive to the society at large (but potentially negative to local stakeholders), we consider such effects inapplicable in the overall impact assessment.

The only negative impact of concern, in this respect, is the effect of *C. canadensis* on *C. fiber* itself. Indeed, a range expansion of *C. canadensis* would expectedly come at the expense of a loss in *C. fiber*'s range. This would tragically set back one of the most spectacular recoveries of a formerly threatened vertebrate in Europe. We assume that this could contribute to *C. fiber* becoming endangered again (locally, regionally, nationally or EU-wide).

In accordance with Qu. 4.2, this translates into a 'major' impact. Given limited information available, this response comes with a medium confidence.

**Qu. 4.20. 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.

- See also guidance to Qu. 4.3.

RESPONSE	minimal minor moderate <b>major</b> massive	CONFIDENCE	low <b>medium</b> high
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Apart from the (at most subtle) changes in introduction (Qu. 1.10), establishment (Qu. 2.10) and spread (Qu. 3.12), the impact of *C. canadensis* is not expected to change under climatically changed conditions. The only relevant impact would still be competition with *C. fiber*, although some additional uncertainty may arise from mismatches between the two species' ranges.

<b>RISK SUMMARIES</b>			
	<b>RESPONSE</b>	<b>CONFIDENCE</b>	<b>COMMENT</b>
<b>Summarise Introduction and Entry*</b>	very unlikely unlikely moderately likely likely <b>very likely</b>	low <b>medium</b> high	The cross-border population of <i>C. canadensis</i> in Finland and the Russian Federation ensures that the species enters the risk assessment area on a regular base. In the long term, there is a real risk for this population to enter Estonia or Latvia. Some unknowns about the Russian population, and competition with <i>C. fiber</i> , reduce confidence. A second, lower but widespread, risk exists for <i>C. canadensis</i> to enter the environment from captivity. Reported holdings are few, and include few individuals, but are geographically dispersed. The true number of specimens in the risk assessment area remains unknown. Although beavers in such holdings are generally well-contained, the risk of escape can never be completely excluded, as exemplified by a few reported cases.
<b>Summarise Establishment*</b>	very unlikely unlikely moderately likely likely <b>very likely</b>	low medium <b>high</b>	<i>C. canadensis</i> is currently established in parts of the risk assessment area (Finland, Germany). (In other parts, previously established populations have been eradicated.) Suitable habitat is widespread, and the climate is very favorable (as confirmed by the distribution model). There are no biotic interactions that would fundamentally prevent establishment.
<b>Summarise Spread*</b>	very slowly slowly <b>moderately</b> rapidly very rapidly	low <b>medium</b> high	<i>C. canadensis</i> has a considerable capacity to disperse naturally throughout the risk assessment area, along large rivers, canals and interconnected lakes. The maximum movement distance ever reported for a trapped and relocated individual was over 200 km (in the native range). The confidence is lowered because of possible competition with <i>C. fiber</i> .

<b>Summarise Impact*</b>	minimal minor moderate <b>major</b> massive	low <b>medium</b> high	The impact of beavers is generally considered positive to society at large, but may be perceived as negative at a stakeholder level. <i>C. canadensis</i> has no added negative impact to the native <i>C. fiber</i> , which is an integral part of Europe's natural landscapes. The only negative impact of concern is the effect on <i>C. fiber</i> itself. Indeed, a range expansion would expectedly come at the expense of <i>C. fiber</i> 's range, setting back one of the most spectacular recoveries of a threatened vertebrate in Europe.
<b>Conclusion of the risk assessment (overall risk)</b>	low moderate <b>high</b>	low <b>medium</b> high	Beavers are both ecosystem engineers and keystone species. Although the North American beaver can fill virtually the same niche as the Eurasian beaver, the interaction among both species is of major concern to the risk assessment area. Indeed, no socio-economic benefits of the presence of the North American beaver have been identified, while there is an ongoing interest to consolidate conservation efforts for the Eurasian beaver.

\*in current climate conditions and in foreseeable future climate conditions

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## 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	No	Yes	Yes	No
Belgium	Yes	No	Yes	Yes	No
Bulgaria	No	No	Yes	Yes	No
Croatia	No	No	Yes	Yes	No
Cyprus	No	No	No	No	No
Czech Republic	No	No	Yes	Yes	No
Denmark	No	No	Yes	Yes	No
Estonia	No	No	Yes	Yes	No
Finland	Yes	Yes	Yes	Yes	Yes
France	Yes	No	Yes	Yes	No
Germany	Yes	Yes	Yes	Yes	Yes
Greece	No	No	Yes	Yes	No
Hungary	Yes	No	Yes	Yes	No
Ireland	No	No	Yes	Yes	No
Italy	No	No	Yes	Yes	No
Latvia	No	No	Yes	Yes	No
Lithuania	No	No	Yes	Yes	No
Luxembourg	Yes	No	Yes	Yes	No
Malta	No	No	No	No	No
Netherlands	No	No	Yes	Yes	No
Poland	Yes	No	Yes	Yes	No
Portugal	No	No	Yes	Yes	No
Romania	No	No	Yes	Yes	No
Slovakia	No	No	Yes	Yes	No
Slovenia	No	No	Yes	Yes	No
Spain	No	No	Yes	Yes	No
Sweden	No	No	Yes	Yes	No

## Biogeographical regions of the risk assessment area

	Recorded	Established (currently)	Possible establishment (under current climate)	Possible establishment (under foreseeable climate)	Invasive (currently)
Alpine	No	No	Yes	Yes	No
Atlantic	Yes	No	Yes	Yes	No
Black Sea	No	No	Yes	Yes	No
Boreal	Yes	Yes	Yes	Yes	Yes
Continental	Yes	Yes	Yes	Yes	Yes
Mediterranean	No	No	Yes	Yes	No
Pannonian	Yes	No	Yes	Yes	No
Steppic	No	No	Yes	Yes	No

## **ANNEX I Scoring of Likelihoods of Events**

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

<b>Score</b>	<b>Description</b>	<b>Frequency</b>
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 occurred somewhere at least once in the last millenium	1 in 1,000 years
Moderately likely	This sort of event has occurred somewhere at least once in the last century	1 in 100 years
Likely	This sort of event has happened on several occasions elsewhere, or on at least once in the last decade	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
	<i>Question 4.1-5</i>	<i>Question 4.6-8</i>	<i>Question 4.9-13</i>	<i>Question 4.14-18</i>
Minimal	Local, short-term population decline, no significant ecosystem impact	No services affected <sup>5</sup>	Up to 10,000 Euro	No social disruption. Local, mild, short-term reversible effects to individuals.
Minor	Local, short-term population loss, Localized reversible ecosystem impact	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	Local to regional long-term population decline/loss, Measureable reversible long-term damage to ecosystem, 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, population loss or extinction of single species	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	Long-term irreversible ecosystem change, widespread, population loss or extinction of several species	Widespread and irreversible effects on one / several services	Above 10,000,000 Euro	Long-term social change, significant loss of employment, migration from affected area. Widespread, severe, long-term, irreversible health effects.

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<sup>5</sup> 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 <i>and/or</i> Impacts are recorded at a spatial scale which is unlikely to be relevant to the assessment area <i>and/or</i> Evidence is poor and difficult to interpret, e.g. because it is strongly ambiguous <i>and/or</i> 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 <i>and/or</i> 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 <i>and/or</i> 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) <i>and</i> Impacts are recorded at a comparable scale <i>and/or</i> There are reliable/good quality data sources on impacts of the taxa <i>and</i> The interpretation of data/information is straightforward <i>and/or</i> Data/information are not controversial or contradictory.

## ANNEX IV CBD pathway categorisation scheme

Overview of CBD pathway categorisation scheme showing how the 44 pathways relate to the six main pathway categories. All of the pathways can be broadly classified into 1) those that involve intentional transport (blue), 2) those in which the taxa are unintentionally transported (green) and 3) those where taxa moved between regions without direct transportation by humans and/or via artificial corridors (orange and yellow). **Note that the pathways in the category “Escape from confinement” can be considered intentional for the introduction into the risk assessment area and unintentional for the entry into the environment.**



## ANNEX V 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	<b>Cultivated <i>terrestrial</i> plants</b>	<p>Cultivated terrestrial plants (including fungi, algae) grown for <u>nutritional purposes</u>;  <u>Fibres and other materials</u> from cultivated plants, fungi, algae and bacteria for direct use or processing (excluding genetic materials);  Cultivated plants (including fungi, algae) grown as a <u>source of energy</u></p> <p><i>Example: negative impacts of non-native organisms to crops, orchards, timber etc.</i></p>
		<b>Cultivated <i>aquatic</i> plants</b>	<p>Plants cultivated by in- situ aquaculture grown for <u>nutritional purposes</u>;  <u>Fibres and other materials</u> from in-situ aquaculture for direct use or processing (excluding genetic materials);  Plants cultivated by in- situ aquaculture grown as an <u>energy source</u>.</p> <p><i>Example: negative impacts of non-native organisms to aquatic plants cultivated for nutrition, gardening etc. purposes.</i></p>
		<b>Reared animals</b>	<p>Animals reared for <u>nutritional purposes</u>;  <u>Fibres and other materials</u> from reared animals for direct use or processing (excluding genetic materials);  Animals reared to provide <u>energy</u> (including mechanical)</p> <p><i>Example: negative impacts of non-native organisms to livestock</i></p>
		<b>Reared <i>aquatic</i> animals</b>	<p>Animals reared by in-situ aquaculture for <u>nutritional purposes</u>;  <u>Fibres and other materials</u> from animals grown by in-situ aquaculture for direct use or processing (excluding genetic materials);  Animals reared by in-situ aquaculture as an <u>energy source</u></p> <p><i>Example: negative impacts of non-native organisms to fish farming</i></p>
		<b>Wild plants</b> (terrestrial and aquatic)	<p>Wild plants (terrestrial and aquatic, including fungi, algae) used for <u>nutrition</u>;  <u>Fibres and other materials</u> from wild plants for direct use or processing (excluding genetic materials);  Wild plants (terrestrial and aquatic, including fungi, algae) used as a <u>source of energy</u></p> <p><i>Example: reduction in the availability of wild plants (e.g. wild berries, ornamentals) due to non-native organisms (competition, spread of disease etc.)</i></p>
		<b>Wild animals</b> (terrestrial and aquatic)	<p>Wild animals (terrestrial and aquatic) used for <u>nutritional purposes</u>;  <u>Fibres and other materials</u> from wild animals for direct use or processing (excluding genetic materials);  Wild animals (terrestrial and aquatic) used as a <u>source of energy</u></p>

			<i>Example: reduction in the availability of wild animals (e.g. fish stocks, game) due to non-native organisms (competition, predations, spread of disease etc.)</i>
	<b>Genetic material</b> from all biota	<b>Genetic material</b> from plants, algae or fungi	<u>Seeds, spores and other plant materials</u> collected for maintaining or establishing a population; Higher and lower plants (whole organisms) used to <u>breed new strains or varieties</u> ; Individual genes extracted from higher and lower plants for the <u>design and construction of new biological entities</u>  <i>Example: negative impacts of non-native organisms due to interbreeding</i>
		<b>Genetic material</b> 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  <i>Example: negative impacts of non-native organisms due to interbreeding</i>
	<b>Water<sup>6</sup></b>	<b>Surface water</b> used for nutrition, materials or energy	Surface water for <u>drinking</u> ; Surface water used as a material ( <u>non-drinking purposes</u> ); Freshwater surface water, coastal and marine water used as an <u>energy source</u>  <i>Example: loss of access to surface water due to spread of non-native organisms</i>
		<b>Ground water</b> for used for nutrition, materials or energy	Ground (and subsurface) water for <u>drinking</u> ; Ground water (and subsurface) used as a material ( <u>non-drinking purposes</u> ); Ground water (and subsurface) used as an <u>energy source</u>  <i>Example: reduced availability of ground water due to spread of non-native organisms and associated increase of ground water consumption by vegetation.</i>
<b>Regulation &amp; Maintenance</b>	<b>Transformation</b> of biochemical or physical inputs to ecosystems	<b>Mediation of wastes or toxic substances</b> of anthropogenic origin by living processes	<u>Bio-remediation</u> by micro-organisms, algae, plants, and animals; <u>Filtration/sequestration/storage/accumulation</u> by micro-organisms, algae, plants, and animals  <i>Example: changes caused by non-native organisms to ecosystem functioning and ability to filtrate etc. waste or toxics</i>
		<b>Mediation of nuisances</b> of anthropogenic origin	<u>Smell reduction; noise attenuation; visual screening</u> (e.g. by means of green infrastructure)  <i>Example: changes caused by non-native organisms to ecosystem structure, leading to reduced ability to mediate nuisances.</i>
	<b>Regulation</b> of physical, chemical, biological conditions	<b>Baseline flows and extreme event</b> regulation	Control of <u>erosion</u> rates; Buffering and attenuation of <u>mass movement</u> ; <u>Hydrological cycle and water flow regulation</u> (Including flood control, and coastal protection); <u>Wind</u> protection; <u>Fire</u> protection

<sup>6</sup> 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.



			<p><i>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.</i></p>
		<b>Lifecycle maintenance</b> , habitat and gene pool protection	<p>Pollination (or 'gamete' dispersal in a marine context); <u>Seed dispersal</u>; Maintaining <u>nursery populations and habitats</u> (Including gene pool protection)</p> <p><i>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</i></p>
		<b>Pest and disease control</b>	<p>Pest control; Disease control</p> <p><i>Example: changes caused by non-native organisms to the abundance and/or distribution of pests</i></p>
		<b>Soil quality regulation</b>	<p><u>Weathering processes</u> and their effect on soil quality; <u>Decomposition and fixing processes</u> and their effect on soil quality</p> <p><i>Example: changes caused by non-native organisms to vegetation structure and/or soil fauna leading to reduced soil quality</i></p>
		<b>Water conditions</b>	<p>Regulation of the <u>chemical condition</u> of freshwaters by living processes; Regulation of the chemical condition of salt waters by living processes</p> <p><i>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</i></p>
		<b>Atmospheric composition and conditions</b>	<p>Regulation of <u>chemical composition</u> of atmosphere and oceans; Regulation of <u>temperature and humidity</u>, including ventilation and transpiration</p> <p><i>Example: changes caused by non-native organisms to ecosystems' ability to sequester carbon and/or evaporative cooling (e.g. by urban trees)</i></p>
<b>Cultural</b>	<b>Direct, in-situ and outdoor interactions</b> with living systems that depend on presence in the environmental setting	<b>Physical and experiential</b> interactions with natural environment	<p>Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through <u>active or immersive interactions</u>;</p> <p>Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through <u>passive or observational interactions</u></p> <p><i>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.</i></p>
		<b>Intellectual and representative</b> interactions with natural environment	<p>Characteristics of living systems that enable <u>scientific investigation</u> or the creation of traditional ecological knowledge;</p> <p>Characteristics of living systems that enable <u>education and training</u>;</p> <p>Characteristics of living systems that are resonant in terms of <u>culture or heritage</u>;</p> <p>Characteristics of living systems that enable <u>aesthetic experiences</u></p>

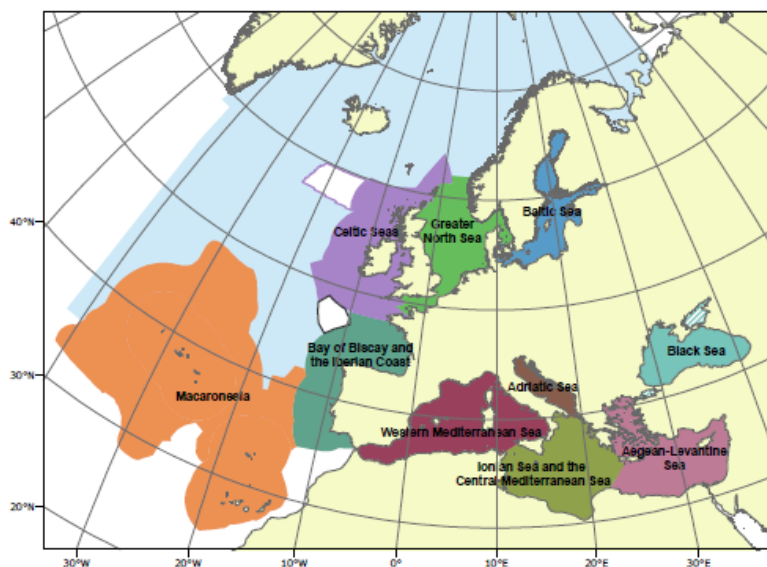
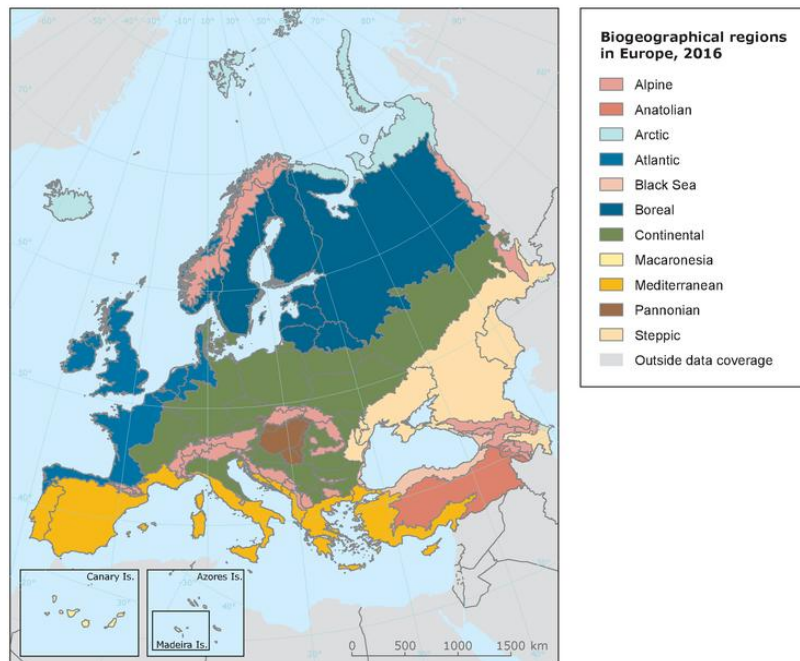
			<i>Example: changes caused by non-native organisms to the qualities of ecosystems (structure, species composition etc.) that have cultural importance</i>
	<b>Indirect, remote, often indoor interactions</b> with living systems that do not require presence in the environmental setting	<b>Spiritual, symbolic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

## ANNEX VI 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/](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 VII Delegated Regulation (EU) 2018/968 of 30 April 2018**

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

## **ANNEX VIII Projection of environmental suitability for *Castor canadensis* establishment in Europe**

Steph Rorke, Megan Williams, Bram D'hondt, Tim Adriaens, Wolfgang Rabitsch and Dan Chapman

14 December 2023

### ***Aim***

To project the suitability for potential establishment of *Castor canadensis* in Europe, under current and predicted future climatic conditions.

### ***Data for modelling***

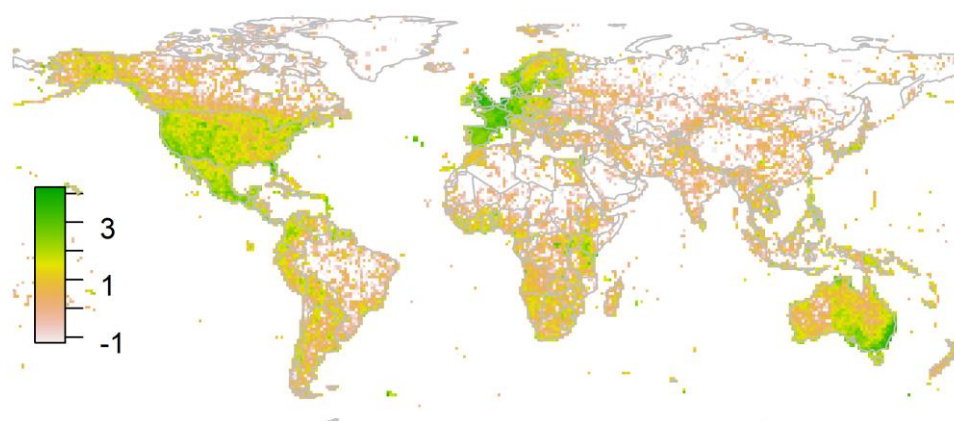
Species occurrence data were obtained from GBIF (62466 records), and additional records from the risk assessment team. We scrutinised occurrence records from regions where the species is not known to be established and removed any dubious records or where the georeferencing was too imprecise (e.g. records referenced to a country or island centroid) or outside of the coverage of the predictor layers (e.g. small island or coastal occurrences). The remaining records were gridded at a 0.25 x 0.25 degree resolution for modelling, yielding 4817 grid cells with occurrences (Figure 1a). As a proxy for recording effort, the density of Mammalia records held by GBIF was also compiled on the same grid (Figure 1b).

**Figure 1.** (a) Occurrence records obtained for *Castor canadensis* and used in the modelling, showing native and invaded distributions. (b) The recording density of Mammalia on GBIF, which was used as a proxy for recording effort.

(a) Species distribution used in modelling



(b) Estimated recording effort (log10-scaled)



Climate data were selected from the 'Bioclim' variables contained within the WorldClim 2.1 database (Fick & Hijmans 2017), originally at 5 arcminute resolution (0.083 x 0.083 degrees of longitude/latitude) and aggregated to a 0.25 x 0.25 degree grid for use in the model.

Based on the biology of *Castor canadensis*, the following climate variables were used in the modelling:

- Mean temperature of the coldest quarter (Bio11)
- Precipitation of the driest quarter (Bio17)

To estimate the effect of climate change on potential species distributions, modelled future climate conditions under Shared Socioeconomic Pathways (SSP) 1-2.6, 2-4.5 and 5-8.5 were obtained from the WorldClim 2.1 database for 2070. These represent a low, medium, and very high emission scenarios respectively. Future bioclimatic variables were obtained as averages of outputs of 25 global climate models, downscaled and calibrated against the WorldClim baseline (see <https://worldclim.org/data/cmip6/cmip6climate.html>).

## ***Species distribution model***

A presence-background (presence-only) ensemble modelling strategy was employed using the BIOMOD2 R package version 4.2-2 (R Core Team 2023, Thuiller et al. 2023). These models contrast the environment at the species' occurrence locations against a random sample of the global background environmental conditions (often termed 'pseudo-absences') in order to characterise and project suitability for occurrence. This approach has been developed for distributions that are in equilibrium with the environment. Because invasive species' distributions are not at equilibrium and subject to dispersal constraints at a global scale, we took care to minimise the inclusion of locations suitable for the species but where it has not been able to disperse to (Chapman et al. 2019). Therefore the background sampling region included:

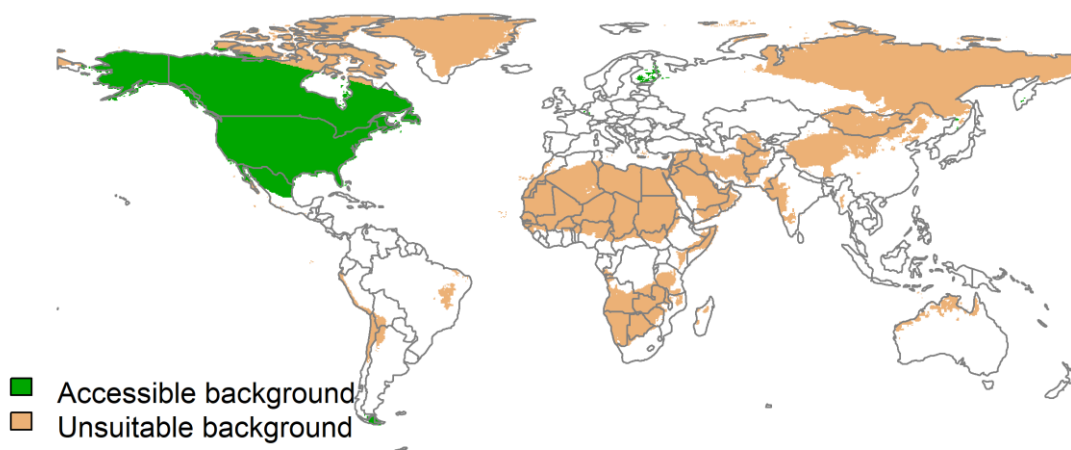
- Firstly, regions where we have an *a priori* expectation of high unsuitability for the species so that absence is assumed irrespective of dispersal constraints (see Figure 2). The following rules were applied to define a region expected to be highly unsuitable for *Castor canadensis* at the spatial scale of the model:
  - Mean temperature of the coldest quarter (Bio11) < -21.14
  - Precipitation of the driest quarter (Bio17) <  $\log_{10}(7.8 + 1)$

Altogether, 2% of occurrence grid cells were located in the unsuitable background region.

- Secondly, the background sampling region included the area “accessible” by native *Castor canadensis* populations, in which the species is likely to have had sufficient time to disperse to all locations, but has failed to establish. Based on presumed maximum dispersal distances, the accessible region was defined as a 400km buffer around the native range occurrences.
- Thirdly, the background included a 30km buffer around the non-native occurrences, encompassing “accessible” regions likely to have had high propagule pressure for introduction by humans and/or dispersal of the species, but where it has failed to establish.

Within the unsuitable background region, 10 samples of 48170 randomly sampled grid cells were obtained (i.e. ten times the number of occurrence grid cells). In the accessible background (comprising the accessible areas around native and non-native occurrences as detailed above), the same number of pseudo-absence samples were drawn as there were presence records (4817), weighting the sampling by a proxy for recording effort (Figure 1(b)) - reflecting higher confidence in records showing a true picture of presence and absence of the species in regions with higher recording effort.

**Figure 2.** The background from which pseudo-absence samples were taken in the modelling of *Castor canadensis*. Samples were taken from areas expected to be highly unsuitable for the species (the unsuitable background region), and additionally from a 400km buffer around the native range and a 30km buffer around non-native occurrences (together forming the accessible background). Samples from the accessible background were weighted by a proxy for recording effort (Figure 1(b)).



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

- Generalised linear model (GLM)
- Generalised boosting model (GBM)
- Generalised additive model (GAM) with a maximum of four degrees of freedom per smoothing spline
- Artificial neural network (ANN)
- Multivariate adaptive regression splines (MARS)
- Random forest (RF)
- Maxent

Since the total background sample was larger than the number of occurrences, prevalence fitting weights were applied to give equal overall importance to the occurrences and the background. Normalised variable importance was assessed and variable response functions were produced using BIOMOD2's default procedure.

Model predictive performance was assessed by the following three measures:

- AUC, the area under the receiver operating characteristic curve (Fielding & Bell 1997). Predictions of presence-absence models can be compared with a subset of records set aside for model evaluation (here 20%) by constructing a confusion matrix with the number of true positive, false positive, false negative and true negative cases. For models generating non-dichotomous scores (as here) a threshold can be applied to transform the scores into a dichotomous set of presence-absence predictions. Two measures that can be derived from the confusion matrix are sensitivity (the proportion of observed presences that are predicted as such, quantifying omission errors), and specificity (the proportion of observed absences that



are predicted as such, quantifying commission errors). A receiver operating characteristic (ROC) curve can be constructed by using all possible thresholds to classify the scores into confusion matrices, obtaining sensitivity and specificity for each matrix, and plotting sensitivity against the corresponding proportion of false positives (equal to  $1 - \text{specificity}$ ). The use of all possible thresholds avoids the need for a selection of a single threshold, which is often arbitrary, and allows appreciation of the trade-off between sensitivity and specificity. The area under the ROC curve (AUC) is often used as a single threshold-independent measure for model performance (Manel et al. 2001). AUC is the probability that a randomly selected presence has a higher model-predicted suitability than a randomly selected absence (Allouche et al. 2006).

- Cohen's Kappa (Cohen 1960). This measure corrects the overall accuracy of model predictions (ratio of the sum of true presences plus true absences to the total number of records) by the accuracy expected to occur by chance. The Kappa statistic ranges from -1 to +1, where +1 indicates perfect agreement and values of zero or less indicate a performance no better than random. Advantages of Kappa are its simplicity, the fact that both commission and omission errors are accounted for in one parameter, and its relative tolerance to zero values in the confusion matrix (Manel et al. 2001). However, Kappa has been criticised for being sensitive to prevalence (the proportion of sites in which the species was recorded as present) and may therefore be inappropriate for comparisons of model accuracy between species or regions (McPherson et al. 2004, Allouche et al. 2006).
- TSS, the true skill statistic (Allouche et al. 2006). TSS is defined as  $\text{sensitivity} + \text{specificity} - 1$ , and corrects for Kappa's dependency on prevalence. TSS compares the number of correct forecasts, minus those attributable to random guessing, to that of a hypothetical set of perfect forecasts. Like Kappa, TSS takes into account both omission and commission errors, and success as a result of random guessing, and ranges from -1 to +1, where +1 indicates perfect agreement and values of zero or less indicate a performance no better than random (Allouche et al. 2006).

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

Projections were classified into suitable and unsuitable regions using a "lowest presence threshold" (Pearson et al. 2007), setting the cut-off as the lowest value at which 98% of all presence records are classified correctly under the current climate (here 0.18). In order to express the sensitivity of classifications to the choice of this threshold, thresholds at which 95% and 99% of records are classified correctly (here 0.66 and 0.04 respectively) were used in the calculation of error bars in Figures 9 and 10 below in addition to taking account of uncertainty in the projections themselves (cf. part (b) of Figs. 5, 7, 8 and 9). In other words, the upper error bars in Figs. 10 and 11 show proportions classified as suitable with a threshold of 0.04 (at which 99% of presence records are classified correctly), and are based on projected suitabilities plus the standard error in projections, while the lower error bars show proportions classified as suitable with a threshold of 0.66 (at which 95% of presence records are classified correctly), and are based on projected suitabilities minus the standard error in projections.

We also produced a limiting factor map for Europe following Elith et al. (2010). For this, projections were made separately with each individual variable fixed at a near-optimal value. These were chosen as the median values at the occurrence grid cells. Then, the most strongly limiting factors were identified as the ones resulting in the highest increase in suitability in each grid cell.

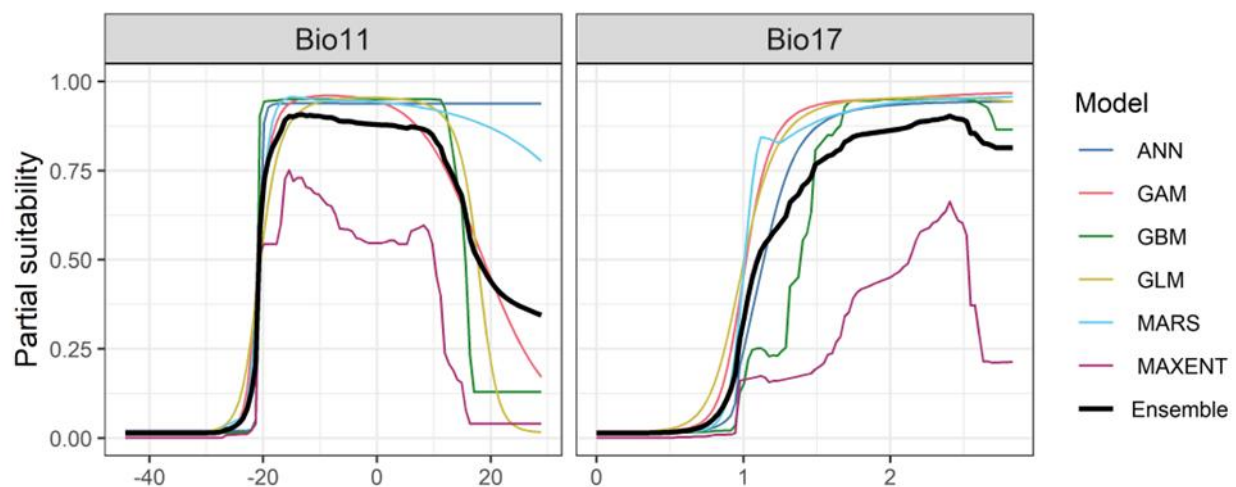
## Results

The ensemble model suggested that suitability for *Castor canadensis* was most strongly determined by Mean temperature of the coldest quarter (Bio11), accounting for 53% of variation explained, followed by Precipitation of the driest quarter (Bio17) (47%), Mean temperature of the coldest quarter (Bio11) (53%) and Precipitation of the driest quarter (Bio17) (47%) (Table 1, Figure 3).

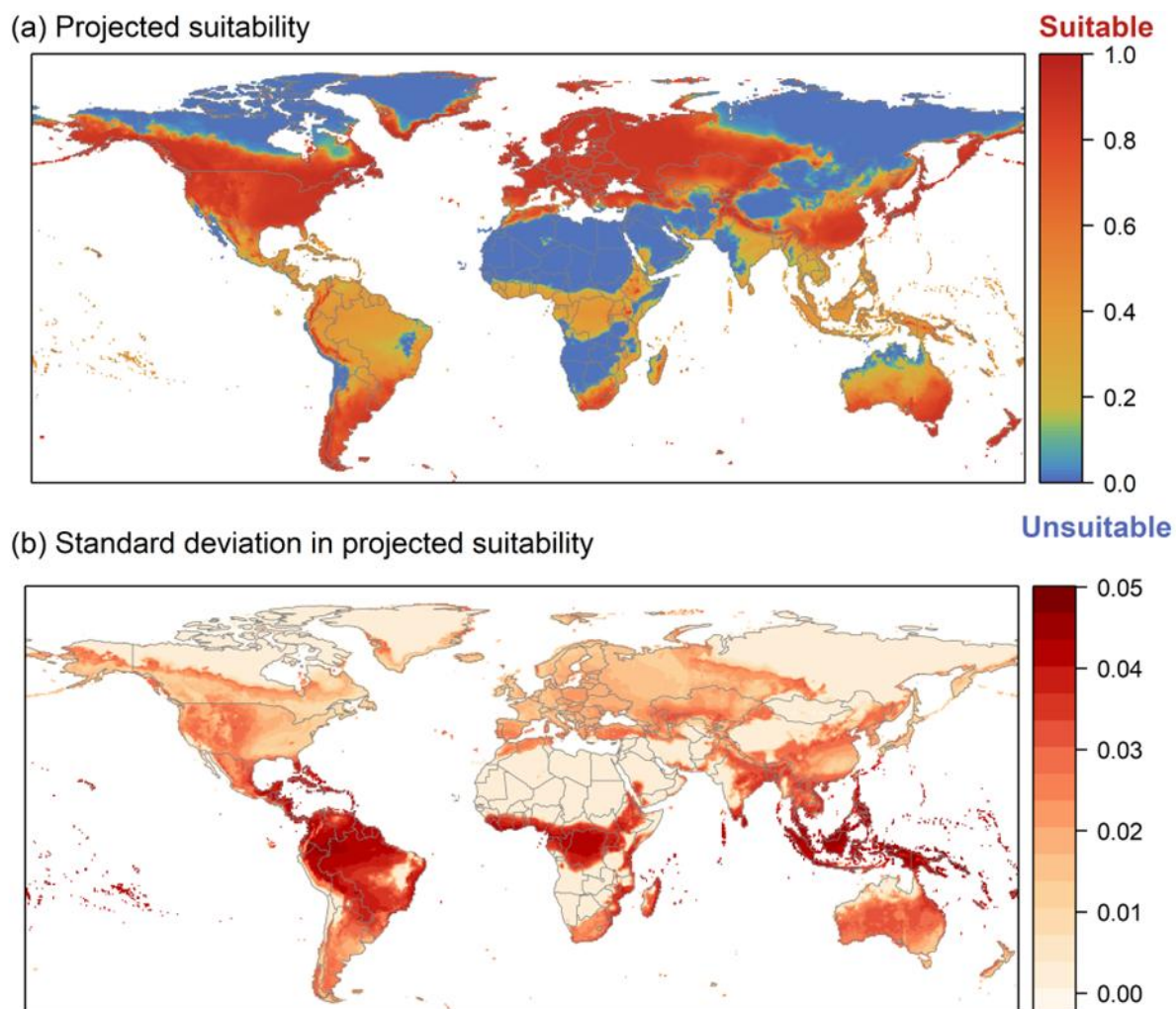
**Table 1.** Summary of the cross-validation predictive performance (AUC, Kappa, TSS) and variable importance of the fitted model algorithms and the ensemble (AUC-weighted average of the best performing algorithms). Results are the average from models fitted to 10 different background samples of the data.

Algorithm	AUC	Kappa	TSS	Used in the ensemble	Variable importance %	
					Mean temperature of the coldest quarter (Bio11)	Precipitation of the driest quarter (Bio17)
ANN	0.965	0.673	0.896	yes	48	52
GAM	0.967	0.676	0.892	yes	55	45
GBM	0.972	0.694	0.901	yes	54	46
GLM	0.967	0.661	0.890	yes	57	43
MARS	0.971	0.693	0.895	yes	50	50
MAXENT	0.973	0.699	0.900	yes	53	47
RF	0.959	0.661	0.889	no	54	46
<b>Ensemble</b>	<b>0.973</b>	<b>0.694</b>	<b>0.897</b>		<b>53</b>	<b>47</b>

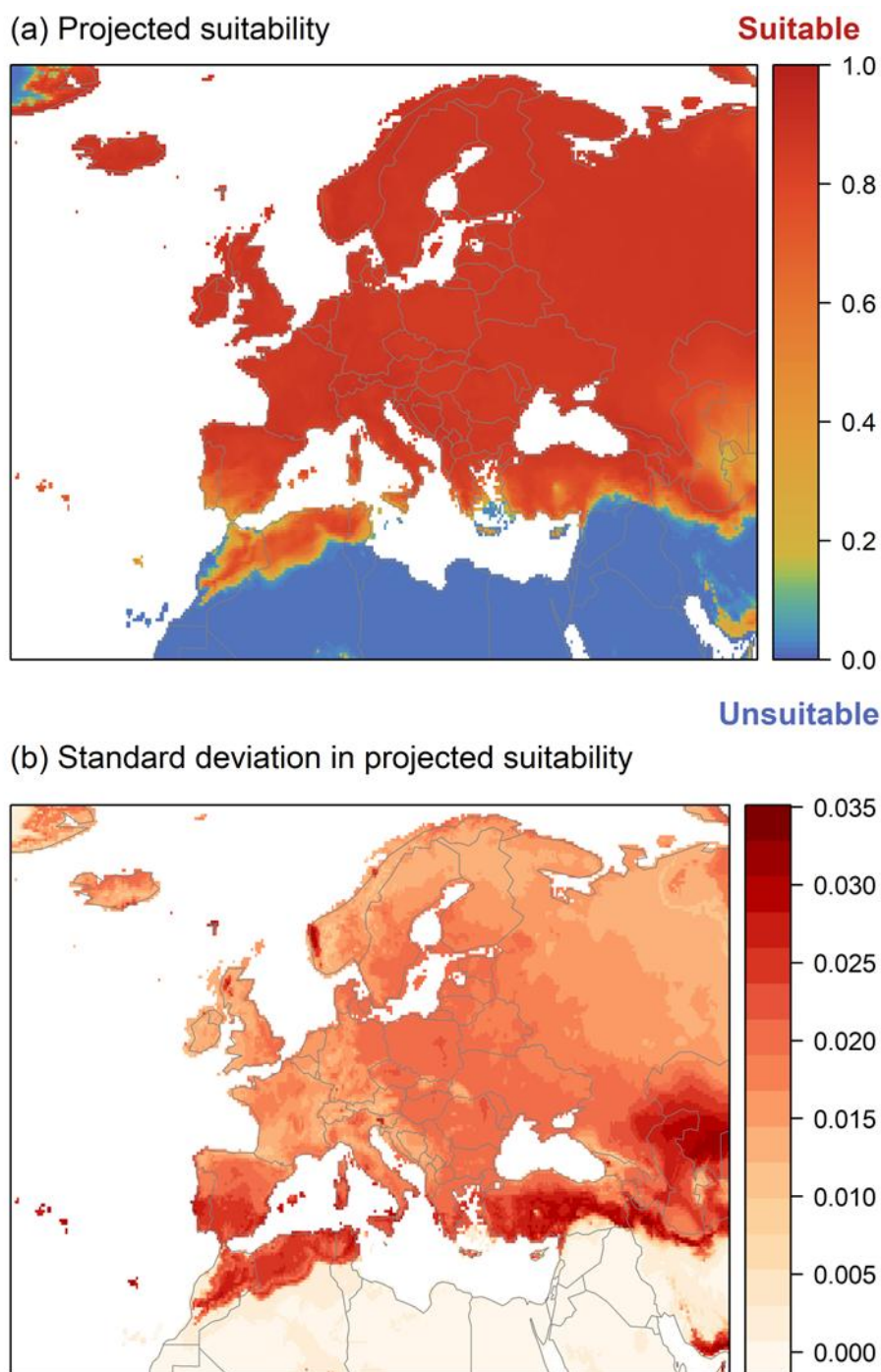
**Figure 3.** Partial response plots from the fitted models. Thin coloured lines show responses from the algorithms in the ensemble, while the thick black line is their ensemble. In each plot, other model variables are held at their median value in the training data. Some of the divergence among algorithms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



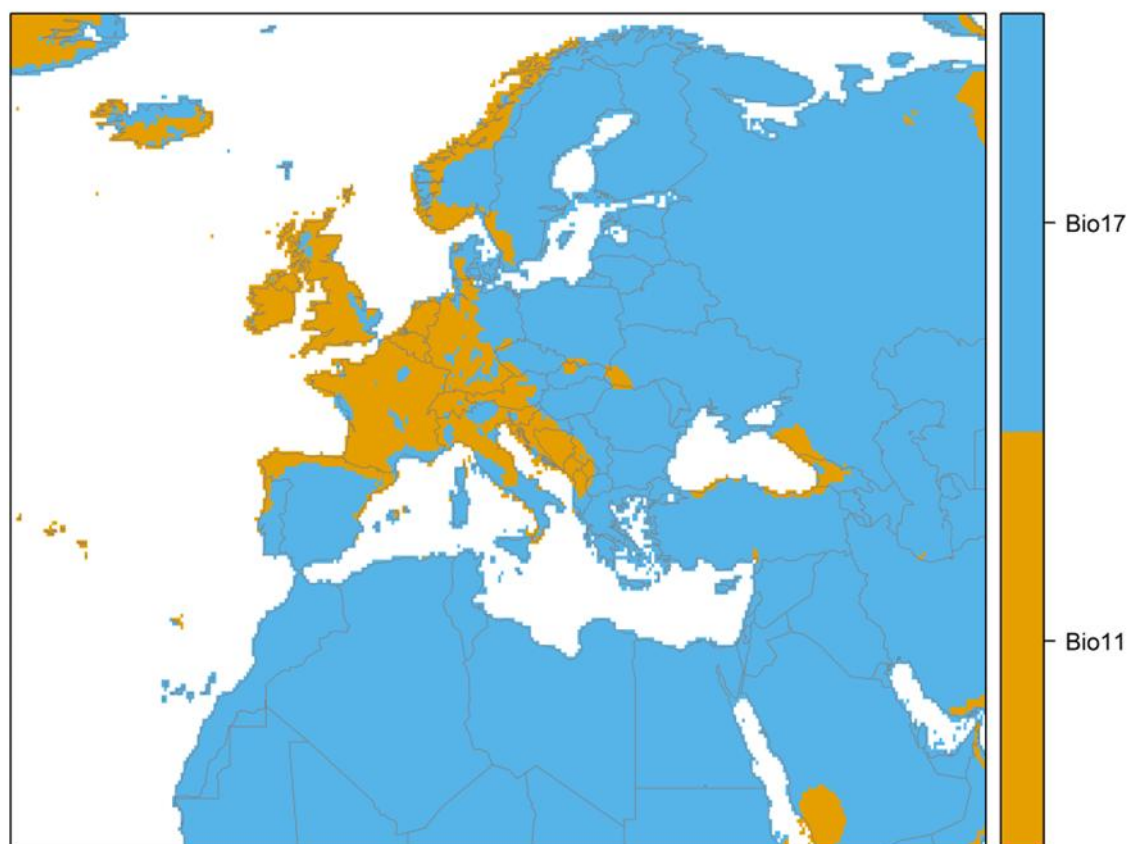
**Figure 4.** (a) Projected global suitability for *Castor canadensis* establishment in the current climate. For visualisation, the projection has been aggregated to a 0.5 x 0.5 degree resolution, by taking the maximum suitability of constituent higher resolution grid cells. Values > 0.18 are likely to be suitable for the species, with 98% of global presence records above this threshold. Values below 0.18 indicate lower relative suitability. (b) Uncertainty in the ensemble projections, expressed as the among-algorithm standard deviation in predicted suitability, averaged across the 10 datasets.



**Figure 5.** (a) Projected current suitability for *Castor canadensis* establishment in Europe and the Mediterranean region. Values > 0.18 are likely to be suitable for the species, with 98% of global presence records above this threshold. Values below 0.18 indicate lower relative suitability. (b) Uncertainty in the ensemble projections, expressed as the among-algorithm standard deviation in predicted suitability, averaged across the 10 datasets.

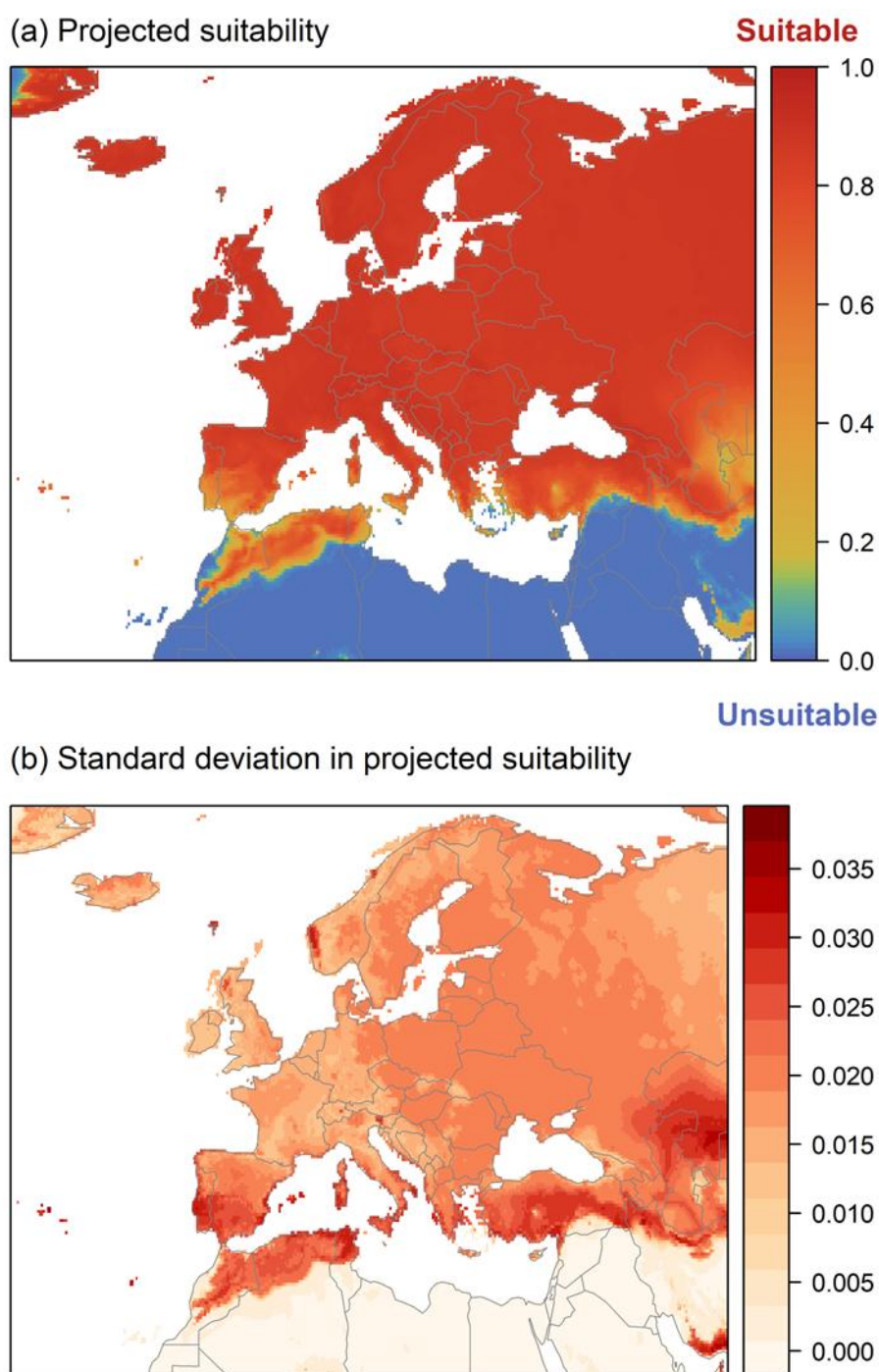


**Figure 6.** The most strongly limiting factors for *Castor canadensis* establishment estimated by the model in Europe and the Mediterranean region in current climatic conditions.

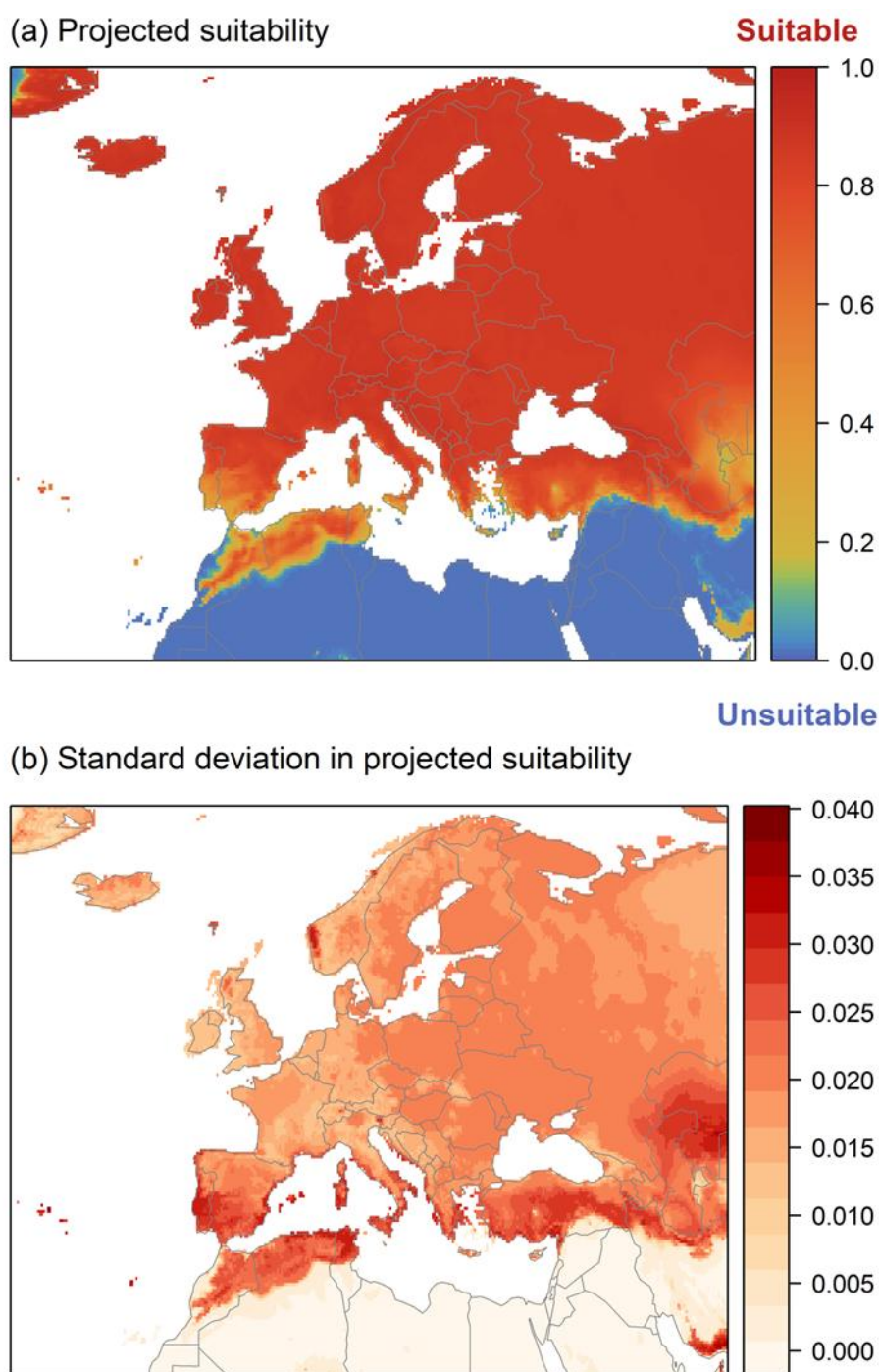




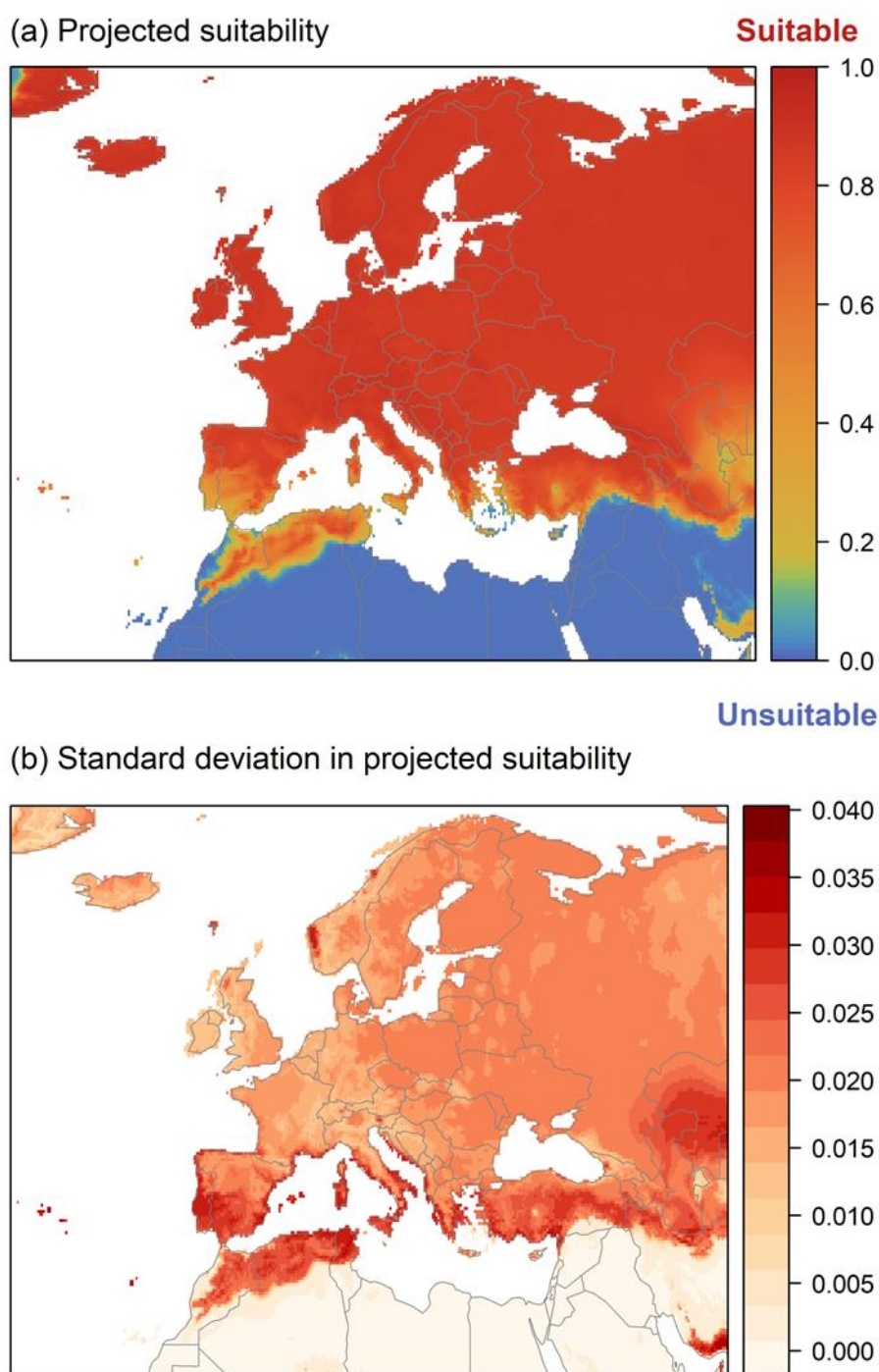
**Figure 7.** (a) Projected suitability for *Castor canadensis* establishment in Europe and the Mediterranean region in the 2070s under climate change scenario SSP1-2.6. Values > 0.18 are likely to be suitable for the species, with 98% of global presence records above this threshold under current climate. Values below 0.18 indicate lower relative suitability. (b) Uncertainty in the ensemble projections, expressed as the among-algorithm standard deviation in predicted suitability, averaged across the 10 datasets.



**Figure 8.** (a) Projected suitability for *Castor canadensis* establishment in Europe and the Mediterranean region in the 2070s under climate change scenario SSP2-4.5. Values > 0.18 are likely to be suitable for the species, with 98% of global presence records above this threshold under current climate. Values below 0.18 indicate lower relative suitability. (b) Uncertainty in the ensemble projections, expressed as the among-algorithm standard deviation in predicted suitability, averaged across the 10 datasets.

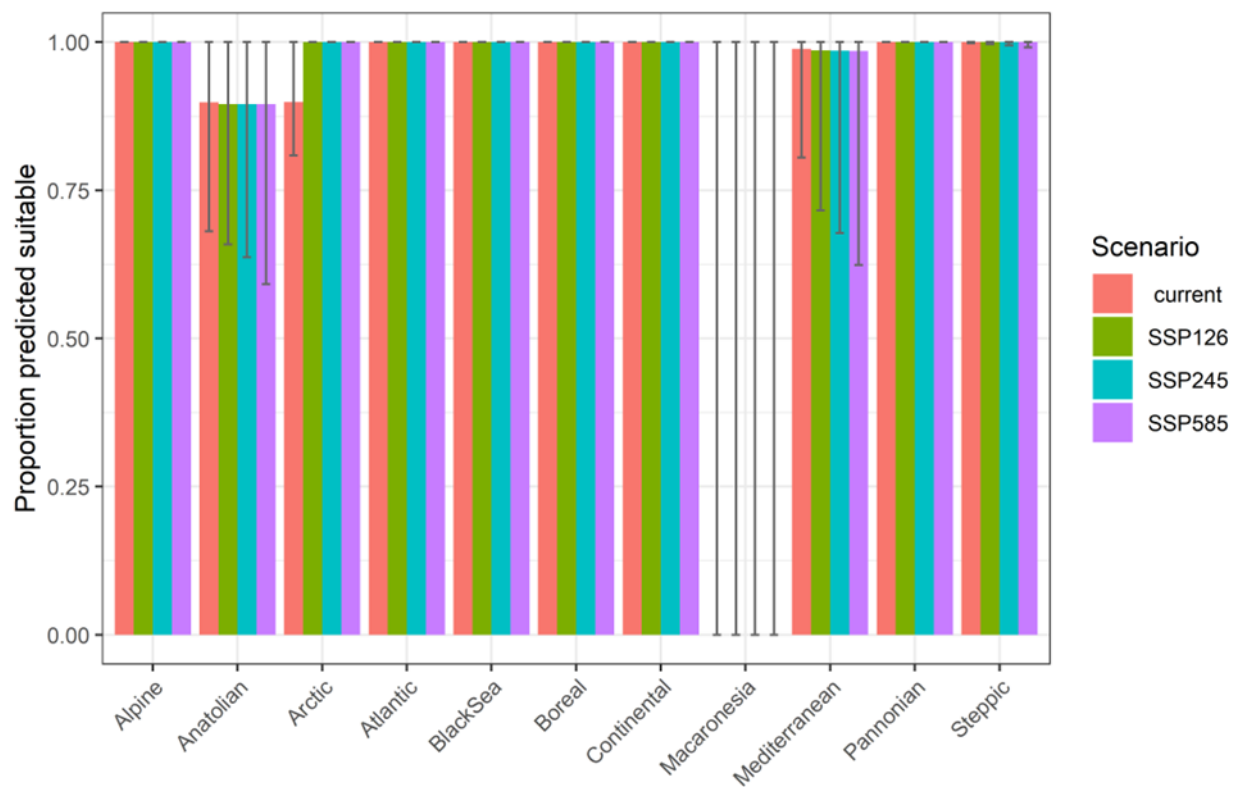


**Figure 9.** (a) Projected suitability for *Castor canadensis* establishment in Europe and the Mediterranean region in the 2070s under climate change scenario SSP5-8.5. Values > 0.18 are likely to be suitable for the species, with 98% of global presence records above this threshold under current climate. Values below 0.18 indicate lower relative suitability. (b) Uncertainty in the ensemble projections, expressed as the among-algorithm standard deviation in predicted suitability, averaged across the 10 datasets.





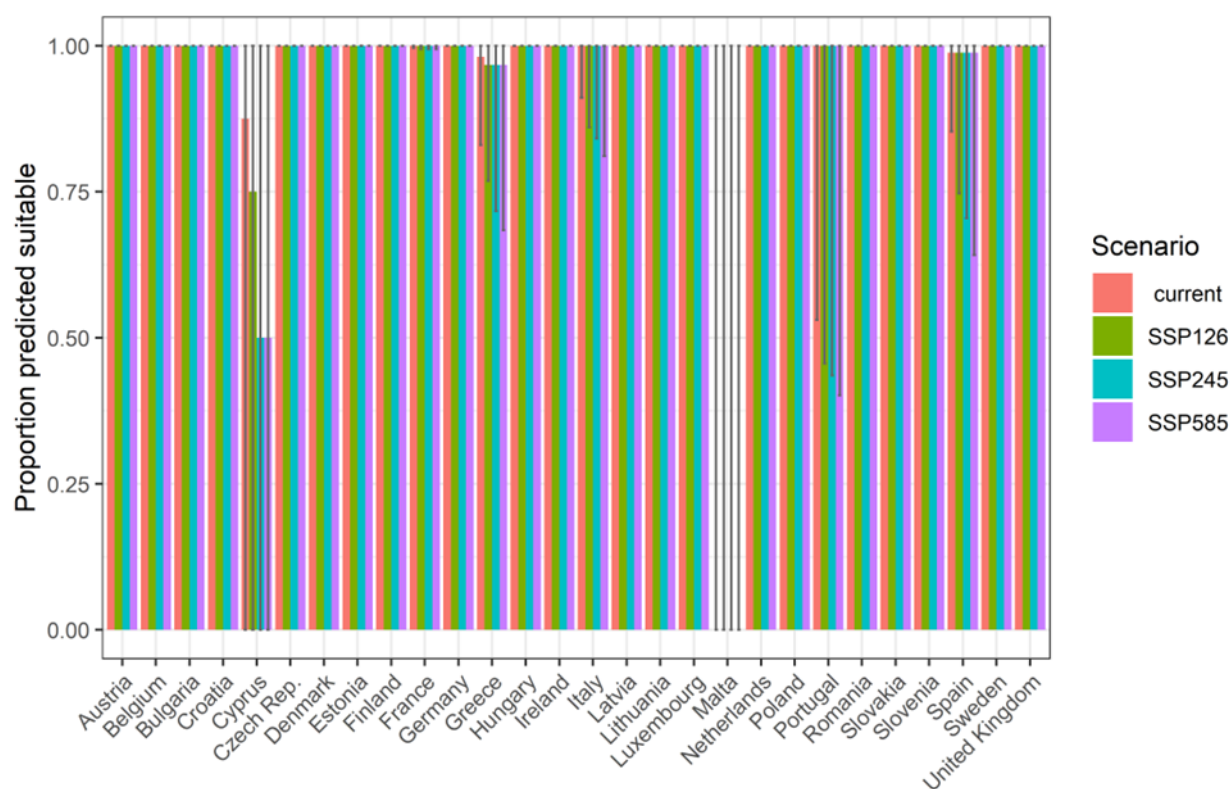
**Figure 10.** Variation in projected suitability for *Castor canadensis* establishment among Biogeographical Regions of Europe (<https://www.eea.europa.eu/data-and-maps/data/biogeographical-regions-europe-3>). The bar plots show the proportion of grid cells in each region classified as suitable (with values > 0.18) in the current climate and projected climates under a SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenario for the 2070s. Error bars indicate uncertainty due to both the choice of classification threshold (cf. above) and uncertainty in the projections themselves (cf. part (b) of Figures 5, 7,8 and 9). The location of each region is also shown. The Anatolian, Arctic and Macaronesian regions are not part of the study area, but are included for completeness.



**Table 2.** Variation in projected suitability for *Castor canadensis* establishment among Biogeographical regions of Europe (numerical values of Figure 10 above). The numbers are the proportion of grid cells in each region classified as suitable in the current climate and projected climates under a SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenario for the 2070s. The Anatolian, Arctic and Macaronesian biogeographical regions are not part of the study area, but are included for completeness.

	current climate			SSP1-2.6			SSP2-4.5			SSP5-8.5		
	lower	current estimate	upper	lower	current estimate	upper	lower	current estimate	upper	lower	current estimate	upper
Alpine	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Anatolian	0.68	0.90	1.00	0.66	0.90	1.00	0.64	0.90	1.00	0.59	0.90	1.00
Arctic	0.81	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Atlantic	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Black Sea	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Boreal	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Continental	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Macaronesia	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	1.00
Mediterranean	0.81	0.99	1.00	0.72	0.99	1.00	0.68	0.99	1.00	0.62	0.99	1.00
Pannonian	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Steppic	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	0.99	1.00	1.00

**Figure 11.** Variation in projected suitability for *Castor canadensis* establishment among European Union countries and the UK. The bar plots show the proportion of grid cells in each country classified as suitable (with values > 0.18) in the current climate and projected climates under a SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenario for the 2070s. Error bars indicate uncertainty due to both the choice of classification threshold (cf. above) and uncertainty in the projections themselves (cf. part (b) of Figures 5, 7 and 8).



**Table 3.** Variation in projected suitability for *Castor canadensis* establishment among European Union countries and the UK (numerical values of Figure 11 above). The numbers are the proportion of grid cells in each country classified as suitable in the current climate and projected climates under a SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenario for the 2070s.

	current climate			SSP1-2.6			SSP2-4.5			SSP5-8.5		
	lower	current estimate	upper	lower	current estimate	upper	lower	current estimate	upper	lower	current estimate	upper
Austria	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Belgium	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Bulgaria	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Croatia	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Cyprus	0.00	0.88	1.00	0.00	0.75	1.00	0.00	0.50	1.00	0.00	0.50	1.00
Czech Rep.	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Denmark	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Estonia	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Finland	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
France	1.00	1.00	1.00	0.99	1.00	1.00	0.99	1.00	1.00	0.99	1.00	1.00
Germany	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Greece	0.83	0.98	1.00	0.77	0.97	1.00	0.72	0.97	1.00	0.68	0.97	1.00
Hungary	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Ireland	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Italy	0.91	1.00	1.00	0.86	1.00	1.00	0.84	1.00	1.00	0.81	1.00	1.00
Latvia	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Lithuania	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luxembourg	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Malta	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	1.00
Netherlands	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Poland	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Portugal	0.53	1.00	1.00	0.46	1.00	1.00	0.44	1.00	1.00	0.40	1.00	1.00
Romania	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Slovakia	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Slovenia	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Spain	0.85	0.99	1.00	0.75	0.99	1.00	0.70	0.99	1.00	0.64	0.99	1.00
Sweden	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
UK	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

## ***Caveats to the modelling***

To remove spatial recording biases, the selection of the background sample from the accessible background was weighted by the density of Mammalia records on the Global Biodiversity Information Facility (GBIF). While this is preferable to not accounting for recording bias at all, it may not provide the perfect measure of recording bias.

There was substantial variation among modelling algorithms in the partial response plots (Figure 3). In part this will reflect their different treatment of interactions among variables. Since partial plots are made with other variables held at their median, there may be values of a particular variable at which this does not provide a realistic combination of variables to predict from.

Other variables potentially affecting the distribution of the species, such as types of land cover were not included in the model.

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