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	23-03-2018
(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	27-03-2018

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

Polish name: Nawłoć późna

Latin name: ***Solidago gigantea*** Aiton

English name: Giant 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 (apart from those given below): *Solidago gigantea* subsp. *gigantea*, *Solidago gigantea* var. *gigantea*, *Solidago gigantea* var. *pitcheri* (Nutt.) Shinners, *Solidago gigantea* var. *salebrosa* (Piper) Friesner, *Solidago gigantea* subsp. *serotina* (Kuntze) McNeill, *Solidago gigantea* var. *serotina* (Kuntze) Cronquist, *Solidago gigantea* var. *shinnersii* Beaudry, *Solidago serotina* var. *gigantea* (Aiton) A. Gray, *Solidago serotinoides* A. & D. Löve, *Solidago shinnersii* (Beaudry) Beaudry, *Solidago* ×*leiophallax* Friesner (The Plant List 2013, CABI 2018 – B). Synonym of the English names (apart from those given below) is Early goldenrod (Stace 1997 – P).

The taxonomic affiliation and nomenclature of species commonly referred to as goldenrods has been subject to many changes depending on the state of knowledge and the authors' approach. *Solidago gigantea* belongs to the *S. canadensis* complex and to the subgenus *Triplinervae*. There is considerable taxonomic variation within the *Solidago* genus, and especially in the *S. canadensis* complex. Similarly, *S. gigantea* exhibits morphological variability, which is reflected in the number of varieties distinguished, e.g. plants found in Japan are described under the name *S. gigantea* Ait. var. *leiophylla* Fern. (Morita 2002 – P). However, it seems that *S. gigantea* is one of the more defined taxa in the *S. canadensis* complex (CABI 2018 – B). In Europe, as in the home range, *S. gigantea* has been found in the form of three cytotypes differing in the number of chromosomes (Jakobs 2004 – P), which together form the *S. gigantea* complex. These include: *S. gigantea* (2n = 18), *S. serotina* (2n = 36) and *S. shinnersii* (2n = 54) (Weber and Jakobs 2005 – P). According to current data, tetraploid populations are most commonly found in Europe (Schlaepfer et al. 2008a, 2008b, Szymura and Szymura 2013 – P).

Polish name (synonym I)	Polish name (synonym II)
Nawłoć olbrzymia	–
Latin name (synonym I)	**Latin name (synonym II)**
Solidago serotina	*Solidago pitcheri*
English name (synonym I)	**English name (synonym II)**
Late goldenrod	Smooth goldenrod

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:

Giant goldenrod *Solidago gigantea* 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 giant goldenrod covers almost entire Poland (Zając and Zając 2001 – P), with concentration of localities in the southern, south-western and western part. There are fewer localities in the northern part of the country and in higher mountain locations (Tokarska-Guzik et al. 2015 – I, Zając and Zając 2015 – P).

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:

Giant goldenrod, as with Canadian goldenrod *S. canadensis*, directly affects the natural environment and is a serious threat to it (Weber and Jakobs 2005 – P, CABI 2018 – B), e.g. by creating dense and single-species populations (Balogh 2001, Szymura and Szymura 2016a – P). The species is considered undesirable especially in unmown meadows, riverside habitats, wetlands, forest margins, also on railways and in urban areas and managed forests (Hartmann and Konold 1995, Botta-Dukát and Dancza 2001a, Weber 2003 – P). It occurs massively on improperly used pastures and fields, it is also troublesome in young forest plantations and in gardens and crops (CABI 2018 – B). Perennial and long-living goldenrods with intense clonal growth, efficient seed production, as well as high competitive ability (Weber 2003, Weber and Jakobs 2005, Güsewell et al. 2006 – P) quickly achieve domination and compete effectively with other plants leading to a reduction in the richness of the native flora (Weber and Jakobs 2005, Hejda et al. 2009, Szymura and Szymura 2011, Pál et al. 2015 – P). They also adversely affect the richness, abundance and diversity of wild species of butterflies (Masło and Najberek 2014 – P), ants (Lenda et al. 2013 – P), insects generally (Moroń et al. 2009 – P) and birds (Skórka et al. 2010 – P) connected with, for example, those meadow habitats often occupied by goldenrods (Tokarska-Guzik et al. 2015 – I). They pose a serious threat to phytocoenoses in protected areas (Otręba and Michalska 2014 – P). Giant goldenrod is rarely a weed of annual crops, because it can be controlled by agrotechnical measures, however, plants limit the processes of spontaneous secondary succession in forest areas (Bornkamm 2007 – P) and abandoned fields (Bartha et al. 2014 – P). The species also has an allelopathic effect, limiting seed germination and the growth of many plant species, by the release of chemical compounds (Pisula et al. 2010, Sekutowski et al. 2012, Baličević et al. 2015, Ravlić et al. 2015 – P). It has also been proved that successful restoration of native vegetation in areas previously colonized by *Solidago gigantea* is unlikely, due to changes in the composition of soil microorganisms that occurred as a result of the invasion (König et al. 2016 – 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. Another negative manifestation of the giant goldenrod invasion is the ability of the species to hybridization with the native European goldenrod species *Solidago virgaurea*, through which the latter may become be endangered (Gudžinskas and Žalneravičius 2016 – P). Giant goldenrod *Solidago gigantea* also forms interspecific hybrids with another invasive species: Canadian goldenrod *S. canadensis* (Jakábová and Krejča 1982 – P). The species is an alternative insect host and can thus be the vector of crop plant pathogens (CABI 2018 – B). No significant effect of giant goldenrod on most physicochemical properties of the soil have been found (Stefanowicz et al. 2017 – P), but it has been shown that the presence of the species, for example, increases the concentration of carbon and phosphorus in soil (Chapuis-Lardy et al. 2006, Koutika et al. 2007 – P) and reduces soil pH (Herr et al. 2007 – P). Coexistence of the species with arbuscular mycorrhizal fungi contributes to the biomass increase of the invasive plants as well as the phosphorous content (Kytovtita et al. 2003, Majewska et al. 2017 – P), whereas soil moisture increases the probability of mycorrhizal colonization (Young et al. 2000 – P, Majewska et al. 2017 – 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). Furthermore, goldenrod patches occurring massively along roads may limit visibility on road curves, screen 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:

Giant goldenrod *Solidago gigantea*, similarly to the Canadian goldenrod *S. canadensis*, is defined as an invasive plant and one treated as troublesome in many countries (Tokarska-Guzik et al. 2012 – P, Tokarska-Guzik et al. 2015 – I). The species is already widespread in Poland, it also occurs in most European countries, including those neighbouring Poland. It can still migrate into Poland from border areas, from the Czech Republic and Slovakia as well as from Germany and spreads mainly through the dispersion of seeds by wind, and vegetatively through rhizomes, fragments of which can be transferred with water (Weber and Jakobs 2005, Nowak and Kącki 2009 – P, Tokarska-Guzik et al. 2015 – I, CABI 2018 – B). *S. gigantea* diaspores "wandering" along river corridors were described in the literature as "*river valley-hikers* " (Ellenberg 1982 – P). Spontaneous spread of giant goldenrod may also take place with the participation of mammals that carry seeds on hair and by birds, especially blackbirds (Czarnecka et al. 2012 – P).

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:

Giant goldenrod *Solidago gigantea* can be introduced into the natural environment due to unintentional human activities with the transport of soil containing plant fragments (seeds, rhizomes), which is then used e.g. during works related to the strengthening of banks, watercourses and water reservoirs, 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. in meadow seed mixes or with cereal grains, if the desired seed was grown with or near the weed, and the material was not cleaned. It is also possible to carry the seeds together with road and rail transport (Tokarska-Guzik et al. 2015 – I). The dispersion process is also facilitated by roadside habitats, where irregular disturbances (e.g. mowing, trampling) limit the growth of native plant species, thus leaving space for goldenrod (Szymura 2012 – A). This promotes the formation of new sources of species introduction and further invasion (CABI 2018 – B).

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:

Giant goldenrod was intentionally introduced into cultivation as an ornamental plant, due to its decorative qualities (shape, attractive inflorescences) (Tokarska-Guzik 2005, Weber and Jakobs 2005 – P). It is also a highly valued nectar- and pollen-providing perennial plant, providing food for bees in the second half of summer, when there is a deficiency of bee forage (Stefanic et al. 2003 – P). Its flowers are eagerly visited by honey bees, bumblebees, beetles, which is why they arouse great interest in beekeepers (Jabłoński 1992 – P, CABI 2018 – B). Along with the Canadian goldenrod, it belongs to the group of biomass energy source plants (Biskupski et al. 2012 – P). These plant properties may contribute to their intentional spreading. In the Code of Good Practice "Horticulture in the face of 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 classified as invasive alien species, for which the need to prevent introduction in sales and from cultivation was agreed (Tokarska -Guzik et al. 2015 – I). However, giant goldenrod is still introduced into cultivation and kept in home gardens, as well as in botanical gardens and arboretums. The presence of the species has been confirmed in a total of 14 gardens and arboretums in Poland (Employees of botanical gardens ... 2018 – N). Even now, seeds and goldenrod seedlings are in the commercial offers of many online nurseries and nursery farms (Nowak and Kącki 2009, Lenda et al. 2014, Szymura et al. 2015a – P, Tokarska-Guzik et al. 2015 – I, CABI 2018 – B). An example of the intended introduction of plants is the collection of shoots in bloom 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 (e.g. into wastelands as well as into gardens), from where it can spread spontaneously to neighbouring areas.

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:

Giant goldenrod *Solidago gigantea* is native to North America (Hegi 1979 – P). The native range extends from the south-eastern and south-western regions of the USA to the north-western territory of Canada (Gleason and Cronquist 1991, Semple et al. 1999 – P), between 30° and 55° north latitude (CABI 2018 – B). Potentially it can colonize areas with a similar climates to those prevailing within the natural range (Tokarska-Guzik et al. 2015 – I). In Europe, the *S. gigantea* range extends from (sub-) southern to moderate and from sub-oceanic to subcontinental regions in the range of 42° N to 63° N latitude (Weber and Jakobs 2005 – P), located less than 1,200 m above sea level. (Polatschek 1997 – P, in the Polish part of the Carpathians, the localities reach up to 700 m above sea level – Zając and Zając 2015

– P), although sometimes it can be observed at higher altitudes (Weber and Jakobs 2005 – P). Giant goldenrod has been confirmed in most European countries, and furthermore in Australia, New Zealand, Japan, Korea, Russia, Hawaii and the Azores islands (Weber and Jakobs 2005 – P, Tokarska-Guzik et al. 2015 – I, CABI 2018 – B). A more oceanic climate with moderate temperatures in summer and winter promotes the growth of *S. gigantea*. Positive correlations have been found between average temperature and growth parameters, such as shoot height, inflorescence length or number of branches in the inflorescence (Voser-Huber 1983 – P). The invasive success of giant goldenrod is connected with vegetative reproduction through the rapid clonal growth of its rhizomes. However, sexual reproduction with the huge production of light seeds and their effective spreading with wind in dry weather is necessary for long-distance spread and the colonization of new areas (Weber 2003, Szymura et al. 2015b – P), but this does not play a significant role in spatial population growth (CABI 2018 – B). Seeds of European goldenrod plants do not require scarification, i.e. damage to seed or fruit cover nor undercooling to accelerate germination (Voser-Huber 1983 – P). The optimal germination temperature is above 24°C (Weber and Jakobs 2005 – 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 success of invasion by the species may also partly result from its ability to produce allelopathic compounds and their impact on other plant species (Pisula et al. 2010, Sekutowski et al. 2012, Baličević et al. 2015, Ravlić et al. 2015 – P). *Solidago gigantea* shows great tolerance towards climatic conditions; it can occur in areas with temperature as low as -23°C, in climates with cool or warm wet summers as well as cold or cool (wet or dry) winters (EPPO 2004 – B). The similarity between the climate of Poland and the climate of both the natural and the secondary range of giant 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	level of confidence
				X	

acomm10. Comments:

In its native range, the giant goldenrod *Solidago gigantea* is found on forest margins, roadsides, fallows and abandoned areas which it colonizes rapidly (Tokarska-Guzik et al. 2015 – I). It is considered as a typical swamp species and can often be found on peat bogs or along river banks. Its vitality is strongly limited in shade conditions; the plants form small populations then, with low shoot density and small inflorescences (Weber and Jakobs 2005 – P). The species has a high tolerance with regard to soil requirements, light, nutrient content, temperature and pH (Ellenberg et al., 2001, Voser-Huber 1983 – P). In its secondary range, giant goldenrod exhibits a wide ecological amplitude and habitat spectrum. In Europe, it colonizes habitats similar to those it occupies in its native range, but also drier, which is why it is characterized by a particularly wide range of soil moisture tolerance (Landolt 1977 – P). In moist and wet habitats it shows higher vitality than in dry places, which often results in the formation of dense single-species patches. In drier habitats *S. gigantea* often co-occurs with other species (Botta-Dukát and Dancza 2001a – P) and is less competitive in such conditions. Giant goldenrod responds to the stress associated with drought, reducing leaf area and thus total biomass (Botta-Dukát and Dancza 2001b – P). The species is very sensitive to flooding over longer periods of time (Hartmann and Konold 1995 – P). It prefers rather moist, nitrogen-rich soils, although it occurs in a wide range of soil fertility and can occupy dry places with low nutrient content, e.g. roadsides, embankments and wastelands (Weber and Jakobs 2005 – P). The increased content of nutrients in the soil corresponds with strong growth, especially of inflorescences and high seed production (Weber and Jakobs 2005 – P). *Solidago gigantea* prefers full

daylight, but it also occurs on shaded forest margins, and even in forests such as under the canopy of deciduous trees (Weber and Jakobs 2005 – P). Giant goldenrod is a highly plastic species; by adjusting its growth pattern, it responds to changes in environmental conditions (Jakobs 2004 – P), which facilitates tolerance of stress conditions and allows plants to occupy a wide spectrum of habitats, including heavily disturbed places (Weber and Jakobs 2005 – P). In the secondary range, the species occurs on unmown meadows, in humid places, on the banks of watercourses and water reservoirs, forest margins, roadsides, railway areas, etc. (Tokarska-Guzik et al. 2015 – I). The habitat spectrum of the species includes both natural and semi-natural habitats as well as human-altered habitats. It colonizes areas with a disturbed soil surface with particular ease (achenes quickly germinate here in the right period of the growing season) (Nowak and Kącki 2009 – P). The first places where goldenrod appears in meadow communities often include molehills or places with plant cover destroyed by off-road vehicles (Tokarska-Guzik et al. 2015 – I). Appropriate habitat conditions are met with all over Poland (Szymura and Szymura 2016, Zając and Zając 2015, 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	level of confidence
		X	

acomm11. Comments:

Dispersion from a single source (type A data).
The effectiveness of goldenrod spread depends on the amount of seeds and vegetative fragments that can initiate the development of the next generation, as well as the frequency and intensity of anthropogenic factors favouring the colonization of new locations. The key vector for the propagation of goldenrod is the dispersion of the light fruit transferred to new areas by wind, water, animal fur (via anemo-, hydro- or epizoochory) (Weber and Jakobs 2005 – P, Tokarska-Guzik et al. 2015 – I, CABI 2018 – B) or by birds (endozoochory) (Czarnecka et al. 2012 – P). A single shoot can produce as much as, or more than 19,000 seeds (Weber and Jakobs 2005 – P). Seeds are necessary for long-distance spread and the colonization of new locations. Experimental results obtained so far suggest the possibility of spreading seeds with the wind to a distance of 4 to as much as 136 m from the parent plant (Soons and Ozinga 2005, Vittoz and Engler 2007 – P). These distances can be multiplied under extreme weather events (strong winds). Another vector for the propagation of goldenrod, although only for short distances, is the dispersion of rhizome fragments with the involvement of water (Weber 2011, Weber and Jakobs 2005 – P, Tokarska-Guzik et al. 2015 – I, CABI 2018 – B). However, the role of rhizomes in establishing new sites is limited and decreases with the age of the clone; population growth by rhizomes is estimated at from 0.3 to 0.8 m/year (Gigon and Bocherens 1985, Weber and Jakobs 2005 – P). On the surface of 1 m^2 there can be from 29 to 167 goldenrod shoots, while the population can cover from a few to as many as 50,000 m^2 (Jakobs et al. 2004, Weber and Jakobs 2005 – P).

Population expansion (type B data).
The rate of goldenrod dispersion is estimated at 910 km^2/year (Weber 1998, Weber and Jakobs 2005 – P). Indirect conclusions can be drawn on the subject of migration, based on the increasing number of *S. gigantea* localities, but it should be taken into account that the results obtained so far mainly reflect the state of species distribution examination. In Poland, the first mentions of giant goldenrod localities come from the second half of the 19th century from the area of Lower Silesia (Tokarska-Guzik 2005 – P). Over 50 years, the species increased its range in Poland from only 150 sites recorded in the middle of the 20th century, to 5300 locations (Tokarska-Guzik 2005 – P). Current data from the Distribution Atlas of Vascular Plants in Poland (ATPOL) cover 9117 localities of the species, although the increase of localities is not transferred to a larger coverage of the country at the 10 × 10 km cartogram scale (Zając and Zając 2015 – P).

In conclusion, the ability of the species to disperse has been assessed as very high due to the rate of the phenomenon and the vectors participating in the dispersion of its diaspores (excluding human involvement).

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:

In the Code of Good Practice "Horticulture in the face of invasive plants of foreign origin" ("Ogrodnictwo wobec roślin inwazyjnych obcego pochodzenia" 2014 – I), the species *Solidago gigantea* was included in the list of plants used in horticulture defined as invasive alien species, for which the need for their non-introduction to sales and cultivation was agreed (Tokarska -Guzik et al. 2015 – I). An analysis of the availability of seeds and seedlings of the giant goldenrod showed that they can be found in a 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 in other regions of the country, especially in urban environments (urban gardens, wastelands), from where the species can spread spontaneously. Species within the *Solidago* genus are similar in terms of biology and the 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 of *Solidago* plants, was about 150 km (Lenda et al. 2014 – P). It is possible to consciously introduce goldenrod for the use of its biomass for energy purposes and for biogas production (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). Giant goldenrod has spread in many parts of the country, in different types of habitats, creating a high probability of further species dispersion 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, *S. gigantea* is both established in the wild and cultivated at the same time, therefore the frequency of species diaspore movement over distance greater than 50 km, with the involvement of intentional and unintended human activities, has been assessed 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 demonstrate these interaction types

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:

Giant goldenrod *Solidago gigantea* is characterized by high competitive abilities against indigenous plant species. It generates plants with intense rhizome growth, enormous seed production and effective spread of seed in the wind (Weber 2003, Weber and Jakobs 2005, Güsewell et al. 2006 – P). The species quickly dominates, creates dense monogeneous patches (Balogh 2001, Szymura and Szymura 2016a – P) leading to the reduction in native plants species richness (Weber and Jakobs 2005, Hejda et al. 2009, Szymura and Szymura 2011, Pál et al. 2015 – P). *Solidago gigantea* reacts plastically to interspecies competition, and the effect depends on the type of competition. Overground competition causes an increase in stem height and size of inflorescences in goldenrods, while underground competition stimulates the growth of their rhizomes (Weber and Jakobs 2005 – P). The morphological plasticity of the species is considered as an important factor favouring its invasiveness in Europe (Botta-Dukát and Dancza 2001a – P). In ruderal habitats colonized by giant goldenrod, there is a significant reduction in the diversity of species, whereas in dry meadows, which are often rich in species, the impact of invasive goldenrods is even more serious. The average number of species on meadows with goldenrod occurence is estimated at about 12 species which is almost two times lower compared to meadows without the occurence of the invasive plants (Schuldes 1988, Voser-Huber 1983 – P). The reduction concerns mainly species such as: yellow loosestrife *Lysimachia vulgaris*, common tormentil *Potentilla erecta*, betony *Betonica officinalis*, meadowsweet *Filipendula ulmaria*, small scabious *Scabiosa columbaria*, greater knapweed *Centaurea scabiosa*, clustered bellflower *Campanula glomerata* and devil's-bit scabious *Succisa pratensis*. More abundant species appear to be less susceptible to goldenrod invasion (Weber and Jakobs 2005 – P). In

the river valleys, dense populations of the giant goldenrod may suppress the development of riparian vegetation, where *S. gigantea* often occurs with other invasive species e.g. Himalayan balsam *Impatiens glandulifera*, giant hogweed *Heracleum mantegazzianum*, Japanese knotweed *Reynoutria japonica* and Jerusalem artichoke *Helianthus tuberosus*. Similarly, in the forests, the development of seedlings of native forest species may be hindered by dense single-species patches of the goldenrod (Zwölfer 1976 – P). The competitive impact of giant goldenrod also concerns insects belonging to the the pollinator groups of meadow habitats (day butterflies, bees, hoverflies). They are sensitive and leave the places occupied by invasive goldenrods; 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 the plots including 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	level of confidence
				X	

acomm15. Comments:

Giant goldenrod *Solidago gigantea* interbreeds with the Polish native European goldenrod species *S. virgaurea*, creating the cross-species hybrid *Solidago* × *snarskisii* (Gudžinskas and Žalneravičius 2016 – P). This was found in southern Lithuania in 2014, on an abandoned meadow with one of the *S. gigantea* parental species, while the second *S. virgaurea* parental species, was overgrowing sandy, xerothermic hills and the edge of the forest. The distance between *S. gigantea* and the population of *S. virgaurea* was about 50 meters (Gudžinskas and Žalneravičius 2016 – P). The hybrid demonstrates characteristics intermediate between its parents in terms of height and morphology; it is formed spontaneously by *S. gigantea* pollination with *S. virgaurea* pollen in the place where both parental species contact (Gudžinskas and Žalneravičius 2016 – P). *Solidago* × *snarskisii* flowers from the beginning of August to mid-September, almost simultaneously with *S. gigantea*, but, compared with *S. gigantea*, its flowering is extended by about two weeks. On the other hand, *S. virgaurea* begins flowering about two weeks earlier than *S.* ×*snarskisii* and, depending on weather conditions, it continues as late as until mid-October (Gudžinskas and Žalneravičius 2016 – P). Individuals of *S.* × *snarskisii* multiply through long and short rhizomes, similar to those of *S. gigantea*, therefore they can persist for a long time until the conditions become unfavourable. The production of vital seeds from the hybrid has not been recorded; all achenes collected were empty (Gudžinskas and Žalneravičius 2016 – P). The formation of the *S.* × *snarskisii* hybrids depends on the presence of both parent species and pollinators. Flowers of invasive goldenrods are intensively visited by bees, bumblebees and other insects, therefore the formation of hybrids is possible in contact zones, even if the ecology of the parent species is slightly different (Gudžinskas and Žalneravičius 2016 – P). In addition, invasive goldenrods can effectively compete for pollinators with native *S. virgaurea*, and their pollination biology may promote potential backcross interbreeding and introgression in the future. The ability to cross giant goldenrod with a native species and form hybrids could pose a real threat to *S. virgaurea* present on farmlands. Apart from Lithuania, the hybrid has not been reported in other regions of Europe, including Poland. There is also insufficient data on its distribution. Assuming that *S. gigantea* occurs throughout Poland, including in the area occupied by populations of the native species *S. virgaurea*, the probability with which the species will interbreed with the native species should be estimated as high, and the effect average, i.e. the impact is defined as large.

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:

In its native range, *Solidago gigantea* is attacked by a huge number of herbivorous insects, as opposed to a small group in the secondary range (Weber and Jakobs 2005 – P), 122 phytophagous species have been identified on giant goldenrod plants in the native range of the species in North America (Fontes et al. 1994 – P). Out of these, 14 are limited to the *Asteraceae* family as hosts, while eight insect species 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 feeding on their leaves: *Ophralella sexvittata* and *Sparganothis distincta* are insects destroying their leaves: *Agromyzidae* sp., *Cremastobombotae solidaginis*, *Asteromyia carbonifera* and *Schizomyia racemicola* and *Schinia nundina* attack goldenrod flowers and seeds (Fontes et al. 1994 – P). In the secondary range, more than 20 different species of insects found on the giant goldenrod have been identified, including bugs (meadow froghopper *Philaenus spumarius*), aphids (*Uroleucon caligatum* and *U. nigrotuberculatus*), beetles (*Trirhabda virgata* and *Exema canadensis*), as well as caterpillars and insects of leaf-feeding species (including *Asteromyia* sp.) (Meyer et al. 2005 – P) and others for which goldenrods are the hosts, e.g. moths (goldenrod gall moth *Epiblema scudderiana* and *Gnorimoschema gallae-solidaginis*) and midges (*Eurosta solidaginis* and *midges* from the *Rhopalomyia* genus) (Abrahamson et al. 2001 – P). However, the effect of herbivorous organisms on *S. gigantea* in Europe is extremely low and the impact is negligible (Jakobs et al. 2004 – P). There is evidence that, compared with North American goldenrod plants, European giant goldenrod plants have lower concentrations of monoterpenes and diterpenes in their leaves, and are therefore more susceptible to leaf caterpillars and pathogens (Meyer et al. 2005, Johnson et al. 2007, Hull-Sanders et al. 2007 – P). *Solidago gigantea* can be an alternative host for insects which are vectors of plant pathogens and insect pests of native plants (CABI 2018 – B). In the native range, the seeds and rhizomes of the goldenrod are attacked, for example, by fungal pathogens such as: *Puccinia dioicae* causing rust of leaves in goldenrod, powdery mildew (*Erysiphe cichoracearum*) and downy mildew (*Golovinomyces asterum* var. *Solidaginis*), recorded on goldenrod plants in Korea (Meyer et al. 2005 – P, CABI 2018 – B). In addition, invasive goldenrods can be a host to the parasitic insect *Nemorimyza posticata* (Pitkin et al. 2007 – B). Plants of the species are also hosts of bacterial pathogens of the genus *Xanthomonas* which attack the leaves of other invasive perennials (Meyer et al. 2005 – P, CABI 2018 – B) which are present on the EPPO A1 and EPPO A2 lists. However, there is insufficient data on which pathogen species have been identified on *S. gigantea* plants, as well as no more detailed data on the transfer of pathogens or parasites to native plant 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 giant goldenrod *Solidago gigantea* causes changes in the soil environment. Even though there has not been found to be a significant effect of giant goldenrod on the

physicochemical properties of the soil (Baranová et al. 2017 – P), it has been demonstrated that *S. gigantea* has an increased ability to absorb nutrients (especially phosphorus) mainly from the surface soil layer (0-10 cm) (Koutika et al. 2011 – P). A 20-30% higher content of unstable phosphorus fractions caused by an increased rate of mineralization and lower pH was found in places colonized by goldenrod, compared to places without goldenrod. Higher availability of phosphorus in the soil with goldenrod present may be the result of, for example,. active acidification of the root zone (Herr et al. 2007 – P). High carbon content in the soil organic matter and high carbon mineralization in soils colonized by *S. gigantea* were also found in comparison with soils occupied by native plant species (Koutika et al. 2007 – P). The species generally increases the above-ground production of biomass in communities, while reducing both the concentration of nutrients in the biomass and the availability of nitrogen in the soil, yet this had no significant impact on plant species richness, soil pH and availability of phosphorus (Scharfy et al. 2010 – 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:

Long-living giant goldenrod plants with intense clonal growth, efficient seed production and high competitive ability (Weber 2003, Weber and Jakobs 2005, Güsewell et al. 2006 – P) quickly achieve domination and compete effectively with other plants leading to a reduction in native plant species richness (Weber and Jakobs 2005, Hejda et al. 2009, Pál et al. 2015 – P). The increase in coverage of giant goldenrod in the vegetation stand results in a significant reduction in biodiversity, although the impact is lower than in the case of Canadian goldenrod (Szymura and Szymura 2011 – P). The plants also adversely affect the richness and abundance, e.g. 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 in particular with the meadow habitats which are often colonized by goldenrod (Tokarska-Guzik et al. 2015 – I). Changes in soil properties induced by *S. gigantea* also have a moderate impact on the diversity and structure of the soil mesofauna of the Collembola group and a low impact on modifications of the trophic structure (Sterzyńska et al. 2017 – P). Invasive goldenrods limit spontaneous secondary succession in forest areas (Bornkamm 2007 – P) and abandoned fields (Bartha et al. 2014 – P). The species also has an allelopathic effect, limiting seed germination and the growth of many plant species, through the release of allelopathic compounds (Pisula et al. 2010, Sekutowski et al. 2012, Baličević et al. 2015, Ravlić et al. 2015 – P). The restoration of native vegetation in areas previously colonized by *Solidago gigantea* is unlikely, due to changes in the composition of the soil microorganism communities that occurred as a result of the invasion (König et al. 2016 – P). A result of the development of goldenrod populations is also the homogenization of the landscape manifested by the presence of monocultures of the species covering vast areas. They are also a serious threat to phytocoenoses in protected areas (Otręba and Michalska 2014 – P). Goldenrods demonstrate negative impact on Natura 2000 natural habitats, including particularly: *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 communities in forest-edge scrub (Nowak and Kącki 2009 – P). Goldenrod is also a problem in forest communities, although in shady places plants often do not flower and reach smaller sizes (Balogh 2001, Tokarska-Guzik et al. 2015 – I). Goldenrods consists of dense, homogeneous and species-poor phytocoenoses (Nowak and Kącki 2009, Szymura and Szymura 2016 – P), often in meadow habitats, river valleys and riparian forests and undergrowth, causing changes in the structure and

functioning of these ecosystems (Nowak and Kącki 2009, Kopeć and Michalska-Hejduk 2016 – P). The species is considered undesirable especially on unmown meadows, in riverside habitats, wetlands, forest margins, also on railways and in urban areas and commercial forests (Hartmann and Konold 1995, Botta-Dukát and Dancza 2001a, Weber 2003 – P). It occurs massively on improperly used pastures and fields, it is also troublesome in young forest plantations and in gardens and crops (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 also 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 **X**	high	level of confidence

acomm20. Comments:

Invasive goldenrods can negatively affect crop plants through intense clonal growth and strong phytotoxic activity via allelopathic compounds, which enables them rapidly to colonize new areas, including abandoned agricultural lands. Giant goldenrod may be, rarely, a weed of annual crops and cause losses in crop yields (CABI 2018 – P). It has been shown that extracts from *S. gigantea* shoots may reduce wheat germination by 7.6% and barley germination by 9.8% (Béres and Kazinczi 2000 – P). The allelopathic properties of the goldenrods effectively inhibit germination and root growth of many cultivated plant species, including buckwheat, sunflower, carrot, barley and wheat (Sekutowski et al. 2012, Baličević et al. 2015, Ravlić et al. 2015 – P). There have been cases of their infestation of willow energy crops (Szymura 2011 – A). Due to the high content of saponins, invasive goldenrods also decrease the fodder value of hay obtained from meadows colonized by them (Swierszcz et al. 2017 – P). In addition, they successfully compete with many plant species for pollinators (Moron et al. 2009 – P). Due to the wide spread of the species in

Poland and the particular structure of crop stands, it should be assumed that the impact of the species on cultivated plants through competition 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:

Giant goldenrod *Solidago gigantea* may indirectly influence the condition and yield of crop plants by hybridizing with the native *S. virgaurea* species, creating *Solidago* ×*snarskisii* populations (Gudžinskas and Žalneravičius 2016 – P). The hybrid was found in the south of Lithuania and so far has not been reported from other regions of Europe, including Poland. There is also insufficient data on its distribution. However, the ability of giant goldenrod to cross and create hybrids with native species may be a threat to *S. virgaurea* occurring on grasslands which reduces the quality of the grassland yield. An inter-species 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 grown in Poland, showing ease of propagation by the division of clumps (Jakábová and Krejča 1982 – P). It has been considered to be the most polliniferous among the goldenrods; it can provide up to 150 kg of pollen from 1 ha of crop (Strzałkowska 2006b – P). Due to the above, the species' impact has been rated as medium (high probability × low effect).

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:

Giant goldenrod *Solidago gigantea* is found in large numbers on improperly managed pastures and arable lands, it is also troublesome in young forest plantations, gardens and crops (CABI 2018 – B). Goldenrod plants limit the processes of spontaneous secondary succession in forest areas (Bornkamm 2007 – P) and abandoned fields (Fenesi et al. 2014 – P). *Solidago gigantea* is rarely a weed of annual crops, because it can be controlled by agrotechnical techniqus. However, extracts from *S. gigantea* shoots may reduce germination of wheat by 7.6% and germination of barley by 9.8% (Béres and Kazinczi 2000 – P), which may cause crop yield loss. In fields previously colonized by goldenrod, accumulation of litter may hinder their return to the pre-invasion state, because the remains of invasive weeds limit the germination of cultivated plants (Béres and Kazinczi 2000 – P). It has also been proved that the allelopathic properties of the goldenrod (Pisula et al. 2010 – P) effectively inhibit seed germination and root growth of many cultivated plant species, including buckwheat, sunflower, carrot, barley, wheat and coriander (Sekutowski et al. 2012, Baličević et al. 2015, Ravlić et al. 2015 – P). Furthermore, the invasion of goldenrods into meadow

communities and the displacement of native species from these habitats leads to a decrease in the feed quality of the hay obtained from meadows (Świerszcz et al. 2017 – P), due to the high saponin content (Weber and Jakobs 2005 – P). The unfavourable influence of giant goldenrod on e.g. the richness and diversity of natural populations of the insects (Moron et al. 2009 – P) or birds (Skórka et al. 2010 – P) associated, for example, with meadow habitats occupied by goldenrods (Tokarska-Guzik et al. 2015 – I) is significant. In taking into account the collected data, the impact of the species on crops by crop integrity disturbances was assessed as large: it is predicted that the impact will affect 1/3 to 2/3 crops (medium probability), which in the worst case will reduce the condition of plants or the yield of a single crop by over 20% (a large effect).

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:

Giant goldenrod *Solidago gigantea* is an alternative host for insects, which can be vectors of plant pathogens and crop insect pests (CABI 2018 – B). In its native range, the seeds and rhizomes of the goldenrod are attacked, for example, by fungal pathogens such as: *Puccinia dioicae* causing rust in goldenrod, powdery mildew (*Erysiphe cichoracearum*) and downy mildew (*Golovinomyces asterum* var. *Solidaginis*), which was recorded on goldenrod plants in Korea (Weber 2000, Meyer et al. 2005 – P, CABI 2018 – B). Plants of the species are also hosts of bacterial pathogens of the genus *Xanthomonas* which attack the leaves of other invasive perennials (Meyer et al. 2005 – P, CABI 2018 – B) on both EPPO lists: five on EPPO A1 and 11 on the EPPO A2 list. However, there is insufficient data on which pathogen species has been identified on *S. gigantea* plants, as well as on the effect of giant goldenrod on plant cultivation associated with the fact it is the host or vector of pathogens and parasites harmful to these plants (CABI 2018 – B). In addition, invasive goldenrods 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: Giant goldenrod *Solidago gigantea*, like other goldenrods, contains significant amounts of active substances such as terpenoids, phenolic compounds, coumarins and essential oils (Weber and Jakobs 2005 – P). Moreover, it contains compounds from the diterpenes group, 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 and Jakobs 2005 – P). At the same time, these compounds have negative impact on the quality of hay obtained from meadows containing growing goldenrods. Animals grazed on areas colonized by goldenrods (including sheep) may be susceptible to poisoning. Many goldenrod species are poisonous to 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:

Giant 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 of the plant 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 (Koutika et al. 2011 – P).

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 are a serious threat to grasslands, i.e. meadows and pastures, the area of which is gradually being reduced due to intensification of production or the abandoning of their

use (Świerszcz et al. 2017 – P), which favours progressive invasion. Therefore, on meadows defined as valuable (packages 4 and 5 of the agro-environmental programme – the 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), goldenrods should be actively eliminated (Świerszcz et al. 2017 – P). Furthermore, goldenrods decrease the attractiveness of recreational and tourist areas (Wasiłowska 1999 – P) through a negative impact on the landscape (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.

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:

Giant goldenrod reduces the feed values of hay obtained from colonised meadows (Świerszcz et al. 2017 – P). However, the presence of the species can be perceived as beneficial, for example by owners of apiaries, due to the melliferous properties of the plant and its late blooming (Stefanic et al. 2003 – P). Nevertheless, the continuous availability of goldenrod flowers in autumn disturbs the cycle of bees entering into their overwintering condition, which results in reduced survival after winter (Tepedino et al. 2008 – P). The species can be considered as an energy plant. It has a similar calorific value to biomass of rape straw, barley straw, maize straw or giant miscanthus biomass, which is within the range 15-16 MJ/kg; goldenrod biomass could be successfully used as a solid fuel (pellets, granules) or processed to obtain secondary energy carriers: gas or hydrogen fuels (Biskupski et al. 2012 – P). Goldenrods are also popular in phytotherapy. Due to the content of specific chemical compounds (including triterpene saponins, flavonoids, chlorogenic acid, carotenoids), goldenrod herb presents diuretic, relaxing and anti-inflammatory properties at low doses (Strzelecka and Kowalski 2000 – 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:

Giant goldenrod *Solidago gigantea* has a negative effect on regulatory services. It affects biomass production by the occupied communities and the rate of cyclic biogeochemical changes (Vanderhoeven et al. 2005, 2006, Chapuis-Lardy et al. 2006, Scharfy et al. 2010 – P). The species generally increases the above-ground production of community biomass, while reducing both the concentration of nutrients and the availability of nitrogen in the soil. Baranova et al. (2017 – P) found no significant effect of Giant Goldenrod on the physicochemical properties of the soil, whereas it has been demonstrated by other researchers that the presence of the species may lead to an increase in the concentration of carbon and phosphorus in the soil, and contribute to an increase in the rate of mineralization in colonized locations (Chapuis-Lardy et al. 2006, Koutika et al. 2007 – P) and the lowering of the pH of the substrate (Herr et al. 2007 – P). On the other hand, the interaction of the species with arbuscular mycorrhizal fungi has been shown to lead to an increase in biomass of invasive plants as well as in the concentration of phosphorus (Kytovtita et al. 2003, Majewska et al. 2017 – P), and the probability of mycorrhizal colonization also increases soil humidity (Young et al. 2000, Majewska et al. 2017 – P).

Giant goldenrod is characterized by high competitive abilities against indigenous plant species. It generates plants with intense rhizome growth, enormous seed production and effective spread of seed in the wind (see a14). The species quickly dominates, creates dense monogeneous patches leading to the reduction in native plants species richness. The competitive impact of giant goldenrod also concerns insects belonging to the the pollinator groups of meadow habitats (day butterflies, bees, hoverflies). There are known cases where, in the plots including invasive plants, the diversity of pollinators decreased by up to 90% (Masło and Najberek 2014 – P).

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

	significantly negative
	moderately negative
X	neutral
	moderately positive
	significantly positive

aconf29. Answer provided with a

low	medium	high
		X

level of confidence

acomm33. Comments:

Analogically to Canadian goldenrod, Giant goldenrod negatively affects the attractiveness of the landscape (Szymura and Wolski 2006 – P), forming dense, extensive patches, often occupying large areas, e.g. in recreational and tourist areas, among others on the banks of rivers and water reservoirs, limiting access to water (Bzdęga 2015 – A), also along tourist trails (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 goldenrod inflorescences are used as a decorative element in floristry (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). Giant goldenrod is a valuable melliferous plant used by beekeepers (Stefanic et al. 2003 – P). The plant contains saponins, flavonoids and phenolic glycosides that have been identified as essential compounds for pharmaceutical use (Weber and Jakobs 2005 – P). *S. gigantea* extracts demonstrate antifungal activity, especially against *Candida pseudotropicalis* (Pepeljnjak et al. 1998 – P). The use of the plant in medicine, e.g. as a urological and anti-inflammatory agent, has been known for centuries (Apati et al. 2003 – 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:

Assuming that in the future the temperature will increase by 1-2°C, the probability that the species will overcome the next barriers related to its occurrence in Poland will not change. Giant goldenrod *Solidago gigantea* prefers a temperate climate with average coldest month temperature >0°C and <18°C and average warmest month temperature >10°C, and a continental climate with average coldest month temperature <0°C and average warmest month temperature >10°C. The range of species tolerance with regard to the preferred climatic parameters is provided by CABI (2018 – B) and EPPO (2004 – B).

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:

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. Giant goldenrod *Solidago gigantea* prefers a temperate climate with average coldest months temperature >0°C and <18°C and average warmest month temperature >10°C, and a continental climate with average coldest month temperature <0°C and average warmest month temperature >10°C. The range of tolerance of the species to the preferred climatic parameters is provided by CABI (2018 – B) and EPPO (2004 – 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. Giant goldenrod *Solidago gigantea* prefers a temperate climate with average coldest month temperature >0°C and <18°C, and average warmest month temperature >10°C, as well as a continental climate with average coldest month temperature <0°C and average warmest month temperature >10°C. The range of tolerance of the species concerning the preferred climatic parameters is provided by CABI (2018 – B) and EPPO (2004 – B). Analysis of the potential distribution of *S. gigantea* 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, Weber and Jakobs 2005 – 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:

It is assumed that due to climate change, the impact of the described species on wild plants and animals, as well as habitats and ecosystems in Poland will not change, assuming that the expected climate changes will increase the air temperature by 1-2°C. However, it has been experimentally proven that an 3°C increase in temperature may increase the invasive success of the species relative to native plants by accelerating its growth rate and increasing the ability to uptake nitrogen from the substrate (Verlinden et al. 2014 – P). *Solidago gigantea* prefers a temperate climate with average coldest month temperature >0°C and <18°C and average warmest month temperature >10°C, and a continental climate with average coldest month temperature <0°C and average warmest month temperature >10°C. The range of species tolerance with regard to the preferred climatic parameters is provided by CABI (2018 – B) and EPPO (2004 – B).

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:

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 gigantea* prefers a temperate climate with average coldest month temperature >0°C and <18°C and average warmest month

	temperature >10°C, and a continental climate with average coldest month temperature <0°C and average warmest month temperature >10°C. The range of species tolerance with regard to the preferred climatic parameters is provided by CABI (2018 – B) and EPPO (2004 – 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: 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 gigantea* prefers a temperate climate with average coldest month temperature >0°C and <18°C and average warmest month temperature >10°C, and a continental climate with average coldest month temperature <0°C and average warmest month temperature >10°C. The range of species tolerance with regard to the preferred climatic parameters is provided by CABI (2018 – B) and EPPO (2004 – 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: It is assumed that due to climate change the effect of the described species on people in Poland will not change. *Solidago gigantea* prefers a temperate climate with average coldest month temperature >0°C and <18°C and average warmest month temperature >10°C, and a continental climate with average coldest month temperature <0°C and average warmest month temperature >10°C. The range of species tolerance with regard to the preferred climatic parameters is provided by CABI (2018 – B) and EPPO (2004 – 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: It is assumed that due to climate change the effect of the described species on other objects in Poland will not change. *Solidago gigantea* prefers a temperate climate with average

coldest month temperature >0°C and <18°C and average warmest month temperature >10°C, and a continental climate with average coldest month temperature <0°C and average warmest month temperature >10°C. The range of species tolerance with regard to the preferred climatic parameters is provided by CABI (2018 – B) and EPPO (2004 – 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	0.70
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	0.92
Overall risk score	0.75	
Category of invasiveness	moderately invasive alien species	

A6 | Comments

This assessment is based on the 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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