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Summary

This report describes a risk assessment of the alien North American beaver (*Castor canadensis*) for the European Union (EU). This species has recently been identified in a horizon scanning as a potentially invasive alien species with a limited distribution in the EU. The species is native to North America (Canada, USA and northern Mexico). The species was introduced in Finland in 1937 and later in several other European countries to supplement the ongoing reintroduction of the nearly extinct Eurasian beaver (*Castor fiber*). At that time, many zoologists recognised only one species. In the past, *C. canadensis* has also been introduced for fur farming, however, this no longer occurs. Several escapes from zoos or private parks in the EU have been reported. Nowadays, there is awareness of the spread and potential impacts of *C. canadensis* on biodiversity and ecosystems within the EU.

The present risk assessment is based on a detailed risk inventory of *C. canadensis*, which includes a science based overview of the current knowledge on taxonomy, habitat preference, introduction and dispersal mechanisms, current distribution, ecological impact, socio-economic impact and consequences for public health of the species. A team of experts applied this information to assess and classify the (potential) risks of spread, invasiveness and impact of *C. canadensis* in the EU using the Harmonia$^+$ and Invasive Species Environmental Impact Assessment (ISEIA) protocols. In addition, the report includes a risk assessment of *C. canadensis* that has been undertaken for the Netherlands.

The alien *C. canadensis* has been introduced to the wild in the following EU member states: Austria, Belgium, Finland, France, Germany, Hungary, Luxembourg and Poland. The populations recorded in Austria, France and Poland appear to be extinct. Recent records are not available for Hungary (status unknown). The recently confirmed occurrences of the species in Belgium, Germany (Rheinland Pfalz) and Luxembourg is of great concern. If the species is able to establish viable populations in these areas and its establishment is not stopped, the species may spread further to other EU countries such as France and the Netherlands. The species has also been introduced and reproduction has been observed or has likely occurred in north-western Russia.

Three pathways for introduction of the species within the EU are recognized: 1) intentional releases to nature areas (no longer occurs), 2) escapes from confinement, i.e., zoos and fur farms (still possible), and 3) unaided (natural) dispersal (ongoing). Natural dispersal to the EU is possible from Russia and between several EU member states.

The endangered area encompasses all undisturbed river, stream and lake habitats surrounded by forest and shrubs (EU Fresh water habitats types HT3100, 3200 en 3210 and forests types HT9000, 9080, HT9100 andHT91E0) in Belgium, Finland, Germany and Luxembourg. Without appropriate management measures C. canadensis will further spread and the endangered area will potentially expand to all undisturbed river, stream and lake habitats surrounded by forest and shrubs in EU from Scandinavia to the Mediterranean.

Beavers are ecosystem engineers and can significantly change the morphological, and consequently the hydrological characteristics and biotic properties of the landscape. The species increases habitat heterogeneity and species diversity at the landscape scale. Moreover, beaver foraging has a considerable impact on the course of ecological succession, species composition and the structure of plant communities, making them a good example of an ecologically dominant species (i.e., keystone species). These impacts are mostly classified as positive within the native ranges of *C. fiber* or *C. canadensis*. In areas where both species are non-endemic or either one of the species is introduced, as in South America, these impacts are classified as negative. In areas where one of the species is endemic and the other is introduced, as in Europe, the impacts of both species are fairly similar. Competition may occur between the two species in several member states of the EU and in Russia. In literature, however, there is no agreement on outcomes and changes in impacts as a result of this competition.

Economic damage can generally be categorized as dike and impoundment damage, tree damage, and flooding. The alien *C. canadensis* is a potential vector of tularaemia (type B), *Giardia* and *Yersinia pseudotuberculosis* which may pose risks for human health.

Risk classifications for *C. canadensis* in the EU have been derived both for areas with and areas without a native *C. fiber* population. The invasion, impact and overall risk scores of *C. canadensis*, derived using the Harmonia^{+} protocol, are high for areas without a native *C. fiber* population. However, the invasion score is high and the impact and overall risk score are medium for areas with a native *C. fiber* population. Following the application of the ISEIA protocol, the species was classified as B1 (Watch list) and A1 (Black list) in the BFIS system for areas with and without *C. fiber* populations, respectively.

Climate change is expected to have no effect on the risks of introduction, establishment or spread of *C. canadensis*. Furthermore, the impacts of the species are not expected to change, considering the broad native geographical and climate range of the species that extends from the southern arctic tundra to the relatively warm and dry areas of northern Mexico and southern USA.

1. Introduction

1.1 Background and problem statement

Recently, several horizon scanning reports have been published that identify potential invasive alien species (IAS) that may be introduced or have a very limited distribution in the Netherlands or the European Union (EU) (Matthews et al. 2014, 2017, Roy et al. 2014, 2015, Galardo et al. 2016). North American beaver (*Castor canadensis*) was one of the species that scored highly for ecological risk for the Netherlands and larger areas of the EU, and is currently present on a limited scale in the EU. Therefore, the Office for Risk Assessment and Research of the Netherlands Food and Consumer Product Safety Authority (NVWA) requested to perform a scientific risk assessment for this species.

C. canadensis is native to North America (Canada, the United States of America (USA) and northern Mexico) (Jenkins & Busher 1979) and has been introduced in South America (Argentina and Chile) (Anderson et al. 2005, Lizarralde et al. 2004). The species has also been introduced in the EU. *C. canadensis* occurs in the wild in Belgium, Finland, Germany and Luxembourg. The species appears to be extinct in Austria, France and Poland, and its status in Hungary is currently unknown (Aldridge 2009, Dewas et al. 2012, Nummi 2010, Parker et al. 2012). *C. canadensis* is invasive in southern Chile and Argentina (Tierra del Fuego), northern Europe, and north-western Russia.

The present report presents a risk assessment of *C. canadensis* for the European Union. Additionally, appendix 2 presents a risk assessment that has been undertaken for the Netherlands for this species. The assessments are based on a detailed risk inventory. The analyses of available data and classifications of risk of the species have been performed by a team of experts using the Harmonia$^+$ and Invasive Species Environmental Impact Assessment (ISEIA) protocols.

1.2 Research goal

The goal of this study is to conduct a risk assessment of the alien *C. canadensis* for the EU that complies with the criteria for listing IAS of EU concern described in Regulation 1143/2014. This assessment analyses the probability of introduction, establishment, spread, colonisation of high conservation value habitats, (potential) ecological and socio-economic effects, and (potential) impact on public health.

1.3 Outline and coherence of the research

The coherence between various research activities and outcomes of the study are visualised in Figure 1.1.

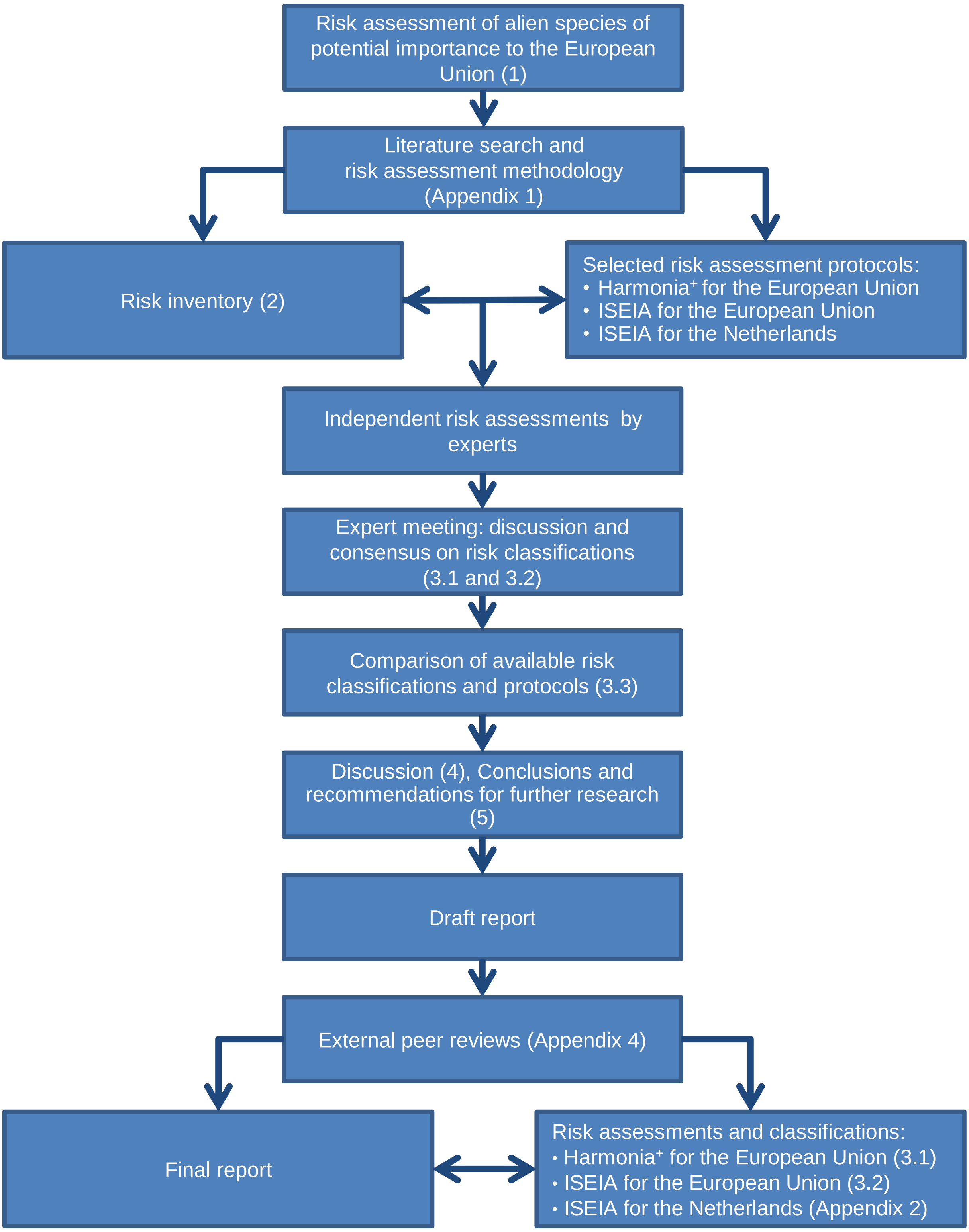


Figure 1.1: Flow chart visualising the coherence of various research activities (chapter numbers are indicated between brackets; ISEIA: Invasive Species Environmental Impact Assessment protocol).

The present chapter describes the problem statement, goals and research questions in order to assess and classify the risks of *C. canadensis* in the European Union. Chapter 2 describes the results of the risk inventory, which includes a science based overview of the current knowledge on taxonomy, habitat preference, introduction and dispersal mechanisms, current distribution, ecological impact, socio-economic impact and consequences for public health of the species. A team of experts used the information provided in the risk inventory to assess and classify the (potential) risks of spread, invasiveness and impact of *C. canadensis* in the EU using the Harmonia$^+$ and ISEIA protocols. Chapter 3 includes the results of these risk assessments and classifications. Moreover, in this chapter, the results of other available risk classifications are summarized and compared with the results of the risk assessments undertaken in this report. Uncertainties, relevant knowledge gaps and differential outcomes of risk assessments are discussed in chapter 4. Chapter 5 draws conclusions and summarizes relevant knowledge gaps. Appendix 1 describes the methods used for the inventory (including literature review and data acquisition), and methods of assessment and classification of risks of introduction and spread of this species. Appendix 2 summarizes the results of the risk classification of *C. canadensis* for the Netherlands using the ISEIA protocol. Finally, details on the outcomes of the peer review procedure for this report are summarized in appendix 3.

2. Risk inventory

2.1 Species description

2.1.1 Nomenclature and taxonomic status

In the first half of the twentieth century many zoologists recognised only one beaver species (Parker et al. 2012). Currently, two separate beaver species are distinguished: the Eurasian *Castor fiber* and the North American *Castor canadensis* (Jenkins & Busher 1979; Figure 2.1). In total 24 subspecies of *C. canadensis* are recognized (Jenkins & Busher 1979). The nomenclature and taxonomic status of *C. canadensis* are summarized in Table 2.1. Based on the current body of knowledge the species can be regarded as a single taxonomic identity. However, identification using external morphological characteristics is difficult.

Table 2.1: Nomenclature and taxonomic status of the North American beaver (*Castor canadensis*).

Scientific name: *Castor canadensis* Kuhl, 1820

Synonyms: *Castor subauratus* Taylor, 1912; *Castor caecator* Bangs, 1913

Taxonomic tree:
According to the NODC taxonomic code, database (version 8.0), taxonomic serial number 180212 (ITIS, 2016):

Domain: Eukaryota
Kingdom: Animalia
Phylum: Chordata
Subphylum: Vertebrata
Superclass: Tetrapoda
Class: Mammalia
Order: Rodentia
Suborder: Castorimorpha
Family: Castoridae
Genus: *Castor*
Species: *Castor canadensis* Kuhl, 1820

Preferred Dutch name: Canadese bever

Preferred English name: North American beaver

Other Dutch names: Not available

Other English names: American Beaver, Canadian beaver, beaver

Native range: Canada, USA, northern Mexico (Baker & Hill 2003)

2.1.2 Species characteristics

The North American beaver *C. canadensis* is the largest rodent in North America and, together with its Eurasian counterpart *C. fiber*, is the second largest rodent in the world. Both beaver species are exceeded in size by the South American capybara. Adults usually weigh from 11 to 26 kg, with 20 kg being typical, and the species maximum incidental weight ranges from 37 to 39 kg (Jenkins & Busher

1979). *C. canadensis*' total length ranges from 100 to 120 cm, its head and body length from 74 to 90 cm, tail length from 258 to 325 mm, tail width 90 to 200 mm, hind foot length 156 to 205 mm and ear length 23 to 29 mm (Jenkins & Busher 1979). The guard hair is long and coarse. The species may range from yellowish-brown to black in colour, with reddish-brown being most common. The tail is flattened dorsoventrally, scaled and relatively hairless. Young animals have black tails that become lighter with age (Jenkins & Busher 1979).

Figure 2.1: North American beaver (*Castor canadensis*; left) and Eurasian beaver (*Castor fiber*; right) (© Photo left: Wikimedia Commons, 2007; right: M. Plomp, 2014).

C. canadensis is semi-aquatic. The beaver has many traits suited to this lifestyle. It has a large flat paddle-shaped tail and large, webbed hind feet. The unwebbed front paws are smaller than the rears, and clawed. The eyes are covered by a nictitating membrane which allows the beaver to see underwater. The nostrils and ears are sealed while submerged. A thick layer of fat under the skin insulates the beaver from its cold water environment. The beaver's fur consists of long, coarse outer hairs and short, fine inner hairs. Scent glands near the genitals secrete an oily substance known as castoreum, which the beaver uses to waterproof its fur (Jenkins & Busher 1979).

Differences with visually similar species

Although North American beavers are superficially similar to the Eurasian beaver, there are several important differences. 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, allowing them a greater range of bipedal locomotion than the European species. The North American beaver has shorter nasal bones than the European 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 the European race which is triangular. The *foramen magnum* is triangular in the North American beaver, and rounded in the European. 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. Finally, the guard hairs of the North American beaver have a shorter hollow medulla at their tips.

The degree to which fur colours, such as brown, reddish, blackish and beige, occur in beaver populations varies between *C. canadensis* and *C. fiber* (Baker & Hill 2003).

Despite morphological and behavioural similarities, the species differ in various skull measurements, the colour and viscosity of their anal gland secretion, and chromosome number (Rosell & Sun 1999). North American beavers have 40 chromosomes, while European beavers have 48. More than 27 attempts have been made in Russia to hybridize the two species, with one breeding attempt between a male North American and a female European beaver resulting in one stillborn kit. The lack of observed hybrids in the wild leads to the conclusion that the two species do not successfully interbreed and that interspecific breeding is unlikely in areas where the two species' ranges overlap (Dewas et al. 2012, Parker et al. 2012).

Although comparative studies have generally found that the North American beaver demonstrates more dam building activity than the Eurasian beaver, the effects of their dams on the environment may not differ significantly. The building activities of the North American and European beavers have been analysed in the north of European Russia (southern Karelia). The results showed that, under similar orographic, edaphic, and hydrological conditions, both species build their lodges and dams with equal frequencies. It was concluded that the building activity of beavers is a response of these animals to specific features of their environment, rather than a species-specific manifestation of the building instinct (Danilov & Fyodorov 2015).

However, two important differences between the species are that the North American beaver may mature earlier and gives birth to larger litters than the Eurasian beaver. Where the two species have been introduced together, the North American beaver often dominates and displaces the Eurasian species. This could be a result of the higher reproductive rate of the North American beaver (Rosell et al. 2005).

Life cycle

The longevity record for wild beaver ranges from 20.5 to 21 years, but few animals live beyond 10 years (Jenkins & Busher 1979).

C. canadensis does not require other species to complete the different stages of its life cycle. This does not include species that supply food, and trees that provide building material for dams and lodges.

Reproduction
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 1) fewer yearlings breed in relatively dense populations, and 2) litter size may be inversely related to the number of beaver in the family, reproduction in beaver may be density dependent (Baker & Hill 2003, Jenkins & Busher 1979). According to Jenkins & Busher (1979), the most important proximate factors that influence litter size are quantity and quality of available food and severity of winter weather. Young beavers are weaned from about six weeks to two months. Lactation continues for at least three months (Jenkins & Busher 1979). Successful reproduction of *C. canadensis* has been observed in several EU member states (currently: Finland, Luxembourg, Belgium, and probably Germany; previously: France and Poland), and neighbouring areas (currently: Russia) (e.g., see Parker et al. 2012; §2.3).

Nests, burrows and dams
Beavers build elaborate nests and burrows, and store food for winter use. Their ability to cut trees is unique, and enables them to build mud and wood “lodges” surrounded by open water, and watertight dams, even in fast-flowing streams. Lodges usually have two or more under water entrances and an inner chamber sited a few inches above water level. Temperatures inside a beaver lodge are higher at low external temperatures and lower at high external temperatures, and are less variable than external air temperatures. Dams may be very long and cause large areas of land to flood. Beavers are stimulated to build dams by the sound of running water. The species also build canals, another example of their habitat altering behaviour.

Size and densities of colonies
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 (± standard deviation) of the North American and Eurasian beaver is 5.2 ± 1.4 and 3.8 ± 1.0 individuals, respectively (Jenkins & Busher 1979). 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^2. This is below the density of colonies found in North America which was measured at 0.2 to 4.6 colonies per km^2 (Jenkins & Busher 1979, Parker et al. 2002, Hyvönen & Nummi 2008).

Dispersal rate and distance

Beavers disperse when they are a yearling (13 to 24 months old) or a sub adult (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 were able to disperse from Tierra del Fuego Island to the mainland via the Strait of Magellan, which is two kilometres wide at its narrowest point (Graells et al. 2015). In Belgium, one *C. canadensis* individual dispersed 15 km (Personal communication E. Branquart). According to Heidecke (1986), the maximum recorded dispersal distance for native *C. fiber* is 150 km.

Foraging behaviour

Beavers are generalist herbivores; they eat the leaves, twigs and bark of most woody plant species which grow near water, and many different kinds of herbaceous plant species, especially aquatic plants. Despite this generality, 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. However, only 6 of these genera accounted for more than 90% of all trees cut. Beavers strongly prefer aspen (*Populus* species) above willows (*Salix* species) and much less conifer (*Pinus* species), but also thrive in the absence of aspen or willow (Jenkins & Busher 1979). Beaver foraging behaviour is strongly influenced by risk of predation. In Ohio (USA), terrestrial foraging by beaver was generally concentrated within 20 m and declined sharply beyond 40 m of the water's edge (Voelker & Dooley 2008).

Natural enemies of (young) American beaver 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*), lynx (*Lynx canadensis*), bobcat (*Lynx rufus*), and mink (*Mustela vison*). Wolves prey on beaver during the ice free period because they are relatively easy to catch. Nearly half their diet may consist of beaver (Baker & Hill 2003). In Europe, (potential) predators may be wolf, brown bear (*Ursus arctos*), otter (*Lutra lutra*), lynx, European mink (*Mustela lutreola*) or American mink (*Neovison vison*). Starvation can be an important cause of mortality, especially at northern latitudes, when beaver are unable to construct a food cache large enough to sustain them through the winter. Sudden snowmelts in midwinter or violent spring ice breakups can raise water levels in streams and may destroy lodges including their occupants, or drown large numbers of beaver under the ice (Baker & Hill 2003).

Conclusion

The alien *C. canadensis* may mature earlier and produces larger litters than its native *C. fiber* counterpart, resulting in a higher reproductive rate for *C. canadensis*. It is highly likely that *C. canadensis* will be able to reproduce in large parts of the EU after deliberate introduction or secondary spread to areas with a lack of predators and sufficiently suitable habitat, such as the banks of water bodies populated by aspen and willow species (e.g., see § 2.3.3).

2.2 Probability of introduction

An important previous introduction pathway of *C. canadensis* was the intentional release of individuals within reintroduction programs, for fur farming, and for game reserves (Table 2.2).

Table 2.2: Active (A) and potential future (F) pathways and vectors for introduction of the North American beaver (*Castor canadensis*) to the European Union.

Category[a]	**Subcategory**[a]	**A**	**F**	**Examples and relevant information**	**Reference**
Release in nature	Introduction for conservation purposes or wildlife management	X		Until 1973, *C. canadensis* and *C. fiber* were regarded as one species. After confirmation that two separate species existed, intentional release of *C. canadensis* in European nature was stopped.	1
Escape from confinement	Botanical garden/zoo/aquaria	X	X [b]		1, 2
Escape from confinement	Fur farms	X	X [b]		1
Unaided	Natural dispersal across international borders of invasive alien species that have been introduced through other pathways	X	X		1

[a] Classification according to UNEP (2012); [b] Assuming a lack of management measures; 1: Nummi (2010); 2: Michaux et al. (2012).

Seven *C. canadensis* individuals were introduced in Finland in 1937 to supplement an ongoing reintroduction of the nearly extinct *C. fiber*. At that time, many zoologists recognised only one species (Parker et al. 2012). North American beavers have also been introduced in the EU in Austria, Belgium, France, Germany, Hungary, Luxembourg, and Poland. It is likely that a few animals have accidentally escaped from zoos, such as the Eifel-Zoo in Prüm, Germany or the Animal and Natura Park in Styria, Austria (Nummi 2010, Michaux et al. 2012, Parker et al. 2012).

For EU member states, the year of first introduction and last observation or current status are summarized in Table 2.3. The actual presence or absence of *C. canadensis* in European zoos is unknown; the species is possibly present in the Eifel-Zoo in Prüm (Germany) and may be present in private parks or on breeding farms. The species is not present in Dutch zoos (Studio Evenaar 2016).

The species already inhabits the EU, but it is possible that new individuals may enter the EU from north-western Russia unaided without the knowledge of relevant authorities.

Table 2.3: First and last observation of the North American beaver (*Castor canadensis*) in EU member states and present populations.

Member state	First observation	Ref.	Last observation	Ref.	Current population status
Austria	1953	1	1986	2	No recent records, probably extinct
Belgium	1998	2	NA		According to Parker et al. (2012), the last observation was in 2000, but recent records have been confirmed[3]
France	1977	2, 4	1985	4	Eradicated [4]
Finland	1937	2	NA		Still present[5]
Germany	1981	2, 6	NA		Is still present in Rheinland Palz[3, 4]
Hungary	1991	2	ND		Status unknown[2]
Luxembourg	Before 2006	2	NA		Previously eradicated, but presence has been recently confirmed[3]
Poland	1926	2	1979[1]	2	No recent records, probably extinct

1: Englisch (2005); 2: Parker et al. (2012); 3: Michaux et al. (2012); 4: Dewas et al. (2012); 5: Danilov et al. (2011); 6: In Bavaria (Germany), *C. canadensis* may have escaped from a breeding farm in 1966, however no sites of establishment have ever been verified (Parker et al. 2012); NA: not applicable; ND: no data (no available literature reporting last observation).

2.3 Probability of establishment

2.3.1 Current global distribution

Europe

North American beavers have been introduced in Europe, i.e., in the EU member states of Austria, Belgium, Finland, France, Germany, Hungary, Luxembourg, and Poland, and in the neighbouring area of north-western Russia (Figure 2.2 and Table 2.3). In Europe, *C. canadensis* is currently recorded in Belgium, Finland, Germany, Luxembourg and north-western Russia (§2.3.2).

North and South America
Before their near extirpation in North America as a result of trapping, North American beavers were practically ubiquitous and lived from the arctic tundra to the deserts of northern Mexico, and from the Atlantic to the Pacific coasts (Wikipedia 2016). North American beavers have also been reported both historically and contemporaneously in Mexico on the Colorado River, Bavispe River and San Bernardino River (Gallo Reynoso et al. 2002). *C. canadensis* occurs nowadays throughout North America except for the arctic tundra and south-western deserts (Baker & Hill 2003, Nummi 2010).

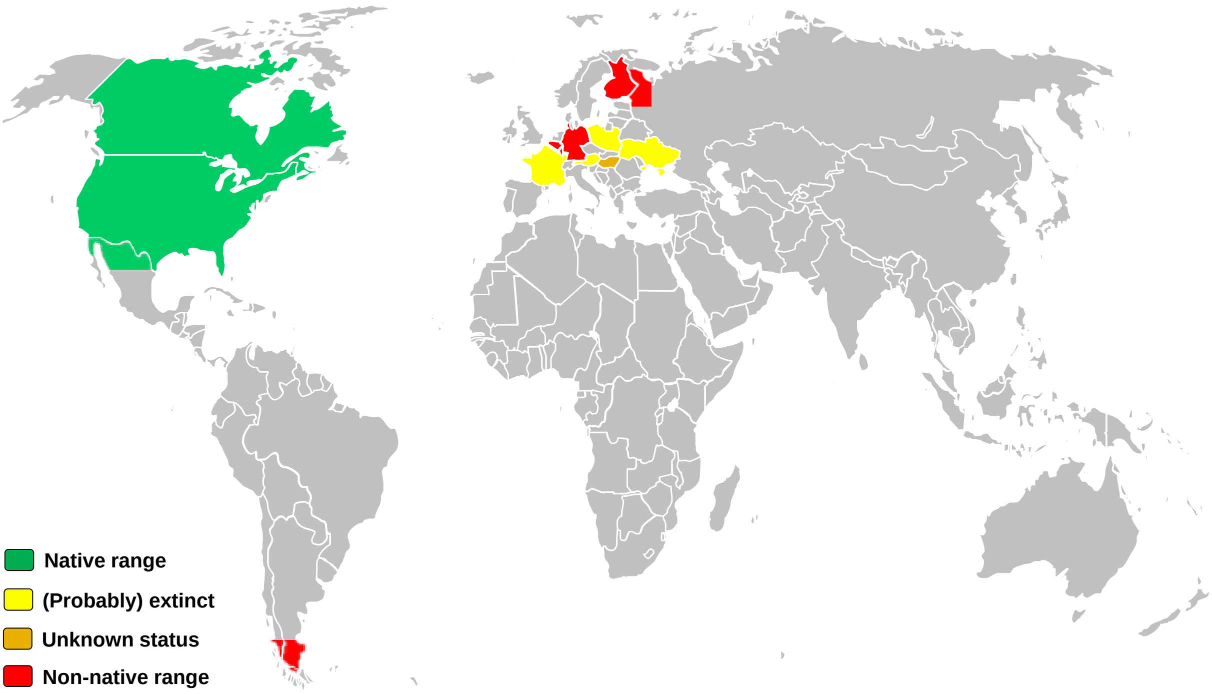


Figure 2.2: Global distribution of North American beaver (*Castor canadensis*) in the native range (green), introduced range (red) and areas where the species (probably) has become extinct (yellow) and with an uncertain current status (orange). Sources: Table 2.3 and §2.3.1 and 2.3.2. Note that the geographical distribution is visualised at nation state level, however, occurrence in some nation states may be restricted to one or few isolated populations.

North American beavers were intentionally introduced to the southernmost part of South America, specifically Tierra del Fuego Island near Fagnano (Argentina) for fur farming purposes in 1946. Here, the species has considerably expanded its range (Lizarralde et al. 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. 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^2. 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).

In 2008, the number of beavers in the Tierra del Fuego archipelago increased to an estimated 100,000. They have invaded roughly 16 million hectares of unique, indigenous forest, leaving a swath of destruction. In November 2016, the authorities of Argentina and Chile signed an agreement to 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 (MercoPress 2016).

Conclusion

The native range of *C. canadensis* extends to Canada, the USA and northern parts of Mexico. The current global introduced range, where the species occurs, consists of the southern parts of Argentina and Chile, north-western Russia, and several EU member states: Finland, Germany, Luxembourg and Belgium.

2.3.2 Current distribution in the European Union and neighbouring areas

North American beavers were unintentionally introduced to **Finland** in 1937 as part of the program to reintroduce the exterminated Eurasian beaver *C. fiber*. The introductions were successful in eastern Finland where two pairs of *C. canadensis* were released. The beavers were later translocated from eastern Finland to the northern, north-eastern and central parts of Finland. During the late 1940s and early 1950s, North American beavers spread to the **Russian side of Karelia** (Nummi 2010). Recently, expanding populations of *C. canadensis* and C*. fiber* have converged on two fronts in Finland and north-western Russia (Figure 2.3; Parker et al. 2012).

North American beavers were also successfully introduced into the Khabarovsk Territory, Amur region and Kamchatka peninsula on the Far East of **Russia** from 1975 to 1979 (Nummi 2010). There are circa 20,000 North American beavers established in **Finland** and **Russian Karelia** (Danilov et al. 2011). *C. canadensis* which originated from the USA was released in Ukraine between 1933 and 1934. This population became extinct in the 1960s (Parker et al. 2012). It is expected that *C. canadensis* will spread to north-western Europe, e.g., towards Sweden (and Norway) in the future. Presently, only *C. fiber* occurs in these regions.

C. canadensis was introduced to Western Europe during the course of the 20th century (Dewas et al. 2012). North American beavers have been introduced to **Poland** (1930s), where the Popielno animal farm is known to have supplied game reserves and zoos in Germany, France (1975) and Austria (1976-1990) (Nolet & Rosell 1998). *C. canadensis* was last observed in Poland in 1979 (Parker et al.

2012). Although the current population status of this species is unknown, *C. canadensis* is now probably extinct in Poland.

Figure 2.3: Distribution of the Eurasian beaver (*Castor fiber*; mid grey) and North American beaver (*Castor canadensis*; dark grey) in western Eurasia. The hatched area indicates the approximate region of population overlap near the Finnish-Russian border (Parker et al. 2012).

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 during the period 1979 to 1981 and in 1984. Furthermore, 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).

In **France**, three North American beavers escaped from a private park and reached the Bourdon reservoir on the Yonne, near Paris in 1977 (Dewas et al. 2012). By 1984, a *C. canadensis* population of at least 15 to 20 individuals was established here. From this initial site, beavers started to colonize surrounding swamps and a tributary of the Loire River. Because native *C. fiber* was also present in the same area, a decision was made to eradicate the *C. canadensis* population. All *C. canadensis* individuals were therefore captured and removed from 1984 to 1985. Following this, no *C. canadensis* populations have been recorded in France (Dewas et al. 2012).

In **Hungary**, *C. canadensis* was recorded in the early 1990s. However, since the 1990s there are no available records. Therefore, the current status of the species in this country is unknown.

The first observation of *C. canadensis* in **Germany** was reported in 1981 in Nordrhein-Westfalen (Parker et al. 2012). Twelve beavers originating from the Popielno animal farm in Poland, where both *C. canadensis* and *C. fiber* were bred, were released between 1981 and 1989 (Dewas et al. 2012). However, the results of a large scale operation to identify beavers to species level with DNA analysis methods was unable to confirm the presence of *C. canadensis* in Nordrhein-Westfalen (Dewas et al. 2012). *C. canadensis* may have escaped from a breeding farm in Bavaria, Germany in 1966, however no sites of establishment originating from these escapees have ever been confirmed (Parker et al. 2012). Furthermore, three *C. canadensis* 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 between Luxembourg and Germany (Rheinland Pfalz) along the River Our. The animal was identified as belonging to *C. canadensis* on the basis of the colour of its anal gland secretion (Dewas et al. 2012). The presence of *C. canadensis* has also recently been confirmed in Rheinland Palz, Germany as a result of a large scale DNA study carried out in Belgium, France, Germany, and Luxembourg (Dewas et al. 2012, Michaux et al. 2012, Frosch et al. 2014).

The presence of *C. canadensis* was later confirmed at four more sites in **Luxembourg** by DNA analyses of collected hair samples (Herr & Schley 2009, Dewas et al. 2012).

Until 2008, all of the 15 individuals tested in **Belgium** were identified as *C. fiber*. However, in 2009, one sample taken from a breeding site at the Our River was identified as *C. canadensis* using the nuclear transcribed mitochondrial encoded Cytochrome B (mtCytB) method. This site has been known about since 2003 and could have been the source of *C. canadensis* spread in the area (Dewas et al. 2012).

Genetic diversity

The recent identification of *C. canadensis* in Belgium, Germany and Luxemburg has cast doubt on the origin and taxonomic status of beavers that have been used for reintroductions in these countries. Michaux et al. (2012) report that the presence of *C. canadensis* may be linked to escapes from a zoo in Rheinland Pfalz which kept *C. canadensis* until 2009. Moreover, other sources or even a combination of sources cannot be ruled out such as zoo escapes, illegal release, beaver introductions from Germany (Bavaria) into Belgium, or from Poland into Germany (Dewas et al. 2012).

The sequencing of the mitochondrial control region and microsatellite genotyping of 235 beaver individuals from five selected regions in Germany, Switzerland, Luxembourg and Belgium showed that beavers from at least four source origins currently form admixed, genetically diverse populations that spread across the study region. While regional occurrences of *C. canadensis* (n = 20) were found, all but one *C. fiber* bore the mitochondrial haplotype of the autochthonous western Evolutionary Significant Unit (Frosch et al. 2014).

Evidence from previous experiences in Eurasia suggests that the two species do not appear to coexist sympatrically. However, it is not yet clear which of the two species outcompetes the other. On the one hand, in Finland, *C. canadensis* has spread much faster and seems to outcompete *C. fiber* in areas where the two species come into contact. On the other hand, in southern Karelia, *C. fiber* seems to outcompete *C. canadensis* (Danilov et al. 2008, Parker et al. 2012).

Conclusion
The alien *C. canadensis* is currently present in Belgium, Finland, Germany and Luxembourg. It is known that large populations have become established in Finland, at least. The scientific literature is not conclusive with respect to the origin of the individuals recorded in Belgium, Germany and Luxembourg, but their spread may be linked to zoo escapes, illegal release or introduced beaver populations. Introduced populations in Austria, France and Poland have probably become extinct. Recent records of the introduced *C. canadensis* in Hungary are lacking, therefore the establishment status of the species in this country is unknown.

2.3.3 Habitat description and physiological tolerance
Beavers are herbivorous and semi-aquatic animals living in creeks, rivers, ponds and lakes (Nummi 2010). The ability of *C. canadensis* to alter existing habitat conditions to meet its needs has allowed populations to inhabit a variety of natural and human-made habitats in North America. The species has successfully colonized tundra and taiga in the far north, bottomland hardwood forests and marshes in the deep South, riparian areas in both cold and hot desert regions, and elevations that vary from sea level to above 3400 m (Baker & Hill 2003).

In the introduced range of *C. canadensis*, i.e., the Tierra del Fuego Islands in southern America, suitable habitat consists of the many rivers and streams surrounded by forests of the Magellanic ecoregion, steppe or cool semi-desert. The vegetation in the forests is characterized by a mix of evergreen trees, such as the beeches *Nothofagus pumilio*, *N. antarctica,* and *N. betuloides* (Grealls et al. 2015).

In Eurasia, the habitat of *C. canadensis* is similar to that of *C. fiber*. This means that the species may potentially establish in areas with rivers, streams and lakes that are surrounded by forests from Scandinavia to the Mediterranean area (mostly small linear habitat types).

In the EU, *C. canadensis* may occur in protected nature areas (e.g., Natura 2000 sites) which are classified according to the EU Habitat Directive (European Commission 2013, European Environment Agency 2016) into:

- Fresh water habitats
  - Standing water (HT3100);
  - Running water (HT3200), which includes sections of water courses with natural or semi-natural dynamics where the water quality shows no significant deterioration, such as Fennoscandian natural rivers (HT 3210);
- Forests
  - Forests of boreal Europe (HT9000), such as Fennoscandian deciduous swamp woods (HT9080);
  - Forests of temperate Europe (HT9100), including riparian forests such as alluvial forests (HT91E0).

Maps of the potential habitat of *C. canadensis* in high conservation value areas of the EU are not available because 1) it is unknown in which Natura 2000 areas *C. canadensis* has established viable populations, and 2) small linear habitats are difficult to visualize on maps at European scale.

Adaptability to physiological conditions facilitating species establishment
Beaver often dig canals to facilitate the movement of food and building material within and among their ponds, or increase water depth for ice free access to a lodge or food cache (Baker & Hill 2003). Beaver dams play a significant role in shaping the morphology of river channels, hydrology, water quality and chemistry (Gibson & Olden 2014). Available data on the physiological conditions tolerated by *C. canadensis* are summarized in Table 2.4.

Table 2.4: Physiological conditions tolerated by the North American beaver (*Castor canadensis*).

Parameter	**Medium**	**Data origin**	**Occurrence**	**References**
pH	Water		5.5-8.3 (average 7.6)	
Temperature (°C)	Water	USA	0-20 Survives under ice	Baker & Hill (2003)
Stream gradient	Water	USA	< 6% preferable; 7-12% less preferable < 3% preferable	Allen (1982) Suzuki & Mc Comb (1998)
Average water fluctuation on annual basis	Water	USA	Small fluctuations preferable	Allen (1982)
Valley width		USA	> 45 m preferable > 25 m preferable	Allen (1982) Suzuki & Mc Comb (1998)

Facilitation of its establishment by capacity to spread

Like the Eurasian beaver, *C. canadensis* has a high capacity to spread and its dispersal ability may facilitate population establishment in areas with suitable habitat in the EU.

Population establishment despite low genetic diversity

Population establishment has occurred in Finland, where *C. canadensis* was introduced intentionally for population development, despite low genetic diversity in the founder population from the state of New York, USA (Parker et al. 2012). Individuals of *C. canadensis* have been recorded in Belgium, Germany and Luxembourg but it is unclear if populations are currently established.

Effects on establishment through competition or predation with other species

The presence of large carnivores (such as wolfs) can affect the establishment of *C. canadensis*. Competition seems to occur with the native Eurasian beaver, but scientific literature is not conclusive in terms of which species is the strongest competitor.

Predators, parasites or pathogens affecting establishment

It is not likely that large carnivores occurring in the EU will influence the establishment of the North American beaver, because they are either present in low densities or are extinct in several member states. Information on parasites or pathogens that may affect the establishment of *C. canadensis* is not available.

Establishment under protected conditions

Population establishment of *C. canadensis* is not likely to occur under protected conditions in Europe in which the environment is artificially maintained (zoological gardens, wildlife parks, glasshouses, aquaculture facilities).

Availability of suitable habitat in the EU

The preferred habitat of *C. canadensis* is widely available in the EU. The habitat requirements of the species are fairly similar to that of the native Eurasian beaver.

Ratio of colonized and available habitat in the EU

The actual geographical distribution of *C. canadensis* in the EU is still limited compared to the area that can potentially be colonised by this species (less than 5%). Potentially, the whole actual and potential range of the Eurasian beaver can also be colonised by *C. canadensis* (i.e., large parts of north-western, central and eastern Europe).

Conclusion

The preferred habitat of *C. canadensis* is widely available in the EU. Its habitat preferences are fairly similar to that of the Eurasian beaver. Potentially, the species can colonise large parts of the European Union that constitute suitable habitat.

2.3.4 Climate match and biogeographical comparison

A biogeographical comparison using the biogeographic classification system of the European Environment Agency shows that the native and introduced ranges of *C. canadensis* show high similarity with the Boreal, Alpine, Atlantic, Continental and Pannonian regions of the EU (2012, Figure 2.4).

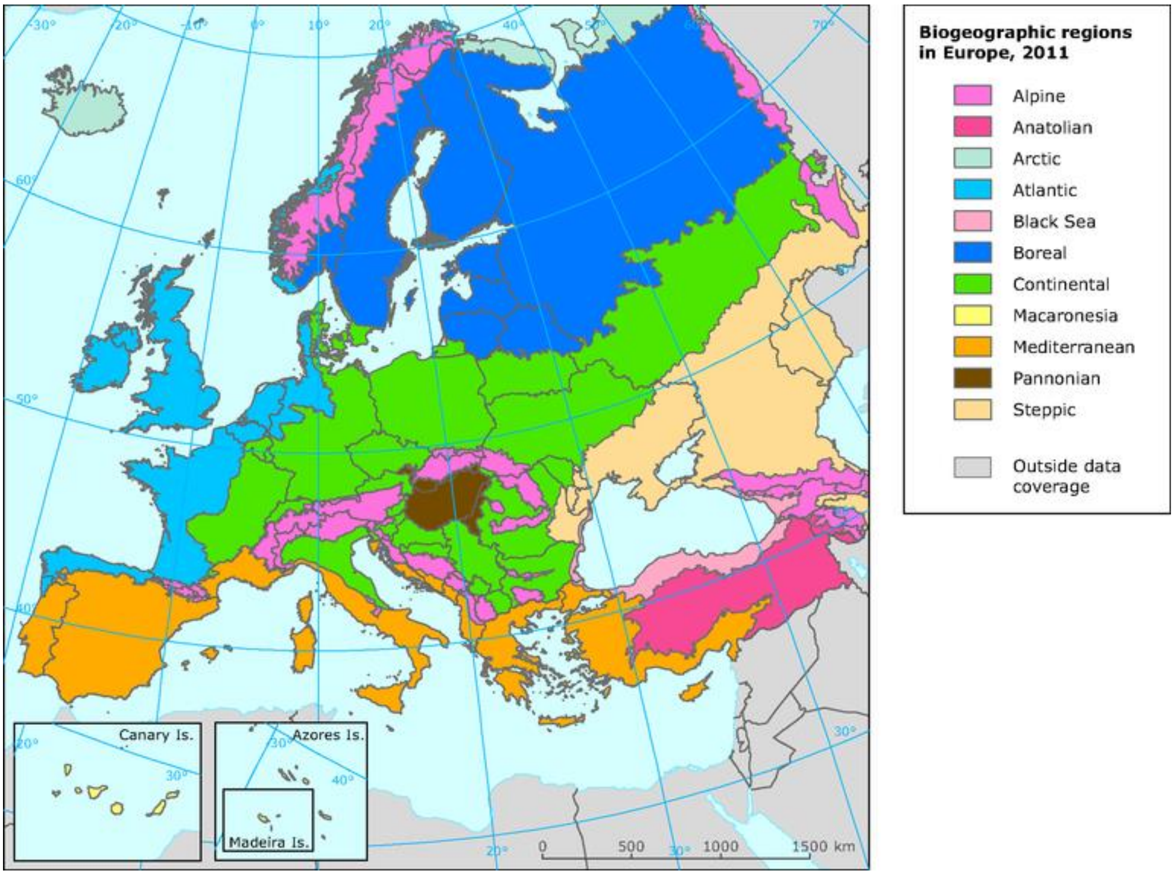
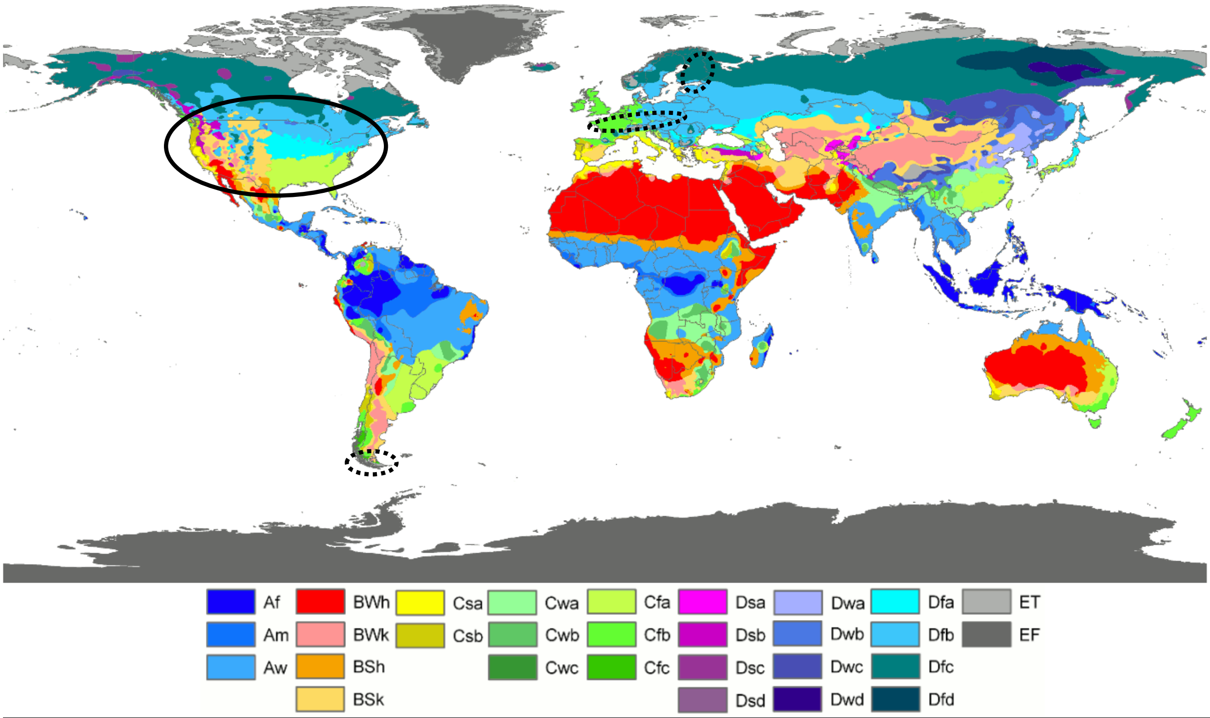


Figure 2.4: Biogeographic regions in Europe (European Environment Agency 2012).

The climatic conditions of the native and introduced ranges of *C. canadensis* mainly match with the warm temperate (C) or snow (D) regions with full humidity and a hot (a), warm (b) or cool (c) summer of the Köppen-Geiger climate classification (Figure 2.5; Kottek et al. 2006). These conditions are characteristic for large parts of the EU. Furthermore, in its native range, *C. canadensis* also occurs in warm temperate regions with a dry summer which is hot or warm (classifications Csa and Csb in California, USA; Lanman et al. 2013).

Currently, *C. canadensis* occurs in Belgium, Germany, Finland and Luxembourg. Given the current climate of its native and introduced ranges, and assuming no management measures to prevent introduction or spread on a European scale, the species may potentially establish in many other EU member states such as Austria, the Czech Republic, Estonia, France, Ireland, Latvia, Lithuania, the Netherlands, Poland, Slovakia, Sweden and the United Kingdom. It may be possible that *C. canadensis* will be able to establish in some more southerly countries, because 1) in its native range the species also occurs in regions with a dry and warm climate such as California (Lanman et al. 2013), and 2) the closely related native *C. fiber* is able to survive in some parts of the Mediterranean, as evidenced by the occurrence of the species in the Rhone-delta (Dewas et al. 2012).



Main climate		Precipitation		Temperature		
A: equatorial	D: snow	W: desert	s: dry summer	h: hot dry	b: warm summer	f: polar frost
B: dry	E: polar	S: prairie	w: dry winter	k: cold dry	c: cool summer	t: polar tundra
C: warm		f: fully humid	m: monsoon system	a: hot summer	d: extremely continenta l	

Figure 2.5: Climate zones according to the Köppen-Geiger climate classification of Kottek et al. (2006). The black circle indicates the native range and the dotted circles indicate the introduced ranges of *C. canadensis* (adapted from Peel et al. 2007).

The species may potentially establish in all undisturbed river, stream and lake habitats surrounded by forest and shrubs within large parts of the EU from Scandinavia to the Mediterranean (e.g., see also §2.3.3). Maps of the potential suitable habitat of *C. canadensis* are not available at EU scale due to the small size and linear character of these habitats.

Conclusion
The native and introduced ranges of *C. canadensis* are climate matched with most EU member states, except for (areas within) countries with an extremely dry and hot climate.

2.3.5 Endangered areas
The geographical distribution (§2.3.2), habitat description (§2.3.3.) and climate match (§2.3.4) reveal that the current endangered area encompasses all undisturbed river, stream and lake habitats surrounded by forest and shrubs (EU Fresh water habitats types HT3100, 3200 en 3210 and forests types HT9000, 9080, HT9100 andHT91E0)

in Belgium, Finland, Germany and Luxembourg. Without appropriate management measures *C. canadensis* will further spread and the endangered area will potentially expand to all undisturbed river, stream and lake habitats surrounded by forest and shrubs in EU from Scandinavia to the Mediterranean (e.g., Austria, Belgium, Denmark, Finland, France, Germany, Hungary, Luxembourg the Netherlands, Poland and Sweden).

2.3.6 Influence of management practices

Establishment despite existing species management practices

In general, there are no specific management practices for *C. canadensis* in the EU except for Scandinavia. In Norway, Sweden and Finland, hunting for both *C. canadensis* and *C. fiber* is allowed. In these countries, 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 (Parker & Rosell 2003, Ministry of Agriculture and Forestry Finland 2016). In Sweden and Norway, hunting in most regions is permitted from the 1st of October to the 15th of May, however, the season may be two weeks shorter in southern ice and snow free areas (Busher & Dzieciolowski 1999). Before 2003, hunting reduced the expected rate of population increase of *C. canadensis* and *C. fiber* in southwest Finland. On the contrary, in Sweden, hunting seemed to have little effect on the mortality rate of the beaver (Parker & Rosell 2003). No information on recent changes to beaver populations in Scandinavia could be obtained from literature. However, as Parker et al. (2012) pointed out, large scale extirpation of *C. canadensis* is technically possible if it is commercially motivated. Near extinction was reached throughout most of the species' range during the hundreds of years of active fur trading in North America (Novak 1987, Parker et al. 2012).

Facilitation of establishment by current management practices

It is unknown if current conservation practices, such as general river habitat improvement, encourages the establishment of *C. canadensis* in the EU.

Effects of eradication campaigns in the EU

Eradication campaigns have resulted in the extirpation of *C. canadensis* in the EU, more specifically in France, but eradication campaigns may have negative effects on *C. fiber* where both species coexist because they are difficult to distinguish in the field. However, the two species exist mostly separately in Finland, therefore risks to *C. fiber* resulting from the *C. canadensis* cull are expected to be low (Personal communication P. Nummi). The survival of *C. canadensis* in South America, despite eradication programs, may be related to the size and remote character of the area in which the species is established (Choi 2008). The distribution of the species in the wild is not yet well known in some EU member states which may increase the challenge of managing *C. canadensis* in the EU.

Conclusion

There are no ongoing management programs for the eradication of *C. canadensis* in the EU. Eradication is difficult due to the similarity of morphological characteristics between *C. canadensis* and the Eurasian beaver, *C. fiber*. To date, eradication programs have not successfully eliminated all *C. canadensis* individuals in South America.

2.4 Pathways and vectors for spread within the EU

Dispersal potential by natural means and human assistance

Populations of *C. canadensis* within the EU are the result of deliberate and unintentional introductions, escapes from zoos and natural dispersal from north-western Russia to the EU (§2.2; Table 2.2). It is likely that individuals from these populations will further spread within the EU via large rivers, streams, canals and interconnected lakes. The natural dispersal ability of *C. canadensis* is high and the species shows a high dispersal rate and a large maximum dispersal distance and high spread rate (§2.1.2).

Dispersal within the EU by natural means currently applies to low numbers of individuals in Belgium, Germany and Luxembourg, and to moderate numbers in Finland. Spread by natural means is likely to increase in the absence of management measures. Spread of *C. canadensis* by human assistance may still occur within the EU because the presence of the species in zoos or parks is not yet well known in some member states. According to the species physiological tolerances (Table 2.4) and natural dispersal in its native and introduced ranges (§2.1.2), it is not likely that seasonal factors will affect the survival of *C. canadensis* during its spread within the EU.

Origins and endpoints of pathways

Finland and the border area of Belgium, Germany and Luxembourg are currently the origins for potential further natural spread within the EU. Potential endpoints of this pathway within the EU are France, the Netherlands and Sweden. Suitable habitat for *C. canadensis* is available in large parts of the EU.

Spread without the knowledge of relevant authorities

Beaver spread may be recognized by road kills, dam building and damaged trees and shrubs. However, species identification is difficult without genetic analysis.

Feasibility of containment

Containment of medium sized mammals such as *C. canadensis* is technically feasible, but will be very costly and difficult to apply in large or remote areas. These problems have been demonstrated during the current management of the muskrat (*O. zibethicus*) in the Netherlands (Bos & Ydenberg 2011, Van Loon et al. 2016).

Conclusion
In the absence of management measures, populations of *C. canadensis* in Belgium, Finland, Germany and Luxembourg may serve as sources for further spread within the EU (e.g., to France, the Netherlands and Sweden).

2.5 Impacts

2.5.1 Environmental effects on biodiversity and ecosystems

Beavers, being ecosystem engineers, are among the few species besides humans that can significantly change the geomorphology, and consequently the hydrological characteristics and biotic properties of the landscape. In doing so, beavers increase heterogeneity and habitat and species diversity at the landscape scale. Beaver foraging also has a considerable impact on the course of ecological succession, species composition and structure of plant communities, making them a good example of an ecologically dominant species (i.e., keystone species) (Rosell et al. 2005). These impacts are mostly classified as positive within the native ranges of *C. fiber* or *C. canadensis*. In areas where both species are non-endemic or either one of the species is introduced, as in South America, these impacts are classified as negative. In areas where one of the species is endemic and the other is introduced, as in Europe, the impacts of both species are fairly similar. Competition may occur between the two species in several member states of the EU and in Russia. In literature, however, there is no agreement on outcomes and changes in impacts as a result of this competition.

Abiotic impacts
The strength of beaver’s impact varies from site to site, depending on the geographical location, relief and impounded habitat type. Consequently, they may not be significant controlling agents of the ecosystem 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^3 in a young pond (area 38 m^2) to 267 m^3 in an older pond (area 588 m^2) (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 causes 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 (Parker 1986, Rosell et al. 2005, Rutherford 1955, Yeager & Hill 1954).

Water quality and chemistry

Beaver dams may increase water temperatures as a result of an increased water surface area, a longer water residence time, and decreased shading by trees (which benefits salmon and trout), in other situations the dams may contribute to cooler water due to increased willow shading and deep pools (Rosell et al. 2005, Gibson and Olden 2014).

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).

Biotic impacts

Competition

The imminent question is whether *C. canadensis* will outcompete *C. fiber* resulting in regional extirpation or eventual extinction. According to Gause's competitive exclusion principle, two species with identical niches cannot coexist indefinitely (Hardin 1960). Additionally, both theoretical and experimental studies of interspecific competition conclude that niche differentiation or different activity patterns, foraging behaviour or habitat use among competing species are necessary for competitive coexistence in communities influenced by density dependent processes (Parker et al. 2012). The alien *C. canadensis* and native *C. fiber* show few differences in these characteristics. For example, a nearly complete niche overlap has been suggested because only minor differences in life history, ecology and behaviour have been found to exist between both species (Parker et al. 2012). Therefore competitive coexistence between *C. canadensis* and *C. fiber* seems unlikely.

However, the few published observations of contact between both beaver species were inconclusive with respect to competitive advantage. Perhaps this is related to the so-called priority effect: the species which colonizes a habitat first negatively affects a species that arrives later by reducing available resources (De Meester et al. 2002). Furthermore, the long-term outcome of competition between these two species is impossible to predict without sufficient field data on their comparative ecology during sympatry (Parker et al. 2012). To conclude, there is no agreement concerning to what extent the alien *C. canadensis* outcompetes the native *C. fiber*.

Hybridization

Genetic introgression becomes a problem when alien and native species hybridize successfully. However, no live born examples of *C. canadensis* or *C. fiber* hybrids are known to be recorded in the wild, and attempts to deliberately produce them in captivity have failed, despite observed mating behaviour (Parker et al. 2012).

Parasites and pathogens

Tularaemia 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 tularaemia in Montana between 1939 and 1940 caused widespread mortality of beaver (several hundred carcasses were found) and coincided with an infection and mortality in meadow voles (*Microtus pennsylvanicus*) that inhabited the grassy streambanks.

Rabies has also been documented in beaver, but little is known about its pathogenesis or epizootiology (Baker & Hill 2003). Possible disease transfer from *C. canadensis* to *C. fiber* is identified as a knowledge gap.

Ecosystem alteration

In their native range, beavers shape riparian ecosystems by selectively feeding on particular plant species, increasing herbaceous richness and creating a distinct plant community.

No documented information could be obtained on ecosystem alterations in the EU resulting from the introduction and establishment of *C. canadensis*. Nevertheless, the effect of *C. canadensis* on ecosystems has been documented for its introduced range in South America, such as Tierra del Fuego. 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 grassland sedge dominated meadows. These forests are strongly dominated by three species of *Nothofagus*, which did not evolve with beaver and have no chemical defences 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, South America, 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).

The growing interest in using beaver in stream conservation plans has outpaced research on the consequences and effectiveness of this approach in dryland streams. A systematic review of the literature revealed that a majority of studies are small-scale and observational, and in many cases lack the replication needed to draw strong inferences. Many hypotheses are supported only by anecdote or speculation. Despite these limitations, work completed indicates that (Gibson & Olden 2014):

1. Dam building behaviour is less likely in dryland than in temperate streams, and stream hydrology probably plays an important role.
2. Beaver activity, including both herbivory and dam building, can be a powerful force in structuring the riparian vegetation community. In some cases, beaver

herbivory may inhibit the regeneration of vulnerable cottonwood populations and/or promote the spread of alien plants.

3. Beaver dams strongly affect local geomorphology, promoting diverse and perennial wetland habitat. It has been demonstrated that the promotion of beaver dams can be an effective technique for the restoration of incised stream channels.
4. Beaver ponds have been implicated in the promotion of a variety of problematic alien animal species, but this hypothesis has not been tested.

Effects on riparian vegetation

Beaver activity alters the riparian community both directly through herbivory and indirectly through dam construction. Beaver are unique in their ability to fell mature trees and thus alter the riparian canopy cover (Baker and 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 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* species) 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 upon (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).

Effects on wildlife

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). Two bat species, *Eptesicus nilssoni* and *Myotis daubentoni*, have been observed to use beaver flowages more than non-beaver ponds. Bats also seemed to forage in larger groups while above beaver ponds compared to control ponds. Beaver flowages appeared to improve bat habitats. A plausible reason for this could be the relatively high number of insects emerging from beaver ponds (Nummi et al. 2011).

Birds

Dryland cottonwood-willow 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). 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 numerical response to flooding. Mallard (*Anas platyrhynchos*) and wigeon (*Anas penelope*) were new species that entered the duck guild in the flooded wetlands. Beaver acted as a whole community facilitator for water birds (Nummi & Holopainen 2014).

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.

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). Similar effects were observed in Finland where the moor frog (*Rana arvalis*) benefitted from pond construction and the removal of trees by beavers (Vehkaoja & Nummi 2015).

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).

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 1996). Beavers also influenced the conservation of endangered invertebrate species in North America (Rosell 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*) (Johnson & Brown 1998, U.S. Fish and Wildlife Service 1993).

Impacts on species and ecosystem functioning in the EU in the future

Competition with the Eurasian beaver is by far the most important potential impact of *C. canadensis* on biodiversity in the EU. Competition impacts may eventually lead to the regional extinction of the native beaver. However, there is no final agreement in literature on the impacts of interspecific competition.

The Eurasian beaver *C. fiber* has a fairly similar impact on biodiversity and ecosystems in its endemic range as *C. canadensis* has in the USA, Canada and Mexico. In areas without endemic beavers (e.g., southern Chile and Argentina), introduction of *C. canadensis* appears to be generating an invasional meltdown

(§2.5.1 ‘Ecosystem alteration’). This type of impact may potentially occur after the introduction of *C. canadensis* in EU areas without (native) beavers. However, it should be noted that the situation in southern Chile and Argentina, where introduced *C. canadensis* overexploit endemic trees, should not be taken as representative of what could occur in the EU. The endemic trees in southern South America have not co-evolved with beavers and have not evolved defence mechanisms to repel them. The native trees in Europe have co-evolved with *C. fiber*. Effects of *C. canadensis* on riparian tree species in Europe may, therefore, be less severe (Personal communication B. Nolet).

The importance of impacts depends on the reference conditions, ecological status and conservation goals of areas that will be colonized by alien beavers.

Declines in conservation status of nature areas

Declines in conservation status of nature areas now and in the future caused by *C. canadensis* (e.g., changes in ecological status of water bodies according to Water framework Directive classification or effects on habitat types or target species in Natura 2000 areas) are not expected in areas where native Eurasian beavers occur. However, in areas without native beavers, changes in conservation status of nature areas are likely due to the impacts of ecosystem engineering and the key stone functioning of *C. canadensis* (see above). The importance of changes in status of nature areas resulting from introductions of *C. canadensis* depends on the reference conservation goals of these areas.

Where environmental impacts are likely to occur in the EU

Impacts of *C. canadensis* on *C. fiber* are likely to occur in all countries where both species live together and potentially in *C. fiber*’s entire range (see Figure 2.3). The impacts on biodiversity and ecosystem functioning described above are likely in all introduced ranges where no native beavers occur.

2.5.2 Effects on cultivated plants

Scientifically sound information describing damage to cultivated plants by *C. canadensis* is very scarce (e.g., data on damage to crops, pasture or horticultural stock as a result of herbivory or the hosting of pathogens or parasites that affects the cultivation system’s integrity). Damage to forests and farmland in Eurasia from tree felling and inundation following dam building is caused by both the native and alien beaver species. Although *C. canadensis* reportedly builds more dams than *C. fiber*, such difference in activity has not been detected in Eurasia. Thus, *C. canadensis* does not appear to cause more damage than *C. fiber* (Parker et al. 2012).

2.5.3 Effects on domesticated animals

Scientifically sound information concerning the effects of *C. canadensis* on domesticated animals in native or introduced ranges is not available. It is unlikely that production animals or companion animals will be affected by *C. canadensis* as a result of predation, parasitism, hosting pathogens or parasites, or via the biological, physical and / or chemical properties of *C. canadensis* that are harmful upon contact. Nevertheless, in the USA beavers have been recognized as reservoirs of *Giardia* sp. parasites which are infective to pets (Dunlap & Thies 2002).

2.5.4 Effects on public health

Waterborne tularaemia 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 tularaemia is responsible for 5-10% of human tularaemia infections in North America but is not fatal to humans. Tularaemia 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).

Beavers have long been recognized as reservoirs of *Giardia* sp. parasites. In east Texas 30 out of 100 examined beavers tested positive for *Giardia* sp. No relationship was found between *Giardia* sp. 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 infective to humans and pets (Dunlap & Thies 2002). In humans, an intestinal infection causes intestinal cramps, a bloated stomach, nausea and attacks of aqueous diarrhoea.

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 which is a severe inflammatory disease (Amphlett 2016).

2.5.5 Socio-economic effects

Economic loss and costs: native geographic range

C. canadensis can damage forest and agricultural fields, and undermine dikes, dams and roads by digging holes and through inundation. Quantitative information on economic loss and costs relating to *C. canadensis* within its existing geographic range (including the cost of any current management) is scarce. Damage can generally be categorized into dike and impoundment damage, tree damage, and flooding or other damage types. According to Loven (1985), these damages totalled $ 9,326,541 for the fiscal years 1983 to 1985 in Texas (USA).

Economic loss and costs: introduced geographic range

Social and economic impacts are likely to occur in all countries where *C. canadensis* is currently established and may become established in the future. In Finland, forests are already affected (Nummi 2010). For example, the size of damaged areas in Finland averaged 2.2 ha in 1998 (Härkönen, 1999). Flood damage resulting from damming was the most important negative impact type (50%). 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).

Current and future economic costs in EU (excluding management costs)

The actual and future economic costs resulting from the introduction of *C. canadensis* in the EU (excluding management costs) are unknown. Scientific cost-benefit analyses are not available. The current costs in the EU are probably low or negligible due to the species' restricted geographical distribution and occurrence in areas with established native Eurasian beavers. The future costs of *C. canadensis* in the EU may significantly rise if no management measures are taken to prevent its further spread and if the species colonizes areas where native beavers are absent. Overall, economic losses and costs of *C. canadensis* are expected to be similar to those of the Eurasian beaver.

Economic costs associated with management in the EU

The economic costs associated with management of *C. canadensis* in the EU in the past and future are unknown. The presence of the species in Germany, Luxembourg and Belgium has led to major concerns surrounding the conservation of native *C. fiber*, especially since the spatial scale of this problem is not yet fully understood. Consequently, efforts should be made to 1) survey watercourses in regions where *C. canadensis* may be present; 2) carry out species identification (AGS methodology in the field, and sequencing of mtCytB in cases of doubt); and 3) remove *C. canadensis* wherever possible. These measures are essential for preventing the further spread of *C. canadensis* (Dewas et al. 2012). Estimations of the total cost of such management efforts for the EU 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).

Management measures

The use of predator chemicals as feeding repellents may be applied to keep beavers away from sensitive areas or single trees, and is a promising approach (Engelhart & Müller-Schwarze 1995). The odours of predators (e.g., solvent extracts of their faeces) can be applied to stem sections of aspen or other trees. Predator odours from wolf, coyote, dog, black bear, river otter, lynx and African lion have been tested. The predator odours reduced feeding relative to untreated or solvent treated controls. Coyote, lynx and river otter odours had the strongest effects. Diesel oil and bitter tasting neem extract (*Azadirachta indica*) had weaker effects. In the Netherlands, the product Wobra is used to grease trunks to prevent beaver-nibbling (Personal communication V. Dijkstra).

Trapping was carried out in Belgium, Rheinland Pfalz and Luxembourg during the winter of 2009 to 2010. By 2010, 13 individuals of *C. canadensis* had been removed from six different sites in Luxembourg and Belgium. Following extensive checks up to three months after the last beaver was caught at each site, all six sites were considered free of North American beaver. Removal of North American beavers continued at other sites during the winter of 2010 to 2011. In Rheinland Pfalz, eight North American beavers were caught at three sites during the winter of 2009 to 2010, six of which were released again after sterilization (Dewas et al. 2012).

Parker et al. (2012) have outlined a chronologically ordered 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, dead trapping, reintroduction and population monitoring are likely to be unnecessary. The strategy consists of several steps: 1) immediate removal of small populations; 2) conduct crucial research on competitive exclusion and hybridization; 3) establish an eradication strategy by introducing a 'wall' of *C. fiber* around larger populations of *C. canadensis*, removing both species from overlap regions, maintain an unoccupied region between the populations of both species; and 4) plan a cull using competent and dedicated hunters and trappers.

2.5.6 Effects on ecosystem services

The effects of establishment of *C. canadensis* populations on various categories of ecosystem services in areas without native beavers are summarized in Table 2.5. The potential effect scores are mainly based on the best professional judgement of the authors owing to a lack of (quantitative) data. The additional effects of *C. canadensis* on ecosystem services in areas with native beaver populations are expected to be negligible.

The effect of *C. canadensis* on provisioning services is expected to be moderately negative for the production of food products (crops, §2.5.2), fibre (timber, §2.5.5) and fresh water supply, due to the contribution of beaver dams to water retention and flooding (§2.5.1).

Table 2.5: Potential effects of North American beaver (*Castor canadensis*) populations on ecosystem services in areas without native beavers (Maes et al. 2013).

Categories and subclasses of ecosystem services	**Effects**
Provisioning services	
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)
Regulating services	
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)
Cultural services	
Cultural diversity	None
Spiritual and religious values	May be valued as positive or negative[1]
Knowledge systems	None
Educational values	None
Inspiration	May be valued as positive or negative[1]
Aesthetic values	May be valued as positive or negative[1]
Social relations	None
Sense of place	May be valued as positive or negative[1]
Cultural heritage values	None
Recreation and ecotourism	May attract tourists (positive)
Supporting services	
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)

1: Valuation of impacts strongly depends on the subjective perceptions of assessors.

The categories regulating and supporting services in Table 2.5 correspond with the ‘regulating and maintenance services’ section of the Harmonia$^+$ risk assessment protocol (Table 3.1). *C. canadensis* may have positive and negative effects on three subclasses of regulating services: water regulation, erosion regulation, and natural hazard regulation, mainly due to the construction of dams (§2.5.1). 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, strongly depending on the subjective perception of the assessor. The overall effect score may therefore be considered neutral for this category.

2.5.7 Influence of climate change on impacts

Climate change (temperature increase of 2°) in the next fifty to hundred years will probably have no impact on the potential distribution range of *C. canadensis*. The species may also establish in warmer regions because it also occurs in regions with a dry and warm climate in its native range such as California. Moreover, the closely related native *C. fiber* can survive in some parts of the Mediterranean, as evidenced by the occurrence of the species in the Rhone-delta (Dewas et al. 2012, Lanman et al. 2013). It is not plausible that climate change will affect other aspects of the risk assessment because the large native and introduced species range covers nearly all climatic zones in Europe (see §2.3.4).

2.5.8 Positive effects

The environmental effect inventory shows that *C. canadensis* may also have effects on ecosystems and native biodiversity that can be considered positive depending on the restoration or conservation goals of the nature area (§2.5.1). Beavers increase heterogeneity at a landscape scale by changing geomorphology, and thus the hydrology and biotic properties of the area (Rosell et al. 2005). For example, in their native range, beavers shape riparian ecosystems by selectively feeding on particular plant species, increasing herbaceous richness and creating a distinct plant community. Indirectly, beaver dams raise and stabilize the surrounding water table, which creates ideal conditions for some riparian plant species such as willow communities (Gibson & Olden 2014).

In its native range in North America, beaver activity has enhanced suitable habitat for aquatic and riparian mammals (e.g., river otter, meadow jumping mouse, bats), riparian and water birds, several trout species, and lentic invertebrate species (Gibson & Olden 2014, Jakober et al. 1998, McDowell & Naiman 1986, Nummi et al. 2011, Nummi & Holopainen 2014, Talabere 2002). The native beaver, *C. fiber*, promotes high quality habitats for amphibians in Germany and Finland (Dalbeck et al. 2007, Vehkaoja & Nummi 2015).

In addition, several effects on ecosystem services may be valued positively (§2.5.6, Table 2.5).

Conclusion

The potential negative impact of *C. canadensis* on native species in the EU mostly relates to competition with *C. fiber*, which may eventually lead to the extinction of this native beaver species. However, scientific literature does not provide conclusive evidence on the outcome of interspecific competition between alien and native beavers. In the EU, *C. fiber* is endemic and has fairly similar impacts on biodiversity, ecosystem functioning and ecosystem services to *C. canadensis* in the USA, Canada and Mexico. Therefore, additional effects and economic costs of *C. canadensis* are limited in areas where *C. fiber* occurs or is likely to establish. Negative effects of *C. canadensis* on the ecosystem of the introduced range in southern Chile and Argentina should, however, not be taken as representative for potential effects that may occur within the EU. This is because endemic trees in southern South America have not co-evolved with beavers and, therefore, have not developed defence mechanisms to repel beavers. Moreover, high impacts relating to alien beaver colonization may only occur in areas within the EU where native beavers are absent.

Quantitative information on the current and future economic losses and costs of *C. canadensis* is not available for the EU. Economic damage can generally be categorized into dike and impoundment damage, tree damage, and flooding or other damage. Potential economic cost depends on the future distribution of the species in the EU. *C. fiber* causes similar damage that also results in economic costs. The economic costs of *C. canadensis* in the EU are currently negligible, but costs may significantly rise in the future.

Transmission of Tularaemia bacteria (type B) and *Giardia* parasites from *C. canadensis* to humans may affect public health.

3. Risk assessment

3.1 Risk assessment and classification with the Harmonia+ protocol

3.1.1 Classification for the current situation

Table 3.1 presents an overview of the risk assessment of *C. canadensis* derived using the Harmonia+ protocol. The expert team exchanged arguments relating to risk scores and came to a consensus. Evidence supporting the risk classification is given in the following paragraphs. The risk scores and confidence levels relate to both the current and future situations for areas without native Eurasian beaver (*C. fiber*) populations in the European Union. As effects of *C. canadensis* are expected to be fairly similar to those of the native beaver, the risk of environmental effects of *C. canadensis* in areas without *C. fiber* will be considerably higher than the additional effects of this species in areas with an established native *C. fiber* population.

Species introduction

The probability that individuals of *C. canadensis* will enter the EU's wild from outside the EU through natural pathways within the time span of a decade is scored high with a high confidence level. This is because the species is currently present in neighbouring parts of EU member states, i.e., north-western Russia. The probability that the species will be introduced into the EU's wild by unintentional human actions is scored medium and by intentional human actions, low, both with a medium confidence level. It appears that the presence of *C. canadensis* in at least Germany may be linked to a zoo in Rheinland Pfalz from which animals are thought to have escaped. This zoo kept North American beavers until 2009. Other zoo escapes cannot be ruled out. The risk of intentional introduction is expected to be low as it is now known that *C. canadensis* and *C. fiber* are separate species.

Establishment

The climate and habitat of the EU are scored as optimal for the establishment of the species, with high confidence. There is a good climate match between most EU member states and *C. canadensis*' native and introduced ranges, excluding the Mediterranean region. The species can live in a wide range of riparian habitats and potentially in any habitat actually or potentially occupied by *C. fiber*.

Spread

The capacity of the species to disperse within the EU by natural means is scored very high, with high confidence. This score was given because the species has the potential to easily disperse over large distances in rivers and other water courses. The risk of spread within the EU by human actions is scored medium, with medium confidence considering that escapes from zoos or maybe from private parks or fur farms are still possible.

Table 3.1: Consensus risk scores for North American beaver (*Castor canadensis*) with confidence levels for both the current and future situations for areas without native Eurasian beaver (*Castor fiber*) populations in the European Union, using the Harmonia+ protocol.

Context		
A01. Assessor(s)	**Consensus scores of five experts**	
A02. Species name	**North American beaver (*Castor canadensis*)**	
A03. Area under assessment	**European Union**	
A04. Status of species in area	**Alien and established within the area's wild**	
A05. Potential impact domain	**Environmental domain**	

Risk category	Risk	Confidence
Introduction		
A06. Probability of introduction by natural means	High	High
A07. Probability of introduction by unintentional human actions	Medium	Medium
A08. Probability of introduction by intentional human actions	Low	Medium
Establishment		
A09. Climate for establishment	Optimal	High
A10. Habitat for establishment	Optimal	High
Spread		
A11. Dispersal capacity within the area by natural means	Very high	High
A12. Dispersal capacity within the area by human actions	Medium	Medium
Impacts: environmental targets		
A13. Effects on native species through predation, parasitism or herbivory	Medium	High
A14. Effects on native species through competition	High	Low
A15. Effects on native species through interbreeding	No/very low	High
A16. Effects on native species by hosting harmful parasites or pathogens	Low	Low
A17. Effects on integrity of ecosystems by affecting abiotic properties	High	High
A18. Effects on integrity of ecosystems by affecting biotic properties	High	High
Impacts: plant targets		
A19. Effects on plant targets through herbivory or predation	Medium	Medium
A20. Effects on plant targets through competition	Inapplicable	High
A21. Effects on plant targets through interbreeding	Inapplicable	High
A22. Effects on integrity of cultivation systems	Medium	Medium
A23. Effects on plant targets by hosting harmful parasites or pathogens	Inapplicable	High
Impacts: animal targets		
A24. Effects on animal health or production through parasitism or predation	Inapplicable	High
A25. Effects on animal health or production by properties hazardous upon contact	Very low	High
A26. Effects on animal health or production by parasites or pathogens	Low	Medium
Impacts: human health		
A27. Effects on human health through parasitism	Inapplicable	High
A28. Effects on human health by properties hazardous upon contact	Very low	High
A29. Effects on human health by parasites or pathogens	Very low	Medium
Impacts: other targets		
A30. Effects by causing damage to infrastructure	Medium	High
Ecosystem services		
A31. Effects on provisioning services	Moderately negative	Low
A32. Effects on regulation and maintenance services	Neutral	Low
A33. Effects on cultural services	Neutral	Medium
Effects of climate change		
A34. Introduction	No change	High
A35. Establishment	No change	High
A36. Spread	No change	High
A37. Impacts: environmental targets	No change	High
A38. Impacts: plant targets	No change	High
A39. Impacts: animal targets	No change	High
A40. Impacts: human health	No change	High
A41. Impacts: other targets	No change	High

Environment
The risks of effects of *C. canadensis* on native species through herbivory are medium, considering that the effects of the native *C. fiber* on native species are generally assessed as medium and that the effects of *C. canadensis* do not differ from those of the native beaver. The effects of *C. canadensis* on native *C. fiber* through competition are high, but with low confidence. There is no agreement on the impacts of competition between *C. canadensis* and *C. fiber*, but where the two species have been introduced together, *C. canadensis* seems to dominate and displace *C. fiber* as a result of the higher reproductive rate of *C. canadensis*. Impacts of *C. canadensis* on *C. fiber* are likely to occur where both species coexist and potentially in the entire *C. fiber* range, possibly preventing its establishment in areas that are occupied firstly by *C. canadensis*.

There is no risk of interbreeding, as recorded trials of hybridization between *C. canadensis* and *C. fiber* have proven unsuccessful. The risk of hosting harmful parasites is assessed as low, with low confidence, because the species is not known to host different parasites to the native beaver and other riparian or aquatic rodents, but little information on this issue was found.

The risks of impact on the abiotic and biotic properties of ecosystems are expected to be high, with a high level of confidence. Although comparative studies have generally found that the North American beaver demonstrates more building activity than the Eurasian beaver, the effects of their dams on the environment may not differ by much. In areas where both native and alien beaver are absent, the establishment and activities of *C. canadensis* (dam building, canal digging and tree cutting) will considerably change the hydrological situation. Areas will likely be flooded, causing trees to die and resulting in changes to water quality and vegetation composition.

Plant crops
Medium effects on plant crops through herbivory and on cultivation systems are expected, considering that damage to forests and farmland resulting from herbivory, tree felling and inundation following dam building is caused by beavers. *C. canadensis* is reported to build more dams than *C. fiber*, but a difference in the impact on the environment between species has not been detected. Effects through competition, interbreeding, parasites or pathogens are inapplicable.

Domestic animals
The category effects of *C. canadensis* on domestic animals as a result of parasitism and predation are inapplicable. This is also the case for effects due to properties that are hazardous upon contact, but the Harmonia$^+$ protocol does not provide an 'inapplicable' option for this criterion and therefore it was scored as very low in Table 3.1. The risk of effects by parasites or pathogens is scored low, with medium confidence, considering that beavers may be infected by parasites that may also have an effect on domestic mammals.

Human health

The category effects of *C. canadensis* on human health through parasitism is inapplicable. This is also the case for effects due to properties that are hazardous upon contact, but the Harmonia$^+$ protocol does not provide an 'inapplicable' option for this criterion and therefore it was scored as very low in Table 3.1. The risk of effects by parasites or pathogens is scored as very low, with medium confidence, considering that beavers may be infected by tularaemia and *Giardia* that pose a very low risk to human health.

Infrastructure

Both North American and Eurasian beavers can damage dikes, dams and roads by digging holes and causing inundation. Beavers thus have a medium impact on infrastructure.

Ecosystem services

Effects on ecosystem services are scored as moderately negative in the case of provisioning services and neutral in the cases of regulation, maintenance and cultural services.

Risk classification

The calculated invasion score (introduction x establishment x spread) is high because of the combined high risks of introduction, establishment and spread (score 1; Table 3.2). The impact score is also high due to the high impact score for environmental targets. As a consequence, the risk of *C. canadensis* to the European Union is classified as high.

Table 3.2: Risk classification and maximum risk scores for *Castor canadensis* with confidence levels in areas without native Eurasian beaver (*Castor fiber*) populations in the European Union calculated with the online version of the Harmonia$^+$ protocol. Please note that classifications and scores are the same for the current and future situations.

Risk category	Risk classification	Risk score	Confidence	Confidence score
Introduction[1]	High	1.00	High	1.00
Establishment[1]	High	1.00	High	1.00
Spread[1]	High	1.00	High	1.00
Impacts: environmental targets[1]	High	1.00	High	1.00
Impacts: plant targets[1]	Medium	0.50	Medium	0.50
Impacts: animal targets[1]	Low	0.25	High	1.00
Impacts: human health[1]	Low	0.00	High	1.00
Impacts: other targets[1]	Medium	0.50	High	1.00
Invasion score[2]	High	1.00	NA	NA
Impact score	High	1.00	NA	NA
Risk score (Invasion x impact)	High	1.00	NA	NA

1: maximum score per risk category; 2: introduction x establishment x spread; NA: not applicable.

3.1.2 Classification for future situation

Climate change is expected to have no effect on the risks of introduction, establishment or spread and also impacts of *C. canadensis* (Table 3.1), considering the broad native geographical and climate range of the species which extends from south of the arctic tundra to relatively warm and dry areas in northern Mexico and southern parts of the USA.

3.2 Risk assessment and classification with the ISEIA protocol

3.2.1 Classification for the current situation

The expert team discussed the risk scores of *C. canadensis* and came to a consensus. Risk scores were allocated separately for areas within the EU without a native *C. fiber* population, and for areas colonized by *C. fiber*. In the former case, the experts allocated a high risk score (score 3) to all risk categories for the current situation (Table 3.3). The total score for the environmental risk of this species is 12, which is the maximum obtainable score. *C. canadensis* is classified as an A1 species according to the list system proposed by the Belgian Forum on Invasive Species (BFIS; Figure 3.1). This is because of its high environmental risk and recorded distribution in the EU (isolated populations). *C. canadensis* qualifies for the black list according to the BFIS list system.

Table 3.3: Consensus risk scores for alien *Castor canadensis* for the current and future situations, including the potential effects of climate change, for areas with and without native *Castor fiber* populations in the European Union, using the ISEIA protocol.

Risk category	For areas with a Eurasian beaver population	For areas without a Eurasian beaver population
Dispersion potential and invasiveness	**3**	**3**
Colonisation of high conservation value habitats	**3**	**3**
Direct or indirect adverse impacts on native species	**2**	**3**
1. Predation/herbivory	1	2
2. Interference, exploitation competition	2	3
3. Transmission of parasites and diseases	DD	DD
4. Genetic effects (hybridisation / introgression with natives)	1	1
Direct or indirect alteration of ecosystem functions	**1**	**3**
1. Modification of nutrient cycling or resource pools	1	2
2. Physical modifications of habitat	1	3
3. Modification to natural succession	1	3
4. Disruption to food webs	1	3
Total score	**9**	**12**
Range of spread	**Isolated populations**	**Isolated populations**
Risk Classification	**B1**	**A1**

DD: data deficiency.

The experts allocated a high risk score to the categories dispersion potential and invasiveness and colonisation of high conservation value habitats for situations where *C. fiber* is present (Table 3.3). However, in consideration of the effects *C. fiber* already has on its environment, the category adverse impact on native species was allocated a medium risk score (score 2), whereas a low risk score was allocated to the category alteration of ecosystem functions. The total score for the environmental risk of *C. canadensis* in areas where *C. fiber* is present is 9 out of a maximum of 12. According to the BFIS system, *C. canadensis* is classified as a B1 species and thus qualifies for the watch list (Figure 3.1). It is expected that native *C. fiber* poses a similar high risk for areas without beavers due to the fairly similar ecosystem engineering effects that it shares with *C. canadensis*. However, the risks of *C. fiber* are not assessed in the current report.

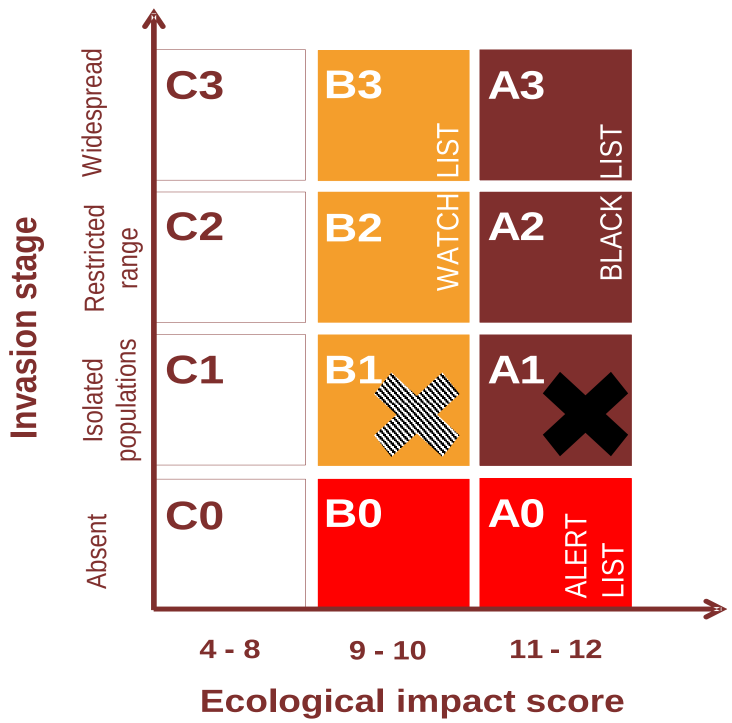


Figure 3.1: The risk classification of the alien North American beaver (*Castor canadensis*) for the current and future situations in areas with (hatched cross) and without (black cross) native Eurasian beaver (*Castor fiber*) populations in the European Union according to the BFIS list system.

Dispersion potential or invasiveness

The risk score is 3 (**high**). The species has the capacity to easily disperse over larger distances in rivers, lakes and canals.

Colonization of high value conservation habitats

The risk score is 3 (**high**). The species is able to establish and spread in interconnected water courses, including streams, lakes and riparian forests with high conservation value.

Adverse impacts on native species

The risk score is 3 (**high**) for locations where native beaver is absent. *C. canadensis* can moderately effect (score 2) populations of native trees and herbaceous plant species through herbivory. However, the risk of effects on native species through interference competition is high, due to the impact beavers can have on the hydrology (including flooding) and other abiotic and biotic conditions resulting from dam building and canal digging. In situations where native beaver is already present, the additional effects of *C. canadensis* through herbivory are expected to be low. As *C. canadensis* is reported to build more dams than *C. fiber*, the additional effect of the species through interference competition is medium. There is insufficient data available to draw conclusions on the risk of transmission of parasites and diseases to native species. There is no risk of genetic effects through hybridization, since hybridization with native *C. fiber* does not occur.

Alteration of ecosystem functions
The risk score is 3 (**high**) for situations without a native beaver population. The species likely has a medium effect on nutrient cycling and a high effect relating to physical modifications of the habitat, modification of natural succession and disruption of food webs. The additional effect of *C. canadensis* on ecosystem functions in situations where *C. fiber* is already present is low.

3.2.2 Classification for the future situation

The future risks of *C. canadensis* were also assessed and classified for areas with and without native *C. fiber* populations in the EU using the ISEIA protocol. Considering the broad native geographical and climate range of the species, from arctic to relatively warm and dry regions, the expert team expects that climate change will have no effect on the ecological establishment risk of the species in the EU. Therefore, the risk classification for the future situation is the same as the risk classification for the current situation (Table 3.3). It should be noted that native *C. fiber* is still expanding within the EU due to natural spread and re-introduction programmes. Therefore, the potential risk of competitive exclusion of *C. fiber* may be especially high in areas suitable for, but not yet occupied by, this native beaver due to possible priority effects that may occur as a result of *C. canadensis* establishment.

3.3 Other available risk assessments

Table 3.4 summarizes available risk assessments and classifications of *C. canadensis* for the EU, its member states (Belgium, Luxembourg and the Netherlands), and other regions (i.e., global scale). The outcomes of these assessments indicate that the establishment of *C. canadensis* will pose a medium to high risk for negative effects on native biodiversity. Overall, the outcomes of these assessments are in line with our results. Differences for some assessment criteria are mainly related to slightly diverging approaches (e.g., assessing effects in areas with or without native beavers, and only accounting for additional effects when assessing locations where native beavers are already present).

3.3.1 EU member states

The Belgian Biodiversity Platform performed a risk assessment on *C. canadensis*, using the ISEIA protocol (Branquart et al. 2010). The goal of this assessment was a risk prioritisation of alien species (i.e., classifying alien species for a black, watch or alert list). The dispersion potential (invasiveness) and colonization of high conservation value habitats scored 3 (high risk). Adverse impact on native species scored 2 (medium risk) and risk of alteration of ecosystem functions was considered likely (score 2). The total environmental impact score of *C. canadensis* was 10 (i.e., medium risk). The species occurs in isolated populations. Therefore, *C. canadensis* was classified as a B1 species (Watch list). A detailed risk assessment of this species has not yet been performed for Belgium.

Table 3.4: Other available risk assessments of the North American beaver (*Castor canadensis*).

	European Union				**Other regions**
	Belgium	**Luxembourg**	**The Netherlands**	**European Network on Invasive Alien Species (NOBANIS)**	**Global Invasive Species Database (GISD)**
Scope	Risk prioritisation of alien species (species listing)	Classification of invasive alien vertebrates	Rapid risk assessment	Identification of species that are or may in the future become invasive	Facilitating effective prevention and management activities
Method	ISEIA	ISEIA	Questionnaire for the selection of potential IAS of EU concern	Invasive alien species fact sheet	Species profile with a generic description of risks
Risk classification	Medium risk (score 10), isolated populations, (B1)	Medium risk (score 9), isolated populations, (B1)	High risk for impact on biodiversity, low risk for effects on ecosystems and ecosystem services	No formal risk classification	No classification of risks
Source	Branquart et al. (2010)	Ries et al. (2014)	Verbrugge et al. (2015)	Nummi (2010)	GISD (2015)
Additional information	Watch list, detailed risk assessment not yet available	Added to the watch list	Focused on additional effects on ecosystems in the presence of native beavers	Briefly describes affected habitats and indigenous organisms, and human health, economic and societal effects	Describes competition with native beaver, damage to forests and risk of flooding

Ries et al. (2014) performed a risk assessment of *C. canadensis* in Luxembourg, using the ISEIA protocol. The score for dispersion potential or invasiveness and colonization of high conservation value habitats was 3 (high risk). The risks of adverse impacts on native species was scored 2 (medium risk) and alteration of ecosystem functions was scored 1 (low risk). The total environmental impact score was 9. In Luxembourg, the species occurs in isolated populations. Based on these outcomes, *C. canadensis* was also classified as a B1 species (Watch list).

The European Network on Invasive Alien Species (NOBANIS) developed a database for the identification of species that are or may become invasive in the future. The *C. canadensis* factsheet does not include a formal risk classification but briefly describes affected habitats and indigenous organisms, and potential effects on human health, economy and society (Nummi 2010). *C. canadensis* may cause competitive exclusion of the Eurasian beaver and is a more active ecosystem engineer than the native species (dam and lodge building).

A Dutch panel of experts performed a rapid risk assessment on *C. canadensis* using a standardized questionnaire for pre-selection of potential invasive species of EU concern (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 and ecosystems were assessed as high (score 3) and absent (score 0), respectively. The risk of effects on ecosystem services was scored low (score 1). The low scores for impact on ecosystems and ecosystem services relate to an assessment of additional effects in comparison with that of native beavers. The high score for impacts on biodiversity was mainly based on information described in the NOBANIS factsheet of Nummi (2010).

3.3.2 Other regions

The Global Invasive Species Database (GISD 2015) is an online source of information about alien and invasive species that negatively impact biodiversity. The GISD aims to facilitate effective prevention and management activities by disseminating specialist's knowledge and experience. The species profile of *C. canadensis* gives a generic description of risks but does not include risk classifications. According to GISD (2015), the species' damming activity can cause flooding which can damage forests in the introduced range. *C. canadensis* also has the ability to quickly cut down large numbers of trees and compete with native beaver populations. In its native range, the species causes the flooding of major highways by plugging highway culverts.

According to the Invasive Species Compendium (Aldridge 2009), *C. canadensis* has been proven to be invasive outside its native range. However, the risks of the species are not quantified. Qualitative descriptions of risks relate to ecosystem change or habitat alteration, modification of hydrology and successional patterns, negative impacts on forestry and transportation disruption.

4. Discussion

4.1 Classification and rating of risks

The expert team classified *C. canadensis* as an alien species with a high risk of environmental impact in the EU. The species has established a large population in Finland and neighbouring parts of Russia. There is only a relatively small area where *C. canadensis* and the native beaver *C. fiber* co-occur in this region. *C. canadensis* seems to dominate and displace *C. fiber* due to the higher reproductive rate of *C. canadensis*. However, there is no final agreement in literature with regard to the impacts of competition between *C. canadensis* and *C. fiber* and therefore effects through competition are classified as high, but with low confidence. *C. fiber* is currently spreading in its native range in Europe following reintroduction programmes that have occurred over the last decades. In areas where *C. fiber* has not yet established, introduction of *C. canadensis* might prevent the establishment of *C. fiber*.

In areas where *C. fiber* is not present, establishment of *C. canadensis* will impact native species, the species composition of vegetation types, forests, and ecosystem functions and services. The environmental and socio-economic effects of *C. canadensis* are, however, expected to be rather similar to those of native *C. fiber*. It is expected that *C. fiber* may also pose a high risk for environmental impact in areas where *C. canadensis* is absent due to its fairly similar ecosystem engineering effects. This implies that management measures designed to discourage *C. canadensis* would not prevent similar effects occurring in the event that *C. fiber* was allowed to establish and spread. Nature conservation often aims to encourage the establishment of *C. fiber* in wetlands. The risks of *C. fiber* establishment were not assessed in the current report.

Although some criteria in the Harmonia$^+$ protocol were scored with a low level of confidence and several with a medium level of confidence, all available information collected during the risk inventory indicates that *C. canadensis* poses a high risk and should be added to the black list in the BFIS system in situations where *C. fiber* is not present. In situations where *C. fiber* is present, *C. canadensis* poses a medium risk and the species qualifies for the watch list, which compares well with other risk assessments from Belgium, Luxembourg, the Netherlands and other regions (i.e., global scale). Although not clearly stated in these risk assessments, it was assumed that they were performed for ecosystems in which native beavers occur, and therefore only account for effects additional to those of native beavers.

4.2 Knowledge gaps and uncertainties

The lack of data concerning the effects of interspecific competition between invasive *C. canadensis* and native *C. fiber* is identified as a gap in knowledge and a source of uncertainty in the risk assessment. It is unknown whether *C. canadensis* invasion may potentially lead to the extinction of the Eurasian beaver at a local or regional scale. These potential effects should be investigated for different habitats and climate regions. The current occurrence of *C. canadensis* in zoos and private parks or fur farms in Europe is not clear, resulting in some uncertainty relating to the probability of introduction and spread by unintentional or deliberate human activities. There is also a lack of knowledge with regard to the effects of *C. canadensis* on native species or domestic animals through the hosting of harmful parasites or pathogens. Finally, there is uncertainty relating to the effects of the species on plant crops and on ecosystem services, especially those relating to forestry, and on the balance between the positive and negative effects of dam building relating to the creation of both water buffers upstream and almost stagnant and eutrophic water bodies. Compared to *C. fiber*, *C. canadensis* is reported to be a more active dam builder and to more effectively control the hydrology of its habitat, but this is not supported by data collected during comparative studies.

4.3 Management

To date, *C. canadensis* has survived eradication programs in South America. However, it is likely that eradication campaigns can remove the species from the EU as was demonstrated by the earlier eradication of *C. fiber*. However, measures aimed at the eradication of *C. canadensis* are likely to impact *C. fiber* negatively where coexistence occurs, mainly because the species are difficult to distinguish in the field. Therefore, *C. canadensis* may be removed more easily from areas where *C. fiber* is absent. Nevertheless, in France a small population of *C. canadensis* co-occurring with *C. fiber* was successfully eradicated following capture of all the alien individuals. There are no existing *C. canadensis* management programs in the EU. In Norway, Sweden and Finland, hunting privileges belong to landowners and beaver hunting is allowed. Landowners may themselves harvest their proportion of a quota set by the government or lease the hunting rights to others (Parker & Rosell 2003, Ministry of Agriculture and Forestry Finland 2016).

5. Conclusions

Current presence in the EU

- The North American beaver (*Castor canadensis*) is present in Europe, with a large, expanding population in Finland. It is expected that the species will spread towards Sweden (and Norway). In the EU, *C. canadensis* individuals have also been introduced to Austria, Belgium, France, Germany, Hungary, Luxembourg, and Poland. The species has recently been eradicated in France and has probably become extinct in Austria and Poland. The current status of the species in Hungary is unknown. Recently, the presence of the species was confirmed in the greater three border region of Belgium, Germany (Rheinland Pfalz) and Luxembourg. The origin of these individuals is still uncertain, but their spread may be linked to zoo escapes, illegal release or misidentified introduced beavers. There is a lack of knowledge with regard to the degree at which the species is currently held in captivity in zoos, private parks and fur farms.

Probability of introduction

- The probability that *C. canadensis* individuals enter the EU's wild from outside the EU through natural pathways is high because of its current presence in north-western Russia.

- The probability that the species will be introduced into the EU's wild by intentional human actions such as deliberate release within beaver reintroduction programs is low as *C. canadensis* and *C. fiber* are now known to be different species.

Probability of establishment

- The climatic requirements for *C. canadensis* are met in most EU member states, except in (areas within) countries that have an extremely dry and hot climate. The species can establish in a wide range of aquatic and riparian habitats, similar to native *C. fiber*.

- Climate change (2° increase) is expected to have no effect on the risk of establishment of *C. canadensis* because the species is also able to establish in warmer regions. In its native range, *C. canadensis* also occurs in regions with a dry and warm climate such as California, and the closely related native *C. fiber* can survive in some parts of the Mediterranean.

Probability of spread

- The capacity of *C. canadensis* to disperse within the EU by natural means is very high. The species can potentially disperse over large distances in rivers and other water courses.

- There is a medium risk of spread within the EU by human actions as escapes from zoos, private parks or fur farms are still possible.

- Because of the wide native as well as introduced geographical and climatic ranges of the species, climate change is expected to have no effect on the risk of spread of the species within the EU.

Probability of impact

- The impact of *C. canadensis* on native species is classified as high because of competition that may potentially occur with native *C. fiber*. Competition between the two species may lead to the potential displacement of *C. fiber* or prevent its establishment in suitable habitats. The effects of *C. canadensis* on other native species through herbivory are medium as they are expected to be similar to those of *C. fiber*. This will also apply to major indirect effects resulting from changes to abiotic and biotic properties.

- Like the native beaver, *C. canadensis* poses a high risk of direct effects on its habitat as a result of dam building and flooding, thereby affecting abiotic and biotic properties. The species likely poses a medium risk of negative effects to nutrient cycling and a high risk of physical modifications to habitat, modification of natural succession and disruption of food webs. There is a low risk that additional effects on ecosystem functions will result from *C. canadensis* establishment in situations where *C. fiber* is present.

Risk classification

- The expert team assigned overall **high** risk classifications for the ecological risks of *C. canadensis* in the EU, using both the Harmonia$^+$ and ISEIA protocols.

- *C. canadensis* is currently present in isolated populations in the EU. According to the BFIS list system used in conjunction with the ISEIA protocol, *C. canadensis* classifies as an **A1** species and qualifies for the **black list** in situations where native *C. fiber* is absent. In areas where the native beaver is present, risk scores allocated to the categories dispersion potential and invasiveness, and colonisation of high conservation value habitats remain the same. However, the risk score allocated to the category adverse impacts on native species was changed to medium from high, and the risk score allocated to the category alteration of ecosystem functions changed to low from high, resulting in *C. canadensis* being classified as a **B1** species which qualifies for the **watch list**. Climate change is expected to have no effect on the ecological risks of the species.

- The classification of *C. canadensis* by experts based on available knowledge resulted in the following risk scores according to the Harmonia$^+$ protocol:
  - Introduction risk: **High** (Confidence: **High**);
  - Establishment risk: **High** (Confidence: **High**);

- Spread risk: **High** (Confidence: **High**);
- Environmental impact risk: **High** (Confidence: **High**)
  - Effects on native species through predation, parasitism or herbivory: **Medium** (Confidence: **High**);
  - Effects on native species through competition: **High** (Confidence: **Low**);
  - Effects on native species through interbreeding: **No/Very low** (Confidence: **High**);
  - Effects on native species through hosting harmful parasites or pathogens: **Low** (Confidence: **Low**);
  - Effects on integrity of ecosystems by affecting abiotic and biotic properties: **High** (Confidence: **High**);
- Risk of effects on plant cultivation: **Medium** (Confidence: **Medium**);
- Risk of effects on domesticated animals and livestock: **Low** (Confidence: **High**);
- Risk of effects on public health: **Low** (Confidence: **High**);
- Other risk effects: **Medium** (Confidence: **High**).

Knowledge gaps

- The effects of interspecific competition between the alien *C. canadensis* and the native beaver *C. fiber* are identified as a gap in knowledge and source of uncertainty in the risk assessment.

- The current presence of *C. canadensis* in zoos and private parks or fur farms in the EU is not clear, resulting in some uncertainty concerning the probability of introduction and spread by deliberate and unintentional human activities.

- The current and potential future distribution of *C. canadensis* in Natura 2000 areas in the EU is unclear.

- There is also a lack of knowledge with respect to the assessment of risk to native species or domestic animals through the hosting of harmful parasites or pathogens by *C. canadensis*.

- *C. canadensis* is reported to more actively build dams and more effectively control the hydrology of its habitat than the native beaver, but this is not supported by data collected during comparative studies. Therefore, there is uncertainty with regard to the effects of the species on plant crops and the balance between positive and negative effects on ecosystem services.

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Appendix 1 – Materials and methods

A1.1 Risk analysis components

The present risk assessment of the North American beaver *Castor canadensis* in the European Union includes analyses of the probability of introduction, establishment and spread within the EU. Also the available literature on the ecological and socio-economic effects, impact on public health and availability of cost-effective options for risk management were analysed. The background information and data collected in the risk inventory are presented in chapter 2 and used as basis for the risk assessments and classification in chapter 3.

Subsequently, an ecological risk assessment and risk classification of the species in the EU was made using the Harmonia$^+$ protocol (D'hondt et al. 2014, 2015). The novel internet version of this protocol includes criteria for an ecological risk assessment as well as modules for the assessment of (potential) impacts on human health, infrastructure and ecosystem services, and a module to assess effects of climate change on the risks posed by alien species. The earlier version of Harmonia$^+$ was nearly compliant with criteria for risk assessment of IAS of EU-concern derived from Regulation 1143/2014 on the prevention and management of the introduction and spread of IAS (Roy et al. 2014). We assumed that the current internet version of Harmonia$^+$ is compliant with these criteria due to the addition of modules concerning the impacts on ecosystem services and the potential effects of climate change on future impacts of alien species.

In addition, a risk assessment was performed using the Invasive Species Environmental Impact Assessment (ISEIA) protocol (Branquart 2009a, b; Vanderhoeven et al. 2015).

A1.2 Risk inventory

An extensive literature review was carried out to compile a science based overview of the current knowledge on taxonomy, habitat preference, introduction and dispersal mechanisms, current distribution, ecological impact, socio-economic impact and consequences for public health of the species. In addition, data on the current distribution in EU member states were acquired. In this risk inventory internationally published knowledge in scientific journals and reports was described. If relevant issues mentioned in the format for this risk inventory could not sufficiently be supported by knowledge published in international literature, 'grey literature' or 'best professional judgement' was used. In the latter case, this has been indicated in the report to clearly identify which arguments may be prone to discussion. Uncertainties and knowledge gaps are also addressed in the discussion.

A1.2.1 Literature review

The Web of science and Google scholar search engines were used to find general information on *C. canadensis* and more specific information on its distribution, tolerances, habitat characteristics and other aspects indicated by the search terms given in (Table A1.1). All hits of the Web of science searches and the first 150 hits of the Google scholar searches were screened for relevance.

Table A1.1. Search strategy to retrieve scientific literature on the invasion biology of the North American beaver (*Castor canadensis*).

Search engine	Search terms (hits)	Search date
Web of Science (All databases)	*Castor canadensis* (671); North American beaver (176), Canadian beaver (108)	26 January 2016 - 2 August 2016
Google scholar	*Castor canadensis* (11,600), Canadian beaver (933), North American beaver (1,190)	November 2015 - 2 August 2016

A1.2.2 Data acquisition on current distribution

Scientific publications retrieved with search engines (Table A1.1) and online databases (i.e., Global Invasive Species Database, Invasive Species Compendium and NOBANIS) were used to acquire data on the current distribution of *C. canadensis* (native and introduced range).

A1.3 Risk assessment and classification

A1.3.1 Selection of risk assessment methods

One of the aims of this project is to provide insight into the risks of *C. canadensis* to biodiversity and ecosystems in the EU. Assessments of ecological risks were therefore required and it was decided to apply both the Harmonia$^+$ and the ISEIA protocol for this purpose. In the current study, the Harmonia$^+$ protocol was used as it includes the assessment of impacts on socio-economic aspects, public health, infrastructure and ecosystem services, as well as the effects of climate change on the establishment, spread, and impacts of alien species. Moreover, the Harmonia$^+$ protocol complies with the criteria of the EU regulation 1143/2014. The ISEIA protocol requires less detailed information on impacts to obtain a risk classification than Harmonia$^+$ and focuses on ecological impacts only. Additionally, classifications obtained for other alien species for the Netherlands using this protocol may be compared with our risk classification of *C. canadensis*. In the Netherlands, the ISEIA protocol has been most frequently used for the risk classification of alien species.

Harmonia$^+$ and ISEIA are protocols for risk screening and are primarily developed for assessing the negative effects of alien species. They do not consider positive effects, except the module on ecosystem services in the Harmonia$^+$ protocol. However, available information on positive effects of alien species has been included in the risk inventory (Chapter 2).

A1.3.2 Harmonia+ ecological risk assessment protocol

The Harmonia+ protocol includes procedures for the risk assessment of potentially invasive alien plant and animal species. This protocol stems from a review of the ISEIA protocol and incorporates all stages of invasion and different types of impacts. The online version of the Harmonia+ protocol (D'hondt et al. 2014, 2015) was used for the risk assessment of *C. canadensis*. All risk scores were calculated using this online version. This risk assessment method comprises 41 questions grouped in the following modules:

A0. Context (assessor, area and organism);
A1. Introduction (probability of the organism to be introduced into the area);
A2. Establishment (does the area provide suitable climate and habitat);
A3. Spread (risks of dispersal within the area);
A4. Potential impact on the following subcategories:

- A4a. Environmental effects: wild animals and plants, habitats and ecosystems;
- A4b. Effects on cultivated plants;
- A4c. Effects on domesticated animals;
- A4d. Effects on human health;
- A4e. Effects on infrastructure;

A5a. Effects on ecosystem services;
A5b. Effects of climate change on the impact of the organism.

Each module contains one or more risk assessment questions and provides options for risk scores in each question. The protocol provides guidance for all questions and includes explanations and examples that serve as a reference for attributing risk scores.

Table A1.2: Concepts and definitions for risk assessments and classifications of alien species with the Harmonia+ protocol (D'hondt et al. 2014).

Conceptual framework

Invasion= f(*Introduction; Establishment; Spread; Impact*$_{a\text{-}g}$)

Risk = *Exposure* x *Likelihood* x *Impact*

Invasion = risk?

Exposure ≡ f_1(*Introduction;Establishment;Spread*) = ***Invasion score***

Likelihood x *Impact* ≡ f_2(*Impact*$_a$; *Impact*$_b$; *Impact*$_c$; *Impact*$_d$; *Impact*$_e$; *Impact*$_f$; *Impact*$_g$) = ***Impact score***

a: environment (biodiversity and ecosystems); b: cultivated plants; c. domesticated animals; d. human health; e: other; f: ecosystem services; g: climate change

Total risk = *Exposure* x *Likelihood* x *Impact* ≡ f_3(*Invasion score*; *Impact score*) = **Invasion**

Mathematical framework

f_1 : (weighed) geometric mean or product

f_2 : (weighed) arithmetic mean or maximum

f_3 : product

Table A1.2 shows the formulas used for the calculation of various risk scores. The protocol allows the assignment of various weighing factors to impact categories (i.e., weighing risks within and between categories). In order to prevent averaging of risks and to keep the highest score of each risk category visible, the highest score was always used to calculate final effect scores for a specific impact category. This 'one out all out' principle has also been used in other risk assessments of alien species (e.g., in ISEIA and the EPPO prioritizing schemes) and other policy domains (such as ecological status assessments of water bodies according to the European Water Framework directive). The default value 1 was always used for weighing between various impact categories (i.e., equal weighing). The product of the introduction, establishment and spread was used to calculate the invasion score. The maximum of the different impact scores was used to calculate the aggregated impact score.

The degree of certainty associated with a given risk was scored as a level of confidence. The level of confidence of risk scores has been consistently reported using low, medium and high, in accordance with the framework of Mastrandrea et al. (2010, 2011). Harmonia+ attributes values of 0, 0.5 and 1 to low, medium and high confidence, respectively, to calculate confidence levels for various impact categories. The cut-off values for risk scores and confidence levels used for the risk classification of *C. canadensis* in the EU are summarized in Table A1.3.

Table A1.3: Cut-off values for risk scores and confidence levels used for the risk classification of the North American beaver (*Castor canadensis*) in the EU, using the Harmonia+ protocol.

Colour code risk	Risk classification	Risk score (RS)*	Colour code confidence	Confidence	Confidence score (CS)*
	Low	<0.33		Low	<0.33
	Medium	0.33 ≤ RS ≤ 0.66		Medium	0.33 ≤ CS ≤ 0.66
	High	>0.66		High	>0.66

*: Arbitrary cut off values for distribution of risk scores between 0 and 1.

A1.3.3 ISEIA ecological risk assessment protocol

The ISEIA protocol assesses risks associated with dispersion potential, invasiveness and ecological impacts only (Branquart 2009a).

The ISEIA protocol contains twelve criteria that match the last steps of the invasion process (i.e., the potential for spread establishment, adverse impacts on native species and ecosystems). These criteria are divided over the following four risk sections: (1) dispersion potential or invasiveness, (2) colonisation of high conservation habitats, (3) adverse impacts on native species, and (4) alteration of ecosystem functions. Definitions for risk classifications relating to the four sections contained within the ISEIA protocol are presented in Table A1.4. Section 3 contains sub-sections referring to (i) predation / herbivory, (ii) interference and exploitation competition, (iii) transmission of diseases to native species (parasites, pest organisms or pathogens), and (iv) genetic effects such as hybridization and introgression with related native species. Section 4 contains sub-sections referring to (i) modifications in nutrient cycling or resource pools, (ii) physical modifications to habitats (changes to hydrological regimes, increase in water turbidity, light interception, alteration of river banks, destruction of fish nursery areas, etc.), (iii) modifications to natural successions and (iv) disruption to food-webs, i.e., a modification to lower trophic levels through herbivory or predation (top-down regulation) leading to ecosystem imbalance.

Each criterion of the ISEIA protocol was scored by five experts (§1.3.4). The scores range from 1 (low risk) to 2 (medium risk) and 3 (high risk). If information obtained from the literature review was insufficient for the derivation of a risk score, then the risk score was based on best professional judgement and field observation leading to a score of 1 (unlikely) or 2 (likely). If no answer could be given to a particular question (no information) a score of 1 was given (DD - deficient data). This is the minimum score that can be applied in any risk category. In cases with data or knowledge limitations, periodical review of new literature and updates of risk scores will be recommended. Finally, the highest score within each section was used to calculate the total ISEIA risk score for the species.

Table A1.4: Definitions of criteria for risk classifications per section used in the ecological risk assessment protocol (Branquart 2009a).

1. Dispersion potential or invasiveness risk	
Low	The species does not spread in the environment because of poor dispersal capacities and a low reproduction potential.
Medium	Except when assisted by man, the species doesn't colonise remote places. Natural dispersal rarely exceeds more than 1 km per year. However, the species can become locally invasive because of a strong reproduction potential.
High	The species is highly fecund, can easily disperse through active or passive means over distances > 1km / year and initiate new populations. Are to be considered here plant species that take advantage of anemochory, hydrochory and zoochory, insects like *Harmonia axyridis* or *Cemeraria ohridella* and all bird species.
2. Colonisation of high conservation habitats risk	
Low	Population of the alien species are restricted to man-made habitats (low conservation value).
Medium	Populations of the alien species are usually confined to habitats with a low or a medium conservation value and may occasionally colonise high conservation habitats.
High	The alien species often colonises high conservation value habitats (i.e., most of the sites of a given habitat are likely to be readily colonised by the species when source populations are present in the vicinity) and makes therefore a potential threat for red-listed species.
3. Adverse impacts on native species risk	
Low	Data from invasion histories suggest that the negative impact on native populations is negligible.
Medium	The alien is known to cause local changes (<80%) in population abundance, growth or distribution of one or several native species, especially amongst common and ruderal species. The effect is usually considered as reversible.
High	The development of the alien species often causes local severe (>80%) population declines and the reduction of local species richness. At a regional scale, it can be considered as a factor for precipitating (rare) species decline. Those alien species form long standing populations and their impacts on native biodiversity are considered as hardly reversible. Examples: strong interspecific competition in plant communities mediated by allelopathic chemicals, intra-guild predation leading to local extinction of native species, transmission of new lethal diseases to native species.
4. Alteration of ecosystem functions risk	
Low	The impact on ecosystem processes and structures is considered negligible.
Medium	The impact on ecosystem processes and structures is moderate and considered as easily reversible.
High	The impact on ecosystem processes and structures is strong and difficult to reverse. Examples: alterations of physicochemical properties of water, facilitation of river bank erosion, prevention of natural regeneration of trees, destruction of river banks, reed beds and / or fish nursery areas and food web disruption.

Consideration was given to the future situation assuming no changes in management measures that will affect the invasiveness and impacts of this invasive plant. The risk assessment and classification of *C. canadensis* for the future situation was performed, with the assumption of a temperature increase of 2 ^{o}C in 2050, which reflects the IPCC scenarios for Climate Change (IPCC 2013) and unchanged policies on exotics in the EU member states.

Subsequently, the Belgian Forum Invasive Species (BFIS) list system for preventive and management actions was used to categorise the species of concern (Branquart 2009a). This list system was designed as a two dimensional ordination (Ecological impact * Invasion stage; Figure A1.1). The BFIS list system is based on guidelines proposed by the Convention on Biological Diversity (CBD decision VI/7) and the European Union strategy on invasive alien species.

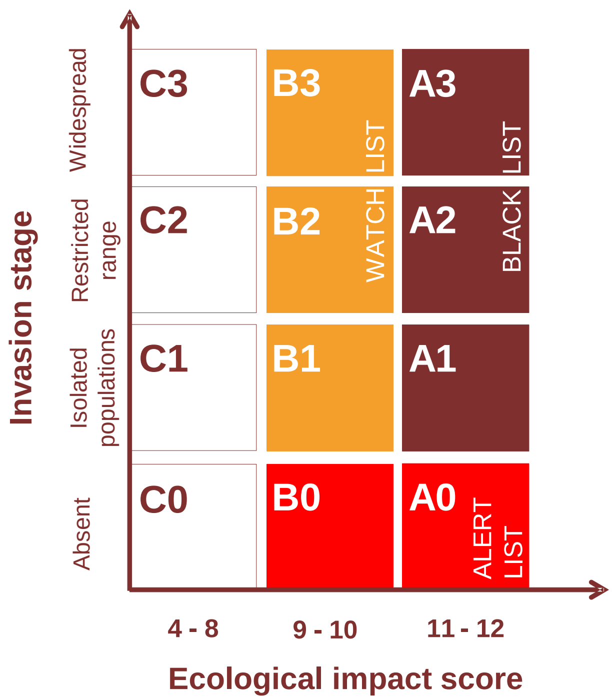

Figure A1.1: BFIS list system to identify species of most concern for preventive and mitigation action (Branquart 2009a; score 4-8: low risk; score 9-10: medium risk; score 11-12: high risk).

Ecological impact of the species was classified into a group represented by the letters A, B or C, which was based on the total ISEIA risk score: low ecological risk score 4-8 (C), moderate ecological risk score 9-10 (B - watch list) and high ecological risk score 11-12 (A - black list) (Figure A1.1). This letter was then combined with a number representing the invasion stage: (0) absent, (1) isolated populations, (2) restricted range, and (3) widespread. A cross was used to indicate the risk classification of the assessed species within the BFIS system. A black cross indicates a species that should appear on either the watch, alert or black list of the BFIS system (e.g., see figure 3.1).

A1.3.4 Expert meeting on risk classification

The risk assessments of *C. canadensis* have been performed by a team of five experts (Dr. E. Branquart, Ir. H. Hollander, Dr. R.S.E.W. Leuven, Dr. G. van der Velde and Dr. G.A. van Duinen), using the ISEIA and Harmonia$^+$ protocol. Each expert thoroughly reviewed the risk inventory (knowledge document). Subsequently, experts independently assessed and classified current and future risks of *C. canadensis*, using both protocols. Future risks were determined with respect to the potential effects of climate change on the introduction, establishment, spread and impacts of the species.

Following the individual assessment of experts, the entire team met, elucidated differences in risk scores, discussed diversity of risk scores and interpretations of key information during a risk assessment workshop. Discussion during the workshop led to agreement on consensus scores and a risk classification relating to both protocols. The consensus scores, risk classifications and justifications for the scores were described in a draft report that was reviewed by the project team, assuring full agreement with the outcomes of the risk assessments.

A1.3.5 Other available risk assessments and classifications

A specific literature search using Web of Science and Google (Scholar) was performed to retrieve other available risk assessments and classifications of *C. canadensis* (Table A1.1). Search terms applied were the scientific species name and English name combined with the following terms: risk, risk assessment, risk analyses and risk classification. The outcomes of these risk assessments and classifications were included in this report and compared for consistency with our risk classifications.

A1.4 Peer review by independent experts

The quality of this risk assessment was assured by an external peer review procedure. The final draft of this report was reviewed by two independent experts:

1. Prof. dr. B. Nolet, Foraging and Movement Ecology Group, Netherlands Institute of Ecology, Wageningen and Computational Geo-Ecology (IBED), University of Amsterdam, the Netherlands.
2. Dr. P. Nummi, Department of Forest Sciences, University of Helsinki, Finland.

Both experts critically reviewed the available data and information described in the risk inventory as well as the outcomes of the risk assessments. Special attention was focused on the justification of the risk classification and relevant scientific uncertainties. Appendix 3 summarizes all comments of the reviewers and how their remarks and suggestions were dealt with in this risk assessment.

Appendix 2 – Risk assessment for the Netherlands

Deze soort is niet bekend uit Nederland. Omdat de Noord-Amerikaanse bever (*Castor canadensis*) een andere soort is dan de inheemse bever (*Castor fiber*) en in diverse regio's binnen en buiten Europa als invasief wordt beschouwd, zullen waarschijnlijk geen bewuste introducties in Nederland plaatsvinden. Er is wel een kleine kans dat de Noord Amerikaanse bever vanuit Duitsland, België of Luxembourg via rivieren Nederland bereikt als de soort daar niet wordt geëlimineerd.

Het deskundigenpanel heeft de risico's van de *C. canadensis* ook voor Nederland geclassificeerd met behulp van het ISEIA protocol (Tabel A2.1 en A2.2). Voor uitleg over dit beoordelingsprotocol wordt verwezen naar Appendix A1.3.3). Risicoscores waren toegekend voor de situatie zonder de aanwezigheid van een populatie van de inheemse bever *C. fiber* en voor de situatie waarin een populatie van *C. fiber* wel aanwezig is. Verder zijn de risicoscores toegekend voor zowel de huidige situatie, als voor een toekomstige situatie met veranderd klimaat.

Tabel A2.1: Risicobeoordeling van de Noord-Amerikaanse bever (*Castor canadensis*) met behulp van het ISEIA protocol voor de huidige en toekomstige situatie van gebieden in Nederland zonder inheemse bever populatie.

Risicocategorie	Consensus scores	
Dispersie potentieel en invasiviteit		**3**
Kolonisatie van waardevolle habitats		**3**
Directe en indirecte negatieve effecten op inheemse soorten		**3**
1. Predatie/begrazing	2	
2. Verstoring en competitie	3	
3. Overdracht van parasieten en ziektes	DD	
4. Genetische effecten (hybridisatie / introgressie met inheemse soorten)	1	
Directe of indirecte verandering van ecosysteem functies		**3**
1. Modificatie van nutriëntencycli of hulpbronnenvoorraad	2	
2. Fysieke modificatie van habitat	3	
3. Modificatie van natuurlijke successie	3	
4. Ontwrichting voedselketens	3	
Totaal score		**12**
Verspreiding		**Afwezig**
Risicoclassificatie		**A0**

DD: data deficiëntie.

Huidige situatie

Voor situaties waar de inheemse bever (nog) niet aanwezig is, is voor alle vier onderdelen de risicoscore "hoog" (score 3) toegekend (Tabel A2.1). De totaalscore voor de risico's van de Noord Amerikaanse bever is 12. Dit is de maximum score en betekent dat de Noord Amerikaanse bever een invasieve exoot is met een hoog risico op negatieve effecten op biodiversiteit en ecosystemen. Gezien dit hoge risico en het gegeven dat deze soort zich nog niet heeft gevestigd in Nederland, komt de

Noord Amerikaanse bever volgens het BFIS systeem in aanmerking voor plaatsing op een alertlijst (Classificatie: **A0**).

Voor situaties waarin de inheemse bever aanwezig is, werden het risico van dispersie en invasiviteit en het risico van kolonisatie van waardevolle habitats “hoog” gescoord door het deskundigenteam (Tabel A2.2). Het risico van negatieve effecten op inheemse soorten werd als “matig” (score 2) gescoord en het risico van veranderingen van ecosysteemfuncties als “laag” (score 1), vanwege de effecten die de inheemse bever al heeft op zijn omgeving. De totaalscore voor de risico’s is in deze situatie 9. Gezien het matige risico van deze soort, die zich bovendien nog niet heeft gevestigd in Nederland, komt de soort volgens het BFIS systeem in aanmerking voor plaatsing op een aandachtlijst (Classificatie: **B0**).

Tabel A2.2: Risicobeoordeling van de Noord Amerikaanse bever (*Castor canadensis*) met behulp van het ISEIA protocol voor de huidige en toekomstige situatie van gebieden in Nederland met een inheemse bever populatie.

Risicocategorie		**Consensus scores**
Dispersie potentieel en invasiviteit		**3**
Kolonisatie van waardevolle habitats		**3**
Directe en indirecte negatieve effecten op inheemse soorten		**2**
1. Predatie/begrazing	1	
2. Verstoring en competitie	2	
3. Overdracht van parasieten en ziektes	DD	
4. Genetische effecten (hybridisatie / introgressie met inheemse soorten)	1	
Directe of indirecte verandering van ecosysteem functies		**1**
1. Modificatie van nutriëntencycli of hulpbronnenvoorraad	1	
2. Fysieke modificatie van habitat	1	
3. Modificatie van natuurlijke successie	1	
4. Ontwrichting voedselketens	1	
Totaal score		**9**
Verspreiding		**Afwezig**
Risicoclassificatie		**B0**

DD: data deficiëntie.

Het risico op dispersie en invasiviteit is als hoog geclassificeerd, vanwege de verspreidingsmogelijkheden van de soort via rivieren en de ruime aanwezigheid van geschikt habitat. Het risico op kolonisatie van waardevolle habitats wordt eveneens als hoog geclassificeerd, omdat de soort in Nederland de rivieren en allerlei daarmee verbonden wateren, oevers en moerassen kan bereiken, waaronder beschermde habitats. De risico’s van negatieve effecten op inheemse soorten en op ecosysteemfuncties worden beiden als hoog geclassificeerd. Als herbivoor heeft de soort een matig effect (score 2) op populaties van inheemse bomen en kruidachtige plantensoorten. Het risico van effecten op inheemse soorten is wel hoog door de impact die de soort heeft op de hydrologie van een gebied (inclusief overstroming) door de aanleg van dammen en daardoor ook op daarmee samenhangende abiotische en biotische omstandigheden. In situaties waar de inheemse bever al voorkomt, is het additionele effect van de Noord Amerikaanse bever via herbivorie gering. Omdat in de literatuur wordt aangegeven dat de Noord Amerikaanse bever actiever is met het bouwen van dammen, is de omvang van het additionele effect van de soort via beïnvloeding van de terreincondities matig. Er is geen risico op genetische effecten omdat hybridisatie met de inheemse bever *C. fiber* niet plaatsvindt.

Toekomstige situatie
Klimaatverandering zal naar verwachting geen gevolgen hebben voor de risico's dat deze soort zich vestigt, gezien de brede geografische en klimatologische range van het inheemse verspreidingsgebied van de Noord Amerikaanse bever, dat zich uitstrekt van arctisch gebied tot relatief droge en warme gebieden in het noorden van Mexico en het zuiden van de VS.

Vergelijking met risicoclassificatie voor EU
De classificatie van de risico's van de Noord Amerikaanse bever voor Nederland komt overeen met de classificatie voor de EU, behalve het feit dat de soort in Nederland niet voorkomt.

Appendix 3 – Quality assurance by peer review

The quality of this risk assessment was assured by an external peer review procedure. The independent experts Prof. Dr. B. Nolet (Foraging and Movement Ecology Group, Netherlands Institute of Ecology, Wageningen and Computational Geo-Ecology (IBED), University of Amsterdam, the Netherlands) and Dr. P. Nummi (Department of Forest Sciences, University of Helsinki, Finland) reviewed the final draft of this report. They assessed the available information used for the risk assessments and the outcome of the assessments, including the justifications for the risk classifications and scientific uncertainties.

The external reviewers generally agreed with the risk assessment because the conclusions are soundly based on the evidence presented. Their remarks mainly concerned the risk inventory and a few comments were related to the risk assessment. They delivered useful comments and suggestions for improvements to the risk inventory and assessment. All remarks and suggestions of the reviewers were implemented in the final version of this report. Textual inconsistency or indistinctness were corrected and clarified. The references were checked and correctly applied in the text and reference list.

Following the comments of reviewers, we clarified that *C. canadensis* and *C. fiber* are distinguished as separate beaver species and that there is no agreement to what extent *C. canadensis* outcompetes *C. fiber*. The argument relating to the mostly separate ranges of the two species in Finland was also included. Furthermore, in the risk assessment more emphasis was put on the differences between the level of potential risks of *C. canadensis* establishment for ecosystems and biodiversity in areas with and without (native) beavers.

In the description of biotic impacts we highlighted that there is a gap in knowledge regarding the potential transmission of diseases via *C. canadensis* to the native *C. fiber*. For clarification a description of Type B tularaemia was included and Type A tularaemia was excluded. This is because Type A is mainly associated with rabbits and not beavers. Furthermore, we contrasted the consequences of *C. canadensis*' overexploitation of trees in Chile and Argentina versus Europe.

In the risk inventory, *C. canadensis* population densities, dispersal rates and distances of *C. canadensis*, and the management of beavers in Scandinavia were addressed in more detail. The description of the current distribution of *C. canadensis* in the EU was improved and the overview of first observations and current status was updated according to the available scientific literature.