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. Beata Woziwoda – external expert
2. Damian Chmura
3. Władysław Danielewicz

acomm01. Comments:

	degree	affiliation	assessment date
(1)	dr hab.	Department of Geobotany and Plant Ecology, Faculty of Biology and Environmental Protection, University of Lodz	26-01-2018
(2)	dr hab.	Institute of Environmental Protection and Engineering, University of Bielsko-Biala	10-04-2018
(3)	dr hab.	Department of Forest Botany, Faculty of Forestry, Poznań University of Life Sciences	30-01-2018

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

Polish name: Dąb czerwony

Latin name: ***Quercus rubra*** L.

English name: Northern red oak

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acomm02. Comments:

The preferred scientific and common name are provided on the basis of The Plant List 2013, Critical List of vascular plants (Mirek et al. 2002 – P) and CABI (2018 – B).

In North America (the USA), this species is known as ”eastern red oak” or ”gray oak”. For *Q. rubra* var. *ambigua* variety, (A. Gray) Fernald, the following synonyms are used: *Q. borealis* Michx. f. or *Q. rubra* var. *borealis* (Michx. f.) Farw., and *Q. rubra* var. *rubra* variety s known as *Q. maxima* (Marsh.) Ashe or *Q. borealis* var. *maxima* (Marsh.) Ashe (Sander 1990 – P, USDA NRCS 2003 – I). This species has been mainly called *Q. rubra* L. (Sander 1990 – P) since 1950.

Polish name (synonym I) –	Polish name (synonym II) –
Latin name (synonym I) *Quercus maxima*	Latin name (synonym II) *Quercus borealis*
English name (synonym I) Red oak	English name (synonym II) American red oak

a03. **Area** under assessment:

Poland

acomm03. Comments:

–

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
		X

level of confidence

acomm04. Comments:

Northern red oak was introduced to Poland at the turn of 18th and 19th centuries as the collector's and ornament species, and then also as the production species (Król 1967 – P). The oldest known forest stands were planted in 1798 in experimental areas in northern and north-western forests in Poland (now, forests of Elbląg and Gryfino forest divisions); the first commercial forest crops were established in southern Poland in 1835 (forests of Tułowice forest division) (Woziwoda et al. 2014 – P). In 1806, *Q. rubra* was added to the collection of the botanical garden in Kraków (Hereźniak 1992 – P).

And the number of anthropogenic stands of northern red oak was rapidly increasing (Tokarska-Guzik 2005a, Woziwoda et al. 2014 – P) until 2003 (Jaworski 2011 – P). Nowadays, this species is commonly reported in forests throughout Poland, except for the highest parts of Carpathians and the Sudetes (Gazda and Augustynowicz 2012, Woziwoda et al. 2014, Zając and Zając 2015 – P). Numerous dispersed stands of northern red oak are along communication routes, in urbanised areas, parks, gardens, and reclaimed post-industrial areas. *Quercus rubra* is kept in collections of 26 botanical gardens and arboreta in Poland (Pracownicy ogrodów botanicznych... 2018 – N).

Since 1968, northern red oak has been classified as a neophyte, an agrophyte – an established alien species occurring in natural habitats (Kornaś 1968, Zając et al. 1998, Tokarska-Guzik 2005b, Tokarska-Guzik et al. 2012 – P). Many authors emphasize the invasive nature of northern red oak in Poland (Woziwoda et al. 2012, 2014, Danielewicz and Wiatrowska 2014, Chmura 2013, 2014, Zarzycki et al. 2015, Jagodziński et al. 2018 – P). This species is a threat to the native biodiversity, particularly in natural valuable areas

(Cichocki and Danielewicz 1993, Danielewicz 1993, Danielewicz and Maliński 1997, Piotrowska et al. 1997, Adamowski et al. 1998, 2002, Chmura 2004, 2009, Jakubowska-Gabara and Mitka 2007, Otręba and Ferchmin 2007, Gazda and Szlaga 2008, Gazda and Fijała 2010; Woziwoda and Obidziński 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
	the domesticated animals domain
	the human domain
	the other domains

acomm05. Comments:

The intentional or spontaneous introduction of *Q. rubra* to forest phytocoenoses result in considerable changes in their structure and species composition. This species causes drastic changes in populations of all native species observed in the ecosystem. In patches of phytocoenoses with a considerable part of *Q. rubra*, the layer of herbaceous, moss, or moss and lichen undergrowth is almost completely reduced. All herbaceous plants, bryophytes, and overground lichens gradually disappear (Woziwoda et al. 2014, 2017 – P). Long-lived rhizomatous perennials, e.g. ferns (Zarzycki et al. 2016 – P), overground mosses forming high "cushions" e.g. *Leucobryum glaucum*, mosses living at the trunk base (Woziwoda et al. 2017 – P), and prostrate shrubs e.g. *Vaccinium myrtillus* (Krzyżanowska et al. 2017 – P) are observed for the longest time in such communities. Communities dominated by *Q. rubra* lose their floral and phytosociological identity. They have poor, and even drastically poor floral composition (Riepšas and Straigyte 2008, Jakubowska-Gabara and Woziwoda 2009, Marozas et al. 2009, Chmura 2013, Woziwoda et al. 2014 – P). This refers to both forests under protection and production forests (Danusevičius et al. 2002, Woziwoda et al. 2014 – P).

Dense and thick leaves of *Q. rubra* tree head significantly reduce the sunlight access to the forest floor and increase the shadow level. This results in changes of thermal and moisture conditions of the ecosystem (Knight et al. 2008, Horodecki and Jagodziński 2017 – P). Litter from northern red oak decomposes slowly (Dobrylovska 2001, Hobbie et al. 2006, Bzdęga et al. 2012, Chmura 2014, Horodecki and Jagodziński 2017 – P). The accumulation of large amounts of biomass with prevailing leaves of northern red oak modifies soil (chemical, thermal and moisture) conditions. A dense layer of oak litter present on the forest floor for the whole year is a physical barrier limiting the germination of seeds and the growth of seedlings (Woziwoda et al. 2012-2018 – A).

Quercus rubra inhibits, and in some cases even prevents, the natural regeneration and growth of native trees and shrubs (Marozas et al. 2009, Rédei et al. 2010, Woziwoda et al. 2014 – P), including important forest-forming species of economic significance.

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:

Northern red oak is present in 34 out of 49 regions in Europe (Lambdon et al. 2008 – P), including neighbouring countries of Poland. Expansive self-dispersion of *Q. rubra* was reported in semi-natural and natural habitats of anthropogenic origin in the Czech Republic (Pyšek et al. 2012, Pergl et al. 2016 – P), Slovakia (Medvecká et al. 2012 – P), Lithuania (Riepšas and Straigyte 2008, Straigyté and Žalkauskas 2012 – P) and Germany (Starfinger and Kowarik 2008 – B, Vor 2005, Major et al. 2013 – P). It is connected with dispersion of northern red oak seeds by animals which can transport acorns over a few kilometres (Starfinger and Kowarik 2008 – B), including cross-border areas.

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 introduction of this species by unintentional human actions into new sites is very probable and connected with cultural services commonly provided by forests and cultivated high green areas, where mature (fruiting) individuals of *Q. rubra* are present. Acorns of oaks, including northern red oak, are also collected during actions of wild animal feeding (Park Mierzeja... 2018 – I), which poses a risk of unintentional spreading of the species.

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:

Northern red oak is introduced to and maintained in production forests in Europe due to economic reasons (Król 1967, Bellon et al. 1977 – P, AHEC 2005 – I, Vansteenkiste et al. 2005, Rédei et al. 2010, Fereiro-Dominguez 2011, Kuc et al. 2012, Major et al. 2013, Głowacki et al. 2016 – P) and ecological issues (Burzyński 1999, Kwiecień 2012 – P). In Poland, northern red oak ceased to be planted (in national forests) for production in 2003 (Jaworski 2011 – P). According to principles of good forest economy within the international certification system for products and forest economy – Forest Stewardship Council (FSC), alien species are allowable providing that they are strictly monitored. Principles of silviculture permit the introduction of alien species as admixtures for afforestation of formerly arable grounds in lowlands if industrial emissions pose the ecological threat (Bodył 2011 – P). Northern red oak is often used for reclamation of degraded areas, e.g. afforestation of waste tips (Domański et al. 1977, Nowak 2012, Horodecki and Jagodziński 2017 – P).

Due to high ornamental values and resistance to pollution, this species is recommended (Bugała 1991, Cedro and Nowak 2013 – P) and commonly used as an element of cultivated high green areas in by-road plantings, parks, green areas, and private gardens (tree lines or solitaire trees growing in the open area) in urbanised areas, plots of summer cottages and among new suburban house estates, from where its diaspores can be transported to

surrounding communities. Large and attractive in terms of shape and form acorns of northern red oak are collected during recreational and teaching visits (hiking or bicycle trips), and then thrown away in accidental places (Woziwoda et al. 2011-2018 – A). It should be added that *Quercus rubra* is in the collection of botanical gardens and arboreta in Poland (cf. question a04), where the oldest documented individuals are from 1896 (Employees of botanical garden... 2018 – N). Spontaneous dispersion through seed formation was reported in case of some (12) gardens (Employees of botanical garden... 2018 – N). According to the Code of Good Practices in horticulture (Ogrodnictwo ... 2014 – I) *Q. rubra* is not recommended for cultivation near forests, dunes, watercourses, open landscape, protected areas, and their protection zone. It is recommended to monitor the population, and remove individuals in justified cases.

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	level of confidence
		X	

acomm09. Comments:

The natural range of *Q. rubra* covers vast eastern areas of North America characterized by diverse climate conditions (Sander 1990 – P). The average rainfall is from 760 mm in the north-western part of the occurrence range to 2030 mm in southern Appalachian Mountains. The average annual temperature is ca. +4^{o}C in the north up to 16^{o}C in the most southward stands, and the number of frost-free days per year is 100 in the north and 220 in the south (Sander 1990 – P). The climate in Poland is similar to the climate in north parts of the occurrence range of *Q. rubra* in North America (Król 1967 – P). The northern part of the occurrence range in the USA shows climate matching to Poland in at least 94%, the remaining occurrence area of northern red oak in the USA matches the climate in Poland in 45%. It means that climatic requirements of the species are met in the whole area of Poland, except for Carpathians and the Sudetes (starting from the top mountain region). However, the most favourable conditions are found in the north-western part of Poland. In the new (European) occurrence range, this species is quite resistant to periodical climatic anomalies – droughts and frost penetration (Kiselev 1950, Straigyte and Žalkauskas 2012 – P). Damage caused by early frosts (according to Murat 2002 – P; also late frosts) stimulate the growth of new buds and shoots. Serious damage caused by frosts is reported in frost pockets and after late frosts (Redei et al. 2010 – P). Light preferences of the species (photophilous, but tolerates side-shading, Murat 2002 – P) favour its spreading along numerous roads crossing forest communities. The structure and species composition of communities are dominated with thin pine forest stands, and favour colonization of such areas by *Q. rubra* (Woziwoda et al. 2012-2018 – A). Differences in life and average weight of oak seeds in Poland between particular nature and woodland areas can be determined by climate and the origin of seeds (Bodył 2011 – P).

The species resistance to atmospheric pollutants (Greszta 1987, Zieliński and Nowak 2011 – P) favours its occurrence in anthropogenic habitats in urbanised and industrialised areas.

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:

This species has a wide tolerance for soil conditions. It grows in both sandy soils, poor in nutrients, and in fertile organic soils, dry, fresh, or wet. But this species usually prefers mezo- and eutrophic, fresh habitats (Sander 1990, Magni-Diaz 2004 – P). Within its native range, this species prefers sides of low mountains with northern or western exposure, clay, clayey, silty and well hydrated soils (Sander 1990, Smith and Vancat 1991 – P). Lower increments of trees are observed in strongly acid, dry or swampy habitats (Redei et al. 2010 – P).

In Poland, northern red oak was introduced into and is observed in the full spectrum of forest and wood habitats, starting from dry and young forests, mixed coniferous forests and mixed forests, to sites of marshy meadows and alder carrs, excluding alpine wood (Król 1967, Bellon et al. 1977, Chmura 2004, Woziwoda et al. 2014 – P). Studies have shown that northern red oak regenerates better within the introduced range than in native North America (Magni-Diaz 2004, Major et al. 2013 – 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:

Northern red oak has overcome geographical and environmental barriers in Poland and is at the expansion phase. Vast areas occupied by *Q. rubra* stands and individual trees/clumps of trees dispersed within the forest space, abundantly producing vital seeds (Bodył 2011 – P), ensure the continuous and regular supply of sporocarps into the environment. Young individuals of *Q. rubra* under favourable conditions grow under canopies of parent trees and within a reasonable distance from them (Chmura 2004, 2013, Gazda and Szlaga 2008, Gazda and Fijała 2010, Woziwoda et al. 2014, Woziwoda and Obidziński 2015, Zarzycki et al. 2015, Głowacki et al. 2016, Woziwoda et al. 2018 – P).

Single-source dispersal (A-type data): According to Starfinger and Kowarik (2008 – B), seeds from a single source (a tree older than 25 years) can be transported at a distance form a few metres to a few kilometres. Within the area of its introduction (Europe), northern red oak has established mutual relations with native species of birds and mammals (Buckley and Sharik 2002, Myczko et al. 2014, Bieberich et al. 2016, Merceron et al. 2017 – P) which participate in dispersion of acorns of native species of oaks. Numerous vectors for seed

dispersion in the woodland (Eurasian jay *Garrulus glandarius* L., wood mouse *Apodemus sylvaticus* L., red squirrel *Sciurus vulgaris* L., rat *Rattus* sp., and wild boar *Sus scrofa* L.) contribute to effective colonisation of new areas by northern red oak (Woziwoda et al. 2012-2018 – A). A dense network of forest roads, drainage ditches, and felling areas used by animals as nesting sites, for storing food and/or as migration routes favour the species dispersion (Woziwoda et al. 2018 – P). Thin pine stands are an attractive place for zoochoric species, which seeds are spread by animals, to store acorns and for seedlings of *Q. rubra* to grow (Chmura 2007 – N, Woziwoda et al. 2012-2018 – A, Woziwoda et al. 2018 – P).

Expansion of population/Approximation (B- and C-type data): The invasion rate of northern red oak is very high. In years 1990-2000, the accumulated number of reported stands increased from ca. 200 to over 1500 (Tokarska-Guzik 2005a – P). Considering the fact that this increase largely reflected the state of knowledge, and not the factual dispersion of the species, this invasion can be assumed to be rapid.

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:

Northern red oak is still being introduced into post-arable forests, reclaimed areas and as an element of high green areas (Bodył 2011 – P). There are also many available offers for seedlings of *Q. rubra*.

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:

Quercus rubra is not a parasitic plant.

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:

Northern red oak reduces the population of all native species of plants. In patches of phytocoenoses with a high content of *Q. rubra*, the layer of herbaceous, moss, or moss and lichen undergrowth is almost completely reduced (Chmura 2013, Woziwoda et al. 2014 – P). All herbaceous plants, bryophytes, and overground lichens gradually disappear. Long-lived rhizomatous perennials, e.g. ferns (Zarzycki et al. 2014, Zarzycki et al. 2015 – P), overground mosses forming high "cushions" e.g. *Leucobryum glaucum*, mosses living at the trunk base (Woziwoda et al. 2017 – P), and prostrate shrubs e.g. *Vaccinium myrtillus* (Krzyżanowska et al. 2017 – P) are observed for the longest time in such communities. This species inhibits, and in some cases even prevents, the natural regeneration and growth of native trees and shrubs (Marozas et al. 2009, Rédei et al. 2010, Woziwoda et al. 2014 – P, cf. Kwiecień 2012 – P).

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

	no / very low
X	low
	medium
	high
	very high

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

acomm15. Comments:

Within its native range, *Q. rubra* interbreeds with many oak species of *Erytrobalanus* subspecies forming the following hybrids: *Quercus* × *columnaris* Laughlin (pin oak *Q. palustris* (note: also planted in Poland) × *Q. rubra*); *Q.* × *fernaldii* Trel. (bear oak *Q. ilicifolia* × *Q. rubra*); *Q.* × *hawkinsiae* Sudw. (eastern black oak *Q. velutina* × *Q. rubra*); *Q.* × *riparia* Laughlin (Shumard oak *Q. shumardii* × *Q. rubra*); and *Q.* × *runcinata* (A. DC.) Engelm. (shingle oak *Q. imbricaria* × *rubra*) (Sander 1990 – P), *Q.* × *heterophylla* Michx. f. (willow oak *Q. phellos* × *Q. rubra*) (Sander 1990 – P, Eastern Native Tree Society 2002-2011 – I), *Quercus* × *benderi* (*Q. rubra* × scarlet oak *Q. coccinea*) (Little 1979 – P, Eastern Native Tree Society 2002-2011 – I), also with *Q. ellipsoidalis* and *Q. marylandica* (Little 1979 – P).

The likelihood of forming spontaneous interspecific hybrids (of different subgenera) with native pedunculate oak *Q. robur*, sessile oak*Q. sessilis* and downy oak *Q. pubescsens*, belonging to *subgenus Quercus=Lepidobalanus* (Boratyński et al. 2006 – P) is not excluded (this issue requires professional studies), especially that interbreeding of *Q. rubra* and *Q. robur* was successful under artificial conditions (Menitski 1984 – P).

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

	very low
	low
X	medium
	high
	very high

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

acomm16. Comments:

The cases of bringing alien pathogenes or parasites with northern red oak have not been reported so far. However, due to a very low level of identification of Micro- and Macromycetes biota and fauna establishing this introduced species, the conclusions can be incorrect. The native range of northern red oak is occupied by more than 130 species of Micromycetes. In Europe, northern red oak is inhabited by species of parasitic fungi (adapted to their new host), usually connected with the native species of oaks, which can pose secondary threat to other native species of trees (Woziwoda and Ruszkiewicz-Michalska 2016 – N).

Studies performed in Poland on determining susceptibility of the species *Q. rubra* to infestation by pathogenic fungi have shown that it is resistant to species causing black rot of *Q. robur* and *Q. petraea* acorns. And inoculation of other pathogenes i.e. infection does not significantly affect the growth of young individuals (Szynkiewicz and Kwaśna 2004 – P). This species is susceptible to infection with a hazardous polyphagous pathogene – *Phytophthora ramorum* (Orlikowski and Szkuta 2003 – P). As a result of studies on the effect of industrial emission on trees inhabited by pathogenic fungi (Domański et al. 1977 – P), 17 species of ascomycota and deuteromycota, including polyphagous organisms*Botrytis cinerea*, *Cytospora intermedia*, *Epicoccum nigrum*, were reported on leaves and shoots of northern red oak. Tree necrosis is connected with interaction between overground (micromycetes) and underground (mainly *Heterobasidion annosum*) parasites.

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

	low
	medium
X	high

aconf13. Answer provided with a

low	medium	high	level of confidence
		X	

acomm17. Comments:

Comments:

The intentional or spontaneous introduction of *Q. rubra* to forest phytocoenoses results in considerable changes in their structure and species composition linked to changes in abiotic conditions. Dense and thick leaves of *Q. rubra* tree head significantly reduce the sunlight access to the forest floor and increase the shadow level. This results in changes of thermal and moisture conditions (Knight et al. 2008, Horodecki and Jagodziński 2017 – P). Litter from northern red oak decomposes slower than litter from many other native species of trees, but it does not cause any significant chemical and physical changes in soil (Dobrylovska 2001, Hobbie et al. 2006 – P, Chmura 2007 – N, Bzdęga et al. 2012, Chmura 2014, Horodecki and Jagodziński 2017 – P). However, studies performed by other authors showed reduced resources of phosphorus in soil (Bonifacio et al. 2015 – P) and soil acidification (Miltner et al. 2016 – P).

The expected positive effects of phytomelioration related to biomass supply from leaves of northern red oak (Bellon et al. 1977, Murat 2002 – P) have not been so far confirmed by research studies. The accumulation of large amounts of biomass with prevailing leaves of northern red oak modifies chemical, thermal and moisture conditions of soil. A dense layer of oak litter present on the forest floor for the whole year is a physical barrier for germinating seeds and growing seedlings (Woziwoda et al. 2012-2018 – A) (although experimental studies showed no significant difference between native pedunculate oak and northern red oak in terms of the effect of dead biomass on the recruitment of seedlings of undergrowth species; Bzdęga et al. 2012 – I). A long-term (over twenty or a hundred of years) effects of *Q. rubra* stands on sites may cause significant, but reversible changes in abiotic conditions.

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:

In the presence of this species, drastic changes in populations of all native species of plants are observed in the ecosystem. In patches of phytocoenoses with a considerable part of *Q. rubra*, the layer of herbaceous, moss, or moss and lichen undergrowth is almost completely reduced. All herbaceous plants, bryophytes, and overground lichens gradually disappear. Long-lived rhizomatous perennials, e.g. ferns (Zarzycki et al. 2015 – P), overground mosses forming high "cushions" e.g. *Leucobryum glaucum*, mosses living at the trunk base (Woziwoda et al. 2017 – P), and prostrate shrubs e.g. *Vaccinium myrtillus* (Krzyżanowska et al. 2017 – P). *Quercus rubra* inhibits, and in some cases even prevents, the natural regeneration and growth of juvenile native trees and shrubs (Marozas et al. 2009, Rédei et al. 2010, Woziwoda et al. 2014 – P). Communities dominated by *Q. rubra* lose their phytosociological identity. They have poor, and even drastically poor floral composition (Riepšas and Straigyte 2008, Jakubowska-Gabara and Woziwoda 2009, Marozas et al. 2009, Chmura 2013 – P). This refers to both forests under protection and production forests (Danusevičius et al. 2002, Woziwoda et al. 2014 – P). Changes in species composition of phytocoenoses trigger changes in species composition of fauna and fungi biota. Woods with a large proportion of northern red oak exhibit poorer content of ornithofauna (Grzędzicka et al. 2017 – P). Soils, in which northern red oak grows on a massive scale, contain less small fungi (Micromycetes) and ammonificated microorganisms (Riepšas and Straigyte 2008 – P).

Trunks and boughs of northern red oak are also inhabited by native species of lichens (Kubiak 2006 – P) and bryophytes (Woziwoda et al. 2017 – P), which can contribute to greater biodiversity in case of anthropogenic pine monoculture (afforestation of formerly arable lands).

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:

Northern red oak is not a parasitic plant.

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

	inapplicable
	very low
	low
	medium
	high
X	very high

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

acomm20. Comments:

Northern red oak is a common element of production forests (Woziwoda et al. 2014 – P). Communities with stands predominated with *Q. rubra* show no natural restorations of native species of trees and shrubs, including important forest-forming species (Vansteenkiste et al. 2005, Rédei et al. 2010, Woziwoda et al. 2014 – P). In fertile and moderately fertile new sites (LMsw, BMsw, Lsw), the competition of northern red oak (also in post-falling areas) prevents cultivation of other species of trees. The reduction of the population of young individuals of northern red oak requires mechanical removal of seedlings and brushwood (cutting out) or the application of chemical substances for at least several times (Solarz et al. 2005 – N, Woziwoda and Obidziński 2016 – P), which produces additional costs of silviculture. The application of substances containing glyphosate, which had been recommended in previous papers (efficient in controlling *Q. rubra*), should be prohibited due to its toxic and carcinogenic properties. The population of young individuals can be limited by increasing the shadow level through planting native species (e.g. beech, hornbeam, linden).

In case of adult trees, they require the clear cutting, and ring barking at the end of flowering period (May). The annual removal of seeds found under parent trees is suggested.

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

	inapplicable
X	no / very low
	low
	medium
	high
	very high

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

acomm21. Comments:

Spontaneous interspecific/subgenera hybrids of northern red oak and pedunculate oak *Q. robur* and/or sessile oak *Q. sessilis* are unlikely to be formed which could reduce the productivity value of these important forest-forming species.

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 **X**	high	level of confidence

acomm22.	Comments: Northern red oak is a production species and thus, an integral part of crops in production forests. However, when this species spontaneously enters crops (as an undesirable species), the integrity of such crops is disturbed. It effectively competes with other (production) species. Oak may exert a greater pressure on fertile and fresh sites in leafy and mixed forests. Poorer forest habitats are not exposed to such a great pressure from this species. More frequent occurrence of northern red oak in mixed coniferous forests and mixed woods is the effect of choices made by foresters, who introduce this species to enrich poorer sites, and not to sites of its preference (Otręba and Ferchmin 2007 – P).

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

	very low
	low
X	medium
	high
	very high

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

acomm23.	Comments: *Quercus rubra* may pose the secondary threat to other trees as a host to European pathogenes and parasites.

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: This species is a non-parasitic plant.

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

X	very low
	low
	medium
	high
	very high

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

acomm25. Comments:

Northern red oak is not the threat to animals.

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:

This species is a plant which does not carry animal pathogenes or parasites.

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:

This species is an autotrophic plant, which exhibits no parasitic properties.

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

X	very low
	low
	medium
	high
	very high

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

acomm28. Comments:

There are no reported cases of negative (e.g. allergenic) or toxic effects of *Q. rubra* on human health. Regarding the risk of a vehicle overturning or skidding on smooth and slippery roads covered with leaves from northern red oak (e.g. after rain), it is recommended to plant this

	species away from communication routes for pedestrians and bicycles, and roadways. Acorns are likely to hit a car window or body, which can distract a driver.

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: Northern red oak is not a vector for human pathogenes or parasites.

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:

X	very low
	low
	medium
	high
	very high

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

acomm30.	Comments: This species can overgrow forest roads, dividing lines, and fire escapes, which hinders works of foresters. Moreover, its negative impact on green areas may be connected with the growth of the root system and may result in damage to pavement surfaces.

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
	moderately negative
	neutral
X	moderately positive
	significantly positive

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

acomm31. Comments:

Quercus rubra is a valuable wood raw material. Timber of this species has a moderate strength and elasticity (Kubiak and Laurow 1994 – P). Straight trunks have no branches up to the height of 13 meters (Spława-Neyman and Owczarek 2006– P) and provide knotless timber or with few knots. Timber is resistant to everyday use, durable (although native species of oak are more durable) and easy to process. It can be used in furniture and construction industries to produce, inter alia, furniture, floors, panelling, doors and coffins (Bodył 2011 – P). This species grows faster (even up to 60%) than the European species, also in case of less fertile soils (Król 1967, Jaworski 1994, Danusevičius et al. 2002, Kuc et al. 2012, Cedro and Nowak 2013 – P).

This species can reduce the access to mushrooms, forest fruits (cowberries, wild strawberries, blackberries) and medicinal herbs for commercial purposes, which adversely affects provision services.

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:

The presence of *Q. rubra* may provide shadow, reduce the content of some nutrients, acidify soil and reduce the space for other species. Being a coniferous species with a specific structure of the head, it ensures a better sunlight penetration into the forest floor in spring and stronger shadow in summer. Thus, evapo-transpiration is more limited and biomass production is increased when compared to pine plantation (Ferreiro-Dominguez et al. 2011 – P). The general impact of *Q. rubra* on site, soil, hydrological, and climatic conditions has still not been thoroughly studied.

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

	significantly negative
	moderately negative
	neutral
X	moderately positive
	significantly positive

aconf29. Answer provided with a

low	medium	high
	X	

level of confidence

acomm33. Comments:

A red colour of northern red oak leaves does not match to the traditional ”Polish golden autumn” and can be negatively perceived as a forest tree by some nature lovers and eco-tourists. This species occurs in 18 out of 23 national parks, and in 70 out of studied 75 landscape parks (Najberek and Solarz 2011 – P), which can adversely influence the appearance of protected areas. On the other hand, strollers may enjoy leaves, and tree stands dominated by northern red oak which recognized as beautiful, especially in autumn. However, neighbourhood with the mentioned tree stands does not arouse the enthusiasm, and can be even negatively perceived by owners of recreational plots (who consider its presence as a factor reducing the plot price). The negative impact on the native biodiversity may also limit the availability of many forest resources and disturb cultural services, such as picking of mushrooms, forest fruits and herbs (Woziwoda et al. 2014 – P). But its impact on cultural services in urbanised areas is definitely positive – due to ornamental values and the possible use of *Q. rubra* in high green areas.

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	high **X**	level of confidence

acomm34.	Comments: This species is present in Poland. It has overcome barriers against its introductio.

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: Preliminary studies have indicated that acorns of northern red oak grow and develop without standstill under conditions of increased moisture content and temperature (Woziwoda et al. 2012-2018 – A). It means that global warming, accompanied by simultaneous humidity increase, will increase the effectiveness of natural restorations of *Q. rubra*. Considering exclusively a rise in temperature one should assumed that the situation of the species would not change.

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
	not change
X	increase moderately
	increase significantly

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

acomm36. Comments:

Results from dendrochronological studies (Bijak et al. 2012 a,b, Cedro and Nowak 2013 – P) indicate that milder, warmer and humid winters, rare days with early or late frosts or no frost days, warm humid spring, as well as humid and warm (but not hot) end of summer and beginning of autumn stimulate higher increments of northern red oak timber. If the climate warming is accompanied by an increase in humidity, larger wood increments can be expected. Climate changes consequently increase the occurrence of extreme climate phenomena, including minimal and maximal temperatures. Frosts cause smaller increments of northern red oak (Bijak et al. 2012b – P). On the other hand, mildening of climate, that is, warmer winters and high temperatures at the end of the vegetation period induce a greater activity of the vascular cambium and wood increment (Bijak et al. 2012a – P). If greater tree mass and faster growth cause larger production of seeds, they may affect the regeneration and more effective dispersion of this species.

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
	not change
X	increase moderately
	increase significantly

aconf33. Answer provided with a

low	medium	high
	X	

level of confidence

acomm37. Comments:

In relation to the assumed climate change (a36), faster increments and a larger number of seeds will lead to more effective spreading of the species, and hence, greater competitiveness of *Q. rubra*. Further dispersion of the species in the natural environment will result in broadening the range of its communities, where northern red oak reduces the native biodiversity and modifies abiotic conditions.

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
	not change
X	increase moderately
	increase significantly

aconf34. Answer provided with a

low	medium	high
	X	

level of confidence

acomm38. Comments:

The predicted increase, in relation to the assumed climate change (a36), in competitiveness of spontaneously spreading *Q. rubra* will have an adverse impact on the natural regeneration of native species, including important production species.

Interspecific hybrids could modify morphological features and changes in properties of timber from native oak species. However, native species were found to react to climate conditions similarly to northern red oak (Bijak et al. 2012 a,b – P). It can be assumed that climate changes may not affect the competitive advantage of northern red oak over other oaks.

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	high **X**	level of confidence

acomm39. Comments:

This species does not affect animal production. Forecasted climate change will not change this.

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	high **X**	level of confidence

acomm40. Comments:

The species impact on human targets is minimal. The climate change will not change the impact of the species on humans.

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 climate will not significantly determine how oaks affect the infrastructure domain.

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)	0.75	0.80
Cultivated plants impact (questions: a19-a23)	0.45	0.60
Domesticated animals impact (questions: a24-a26)	0.00	1.00

Human impact (questions: a27-a29)	0.00	1.00
Other impact (questions: a30)	0.00	1.00
Invasion (questions: a06-a12)	1.00	1.00
Impact (questions: a13-a30)	0.75	0.88
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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