Appendix A

Harmonia+PL – procedure for negative impact risk assessment for invasive alien species and potentially invasive alien species in Poland

QUESTIONNAIRE

A0 | Context

Questions from this module identify the assessor and the biological, geographical & social context of the assessment.

a01. Name(s) of the assessor(s):

first name and family name

1. Magdalena Szymura
2. Katarzyna Bzdęga
3. Barbara Tokarska-Guzik

acomm01. Comments:

	degree	affiliation	assessment date
(1)	dr hab.	Division of Grassland and Green Areas Management, Institute of Agroecology and Plant Production, Wrocław University of Environmental and Life Sciences	28-02-2018
(2)	dr	Faculty of Biology and Environmental Protection, University of Silesia in Katowice	25-05-2018
(3)	prof. dr hab.	Faculty of Biology and Environmental Protection, University of Silesia in Katowice	21-03-2018

a02. Name(s) of ***the species*** under assessment:

Polish name: Nawłoć kanadyjska

Latin name: ***Solidago candensis*** L.

English name: Canadian goldenrod

Współfinansowano w ramach projektu nr POIS.02.04.00-00-0100/16 pn. *Opracowanie zasad kontroli i zwalczania inwazyjnych gatunków obcych wraz z przeprowadzeniem pilotażowych działań i edukacją społeczną* ze środków Unii Europejskiej w ramach Programu Infrastruktura i Środowisko 2014-2020

acomm02. Comments:

The Latin and Polish names are given according to the Krytyczna lista roślin naczyniowych Polski/Flowering plants and pteridophytes of Poland – a checklist (Mirek et al. 2002 – P). The taxon is also described under many other synonyms: *Solidago canadensis* subsp. *altissima* (L.) O. Bolos & Vigo, *Solidago canadensis* var. *arizonica* A. Gray, *Solidago canadensis* var. *bartramiana* Beaudry, *Solidago canadensis* f. *canadensis*, *Solidago canadensis* subsp. *canadensis*, *Solidago canadensis* var. *canadensis*, *Solidago canadensis* var. *canescens* A. Gray, *Solidago canadensis* subsp. *elongata* (Nutt.) D.D. Keck, *Solidago canadensis* var. *elongata* (Nutt.) M. Peck, *Solidago canadensis* var. *fallax* (Fernald) Beaudry, *Solidago canadensis* var. *gilvocanescens* Rydb., *Solidago canadensis* subsp. *gilvocanescens* (Rydb.) Á. Löve & D. Löve, *Solidago canadensis* var. *rupestris* (Raf.) Porter, *Solidago canadensis* subsp. *salebrosa* (Piper) D.D. Keck, *Solidago canadensis* var. *salebrosa* (Piper) M.E. Jones, *Solidago canadensis* var. *subserrata* (DC.) Cronquist (The Plant List 2013 – B).

The taxonomic affiliation and nomenclature of the species commonly referred to as goldenrods has been subject to many changes depending on the state of knowledge and authors' approach. *Solidago canadensis* is very variable in terms of morphological features, and its taxonomic status is still not clear and is difficult to define. In its native range, in North America, it is treated as a *S. canadensis* complex encompassing several different taxonomic units that have been classified as subspecies in the past (CABI 2018 – B). Former taxa, *S. canadensis* subsp. *altissima* or *S. canadensis* var. *scabra*, are now treated as one species of *S. altissima*, especially in Europe (Weber 1997, 2000 – P). European plants resemble the "*S. altissima*" morphology and although their origin in Europe was described by Scholtz (1993) and Weber (1997 – P), their taxonomic identity remains unclear. From several varieties described earlier, with the exception of *S. canadensis* var. *hargeri* (Harger's goldenrod), none currently has a species rank, and all were included in the *S. canadensis* complex (ITIS 2017, GBIF 2018 – B). Nevertheless, *Solidago canadensis* var. *lepida* (DC.) Cronquist is still considered a variety (The Plant List 2013 – B). Further research and taxonomic revision of the *S. canadensis* complex should be expected in the future. *S. canadensis* var. *canadensis* and *S. canadensis* var. *scabra* which is recognized as a separate species *S. altissima* (Rutkowski 2006 – P) are present in Poland. The described taxa can be distinguished by the micromorphological features of leaf epidermis (Szymura and Wolski 2011 – P). However, due to the high morphological variability of these taxa, the formation of hybrids, difficulties of separation, as well as the unexplained taxonomic status (Weber 2000 – P), they have been treated as a single species of *S. canadensis* in this study. *Solidago canadensis* forms hybrids with the native goldenrod *S. virgaurea*, named *Solidago × niederederi* (Pliszko 2013, Migdałek et al. 2014 – P).

Polish name (synonym I)	Polish name (synonym II)
–	–
Latin name (synonym I)	Latin name (synonym II)
Solidago canadensis subsp. altissima	*Solidago canadensis subsp. canadensis*
English name (synonym I)	English name (synonym II)
–	–

a03. **Area** under assessment:

Poland

acomm03. Comments:

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a04. **Status** of *the species* in Poland. *The species* is:

- [ ] native to Poland
- [ ] alien, absent from Poland
- [ ] alien, present in Poland only in cultivation or captivity

	alien, present in Poland in the environment, not established
X	alien, present in Poland in the environment, established

aconf01.	Answer provided with a	low	medium	high	level of confidence
				X	

acomm04. Comments:

Canadian goldenrod *Solidago canadensis* has the status of an invasive kenophyte in Poland (Tokarska-Guzik 2005 – P). In 2012, it was included in the group of alien, established and invasive species (Tokarska-Guzik et al. 2012 – P). The range of Canadian goldenrod covers almost the whole of Poland (Zając and Zając 2001 – P), with concentration of localities in the southern and south-western part. On the other hand, it has a smaller presence in the eastern part (Tokarska-Guzik et al. 2015 – I). These data, however, concern the species in the broad taxonomic approach of the last years of the twentieth century, when *S. canadensis* var. *scabra*, currently treated as the separate species *S. altissima*, was not distinguished. However, new studies in the south-western regions of the country (Lower Silesia) showed that the typical species *S. canadensis* occurs less frequently in comparison to *S. altissima*, at 21 and 116 localities, respectively (Szymura et al. 2015b – P). If such a narrow taxonomic approach is assumed, one should bear in mind that the distribution of *S. canadensis* requires verification in other regions of Poland (Tokarska-Guzik et al. 2015 – I).

a05. The impact of *the species* on major domains. *The species* may have an impact on:

X	the environmental domain
X	the cultivated plants domain
X	the domesticated animals domain
X	the human domain
X	the other domains

acomm05. Comments:

Canadian goldenrod, as with the giant goldenrod *S. gigantea*, directly affects the natural environment and is a serious threat to it (CABI 2018 – B), e.g. by creating dense and extensive single-species populations (Szymura and Szymura 2016 – P). The species is considered a harmful weed especially on river banks, wetlands, grasslands, the margins of dry meadows, as well as on railway and urban areas, and in managed forests and fallow fields (CABI 2018 – B). It occurs massively on improperly used pastures and fields, it is also troublesome in young forest plantations and in gardens and crops (Werner et al. 1980 – P). These long-lived goldenrods, with rapid clonal growth and efficient seed production (Weber 2003 – P), compete effectively with other plants for light, space and nutrients, leading to a reduction in the richness of the indigenous vascular plant flora (Groot et al. 2007, Fenesi et al. 2015a – P). They also adversely affect the richness, abundance and diversity of wild species of butterflies (Groot et al. 2007, Masło and Najberek 2014 – P), ants (Lenda et al. 2013 – P), insects in general (Moroń et al. 2009 – P) and birds (Skórka et al. 2010 – P) connected with, for example, the meadow habitats often occupied by goldenrods (Tokarska-Guzik et al. 2015 – I). At the same time, some beneficial importance of the biomass of Canadian goldenrod on the habitats occupied has been proved: they have been shown to be a feeding place for many species of spiders (Dudek et al. 2016 – P). *Solidago canadensis* has a negative effect on the reproduction of native plants pollinated by insects (Fenesi et al. 2015a – P). Goldenrods also limit the processes of spontaneous secondary succession in forest areas (Bornkamm 2007 – P) and abandoned fields (Fenesi et al. 2015a – P). The species shows strong allelopathic effects (Butcko et al. 2002, Dong et al. 2006, Abhilasha et al. 2008 – P). Although its allelopathic effect on species in the natural environment has not yet been proven, it probably limits and prevents seed germination of many native plant species by the release of allelopathic compounds that inhibit the growth of the other plants (Kabuce and Priede 2010 – B, Wang et al. 2016 – P). It has however been proved thatgoldenrod's allelopathic properties can effectively limit the development of soil pathogens (Zhang et al. 2009b – P), and thus facilitate the invasion of the species and reinforce its dominance in the areas occupied (Sun et al. 2006, Wang et al. 2006, Yuan et al.

– P). As a result of goldenrod invasion, homogenization of the landscape occurs, which is manifested by the presence of monocultures of the species covering extensive areas (Kabuce and Priede 2010 – B). Another negative factor is the ability of *Solidago canadensis* to hybridization with the native species of European goldenrod *Solidago virgaurea*, which may endanger the native species (Kabuce and Priede 2010 – B). Although rarely, Canadian goldenrod can act as a weed of annual crops; it can negatively affect arable crops, for example by overgrowing wheat fields and thereby cause crop losses (Gu et al. 2006 – P). In addition, the species is an alternative insect host, which can be the vector of crop plant pathogens (CABI 2018 – B). An investigation showed that here was no significant effect of Canadian goldenrod on the physicochemical properties of soil (Baranová et al. 2017 – P), yet it has been demonstrated that the presence of the species changessoil properties leading to an increase in the pH of the substrate, also increasing the content of nitrogen, carbon and organic substances, while reducing the inorganic nitrogen pool (Jianzhong et al. 2005 – P). The ability of *S. canadensis* to form mycorrhizae may lead to an increase in the availability of phosphorus, and thus facilitate goldenrod colonization of newly recultivated habitats (Jin et al. 2004 – P). Negative effects also include the impact of goldenrod on human and animal health (allergies, hay fever, impact on air and water quality) (Tokarska-Guzik et al. 2015 – I). Goldenrods decrease the attractiveness of tourist areas (Wasiłowska 1999 – P) through a negative impact on the landscape (Szymura and Wolski 2006 – P). In addition, goldenrod patches occurring massively along roads may limit visibility on road curves, obscure road signs or restrict access to water reservoirs, e.g. for anglers.

A1 | Introduction

Questions from this module assess the risk for *the species* to overcome geographical barriers and – if applicable – subsequent barriers of captivity or cultivation. This leads to *introduction*, defined as the entry of *the organism* to within the limits of *the area* and subsequently into the wild.

a06. The probability for ***the species*** to expand into Poland's natural environments, **as a result of self-propelled expansion** after its earlier introduction outside of the Polish territory is:

	low
	medium
X	high

aconf02.	Answer provided with a	low	medium	high **X**	level of confidence

acomm06. Comments:

Canadian goldenrod *Solidago canadensis* is an established species that spreads with light seeds which disperse over long distances, and then spreads in the affected habitats by rhizomes (Szymura and Szymura 2016b – P). It belongs to lists of highly invasive and troublesome plants in many countries (Tokarska-Guzik et al. 2012 – P, Tokarska-Guzik et al. 2015 – I). The species is already widespread in Poland, it is also present in most European Union countries and in countries neighbouring Poland which are not EU members, yet it can still migrate into Poland from border areas, from the Czech Republic, Slovakia and Germany, and then spread mainly through the dispersion of seeds with the wind, and vegetatively by rhizomes, also through water (Weber 2000, Nowak and Kącki 2009 – P, Tokarska-Guzik et al. 2015 – I, CABI 2018 – B) if the plants occur in the periphery of a watercourse.

a07. The probability for *the species* to be introduced into Poland's natural environments by **unintentional human actions** is:

	low
	medium
X	high

aconf03.	Answer provided with a	low	medium	high X	level of confidence

acomm07. Comments:

The spread of the species is associated with communication routes such as roads and railway lines.It is facilitated by the production of a large number of light seeds (Szymura et al. 2016 – P, Tokarska-Guzik et al. 2015 – I). The dispersion process is also facilitated by roadside habitats, where irregular disturbances (mowing, trampling) limit the growth of native species, leaving free space for goldenrod (Szymura 2012 – A). Canadian goldenrod can be introduced into the natural environment due to unintentional human activities together with the transport of soil containing plant fragments (seeds, rhizomes), which is then used e.g. during works related to the strengthening of banks, construction of roads, parking lots or even as land for gardens, etc. (CABI 2018 – B, Bzdęga 2014-2017 – A). The species can also be introduced with crop plants, e.g. cereal grains, if it the latter have been grown in or near the weed, and the seed material was not cleaned (Tokarska-Guzik et al. 2015 – I).

a08. The probability for *the species* to be introduced into Poland's natural environments by **intentional human actions** is:

	low
	medium
X	high

aconf04.	Answer provided with a	low	medium	high X	level of confidence

acomm08. Comments:

Canadian goldenrod was intentionally introduced into cultivation as an ornamental plant, due to its decorative qualities (shape and size of plants, attractive inflorescences) (Tokarska-Guzik 2005, Nowak and Kącki 2009 – P). It is also a highly valued nectar- and pollen-providing perennial plant, providing food to bees in the second half of Summer, when there is a deficiency of bee forage species. Its flowers are eagerly visited by honey bee worker bees, which is why they arouse great interest in beekeepers (Jabłoński 1992, Strzałkowska 2006a – P). Along with the giant goldenrod, this plant has been suggested for used in biomass production (Patrzałek et al. 2016, Biskupski et al. 2012 – P). These properties of Canadian goldenrod may contribute to its intentional spreading. In the Code of Good Practice "Horticulture against invasive plants of foreign origin" ("Ogrodnictwo wobec roślin inwazyjnych obcego pochodzenia"; General Directorate for Environmental Protection 2014 – I), the species was included in the list of plants used in horticulture toconsidered as invasive alien species, for which the need for non-introduction from sales and cultivation was agreed (Tokarska-Guzik et al. 2015 – I). However, Canadian goldenrod is still introduced into cultivation for ornamental purposes and as a honey plant, kept in home gardens, as well as in botanical gardens and arboretums. The presence of the species has been confirmed in a total of 40 gardens, arboretums and collections (Employees of botanical gardens ... 2018 – N). Goldenrod seeds and seedlings are still available for sale through catalogues and websites of commercial nurseries and botanical gardens, which may be the source of further introductions of the species (Nowak and Kącki 2009 – P, Tokarska-Guzik et al. 2015 – I, CABI 2018 – B). An example of the intentional introduction of plants is also collecting blooming shoots for decorative purposes, and then throwing them, for example, on landfills or often outside gardens, e.g. onto river banks, from which they can then be transported downstream; especially during flood episodes; rhizome fragments can be transferred in the same way. This promotes the emergence of new sources of species introduction and further invasion (Kabuce and Priede 2010, CABI 2018 – B).

In addition, it cannot be ruled out that the species is still intentionally introduced by humans, especially in the urban environment (especialy into urban waste land), from where it can spread spontaneously (mainly vegetatively).

A2 | Establishment

Questions from this module assess the likelihood for *the species* to overcome survival and reproduction barriers. This leads to *establishment*, defined as the growth of a population to sufficient levels such that natural extinction within *the area* becomes highly unlikely.

a09. Poland provides **climate** that is:

	non-optimal
	sub-optimal
X	optimal for establishment of *the species*

aconf05.	Answer provided with a	low	medium	high **X**	level of confidence

acomm09. Comments:

Canadian goldenrod *Solidago canadensis* is native to North America (Hegi 1979 – P). In the USA, its range extends from North Dakota, south to Florida, Texas and Arizona, and in Canada from Nova Scotia to Ontario (Weber 2000 – P). It is located in the USA and Canada from 26°N and 45°N latitude, reaching 65° latitude in western Canada and Alaska (Weber 1998 – P). Potentially, it can colonize regions with a similar climate on other continents (Tokarska-Guzik et al. 2015 – I), up to 800 m above sea level (CABI 2018 – B). The Canadian goldenrod has been confirmed in most European countries, moreover in Australia, New Zealand, Japan, China and Taiwan (Nakagawa and Enomoto 1975, Weber 2000 – P, CABI 2018 – B). The colonization success of invasive goldenrod is associated with vegetative reproduction through rapid clonal growth of rhizomes. However, sexual reproduction through huge production of light seeds and effective spreading with wind in dry weather is necessary for long-distance spread and colonization of new areas (Weber 2000 – P). Seeds do not however play a significant role in spatial population growth (CABI 2018 – B). Seeds of produced in Europe do not require scarification, i.e. damage to seed or fruit cover to speed up sprouting, nor supercooling (Voser-Huber 1983 – P). The optimal germination temperature is 25-30°C (Werner et al. 1980 – P). Germination is common in abandoned fields and neglected meadows, and the most suitable conditions for germination are the intact surface of soils, on unmown meadows (CABI 2018 – B). The invasive success of the speciesmay also partly result from its ability to produce allelopathic compounds and their impact on native plant species, although some other plants may survive in its presence, e.g. rapeseed (Sun et al. 2006, Abhilasha et al. 2008 – P). Canadian goldenrod demonstrates relatively high tolerance towards climatic requirements; it can be found in a climate with both cool and hot summers, as well as with cool (-40 to -34°C), dry or wet winters (CABI 2018 – B). The similarity between the climate of Poland and the climate of both the natural and the secondary range of Canadian goldenrod ranges from 94 to 100%, which means that the climatic requirements of the species are met in Poland and do not constitute a significant obstacle to the spread of the species throughout the country; this is also confirmed by the current range of this species in the country (Tokarska-Guzik et al. 2015 – I).

a10. Poland provides **habitat** that is

	non-optimal
	sub-optimal
X	optimal for establishment of *the species*

aconf06.	Answer provided with a	low	medium	high **X**	level of confidence

acomm10. Comments:

In its homeland, Canadian goldenrod *Solidago canadensis,* appears on the edge of forests, roadsides, fallow fields and other wasteland. The species has a relatively high tolerance in terms of soil requirements (Werner et al. 1980, Weber and Jacobs 2005, Szymura and Szymura 2013 – P). In its secondary range, Canadian goldenrod exhibits a wide ecological

	amplitude and habitat spectrum. The species is an indicator of nutrient-rich clay soils (Oberdorfer 1994 – P), although it occurs on soils with different degrees of fertility, but requires well-light conditions. Soils with goldenrod presence are mostly rich in nutrients and humid, but the species can live on relatively poor ones, e.g. on the river banks or on wastelands (Weber 2000, Szymura and Szymura 2013 – P). Goldenrod reaches dominance more rapidly on nutrient-rich soils that contain clay (180-580 mg K/kg) than on sandy soils with low nutrient content (90-110 mg K/kg) (Bornkamm and Hennig 1982 – P). During a dry summer, annual plant shoots may die, while rhizomes survive, whereas long-term periods with excessive humidity or negative temperatures lead to flower death. The species is susceptible to long-term flooding (Weber 2000 – P). In its secondary range, it colonizes habitats similar to those occupied within the native range. It occurs both in semi-natural and natural, as well as in anthropogenic habitats, in forests, undergrowth, in valleys and on the river banks and water reservoirs, in dry and damp meadows, on embankments, dikes between ponds, in orchards, on roadsides and railway areas (Guzikowa and Maycock 1986 – P, EPPO 2004, CABI 2018 – B). *Solidago canadensis* is an established species in Poland, habitat conditions suitable for it are found throughout the entire country (Zając and Zając 2015, Szymura and Szymura 2016, Szymura et al. 2018 – P).

A3 | Spread

Questions from this module assess the risk of *the species* to overcoming dispersal barriers and (new) environmental barriers within Poland. This would lead to spread, in which vacant patches of suitable habitat become increasingly occupied from (an) already-established population(s) within Poland.

Note that spread is considered to be different from range expansions that stem from new introductions (covered by the Introduction module).

a11. The capacity of *the species* to disperse within Poland by natural means, **with no human assistance**, is:

	very low
	low
	medium
	high
X	very high

aconf07.	Answer provided with a	low	medium	high X	level of confidence

acomm11.	Comments: Dispersion from a single source (type A data). *Solidago canadensis* was brought to Europe from America in the seventeenth or eighteenth century as an ornamental plant, the first populations outside cultivation were recorded in 1850 (Wagenitz 1964, Weber 1998 – P). The effectiveness of goldenrod spread depends on the amount of seeds and vegetative parts available to initiate the development of the next generation, as well as the frequency and intensity of anthropogenic factors occurring which favour the colonization of new locations. The key vector for the propagation of goldenrod is the dispersion of the light fruits which fall near the mother plants, which are then transferred to new areas by wind, water or on animal hair (through anemo-, hydro- or epizochory). A single shoot can produce as much as, or more than, 10,000 seeds (Meyer and Schmid 1991, Weber 2000 – P). Seeds are necessary for long-distance spread and colonization. Experimental results obtained so far indicate the possibility of seeds spreading to a distance of up to 2.4 m away from the parent population at wind speed of up to 5 m/s (Tiébré et al. 1980 – P). Another vector for the propagation of goldenrod, although for short distances, is the dispersion of rhizome fragments with the involvement of water (Weber 2000, Nowak and Kącki 2009 – P, Tokarska-Guzik et al. 2015 – I, CABI 2018 – B). However, the role of rhizomes in populating new places is limited, their clonal growth ensures the growth of a population; individual clones are long-lived and can reach the age of 100 years (Weber 1998, Weber 2000 – P). About 309 shoots of goldenrod can be found in 1 m^2

(Kabuce and Priede 2010 – B). In the first stage of occupying a new area, Canadian goldenrod spreads using seeds bearing a flying apparatus, while as a part of an already occupied habitat, it grows mainly through rhizomes (Hartnett and Bazzaz 1985 – P, Bartha et al. 2014 – P, Fenesi et al. 2015b – P, Meyer and Schmid 1999a, b). Once the particular habitat is occupied, the population of the Canadian goldenrod remains on it for a long time. A single *S. canadensis* clonal colony can live 20-100 years (Whitham 1983 – P, Carson and Root 2000 – P).

Population expansion (type B data).
The rate of goldenrod proliferation is estimated at 741 km^2/year (Weber 2000 – P). Indirect conclusions can be drawn on the subject of migration, based on the increasing number of *S. canadensis* localities, but it should be taken into account that the results obtained so far mainly reflect the state of distribution examination. In Poland, the first mentions of Canadian goldenrod stocks come from the second half of the 19th century from the Lublin and Małopolska Uplands (Tokarska-Guzik 2003 – P). The species increased the area of its occurrence within 50 years from only 60 sites recorded in the middle of the 20th century, to 3,500 locations in 2009 (Tokarska-Guzik 2005, Nowak and Kącki 2009 – P). Over the last 15 years, there has been a further, rapid increase in the number of localities, with over 2,000 new ones being recorded, which, when translated into the cartogram units of the Distribution Atlas of Vascular Plants in Poland – ATPOL, results in the completion of a further 200 cartogram (10x10 km) fields (Zając and Zając 2015 – P).

In conclusion, the ability of the species to spread has been rated as very high due to the rate of spread. However, one should not exclude human participation in increasing the range of the species in this case.

a12. The frequency of the dispersal of *the species* within Poland by **human actions** is:

	low
	medium
X	high

aconf08.	Answer provided with a	low	medium	high **X**	level of confidence

acomm12. Comments:

Canadian goldenrod has generally been imported as an ornamental and melliferous plant. Nowadays, it is also planted deliberately in home gardens and green areas in cities (Szymura et al. 2015a – P). It is also maintained by beekeepers as a good source of late melliferous plants (Strzałkowska 2006a – P). In the Code of Good Practice "Horticulture against invasive plants of foreign origin" (“Ogrodnictwo wobec roślin inwazyjnych obcego pochodzenia”; General Directorate for Environmental Protection 2014 – I), the species *Solidago canadensis* was included in the list of invasive alien plant species used in horticulture, for which the need for their non-introduction via sales and cultivation was agreed (Tokarska -Guzik et al. 2015 – I). An analysis of the availability of seeds and seedlings of the Canadian goldenrod showed that they can be found in commercial offers in Podlasie (Mackiewicz 2015 – I). However, the decorative and utility qualities of the plant (its attractive appearance, large size, late flowering – benefit for bees) make it impossible to exclude intentional introduction by humans, including in other regions of the country, especially in urban environments (gardens, wastelands), from where the species can spread spontaneously. Species within the *Solidago* genus are similar in terms of biology and habitat they occupy, which is why in gardening, they are rarely distinguished at the species level and are often sold in garden stores and online auctions under the same name as *Solidago* sp. (Lenda et al. 2014 – P). It has been proven that in Poland the transport distances of invasive goldenrod were several times higher when the plants were ordered over the Internet than in case of their traditional sale; the average distance of the Internet shop from the buyer in case of *Solidago* plants, was estimated at about 150 km (Lenda et al. 2014 – P). It is also possible to consciously introduce goldenrod for the use of its biomass for energy purposes and for biogas production (Patrzałek et al. 2016, Biskupski et al. 2012 – P). Currently, shoots and inflorescences of plants are used in floristry (not recommended, particularly due to the

	possibility of creating new sites of introduction). Canadian goldenrod has spread in many parts of the country, in different types of habitats, creating a high probability of further spread of the species during various types of earthworks (e.g. construction of roads, power lines) and regulatory works (regulation of river channels, strengthening flood embankments) together with the earth, water, and equipment being used. In Poland, the species is established, which is why the frequency of spread of the species, with the participation of intentional and unintended human activities, has been rated as high.

A4a | Impact on the environmental domain

Questions from this module qualify the consequences of *the species* on wild animals and plants, habitats and ecosystems.

Impacts are linked to the conservation concern of targets. Native species that are of conservation concern refer to keystone species, protected and/or threatened species. See, for example, Red Lists, protected species lists, or Annex II of the 92/43/EWG Directive. Ecosystems that are of conservation concern refer to natural systems that are the habitat of many threatened species. These include natural forests, dry grasslands, natural rock outcrops, sand dunes, heathlands, peat bogs, marshes, rivers & ponds that have natural banks, and estuaries (Annex I of the 92/43/EWG Directive).

Native species population declines are considered at a local scale: limited decline is considered as a (mere) drop in numbers; severe decline is considered as (near) extinction. Similarly, limited ecosystem change is considered as transient and easily reversible; severe change is considered as persistent and hardly reversible.

a13. The effect of *the species* on native species, through **predation, parasitism or herbivory is**:

X	inapplicable
	low
	medium
	high

aconf09.	Answer provided with a	low	medium	high	level of confidence

acomm13.	Comments: The species is a plant. It does not affect native species by predation, parasitism or herbivory.

a14. The effect of *the species* on native species, through **competition** is:

	low
	medium
X	high

aconf10.	Answer provided with a	low	medium	high **X**	level of confidence

acomm14.	Comments: Canadian goldenrod *Solidago canadensis*,due to its greater growth dynamics and its ability to use existing habitat resources more efficiently, competes effectively with native plant species, including European goldenrod *Solidago virgaurea* or common tansy *Tanacetum vulgare,* as well as with other invasive goldenrods: giant goldenrod *S. gigantea* and grass-leaved goldenrod *S. graminifolia* (Szymura and Szymura 2016b – P). The species is characterized by very fast clonal growth which allows the creation of compact and dense single-species patches hindering the growth and regeneration of other plants and, as a result, leads to a reduction in native plant species richness (Groot et al. 2007, Hejda et al. 2009, Szymura and Szymura 2011, 2016a, Fenesi et al. 2015a, b – P). Canadian goldenrod may prevent seed germination of many native species, through the release of allelopathic compounds that inhibit the development of other plants (Kabuce and Priede 2010 – B, Wang et al. 2016 – P). Goldenrod's allelopathic properties also effectively limit the

development of soil pathogens (Zhang et al. 2009b – P). This promotes the invasion of the species and strengthens its dominance in the colonized areas (Sun et al. 2006, Wang et al. 2006, Abhilasha et al. 2008, Yuan and in 2013 – P), and then leads to homogenization of the landscape, i.e. the formation of single-species populations of goldenrod with a compact character and considerable species poverty (Kabuce and Priede 2010 – B). As a result of effective competition with native plant species, for light, space and nutrients in the substrate, Canadian goldenrod also contributes to reducing the number of pollinators, especially bees and hoverflies, visiting native plant flowers (indirect competition) (Moron et al. 2009, Fenesi et al. 2015a – P). However, the positive effect of *S. canadensis* on pollinators is manifested by the large amount of pollen and nectar supplied by goldenrods in late summer, which makes bumblebees and hoverflies eagerly pollinate them in August (indirect competition) (Fenesi et al. 2015a – P). In addition, it has been proven that insects belonging to many pollinator groups in meadow habitats (day butterflies, bees, hoverflies) are sensitive and leave the places occupied by invasive goldenrods because they are unable to thrive; goldenrods provide nectar, but they are not able to replace the repressed native melliferous species of plants in terms of both the diversity and the amount of nectar (Moron and in 2009 – P). There are known cases where in plots which include invasive plants, the diversity of pollinators decreased by up to 90% (Masło and Najberek 2014 – P).

a15. The effect of *the species* on native species, through **interbreeding** is:

	no / very low
	low
	medium
X	high
	very high

aconf11.	Answer provided with a	low	medium	high **X**	level of confidence

acomm15. Comments:

The hybridization of Canadian goldenrod *Solidago canadensis* with the native species: European goldenrod *S. virgaurea*, which occurs in Poland, leads to the creation of the cross-species hybrid *Solidago* × *niederederi* (Pliszko 2013, Migdałek et al. 2014, Pliszko and Zalewska-Gałosz 2016 – P). The hybrid has characteristics intermediate between its parents; it is probably common throughout the country and forms spontaneously in places where both parental species (Pliszko 2013 – P) are in contact, especially in young forest plantations and abandoned fields (Pliszko and Kostrakiewicz-Gierałt 2017 – P). It is not completely sterile (Nilsson 1976 – P); in addition to vegetative reproduction, through rhizome growth, it is able to create fertile fruits (achenes) (Pliszko and Kostrakiewicz-Gierałt 2017 – P). However, their number is limited due to reduced pollen fertility (Migdałek et al. 2014, Karpavičiene and Radušiene 2016 – P). The generative success of *S.* × *niederederi* depends on the presence of both parental species and pollinators (Nilsson 1976, Pagitza 2016 – P). The possibility of invasive goldenrod interbreeding with native European goldenrod *S. virgaurea* may pose a threat to it (Kabuce and Priede 2010 – B). In addition, observations in Poland have shown that the hybrid attracts many pollinating insects, and thus can compete effectively with native *S. virgaurea*, because its pollination biology promotes back-crossing and introgression (Pagitz 2016 – P). Outside Poland, the hybrid has been reported from several European countries, including Denmark, Norway, Sweden (Nilson 1976, Sunding 1989 – P), also several places in Austria and the United Kingdom (Burton 1980 – P). The climate model shows the possible spread of the taxon over almost all Europe (Jaźwa et al. 2018 – P). Assuming that *S. canadensis* occurs throughout Poland, including the entire area occupied by populations of *S. virgaurea* native species, the probability with which the species will hybridize with the native species should be estimated as high and the average effect gives a basis for determining the impact as "large". Because of that, it is recommended to check the known localities of this taxon (Jazwa et al. 2018 – P).

a16. The effect of *the species* on native species by **hosting pathogens or parasites** that are harmful to them is:

	very low
X	low
	medium
	high
	very high

aconf12.	Answer provided with a	low	medium **X**	high	level of confidence

acomm16. Comments:

Solidago canadensis was found to have many natural enemies in its native range, as opposed to a lack of them in its secondary range (CABI 2018 – B). In the native range (North America), 122 species of phytophagous species (herbivores) have been recognized on goldenrod plants (Fontes et al. 1994 – P). Out of these, only 14 are limited to the *Asteraceae* family as hosts, while eight were considered a potential source of biological control for plants of the *Solidago* genus. These include: *Eurosta* sp., which attack the plant roots, two species of beetles which feed on their leaves: *Ophralella sexvittata* and *Sparganothis distincta* are insects destroying the leaves; *Agromyzidae* sp., *Cremastobombotae solidaginis*, *Asteromyia carbonifera* and *Schizomyia racemicola* and *Schinia nundina* attack goldenrod flowers and seeds (Fontes et al. 1994 – P). In Europe, the pressure of herbivorous insects (phytophages) on goldenrod is low, e.g. in Switzerland there are 18 phytophagous feeding on Canadian goldenrod (Weber 2000 – P), but none of them is selective in relation to this particular invasive plant (Sheppard et al. 2006 – P). From the Canadian native range, no pathogenic and parasitic species of goldenrod have been transferred to Europe (Weber 2000 – P). Plants are often attacked by the powdery mildew *Erysiphe cichoracearum* (Weber 2000 – P). In addition, they can be a host to the parasitic insect *Nemorimyza posticata* (Pitkin et al. 2007 – B). The impact on native species has been identified as low because no common pathogens or parasites are known for both Canadian goldenrod and native species, but there are reasons to believe that there may actually be common pathogens. However, there is no more detailed data on the transmission of pathogens or parasites to native species.

a17. The effect of *the species* on ecosystem integrity, by **affecting its abiotic properties** is:

	low
X	medium
	high

aconf13.	Answer provided with a	low	medium	high **X**	level of confidence

acomm17. Comments:

The presence of Canadian goldenrod *Solidago canadensis* causes changes in the soil environment. The accumulation of toxic allelopathic compounds and a decrease in the concentration of macro- and micronutrients lead to changes in the physical and chemical properties of the soil (Jezierska-Domaradzka and Domaradzki 2012 – P). The influence of Canadian goldenrod is not considered to be significant (Baranová et al. 2017 – P), yet the invasion may create better soil conditions for the species by improving the microbial soil structure and functional diversity, which in turn promotes the growth of *S. canadensis* (Liao et al. 2013 – P). It has been shown that in areas of goldenrod occurrence, the soil is characterized by higher humidity and magnesium content, and a smaller share of humus, phosphorus and potassium (Baranová et al. 2017 – P). According to Jianzhong et al. (2005 – P) and Zhang et al. (2009a – P) presence of the species contributes to increasing the pH of the substrate and its nitrogen, carbon and organic substance content, while reducing the inorganic nitrogen pool. Goldenrod plants have an effect on the concentration and activity of soil microorganisms (Jianzhong et al. 2005, Zhang et al. 2009b, Paré et al. 2017 – P).

a18. The effect of *the species* on ecosystem integrity, by **affecting its biotic properties** is:

	low
	medium
X	high

aconf14.	Answer provided with a	low	medium	high X	level of confidence

acomm18. Comments:

Canadian goldenrod plants successfully compete with native plant species (Groot et al. 2007, Fenesi et al. 2015a – P). They also adversely affect the richness and abundance of fauna, including butterflies (Groot et al. 2007, Masło and Najberek 2014 – P), ants (Lenda et al. 2013 – P), insects in general (Moroń et al. 2009 – P) and birds (Skórka et al. 2010 – P) associated in particular with the meadow habitats which are often colonized by goldenrod (Tokarska-Guzik et al. 2015 – I). *Solidago canadensis* has negative effect on the reproduction of native plants pollinated by insects (Fenesi et al. 2015a – P). It also limits the processes of spontaneous secondary succession in forest areas (Bornkamm 2007 – P) and abandoned fields (Fenesi et al. 2015a – P). Strong allelopathic chemical substances produced by the species may inhibit the development and growth of other plants (Kabuce and Priede 2010 – B, Wang et al. 2016 – P), and moreover effectively limit the development of soil pathogens (Zhang et al. 2009b – P), thus facilitating the invasion of goldenrod outwards from occupied areas (Sun et al. 2006, Wang et al. 2006, Yuan et al. – P). The species demonstrates negative impacts on Natura 2000 natural habitats, particularly including: *Molinia* meadows on calcareous, peaty or clayey-silt-laden soils (*Molinion caeruleae*) (6410), hydrophilous tall herb fringe communities of plains and of montane to alpine levels (6430) and lowland hay meadows (*Alopecurus pratensis, Sanguisorba officinalis*) (6510) (Tokarska-Guzik et al. 2015 – I, Kopeć and Michalska-Hejduk 2016 – P). Plant species found in moist habitats are the most affected by goldenrod; moist forests and thickets, meadows and river banks, meadow and forest communities in forest-edge scrub, (Nowak and Kącki 2009 – P). Goldenrods consists of dense, homogeneous and species-poor phytocoenoses (Nowak and Kącki 2009, Kabuce and Priede 2010, Szymura and Szymura 2016 – P), often occupying extensive areas in meadow habitats, riverside valleys and riparian forests and undergrowth, causing changes in structure and functioning of these ecosystems (Nowak and Kącki 2009, Kopeć and Michalska-Hejduk 2016 – P). The species is considered a harmful weed also in wetlands, grasslands, the margins of dry meadows, as well as on railways and in urban areas, and inmanaged forests and fallowfields (CABI 2018 – B).

A4b | Impact on the cultivated plants domain

Questions from this module qualify the consequences of *the species* for cultivated plants (e.g. crops, pastures, horticultural stock).

For the questions from this module, consequence is considered ‘low’ when presence of *the species* in (or on) a population of target plants is sporadic and/or causes little damage. Harm is considered ‘medium’ when *the organism’s* development causes local yield (or plant) losses below 20%, and ‘high’ when losses range >20%.

a19. The effect of *the species* on cultivated plant targets through **herbivory or parasitism** is:

	inapplicable
X	very low
	low
	medium
	high
	very high

aconf15.	Answer provided with a	low	medium	high X	level of confidence

acomm19.	Comments: The species is a plant, it has no parasitic properties.

a20. The effect of *the species* on cultivated plant targets through **competition** is:

	inapplicable
	very low
	low
	medium
X	high
	very high

aconf16.	Answer provided with a	low	medium	high X	level of confidence

acomm20.	Comments: Invasive goldenrods can negatively affect crop plants due to intense clonal growth and strong phytotoxic activity via allelopathic compounds, which enables them rapidly to colonize new areas, including abandoned agricultural lands. Furthermore, although rarely, goldenrods may also appear as weeds in annual crops, causing losses in crop yields; there have been cases of overgrowth by Canadian goldenrods, e.g. in wheat fields in China (Gu et al. 2006 – P). There have been cases of infestation of energy willow crops by goldenrods (Szymura 2011 – A). The allelopathic properties of goldenrod effectively inhibit seed germination and root growth, e.g. in radishes and lettuce (Sawabe et al. 2000, Butcko and Jensen 2002, Wang et al. 2016 – P). They also reduce the feed values of hay obtained from meadows colonized by these invasive plants (Fenesi et al. 2015b, Świerszcz et al. 2017 – P). Extracts from *S. canadensis* also demonstrate positive effect by inhibiting the development of *Pythium ultimum* fungi and *Rhizoctonia solani* which attack tomato crops (Zhang et al. 2009b – P). Positive inhibitory effects of goldenrod extracts against *Streptomyces scabiei*, a soil pathogen responsible for scab disease in potato crops are also reported (Paré et al. 2017 – P). In addition, goldenrod effectively competes for pollinators (Moron et al. 2009 – P). Considering that the species is widespread in Poland and due to the structure of crops, it should be assumed that its impact is high (high probability × medium effect).

a21. The effect of *the species* on cultivated plant targets through **interbreeding** with related species, including the plants themselves is:

	inapplicable
	no / very low
	low
X	medium
	high
	very high

aconf17.	Answer provided with a	low	medium X	high	level of confidence

acomm21.	Comments: Canadian goldenrod *Solidago canadensis* may indirectly influence the condition and yield of pastures by hybridizing with the native *S. virgaurea* species, creating *Solidago* × *niederederi* hybrid populations (Pliszko 2013, Migdałek et al. 2014 – P). Although the occurrence of a hybrid does not seem to be permanent and widespread (Weber 2000 – P), the ability to cross with the native species of goldenrod may pose a threat to it (Kabuce and Priede 2010 – B). The presence of *Solidago* ×*niederederi* has been recorded in meadow communities, which reduces the quality of the yield. The hybrid has already reported outside Poland, e.g. in Denmark, Norway, Sweden (Nilson 1976, Sunding 1989 – P), Austria and the United Kingdom (Burton 1980 – P). An interspecific hybrid named *Solidago hybrida* is also known, formed from the cross between two invasive goldenrod species: *Solidago canadensis* and *S. gigantea* (Jakábová and Krejča 1982 – P). *Solidago hybrida* is cultivated in Poland as an

	ornamental plant, and is the most polliniferous species among goldenrods; it can produce up to 150 kg of pollen from 1 ha of crop (Strzałkowska 2006b – P). High probability × low effect = medium impact.

a22. The effect of *the species* on cultivated plant targets by **affecting the cultivation system's integrity** is:

	very low
	low
	medium
X	high
	very high

aconf18.	Answer provided with a	low	medium	high **X**	level of confidence

acomm22.	Comments: Canadian goldenrod *Solidago canadensis* is found in large numbers on improperly managed lands: pastures and arable lands, it is also troublesome in young forest plantations, gardens and crops (Werner et al. 1980 – P). The presence of the plants limits the processes of spontaneous secondary succession in forest areas (Bornkamm 2007 – P) and post-agricultural wastelands (Fenesi et al. 2015b – P). Although Canadian goldenrod is rarely a weed of annual crops, it can negatively affect crops, e.g. by the overgrowth of fields used for arable crops, thus causing losses in yields of e.g. wheat (Gu et al. 2006 – P). It has also been proven that the allelopathic properties of goldenrod effectively inhibit seed germination and root growth of many cultivated plant species, including radishes and lettuce (Sawabe et al. 2000, Butcko and Jensen 2002, Wang et al. 2016 – P). Furthermore, the invasion of goldenrod into meadow communities and the displacement of native species from these habitats leads to a decrease in the feed values of the hay obtained from meadows (Fenesi et al. 2015b, Świerszcz et al. 2017 – P). The unfavourable influence of Canadian goldenrod plants on, for example, the richness and diversity of natural populations of the insects (Moron et al. 2009 – P) or birds (Skórka et al. 2010 – P) often associated with meadow habitats (including grassland) occupied by goldenrods (Tokarska-Guzik et al. 2015 – I). Medium probability × large effect = large impact.

a23. The effect of *the species* on cultivated plant targets by hosting **pathogens or parasites** that are harmful to them is:

	very low
X	low
	medium
	high
	very high

aconf19.	Answer provided with a	low	medium **X**	high	level of confidence

acomm23.	Comments: Canadian *goldenrod Solidago canadensis* is an alternative host for insects which can be vectors of plant pathogens and crop insect pests (Kabuce and Priede 2010, CABI 2018 – B). However, there is insufficient data on the effect of the species on crops associated with the fact that it is a host or vector of pathogens and parasites harmful to these plants (Kabuce and Priede 2010, CABI 2018 – B). Plants are often attacked by powdery mildew *Erysiphe cichoracearum* (Weber 2000 – P). In addition, they can be a host to the parasitic insect *Nemorimyza posticata* (Pitkin et al. 2007 – B). Due to the fact that the species is probably a host to pathogens and parasites which are harmful to crops, but have not yet been identified, the impact has been assessed as low.

A4c | Impact on the domesticated animals domain

Questions from this module qualify the consequences of *the organism* on domesticated animals (e.g. production animals, companion animals). It deals with both the well-being of individual animals and the productivity of animal populations.

a24. The effect of *the species* on individual animal health or animal production, through **predation or parasitism** is:

X	inapplicable
	very low
	low
	medium
	high
	very high

aconf20.	Answer provided with a	low	medium	high	level of confidence

acomm24. Comments:

The species is a plant.

a25. The effect of *the species* on individual animal health or animal production, by having properties that are hazardous upon **contact**, is:

	very low
	low
X	medium
	high
	very high

aconf21.	Answer provided with a	low	medium	high X	level of confidence

acomm25. Comments:

Canadian goldenrod *Solidago canadensis*, also other goldenrods, contains compounds from the group of diterpenes, several of which are polyacetyl derivatives demonstrating seasonal variations and acting as substances inhibiting the growth of other organisms or as a "weapon" against insects (Weber 2000 – P). At the same time, these compounds have a negative effect on the quality of fodder obtained from meadows invaded by by goldenrod, and animals fed with hay with a high content of goldenrod may be susceptible to poisoning; cases of fatal poisoning in horses have been recorded, e.g. in Germany (Chizzola and Brandstätter 2006 – P). Many goldenrod species are also poisonous for cattle (Łuczaj 2004 – P).

Medium probability × medium effect = medium impact.

a26. The effect of *the species* on individual animal health or animal production, by hosting **pathogens or parasites** that are harmful to them, is:

X	inapplicable
	very low
	low
	medium
	high
	very high

aconf22.	Answer provided with a	low	medium	high	level of confidence

acomm26. Comments:

The species is a plant. Plants are not hosts nor vectors of animal parasites/pathogens.

A4d | Impact on the human domain

Questions from this module qualify the consequences of *the organism* on humans. It deals with human health, being defined as a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity (definition adopted from the World Health Organization).

a27. The effect of *the species* on human health through **parasitism** is:

X	inapplicable
	very low
	low
	medium
	high
	vert high

aconf23.	Answer provided with a	low	medium	high	level of confidence

acomm27. Comments:

The species is not a parasitic organism.

a28. The effect of *the species* on human health, by having properties that are hazardous upon **contact**, is:

	very low
X	low
	medium
	high
	very high

aconf24.	Answer provided with a	low	medium	high X	level of confidence

acomm28. Comments:

Canadian goldenrod can adversely affect human and animal health by causing allergies, hay fever, and also by adversely affecting the quality of air and water (Tokarska-Guzik et al. 2015 – I). However, the heavy and sticky pollen is transported by insects or washed away with raindrops when deposited near plants. It may, rarely, be troublesome for susceptible persons, especially during windy and dry weather (Frankton 1963 – P). No other negative effects on human health are known (Kabuce and Priede 2010 – B).

a29. The effect of *the species* on human health, by hosting **pathogens or parasites** that are harmful to humans, is:

X	inapplicable
	very low
	low
	medium
	high
	very high

aconf25.	Answer provided with a	low	medium	high	level of confidence

acomm29. Comments:

The species is a plant. Plants are not hosts or vectors of human parasites/pathogens.

A4e | Impact on other domains

Questions from this module qualify the consequences of *the species* on targets not considered in modules A4a-d.

a30. The effect of *the species* on causing damage to **infrastructure** is:

	very low
	low
	medium
X	high
	very high

aconf26.	Answer provided with a	low	medium	high X	level of confidence

acomm30.	Comments: Goldenrods negatively affect the area of meadows and pastures; in meadows defined as valuable (maintained as part of packages 4 and 5 of the agro-environmental programme – so-called nature packages, i.e. subsidies for farmers for extensive use of meadows and pastures consisting of reducing fertilization and number of mowings or grazing intensity, in order to preserve valuable habitats and endangered species of birds), therefore they should be actively eliminated (Świerszcz et al. 2017 – P). Goldenrods also cause a decrease in the attractiveness to tourists of the area due to a negative effect on the landscape (Wasiłowska 1999, Szymura and Wolski 2006 – P). Goldenrod stands occurring massively along roads may also limit visibility on road curves, screen road signs or restrict access to water reservoirs, e.g. for anglers. High probability × medium consequences = high impact.

A5a | Impact on ecosystem services

Questions from this module qualify the consequences of *the organism* on ecosystem services. Ecosystem services are classified according to the Common International Classification of Ecosystem Services, which also includes many examples (CICES Version 4.3). Note that the answers to these questions are not used in the calculation of the overall risk score (which deals with ecosystems in a different way), but can be considered when decisions are made about management of *the species*.

a31. The effect of *the species* on **provisioning services** is:

	significantly negative
X	moderately negative
	neutral
	moderately positive
	significantly positive

aconf27.	Answer provided with a	low	medium	high X	level of confidence

acomm31.	Comments: Goldenrods may cause a decrease in the productive value of meadows and pastures (Świerszcz et al. 2017 – P). At the same time, the presence of Canadian goldenrod can be perceived as beneficial, for example by owners of apiaries, due to the melliferous properties of the plant and its late blooming. However, the continuous availability of goldenrod flowers in autumn disturbs the cycle of bees entering in their overwintering condition, which results in reduced survival after winter (Tepedino et al. 2008, Masło and Najberek 2014 – P). Goldenrods are also included in the group of species potentially possible to use in the production of biomass for the purposes of renewable energy production (Jezierska-Domaradzka and Domaradzki 2012 – P). They are characterized by high yields of green biomass, which can be obtained without major expenditure, also by low content of heavy metals in stems and leaves, high energy value and the high amount of biogas obtained from

	the plants. For this purpose, harvesting from post-industrial wastelands dominated by them has been considered (Patrzałek et al. 2016 – P). The average value of the heat of combustion and the average heating value of the goldenrod are comparable with the values for lignite and are: 16.56 MJ/kg-1 and 18.18 MJ/kg-1, respectively (Patrzałek et al. 2016 – P). Simultaneously, 1000 kg of fresh goldenrod leaves and stem can provide 173.8 and 188.1 m^3 of biogas (methane), respectively. The amount of biogas obtained from goldenrod is comparable to the amount obtained from other crops, such as shredded corn cobs or cereal grains, but for economic reasons it seems more profitable to obtain biogas from goldenrod (Lookrzek et al. 2016 – P). Studies by Solymosi (1994 – P), Dong et al. (2006 – P), as well as Abhilasha et al. (2008 – P), demonstrated the phytotoxic effect of Canadian goldenrod, which makes it possible to use it as a natural herbicide. The plant also contains compounds that are useful for combating fungal pathogens. extracts from the roots and rhizomes of *S. canadensis* significantly inhibit growth and pathogenic activity of e.g. *Pythium ultimum* and *Rhizoctonia solani* on tomatoes (Zhang et al. 2009b – P) or *Streptomyces scabiei*, causing scab in potato crops (Paré et al. 2017 – P). At the same time, however, these compounds facilitate invasion by the species and reinforce its dominance in the colonized areas (Sun et al. 2006, Wang et al. 2006, Yuan et al. 2013 – P). Goldenrods are also popular in phytotherapy. Due to the content of specific chemical compounds (including triterpene saponins, flavonoids, chlorogenic acid, carotenoids): Canadian goldenrod herb at a low dose has diuretic, relaxing and anti-inflammatory properties (Strzelecka and Kowalski 2000 – P). In addition, it is probably possible to consume boiled young goldenrod leaves and shoots with flowers. The native Americans collected seeds and consumed boiled roots (Luczaj 2004 – P). Canadian goldenrod is considered to be a valuable melliferous plant and is still used as such by beekeepers, e.g. in north-eastern Croatia (Stefanic et al. 2003 – P).

a32. The effect of *the species* on **regulation and maintenance services** is:

	significantly negative
X	moderately negative
	neutral
	moderately positive
	significantly positive

aconf28.	Answer provided with a	low	medium	high **X**	level of confidence

acomm32.	Comments:
	Canadian goldenrod has a moderately negative impact on regulatory services. In one study, although there was no significant impact of the species on the physico-chemical properties of the soil or the dependence between its presence and changes in soil properties, in places where the Canadian goldenrod was present, the soil was characterized by higher humidity and magnesium content, and a smaller share of humus, phosphorus and potassium (Baranová et al. 2017 – P). The presence of the species also contributes to increasing the pH of the substrate, nitrogen, carbon and organic substance content (Jianzhong et al. 2005, Zhang et al. 2009a – P). On the other hand, the secretion of organic acids by *S. canadensis* roots, as well as the ability of the species to interact with mycorrhizal fungi (species of the *Glomus* genus), may contribute to increasing the availability of phosphorus in soil (Frossard et al. 1995, Geelhoed et al. 1999 – P), and thus facilitate goldenrod colonization of newly recultivated habitats (Jin et al. 2004 – P). Allelopathic chemical compounds produced by *S. canadensis* inhibit seed germination and growth in other plants (Kabuce and Priede 2010 – P, Wang et al. 2016 – P), and also effectively limit the development of soil pathogens (Zhang et al. 2009b – P) thus facilitating the invasion of the species (Sun et al. 2006, Wang et al. 2006, Yuan et al. – P). The use of Canadian goldenrod acetone extracts as a means to control weeds is also known; they are effective when used in large quantities (50-200 ml/12.5 m^2), and their breakdown in the soil occurs in less than 2 months (Solymosi 1994 – P). Nevertheless, the final assessment, summarizing the *S. canadensis* impact on regulatory services remains moderately negative.

a33. The effect of *the species* on **cultural services** is:

	significantly negative
X	moderately negative
	neutral
	moderately positive
	significantly positive

aconf29.	Answer provided with a	low	medium	high X	level of confidence

acomm33. Comments:

Canadian goldenrod affects negatively the attractiveness of the landscape (Szymura and Wolski 2006 – P) creating dense, extensive patches, often occupying large areas, including in recreational and tourist areas, e.g. on the banks of rivers and water reservoirs, limiting access to water (Bzdęga 2015 – A), also along tourist routes (Wasiłowska 1999 – P, Bzdęga 2014-2017 – A). The presence of tall plants along roads may reduce visibility and cause a threat to road safety. At the same time, the plant has decorative and utility values. Stems with Canadian goldenrod inflorescences are used as a decorative element in flower arranging (Bzdęga 2014 – A). They are often also a part of bouquets blessed on the day of Our Lady of Herbs (August 15) in Roman Catholic churches in Poland (Łuczaj 2011, 2013 – P). In addition, the healing properties of the goldenrod have been known for centuries; extracts from dry shoots collected at the beginning of flowering have been used in phytotherapy as a urological and anti-inflammatory agent (Apati et al. 2003 – P). Some compounds obtained from the roots of goldenrod inhibit the growth of cancer cells (Matsunaga et al. 1990, Lu et al. 2006 – P).

A5b | Effect of climate change on the risk assessment of the negative impact of *the species*

Below, each of the Harmonia[+PL] modules is revisited under the premise of the future climate. The proposed time horizon is the mid-21st century. We suggest taking into account the reports of the Intergovernmental Panel on Climate Change. Specifically, the expected changes in atmospheric variables listed in its 2013 report on the physical science basis may be used for this purpose. The global temperature is expected to rise by 1 to 2°C by 2046-2065.

Note that the answers to these questions are not used in the calculation of the overall risk score, but can be but can be considered when decisions are made about management of *the species*.

a34. INTRODUCTION – Due to climate change, the probability for *the species* to overcome geographical barriers and – if applicable – subsequent barriers of captivity or cultivation in Poland will:

	decrease significantly
	decrease moderately
X	not change
	increase moderately
	increase significantly

aconf30.	Answer provided with a	low	medium X	high	level of confidence

acomm34. Comments:

The species is already found in Poland (Tokarska-Guzik et al. 2012 – P). Assuming that in future the temperature will increase by 1-2°C, the probability that the species will overcome subsequent barriers related to its occurrence in Poland will not change. The wide geographical range of the occurrence of *Solidago canadensis* confirms the wide range of the species' tolerance with regard to climatic requirements. The range of species tolerance with regard to preferred climatic parameters is given by CABI (2018 – B). Assessment ofpotential *S. canadensis* distribution based on key bioclimatic variables (average daily temperature

	range, average temperature in the warmest three months, amount of precipitation in the driest month, and precipitation seasonality) assumes the probability of significant species spread which can be attributed to a relatively warmer and more humid future bioclimatic situation than at the moment (Xu et al. 2014 – P).

a35. ESTABLISHMENT – Due to climate change, the probability for *the species* to overcome barriers that have prevented its survival and reproduction in Poland will:

	decrease significantly
	decrease moderately
X	not change
	increase moderately
	increase significantly

aconf31.	Answer provided with a	low	medium **X**	high	level of confidence

acomm35.	Comments: The species is already established all over Poland (Tokarska-Guzik et al. 2012 – P). Assuming that in the future the temperature will increase by 1–2°C, the probability that the species will overcome next barriers related to subsistence and reproduction in Poland will not change. *Solidago canadensis* prefers both a warm temperate climate, with an average summer temperature >10°C anda winter temperature >0°C, as well as a warm temperate climate with a dry summer or a dry winter. The species also tolerates a continental climate with a dry summer or a dry winter with an average temperature of the hottest month above 10°C and the coldest below 0°C. It also copes well in tundra climate conditions where the average temperature of the warmest month is within the range of 1-10°C. The range of tolerance for the species to the preferred climatic parameters is given by CABI (2018 – B).

a36. SPREAD – Due to climate change, the probability for *the species* to overcome barriers that have prevented its spread in Poland will:

	decrease significantly
	decrease moderately
X	not change
	increase moderately
	increase significantly

aconf32.	Answer provided with a	low	medium **X**	high	level of confidence

acomm36.	Comments: Assuming that in the future the temperature will increase by 1-2°C, the probability that the species will overcome further barriers – which so far have prevented it from spreading in Poland – will not change. *Solidago canadensis* prefers both a warm temperate climate, with an average summer temperature >10°C and winter temperature >0°C, as well as a warm temperate climate with a dry summer or dry winter. The species also tolerates a continental climate with a dry summer or dry winter with an average temperature of the hottest month above 10°C, and of the coldest one below 0°C. It also copes well in tundra climate conditions where the average temperature of the warmest month is within the range of 1-10°C. The range of tolerance for the species to the preferred climatic parameters is provided by CABI (2018 – B). Analysis of the potential distribution of *S. canadensis* in Europe, based on 9 climatic variables reflecting the average annual temperature, rainfall and annual variations and the length of the vegetative season showed that the species may potentially occupy a much larger area in the future (Weber 2001 – P), although the species already occurs throughout the entire country (Zając and Zając 2001, Tokarska-Guzik et al. 2012 – P).

a37. IMPACT ON THE ENVIRONMENTAL DOMAIN – Due to climate change, the consequences of *the species* on wild animals and plants, habitats and ecosystems in Poland will:

	decrease significantly
	decrease moderately
X	not change
	increase moderately
	increase significantly

aconf33.	Answer provided with a	low	medium **X**	high	level of confidence

acomm37. Comments:

The species is already established (Tokarska-Guzik et al. 2012 – P) and occurs throughout Poland (Zając and Zając 2001 – P). It is assumed that due to climate change the effect of the described species on wild plants and animals – as well as habitats and ecosystems in Poland – will not change. *Solidago canadensis* prefers both a warm temperate climate, with an average summer temperature >10°C and winter temperature >0°C, as well as a warm temperate climate with a dry summer or dry winter. The species also tolerates a continental climate with a dry summer or a dry winter with an average temperature of the hottest month above 10°C, and of the coldest one below 0°C. It also copes well in tundra climate conditions where the average temperature of the warmest month is within the range of 1-10°C. The range of tolerance for the species to the preferred climatic parameters is provided by CABI (2018 – B). The potential effect of climate change on the impact of goldenrod on wild plant and animal populations may be related to their use by wild pollinators that benefit from late forage.

a38. IMPACT ON THE CULTIVATED PLANTS DOMAIN – Due to climate change, the consequences of *the species* on cultivated plants and plant domain in Poland will:

	decrease significantly
	decrease moderately
X	not change
	increase moderately
	increase significantly

aconf34.	Answer provided with a	low	medium **X**	high	level of confidence

acomm38. Comments:

The species is already established (Tokarska-Guzik et al. 2012 – P) and occurs throughout Poland (Zając and Zając 2001 – P). It is assumed that due to climate change the effect of the described species on crops or plant production in Poland will not change. *Solidago canadensis* prefers both a warm temperate climate, with an average summer temperature >10°C and a winter temperature >0°C, as well as a warm temperate climate with a dry summer or dry winter. The species also tolerates a continental climate with a dry summer or a dry winter with an average temperature of the hottest month above 10°C and the coldest below 0°C. It also copes well in tundra climate conditions where the average temperature of the warmest month is within the range of 1-10°C. The range of tolerance for the species to the preferred climatic parameters is given by CABI (2018 – B).

a39. IMPACT ON THE DOMESTICATED ANIMALS DOMAIN – Due to climate change, the consequences of *the species* on domesticated animals and animal production in Poland will:

	decrease significantly
	decrease moderately
X	not change
	increase moderately
	increase significantly

aconf35.	Answer provided with a	low	medium X	high	level of confidence

acomm39. Comments:

The species is already established (Tokarska-Guzik et al. 2012 – P) and occurs throughout Poland (Zając and Zając 2001 – P). It is assumed that due to climate change, the impact of the described species on livestock and household animals as well as animal production in Poland will not change. *Solidago canadensis* prefers both a warm temperate climate, with an average summer temperature >10°C and a winter temperature >0°C, as well as a warm temperate climate with a dry summer or a dry winter. The species also tolerates a continental climate with a dry summer or a dry winter with an average temperature of the hottest month above 10°C and the coldest below 0°C. It also copes well in tundra climate conditions where the average temperature of the warmest month is within the range of 1-10°C. The range of tolerance for the species to the preferred climatic parameters is given by CABI (2018 – B).

a40. IMPACT ON THE HUMAN DOMAIN – Due to climate change, the consequences of *the species* on human in Poland will:

	decrease significantly
	decrease moderately
X	not change
	increase moderately
	increase significantly

aconf36.	Answer provided with a	low	medium X	high	level of confidence

acomm40. Comments:

The species is already established (Tokarska-Guzik et al. 2012 – P) and occurs throughout Poland (Zając and Zając 2001 – P). It is assumed that due to climate change the effect of the described species on people in Poland will not change. *Solidago canadensis* prefers both a warm temperate climate, with an average summer temperature >10°C and a winter temperature >0°C, as well as a warm temperate climate with a dry summer or adry winter. The species also tolerates a continental climate with a dry summer or a dry winter with an average temperature of the hottest month above 10°C and the coldest below 0°C. It also copes well in tundra climate conditions where the average temperature of the warmest month is within the range of 1-10°C. The range of tolerance for the species to the preferred climatic parameters is given by CABI (2018 – B).

a41. IMPACT ON OTHER DOMAINS – Due to climate change, the consequences of *the species* on other domains in Poland will:

	decrease significantly
	decrease moderately
X	not change
	increase moderately
	increase significantly

aconf37.	Answer provided with a	low	medium X	high	level of confidence

acomm41. Comments:

The species is already established (Tokarska-Guzik et al. 2012 – P) and occurs throughout Poland (Zając and Zając 2001 – P). It is assumed that due to climate change the effect of the described species on other objects in Poland will not change. *Solidago canadensis* prefers both a warm temperate climate, with an average summer temperature >10°C and a winter temperature >0°C, as well as a warm temperate climate with a dry summer or a dry winter. The species also tolerates a continental climate with a dry summer or a dry winter with an average temperature of the hottest month above 10°C and the coldest below 0°C. It also copes well in tundra climate conditions where the average temperature of the warmest month is within the range of 1-10°C. The range of tolerance for the species to the preferred climatic parameters is given by CABI (2018 – B).

Summary

Module	Score	Confidence
Introduction (questions: a06-a08)	1.00	1.00
Establishment (questions: a09-a10)	1.00	1.00
Spread (questions: a11-a12)	1.00	1.00
Environmental impact (questions: a13-a18)	0.70	0.90
Cultivated plants impact (questions: a19-a23)	0.45	0.80
Domesticated animals impact (questions: a24-a26)	0.50	1.00
Human impact (questions: a27-a29)	0.25	1.00
Other impact (questions: a30)	0.75	1.00
Invasion (questions: a06-a12)	1.00	1.00
Impact (questions: a13-a30)	0.75	0.94
Overall risk score	0.75	
Category of invasiveness	moderately invasive alien species	

A6 | Comments

This assessment is based on information available at the time of its completion. It has to be taken into account, however, that biological invasions are, by definition, very dynamic and unpredictable. This unpredictability includes assessing the consequences of introductions of new alien species and detecting their negative impact. As a result, the assessment of the species may change in time. For this reason it is recommended that it regularly repeated.

acomm42. Comments:
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Data sources

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