Risk assessment template developed under the "Study on Invasive Alien Species – Development of risk assessments to tackle priority species and enhance prevention" Contract No 07.0202/2018/788519/ETU/ENV.D.2[1]

Name of organism: *Axis axis* (Erxleben, 1777)

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

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[1] This template is based on the Great Britain non-native species risk assessment scheme (GBNNRA). A number of amendments have been introduced to ensure compliance with Regulation (EU) 1143/2014 on IAS and relevant legislation, including the Delegated Regulation (EU) 2018/968 of 30 April 2018, supplementing Regulation (EU) No 1143/2014 of the European Parliament and of the Council with regard to risk assessments in relation to invasive alien species (see https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A32018R0968).

Contents

SECTION A – Organism Information and Screening

A1. Identify the organism. Is it clearly a single taxonomic entity and can it be adequately distinguished from other entities of the same rank?

including the following elements:

- the taxonomic family, order and class to which the species belongs;
- the scientific name and author of the species, as well as a list of the most common synonym names;
- names used in commerce (if any)
- a list of the most common subspecies, lower taxa, varieties, breeds or hybrids

As a general rule, one risk assessment should be developed for a single species. However, there may be cases where it may be justified to develop one risk assessment covering more than one species (e.g. species belonging to the same genus with comparable or identical features and impact). It shall be clearly stated if the risk assessment covers more than one species, or if it excludes or only includes certain subspecies, lower taxa, hybrids, varieties or breeds (and if so, which subspecies, lower taxa, hybrids, varieties or breeds). Any such choice must be properly justified.

This risk assessment covers one species, axis deer *Axis axis* (Erxleben, 1777), also known as chital, cheetal, spotted deer or Indian spotted deer (Class: Mammalia, Order: Artiodactyla, Family: Cervidae, Subfamily: Cervinae, Genus: *Axis*).

Synonym(s): *Cervus axis* Erxleben, 1777

According to Wilson and Reeder (2005) the genus *Axis* includes three species:

- *A. axis* in India (including Sikkim), Nepal, and Sri Lanka (plus a number of countries where the species is alien, see details in point A5 below);
- the Calamian deer *A. calamaniensis* (Heude, 1888), found in the Calamian Islands in the Philippines;
- the Indian hog deer *A. porcinus* (Zimmermann, 1780), known from Bangladesh, Burma, Cambodia, China, India, Laos, Nepal, Pakistan, Sri Lanka (perhaps introduced), and Vietnam, with introduced populations in Australia and South Africa.

Wilson and Mittermeier (2011) further include the Bawean deer *Axis kuhlii* (Temminck, 1836) in the genus, which other authors include in the genus *Hyelaphus*.

No subspecies of *A. axis* is recognised by Wilson and Reeder (2005) and Wilson and Mittermeier (2011).

There are no hybrids known to occur in the wild, however, as this cannot be completely excluded, as a precaution this risk assessment includes all *A. axis* hybrids. Attempts to cross axis deer with sika deer (*Cervus nippon*) by artificial insemination are reported (Asher et al 1999). One recorded case of hybridization arising from natural mating between sika deer and axis deer is also reported by Asher et al. (1999). In this case, the widest cross yet observed within the subfamily Cervinae, a hind exhibiting physical characteristics intermediate between the two species was born on a Tennessee deer farm sometime in 1995. Electrophoresis analysis initially verified that hybridization had occurred, but fertility of the hybrid remained to be assessed. The potential for hybridization between axis deer and fallow deer (*Dama dama*) was explored by Willard et al. (2005), also using artificial insemination; in this case, reciprocal hybridization of the two species did not result in the establishment of hybrid pregnancies. Although anecdotal and undocumented accounts for the existence of such hybrids were reported (e.g. between sika deer and axis deer, see Bartos 2009), hybridization between these two species appears unlikely under natural conditions (Willard et al. 2005).

A2. Provide information on the existence of other species that look very similar [that may be detected in the risk assessment area, either in the environment, in confinement or associated with a pathway of introduction]

Include both native and non-native species that could be confused with the species being assessed, including the following elements:

- other alien species with similar invasive characteristics, to be avoided as substitute species (in this case preparing a risk assessment for more than one species together may be considered);
- other alien species without similar invasive characteristics, potential substitute species;
- native species, potential misidentification and mis-targeting

The axis deer is a moderately large deer standing 88-97cm at the shoulders. Hinds are generally smaller than stags, which may weight up to 113 kg (and even over 136 kg in farms, see Centore 2016). Antlers are about 76 cm long and take roughly five months to fully develop (they are present only on stags). The species is characterised by a reddish brown coat covered with typical small white spots (retained at all ages and all seasons), arranged on the lower flanks in longitudinal rows. Under parts are white, as well as inner hind legs and under tail. A dorsal dark stripe is present from the nape to the tip of the tail (for further details see descriptions in Wilson and Mittermeier 2011, GISD 2015, Long 2003, Prater 1965). All the features mentioned above are useful to distinguish this species from other native deer in the risk assessment area. Otherwise only the prominent white throat is absolutely distinctive, because axis deer are in other respects not easy to distinguish (from superficial observation) from fallow deer or some spotted subspecies of sika. For example, in fallow deer younger bucks and does (especially of so-called ‘common’ or ‘menil’ coloration) do not have the distinctive palmated antlers which are typical of mature bucks, therefore they might be confused with axis deer in fleeting observation. Likewise, some colour variants of sika deer and pure Japanese sika deer in summer coat could be confused. Both common-coloured fallow deer, and sika deer, also have a darker dorsal stripe and dark line extending down the tail. Albino animals are occasionally reported (Dinesan et al 2006, Leo Prabu et al. 2013).

A3. Does a relevant earlier risk assessment exist? Give details of any previous risk assessment, including the final scores and its validity in relation to the risk assessment area.

A risk assessment for the axis deer exists for Poland (Okarma et al. 2018). The result shows that the risk for the country is considered “Medium” and the species is considered moderately invasive on the ground of its impact on the environment. In relation to the risk assessment area, this result may be considered valid particularly for the Continental biogeographic region.

The species was also assessed by Nentwig et al. (2018) according to whom out of 486 alien species established in Europe from a wide range of taxonomic groups, the axis deer ranked 31, among those with the highest environmental and socioeconomic impact (following the generic impact scoring system GISS, as calculated by Nentwig et al. 2010).

In Australia, a risk assessment for the species was made in Western Australia. The risk of establishing populations in the wild and the risk of becoming a pest have been assessed as “extreme” (Massam et al. 2010, Page et al. 2008). The map of Australia included in the risk assessment shows the partial suitability of the Mediterranean climate area for the species (Page et al. 2008). In Western Australia the species (either captive or released animals) was also considered as moderately dangerous” in relation to public safety, e.g. in relation to the potential for zoonoses, deer-vehicle collisions, injuries following aggressive behaviour (Massam et al. 2010, Page et al. 2008).

A4. Where is the organism native?

including the following elements:

- an indication of the continent or part of a continent, climatic zone and habitat where the species is naturally occurring
- if applicable, indicate whether the species could naturally spread into the risk assessment area

The axis deer is a tropical or sub-tropical species, native to Asia, endemic of the Indian subcontinent, i.e. India (including Sikkim), Nepal, Bhutan, Bangladesh and Sri Lanka (Long 2003, Wilson and Reader 2005, Duckworth et al. 2015).

Axis deer is typical of the grassland-forest ecotone (Wilson and Mittermeier 2011). As summarised by Duckworth et al. (2015) the axis deer thrive in a wide range of habitats throughout its native range (see also Moe and Wegge 1994), but prefers moist and dry deciduous forest near water, interspersed with dry thorn scrublands or grasslands (Eisenberg and Seidensticker 1976). Mangrove forests (Sankar and Acharya 2004), mixed forests or plantations (with Teak *Tectona grandis* and Sal *Shorea robusta*) (Wilson and Mittermeier 2011) and agricultural crops such as coffee areas, are used too (Bali et al. 2007). This species lives mostly in flat areas and at lower elevations, usually below 1000 m, avoiding slopes, hills and mountain areas, but has also been found at high elevations (2,209 m) in India (Wilson and Mittermeier 2011, Duckworth et al. 2015, Schaller 1967, Deepan et al. 2018).

In general, this species avoids extreme habitats such as open semi-desert or desert, dense moist (evergreen) forests but introduced populations show some flexibility in this regard. For example, animals in the Andaman Islands are found in dense evergreen forests (Ali 2004, Sankar and Acharya 2004) and in Hawaii they are found in areas ranging from semi-deserts to rainforest (Moe and Wegge 1994), up to 2150 m (Waring 1996).

The native range is characterized by significant seasonal changes in temperature and, more importantly, extreme swings in precipitation (Anderson 1999), but axis deer have adapted very well to the European eco-climatic zones. For example, the typical habitat occupied in Croatia is represented by scrublands and woodlands of Euro-Mediterranean vegetation (Centore et al. 2018), while in Russia the species was successfully introduced to an area south of Moscow, characterized by deciduous and mixed forests with oak and undergrowth of spindle tree, buckthorn, dogwood, and other shrubs (Bobrov et al. 2008). In Croatia, the species could not adapt to continental climate (Kusak and Krapinec 2010).

Four key factors were identified as delineating the axis deer’s distribution: (1) the need for water; (2) the need for shade; (3) an avoidance of high, rugged terrain; and (4) a preference for grass as forage (Schaller 1967, Kushwaha 2018). Habitat use varies seasonally, reflecting food availability (see also Centore 2016). The axis deer easily habituates to human presence, and herds often congregate in open areas near habitation or forest camps to spend the night, possibly due to greater safety from predators and poachers (Duckworth et al. 2015). In fact, the limiting factor seems to be winter conditions, particularly strong frosts and thick snow cover (Okarma et al. 2018).

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

Outside the risk assessment area, the axis deer was successfully introduced in the following countries:

- Europe (Russia, and possibly Moldova and Ukraine, but see below);
- Asia (Armenia, Azerbaijan, Andaman Islands, Pakistan);
- North America (USA: California, Florida, Texas and Hawaiian Islands, México);
- South America (Argentina, Brazil, Uruguay);
- Australia

For details, see Long (2003), Lever (1985), Wilson and Reader (2005), Duckworth et al. (2015), Wilson and Mittermeier (2011), Álvarez-Romero and Medellín (2005). According to Šprem and Zachos (2020) introductions to Ukraine and Moldova (as well as to the British Isles) are sometimes mentioned, but there is no reliable information available about this or any free-living populations resulting from these alleged introductions.

The species is also present in South Africa (https://www.invasives.org.za/legislation/item/709-axis-deer-axis-axis, accessed on 26/07/2019).

Axis deer were considered as introduced without success in New Zealand and New Guinea by Long (2003), while Forsyth and Duncan (2001) considered the introduction of this species as “successful” in New Zealand, because the species had a self-sustaining wild population before being eradicated by hunting. This shows that axis deer could have persisted in the climatic and environmental conditions in this country.

A6. In which biogeographic region(s) or marine subregion(s) in the risk assessment area has the species been recorded and where is it established? The information needs be given separately for recorded and established occurrences.

A6a. Recorded: List regions

A6b. Established: List regions

Freshwater / terrestrial biogeographic regions:

- Alpine, Atlantic, Black Sea, Boreal, Continental, Mediterranean, Pannonian, Steppic

Marine regions:

- Baltic Sea, North-east Atlantic Ocean, Mediterranean Sea, Black Sea

Marine subregions:

- Greater North Sea, incl. the Kattegat and the English Channel, Celtic Seas, Bay of Biscay and the Iberian Coast, Western Mediterranean Sea, Adriatic Sea, Ionian Sea, Central Mediterranean Sea, Aegean-Levantine Sea.

Comment on the sources of information on which the response is based and discuss any uncertainty in the response.

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

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

(6a): Alpine, Continental, Mediterranean
(6b): Mediterranean

The source of information on which the response is based can be found in Qu. A8.

A7. In which biogeographic region(s) or marine subregion(s) in the risk assessment area could the species establish in the future under current climate and under foreseeable climate change? The information needs be given separately for current climate and under foreseeable climate change conditions.

A7a. Current climate: List regions

A7b. Future climate: List regions

With regard to EU biogeographic and marine (sub)regions, see above.

With regard to climate change, provide information on

- the applied timeframe (e.g. 2050/2070)
- the applied scenario (e.g. RCP 4.5)
- what aspects of climate change are most likely to affect the risk assessment (e.g. increase in average winter temperature, increase in drought periods)

The assessment does not have to include a full range of simulations on the basis of different climate change scenarios, as long as an assessment with a clear explanation of the assumptions is provided. However, if new, original models are executed for this risk assessment, the following RCP pathways shall be applied: RCP 2.6 (likely range of 0.4-1.6°C global warming increase by 2065) and RCP 4.5 (likely range of 0.9-2.0°C global warming increase by 2065). Otherwise, the choice of the assessed scenario has to be explained.

(7a):
Boreal, Continental, Mediterranean, Alpine, Atlantic, Black Sea, Pannonian, Steppic (see details in Annex VII).
(7b):
Boreal, Continental, Mediterranean, Alpine, Atlantic, Black Sea, Pannonian, Steppic (see details in Annex VII).

A8. In which EU Member States has the species been recorded and in which EU Member States has it established? List them with an indication of the timeline of

observations. The information needs be given separately for recorded and established occurrences.
A8a. Recorded: List Member States
A8b. Established: List Member States
Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden
The description of the invasion history of the species shall include information on countries invaded and an indication of the timeline of the first observations, establishment and spread.

(8a): Czech Republic, France, Ireland, Slovenia; and the United Kingdom

Attempts to introduce axis deer were made as early as 1890 in France, but they did not succeed (Dorst and Giban 1954, Lever 1985).

Axis deer was introduced to west-central Slovenia (from the Brijuni islands) in the late 1940s or in 1950, but this introduction failed (one stag, shot on 12 October 1950 is now in the Natural History Museum of Slovenia, see Duckworth et al. 2015). The species is considered as extinct in Slovenia (Mitchell-Jones et al. 1999).

According to Long (2003) axis deer were reported to be feral in Buckinghamshire, England, in 1944-45, but there is no evidence that they have been present outside a deer park and there is only one record of an escape by a single animal (hence it is dubious whether any population persisted in the wild). According to Fitter (1959) there were a number of reports of individual axis deer in England, but no evidence of breeding (one individual was shot in 1888 in West Sussex, and other animals were seen in 1944-45 in Combe at about the same time in other counties too). According to Šprem and Zachos (2020) introductions to the British Isles are sometimes mentioned, but there is no reliable information available about this or any free-living populations resulting from these alleged introductions.

Occasional records are available also for the following countries:

- Czech Republic: the species was considered as present in game reserves in the Czech Republic as early as 1850 (Mlíkovský and Stýblo 2006) but is now considered extinct (Nobanis 2019).
- Ireland (Fairley 1975).

(8b): Croatia (introduced in 1911)

The only wild populations in the EU are in Croatia, on the islands of Brijuni and Dugi Otok (Šprem and Zachos 2020, Linnell and Zachos 2011, Duckworth et al. 2015).

Axis deer are present on the Veliki Brijun island, the largest island in the Brijuni archipelago. Animals are free on the island, which has a surface of 560 ha. Despite the fact that axis deer are described as capable swimmers (Nowak 1991), Axis deer has never been seen swimming from one island to another, unlike fallow deer (*Dama dama*), so it is considered that the population is restricted in these 560 ha (Public Institution National Park Brijuni and Hunting Directorate of the Ministry of Agriculture, pers. comm. 2020). However, according to Kusak and Krapinec (2010) some animals are observed to swim sometimes from Brijuni to the mainland in the estuary of Mirna river. Also Šprem and Zachos (2020) mention that several cases had been reported of axis deer swimming from Brijuni Islands to the mainland (ca. 3 km), but establishment of new populations was unsuccessful. See also Qu. 4.1.

According to Centore (2016), the first introduction in Croatia dates back to 1911, when several individuals were introduced into Brijuni island from Germany (Šprem et al. 2008). The genetic origin of the introduced animals, however, is unknown (Kusak and Krapinec 2010). According to Long (2003) the population derived from animals which escaped from captivity in 1911 and have increased in numbers substantially. In 2008 the population in the Brijuni National Park reached about 100 individuals, was considered stable and rather numerous (Šprem et al. 2008). According to Šprem and Zachos (2020), some 150 individuals were present in the islands of Brijuni in 2017 (but the same authors also stated that up to 200 animals are removed each year for population control, which may create some confusion about the actual population size in the island). As of April 1, 2019, 76 animals were present according to the Hunting Directorate of the Ministry of Agriculture (Public Institution National Park Brijuni and Hunting Directorate of the Ministry of Agriculture, pers. comm. 2020).

In the area of Dugi Otok island, axis deer is currently present in two hunting grounds: a common open hunting ground number: XIII / 107 " DUGI OTOK – ISTOK" in which the number of axis deer is estimated at 10 individuals, and the state open hunting ground number: XIII / 4 " DUGI OTOK" in which the number is estimated at 12 individuals (as of April 1, 2019). Axis deer in these hunting grounds are not managed, but are removed from the wild in accordance to the relevant legislation (Public Institution National Park Brijuni and Hunting Directorate of the Ministry of Agriculture, pers. comm. 2020). According to Šprem and Zachos (2020) the existence of the axis deer population on the island of Dugi Otok originated in 2012 by 13 individuals escaped from a fenced area from the Brijuni Islands, and increased to about 60 individuals in 2018.

Additional introductions with animals from Brijuni were made in other parts of Croatia but did not succeed. For example, in 1953 the population introduced in the island of Cres declined gradually over the years, the last specimen being recorded in the early 1990s (Frković 2014). The species is considered well established in Brijuni, and according to Centore (2016) survived until the present day due to the favourable climate.

Lever (1985) and Long (2003) report the introduction of two dozen axis deer released in Lithuania in 1954 (which reportedly adapted well and increased to 67 by 1961). However, this information seems not correct, and may well refer to sika deer (*Cervus nippon*) (see for example relevant information on Baleišis et al. 2003), in fact no information was found that axis deer has been ever introduced in Lithuania (Viktorija Maceikaite, pers. comm. 2019). In any case, no mention is made on the species in the review for Baltic countries made by Andersone-Lilley et al. (2010).

A9. In which EU Member States could the species establish in the future under current climate and under foreseeable climate change? The information needs be given separately for current climate and under foreseeable climate change conditions.

A9a. Current climate: List Member States

A9b. Future climate: List Member States

With regard to EU Member States, see above.

With regard to climate change, provide information on

- the applied timeframe (e.g. 2050/2070)

- the applied scenario (e.g. RCP 4.5)
- what aspects of climate change are most likely to affect the risk assessment (e.g. increase in average winter temperature, increase in drought periods)

The assessment does not have to include a full range of simulations on the basis of different climate change scenarios, as long as an assessment with a clear explanation of the assumptions is provided. However, if new, original models are executed for this risk assessment, the following RCP pathways shall be applied: RCP 2.6 (likely range of 0.4-1.6°C global warming increase by 2065) and RCP 4.5 (likely range of 0.9-2.0°C global warming increase by 2065). Otherwise, the choice of the assessed scenario has to be explained.

(9a):
Austria, Belgium, Bulgaria, Croatia, Republic of Cyprus, Czech Republic, Denmark, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden; and the United Kingdom (see details in Annex VII).

(9b):
Austria, Belgium, Bulgaria, Croatia, Republic of Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden; and the United Kingdom (see details in Annex VII).

A10. Is the organism known to be invasive (i.e. to threaten or adversely impact upon biodiversity and related ecosystem services) anywhere outside the risk assessment area?

The species is known to be invasive in several countries outside the risk assessment area (see review in Okarma et al. 2018). For example, in its alien range it is considered invasive in the Andamane Islands (Banerji 1955, Ali and Pelkey 2013, Mohanty et al 2016) and the US, i.e. in Hawaii (Anderson 1999, GISD 2015) and Texas (Long 2003), as well as in Argentina (Flueck 2009), and Russia (Bobrov et al. 2008).

A11. In which biogeographic region(s) or marine subregion(s) in the risk assessment area has the species shown signs of invasiveness? Indicate the area endangered by the organism as detailed as possible.

Freshwater / terrestrial biogeographic regions:

- Alpine, Atlantic, Black Sea, Boreal, Continental, Mediterranean, Pannonian, Steppic

Marine regions:

- Baltic Sea, North-east Atlantic Ocean, Mediterranean Sea, Black Sea

Marine subregions:

Greater North Sea, incl. the Kattegat and the English Channel, Celtic Seas, Bay of Biscay and the Iberian Coast, Western Mediterranean Sea, Adriatic Sea, Ionian Sea, Central Mediterranean Sea, Aegean-Levantine Sea

Mediterranean: see answer to A12.

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

Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden

Croatia: At high population density axis deer was reported to cause significant damage in gardens, orchards and vineyards (Frković 2014). The species is mentioned as invasive in Croatia by CABI database (https://www.cabi.org/isc/datasheet/89941) but very little information was found on the impact on biodiversity. As reported by the Public Institution National Park Brijuni and Hunting Directorate of the Ministry of Agriculture (pers. comm. 2020), it is difficult to say how much impact the axis deer itself has on the biodiversity of Brijuni National Park, but it is certain that mouflon and deer species significantly affect the biodiversity of Veliki Brijun islands where axis deer, mouflon and fallow deer are present. In the past, axis deer dominated over the other two species, but due to one harsh winter in the past many died and fallow deer has since prevailed. As the Public Institution National Park Brijuni has been reducing the number of deer specimens in recent years, currently mouflons are predominant. All three species together have a great impact on grasslands and forests of the island Veliki Brijun. Browsing and grazing of large herbivores that live on the island without natural predators affect lower layers of forests causing a problem for the natural reforestation and affect biodiversity of grassland allowing plants that the animals avoid (for example the Spanish oyster thistle *Scolymus hispanicus*) to overly spread.

According to the few data available from literature (see Šprem et al. 2008) the axis deer forages on *Fraxinus ornus*, *Quercus ilex* leaves and acorns, and sometimes browses the areas of *Myrtus communis*, new stems of blackberry *(Rubus spp.)*, moss growing on rocks and cedar *(Cedrus spp.)* seeds. However, axis deer on the Brijuni Islands regularly consume supplementary feed such as hay and corn, regardless of the quality of the grassy areas (Šprem and Zachos 2020), therefore is likely that this prevents the species from having a greater (visible) impact on the island ecosystem. The evidence of higher impact may also be hidden by the fact that the populations in Croatia are all controlled through hunting (see Šprem and Zachos 2020). Always according to Šprem and Zachos (2020) axis deer impact on forest regeneration is less than other ungulates (i.e. European mouflon), but both terminal and lateral shoots are damaged.

A13. Describe any known socio-economic benefits of the organism.

including the following elements:

- Description of known uses for the species, including a list and description of known uses in the Union and third countries, if relevant.
- Description of social and economic benefits deriving from those uses, including a description of the environmental, social and economic relevance of each of those uses and an indication of associated beneficiaries, quantitatively and/or qualitatively depending on what information is available.

If the information available is not sufficient to provide a description of those benefits for the entire risk assessment area, qualitative data or different case studies from across the Union or third countries shall be used, if available.

The axis deer is considered by some as amongst the most beautiful of all deer (Prater 1965) and this may explain the popularity in zoological gardens and parks around the world (Schaller 1967, Sankar and Acharya 2004). According to the European Association of Zoos and Aquaria, about 625 specimens were kept by zoos across 12 EU Member States[2] and the United Kingdom in October 2019 (EAZA, pers. comm. 2019). These numbers concern only zoos that are members of EAZA and can only provide an indication about the situation across the EU.

As summarised by GISD (2015) the meat of axis deer (venison) is highly regarded as it is extremely lean. It consistently ranks in the top ten of all venison in the world (Anderson 1999). As a result, there is an economic value for the meat.

The axis deer is also a prized hunting quarry, owing to its beauty, especially stags with antlers longer than 76 cm (although it was considered as an unattractive trophy animal in Croatia by Frković, 2014). Recreational deer hunting can thus provide both tangible and intangible social benefits (Jesser 2005). Many game ranches receive upwards of US$1000 for each trophy stag taken (Anderson 1999). In South Africa the costs for a trophy fee is €2,500 (http://www.fgsafaris.com/PriceList.htm, accessed on 26/07/2019). Poaching and black-market sales are common wherever the species occurs (Anderson 1999), and some documented evidence of skins and antlers seized from wildlife smugglers is available for India (TRAFFIC 2017).

[2] Austria, Denmark, Czechia, Estonia, France, Germany, Hungary, Italy, Netherlands, Portugal, Spain, Sweden.

SECTION B – Detailed assessment

Important instructions:

- In the case of lack of information the assessors are requested to use a standardized answer: "No information has been found."
- With regard to the scoring of the likelihood of events or the magnitude of impacts see Annexes I and II.
- With regard to the confidence levels, see Annex III.
- Highlight the selected response score and confidence level in **bold** but keep the other scores in normal text (so that the selected score is evident in the final document).

1 PROBABILITY OF INTRODUCTION

Important instructions:

- **Introduction** is the movement of the species into the risk assessment area (it may be either in captive conditions and/or in the environment, depending on the relevant pathways).
- **Entry** is the release/escape/arrival in the environment, i.e. occurrence in the wild and is treated in the next section (N.B. introduction and entry may coincide for species entering through pathways such as "corridor" or "unaided)".
- The classification of pathways developed by the Convention of Biological Diversity (CBD) should be used. For detailed explanations of the CBD pathway classification scheme consult the IUCN/CEH guidance document[3] and the provided key to pathways[4].
- For organisms which are already present in the risk assessment area, only complete this section for current active pathways and, if relevant, potential future pathways.

Qu. 1.1. List relevant pathways through which the organism could be introduced. Where possible give details about the specific origins and end points of the pathways as well as a description of any associated commodities.

For each pathway answer questions 1.2 to 1.7 (copy and paste additional rows at the end of this section as necessary). Please attribute unique identifiers to each question if you consider more than one pathway, e.g. 1.2a, 1.3a, etc. and then 1.2b, 1.3b etc. for the next pathway.

In this context a pathway is the route or mechanism of introduction of the species.

The description of commodities with which the introduction of the species is generally associated shall include a list and description of commodities with an indication of associated risks (e.g. the volume of trade; the likelihood of a commodity being contaminated or acting as vector).

If there are no active pathways or potential future pathways this should be stated explicitly

[3] https://circabc.europa.eu/sd/a/738e82a8-f0a6-47c6-8f3b-aeddb535b83b/TSSR-2016-010%20CBD%20categories%20on%20pathways%20Final.pdf
[4] https://circabc.europa.eu/sd/a/0aeba7f1-c8c2-45a1-9ba3-bcb91a9f039d/TSSR-2016-010%20CBD%20pathways%20key%20full%20only.pdf

here, and there is no need to answer the questions 1.2-1.9

The following active pathways of introduction have been identified in the risk assessment area:

a) Hunting (Release in nature)
b) Farmed animals (including animals left under limited control) (Escape from confinement)
c) Botanical garden/zoo/aquaria (excluding domestic aquaria) (Escape from confinement)

Another pathway known for the axis deer is “Landscape / flora / fauna “improvement” in the wild (release in nature)”. However, this pathway is only known in regions other than Europe (no evidence was available for the risk assessment area). For example, in Australia, the establishment of wild deer populations began in the mid-1800s, when Acclimatisation Societies released deer for hunting or for aesthetic reasons (Moriarty 2004, Long 2003, Davis et al. 2016). The species was introduced as ornamental also in Argentina (Novillo and Ojeda 2008). As this pathway is considered not active in the risk assessment area, it is not considered further in this document.

The “natural spread” of individuals from neighbouring countries, e.g. Moldova, Russia, Ukraine (Long 2003, Duckworth et al. 2015) is another possibility. The likelihood of the species appearing in the natural environment of Poland as a result of expansion from Ukraine (near Dnipropetrovsk and in the Volga region, i.e. over 1000 km from the Polish border), however, was considered very low within the next 15 years (Okarma et al. 2018). Moreover, the occurrence of any free-living population in Ukraine and Moldova is considered questionable by Šprem and Zachos (2020). Therefore, also this pathway, is not considered active in the risk assessment area, and not considered further in this document. Similarly, it is likely that some animals are kept as pets by private owners, for example in Croatia (according to the Public Institution National Park Brijuni and Hunting Directorate of the Ministry of Agriculture, pers. comm. 2020) and in France (where according to JF Maillard, OFB/UPADE, as pointed out in a note to the EC, it must be rarely present with private owners due to administrative constraints, hence the risk exists but it must be low). However, as no escapes are reported from this pathway, this is not considered active in the risk assessment area, and not considered further in this document.

a) Hunting (release in nature)

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

RESPONSE	**intentional** unintentional	**CONFIDENCE**	low medium **high**

This pathway refers to animals introduced into the risk assessment area to be hunted for food and/or to provide recreational hunting opportunities (including collection of hunting trophies). This is the typical pathway of introduction also in other regions, for example in Ukraine (Page et al. 2008), USA (GISD 2015), Argentina (Carpinetti and Merino 2000, Novillo and Ojeda 2008), Andamane Islands (Long 2003, Ali and Pelkey 2013, Banerji 1955), Australia (Massam et al. 2010, Moriarty 2004) and South Africa (https://www.invasives.org.za/legislation/item/709-axis-deer-axis-axis, accessed on 26/07/2019).

Qu. 1.3a. How likely is it that large numbers of the organism will be introduced through this pathway from the point(s) of origin over the course of one year? including the following elements: • discuss how likely the organism is to get onto the pathway in the first place. Also comment on the volume of movement along this pathway. • an indication of the propagule pressure (e.g. estimated volume or number of individuals / propagules, or frequency of passage through pathway), including the likelihood of reinvasion after eradication • if relevant, comment on the likelihood of introduction based on propagule pressure (i.e. for some species low propagule pressure (1-2 individuals) could result in introduction whereas for others high propagule pressure (many thousands of individuals) may not.

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

Based on evidence relevant to past events, it is possible to expect further introductions and translocations of this species motivated by hunting purposes. Introduction is not expected to take place with large quantities (e.g. hundreds) of animals at one time. It would be expected, however, to be a number large enough to establish viable wild populations (considering that a number just above 7 animals is considered sufficient, see Qu. 2.3a.).

Several introductions occurred in Croatia, despite the unsuccessful result. As summarised by Frković (2014) as part of an extensive programme of introductions to continental hunting grounds, axis deer were brought from the Brijuni islands into several sites in the Croatian Littoral in 1953. A number of factors, such as the inadequately organized capture and transport of the animals, the insufficient preparation of the introduction sites, the poor adaptation of the animals to new habitat conditions, the inability to roam, and the calf mortality in winter season, led to the failure of such introductions. The only site where the number of the introduced axis deer increased was in Punta Križa (island of Cres), where it was hunted as early as in 1955. However, due to the damage it inflicted to vineyards and households, the axis deer was hunted freely without any protection for several years (1965–1970). When the more attractive mouflon (*Ovis musimon*) and fallow deer (*Dama dama*) were introduced to the area in 1962 and 1966, the axis deer population of Punta Križa gradually declined over the years, so that the last specimen was recorded in the early 1990s. Therefore, the only wild populations still present in Croatia are those of the islands of Brijuni and Dugi Otok (Šprem and Zachos 2020).

Qu. 1.4a. How likely is the organism to survive, reproduce, or increase during transport and storage along the pathway (excluding management practices that would kill the organism)?

RESPONSE	very unlikely unlikely	**CONFIDENCE**	low medium

	moderately likely likely **very likely**		**high**

The species is able to survive during passage along the pathway, as demonstrated by the fact that it has been successfully introduced in the past (e.g. in Croatia) and that secondary translocations occurred too. Hence, it is very likely that the animals survive during transport and storage along the pathway (provided appropriate animal welfare standards). The species is unlikely to reproduce or increase during such transport.

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

RESPONSE	**N/A** very unlikely unlikely moderately likely likely very likely	**CONFIDENCE**	low medium high

There are no management measures applicable during the introduction of animals.

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

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

The intentional introduction for hunting purposes cannot go undetected (although this is valid for authorised releases only, as any illegal introduction would likely go undetected).

Qu. 1.7a. Estimate the overall likelihood of introduction into the risk assessment area based on this pathway?

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

The species was already introduced to the risk assessment area in the past along this pathway, but only in a very limited number of occasions.

b) Farmed animals (including animals left under limited control) (Escape from confinement)

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

RESPONSE	**intentional** unintentional	CONFIDENCE	low medium **high**

This pathway refers to animals that have been introduced for farming into confinements, where they were kept with the primary purpose to provide food, resources and/or as working animals (it does not include animals held in zoos, deer parks and the likes, which are treated in the points below 1.2c to 1.7c). However, the number of axis deer farms present in the EU is unknown, and no information is available about the numbers of axis deer kept in such facilities.

The only documented evidence is a small population occurring in Croatia in a fenced area in the island of Rab (Centore 2016). In Germany, the species is kept in enclosures since 1707, although no occurrences are documented in the wild (Geiter et al. 2002, Nehring et al. 2015).

In Australia, the axis deer is the most popular farmed species among deer, and the most commonly released (Moriarty 2004). According to Massam et al. (2010), the species is used as livestock, e.g. for venison production, since the early 1800s in New South Wales (Moriarty 2004). In Texas the species occurs as a confined animal on ranches in 67 counties (Davis and Schmidly 1997, Long 2003).

Qu. 1.3b. How likely is it that large numbers of the organism will be introduced through this pathway from the point(s) of origin over the course of one year?
including the following elements:

- discuss how likely the organism is to get onto the pathway in the first place. Also comment on the volume of movement along this pathway.
- an indication of the propagule pressure (e.g. estimated volume or number of individuals / propagules, or frequency of passage through pathway), including the likelihood of reinvasion after eradication
- if relevant, comment on the likelihood of introduction based on propagule pressure (i.e. for some species low propagule pressure (1-2 individuals) could result in introduction whereas for others high propagule pressure (many thousands of individuals) may not.

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

It is possible to expect further introductions and translocations of this species motivated by farming purposes, although data on this regard are not available. It is moderately likely that large numbers of animals are introduced for farming within one year.

Qu. 1.4b. How likely is the organism to survive, reproduce, or increase during transport and storage along the pathway (excluding management practices that would kill the

organism)?

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

As demonstrated by the fact that it has been frequently kept in captive facilities, the likelihood of the animals to survive during transport and storage along the pathway is high, provided that appropriate animal welfare standards are ensured. Also, the likelihood of the axis deer to survive, reproduce, or increase in a fenced area is high, provided that the species requirements are duly considered and ensured (see for example Centore 2016, Centore et al. 2018).

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

RESPONSE	N/A very unlikely unlikely moderately likely **likely** very likely	CONFIDENCE	low medium **high**

The likelihood of the axis deer to survive existing management practices in a fenced area will vary depending on the type of deer management and extent of disturbance in the area. In principle it might be high, provided that the species requirements are duly considered and ensured (see for example Centore 2016). For example, as reported by Centore et al. (2018), the population in the fenced area in the island of Rab is actively managed through hunting. The hunting technique is stalking, distributed year round, depending on hunting season, and is characterised by an annual hunting bag of 6 animals (4 adults and 2 yearling) with a sex ratios of 0.86:1 in favour of stags. However, this is not deemed to affect the population, which in fact was specifically created and maintained for hunting purposes.

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

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

The intentional introduction for farming purposes cannot go undetected.

Qu. 1.7b. Estimate the overall likelihood of introduction into the risk assessment area based on this pathway?

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

The species was already introduced into the risk assessment area in the past along this pathway, but only in a very limited number of occasions.

c) Botanical garden/zoo/aquaria (excluding domestic aquaria) (Escape from confinement)

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

RESPONSE	**intentional** unintentional	CONFIDENCE	low medium **high**

Axis deer are known to be kept in zoos and wildlife parks for ornamental reasons. In fact this species was considered for centuries a favourite with zoological gardens and parks around the world (Schaller 1967, Sankar and Acharya 2004), and managed herds still occur in parks throughout the native and introduced range (Duckworth et al. 2015).

In Europe, the species is currently known to be present in captive facilities for ornamental reasons in many countries, like in the UK (Long 2003), Italy (Boitani et al. 2003), in Poland (Okarma et al. 2018), as well as in Denmark, Estonia, France, Croatia, Netherlands, Austria, Portugal, Sweden, Spain, Czech Republic, Cyprus and Germany (see https://www.zootierliste.de/?klasse=1&ordnung=121&familie=12110&art=1160403). According to the data from the European Association of Zoos and Aquaria (EAZA, pers. comm. 2019) taken from Species360 ZIMS the axis deer population in EAZA associated facilities is represented by 96 males, 236 females and 294 animals of unknown sex across 12 EU Member States[5] and the United Kingdom (information correct as of 03/10/2019).

Qu. 1.3c. How likely is it that large numbers of the organism will be introduced through this pathway from the point(s) of origin over the course of one year? including the following elements: • discuss how likely the organism is to get onto the pathway in the first place. Also comment on the volume of movement along this pathway. • an indication of the propagule pressure (e.g. estimated volume or number of individuals / propagules, or frequency of passage through pathway), including the likelihood of reinvasion after eradication • if relevant, comment on the likelihood of introduction based on propagule pressure (i.e. for some species low propagule pressure (1-2 individuals) could result in introduction whereas for others high propagule pressure (many thousands of individuals) may not.

RESPONSE	very unlikely	CONFIDENCE	low

[5] Austria, Denmark, Czechia, Estonia, France, Germany, Hungary, Italy, Netherlands, Portugal, Spain, Sweden

	unlikely **moderately likely** likely very likely		**medium** high

It is moderately likely that large numbers of animals are introduced for keeping in zoos and deer parks within one year. So far, according to the data from the European Association of Zoos and Aquaria (EAZA, pers. comm. 2019) taken from Species360 ZIMS the axis deer population in EAZA associated facilities, there are 29 zoos hosting axis deer, with a number of animals ranging from 3 to 76 in each single facility, and about 2/3 of the facilities have at least 10 animals.

Qu. 1.4c. How likely is the organism to survive, reproduce, or increase during transport and storage along the pathway (excluding management practices that would kill the organism)?

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

The likelihood of the animals to survive during transport and storage along the pathway is high, as demonstrated by the fact that it has been frequently kept in captive facilities (hence provided that appropriate animal welfare standards are ensured). Also, the likelihood of the axis deer to survive, reproduce, or increase in a fenced area is high, provided that the species requirements are duly considered and ensured (see for example Centore 2016, Centore et al. 2018).

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

RESPONSE	**N/A** very unlikely unlikely moderately likely likely very likely	**CONFIDENCE**	low medium high

There are no management measures applicable during the introduction of animals.

Qu. 1.6c. How likely is the organism to be introduced into the risk assessment area undetected?

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

The intentional introduction into a zoological facility cannot go undetected.

Qu. 1.7c. Estimate the overall likelihood of introduction into the risk assessment area based on this pathway?

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

Axis deer is abundant in zoos and deer parks and the likelihood of further introductions or transport of animals between existing facilities (from outside the EU into the risk assessment area) is moderately likely.

End of pathway assessment, repeat Qu. 1.3 to 1.7 as necessary using separate identifier.

Qu. 1.8. Estimate the overall likelihood of introduction into the risk assessment area based on all pathways and specify if different in relevant biogeographical regions in current conditions. Provide a thorough assessment of the risk of introduction in relevant biogeographical regions in current conditions: providing insight in to the risk of introduction into the Union.

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

The species is already present in the risk assessment area through the described pathways, possibly leading to a risk of introduction in all biogeographical regions (but paucity of information on animals held in farms and parks does not allow to assess which regions exactly). It is to be noted, however, that apart from the one wild population in Croatia, itself restricted to an island, all current populations (by whatever route to date) are relative to animals held in confinement.

Qu. 1.9. Estimate the overall likelihood of introduction into the risk assessment area based on all pathways in foreseeable climate change conditions? Thorough assessment of the risk of introduction in relevant biogeographical regions in foreseeable climate change conditions: explaining how foreseeable climate change conditions will influence this risk. With regard to climate change, provide information on • the applied timeframe (e.g. 2050/2070) • the applied scenario (e.g. RCP 4.5) • what aspects of climate change are most likely to affect the likelihood of introduction (e.g. change in trade or user preferences)

The thorough assessment does not have to include a full range of simulations on the basis of different climate change scenarios, as long as an assessment of likely introduction within a medium timeframe scenario (e.g. 30-50 years) with a clear explanation of the assumptions is provided. However, if new, original models are executed for this risk assessment, the following RCP pathways shall be applied: RCP 2.6 (likely range of 0.4-1.6°C global warming increase by 2065) and RCP 4.5 (likely range of 0.9-2.0°C global warming increase by 2065). Otherwise, the choice of the assessed scenario has to be explained.

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

There is no evidence that climate change will have any effect on the likelihood of introduction via hunting, farming or keeping animals in zoological facilities.

2 PROBABILITY OF ENTRY

Important instructions:

- Entry is the release/escape/arrival in the environment, i.e. occurrence in the wild. Entry is not to be, the movement of an organism within the risk assessment area.
- The classification of pathways developed by the Convention of Biological Diversity (CBD) should be used. For detailed explanations of the CBD pathway classification scheme consult the IUCN/CEH guidance document[6] and the provided key to pathways[7].
- For organisms which are already present in the risk assessment area, only complete this section for current active or if relevant potential future pathways. This section need not be completed for organisms which have entered in the past and have no current pathway of entry.

Qu. 2.1. List relevant pathways through which the organism could enter into the environment.
For each pathway answer questions 2.2 to 2.7 (copy and paste additional rows at the end of this section as necessary). Please attribute unique identifiers to each question if you consider more than one pathway, e.g. 2.2a, 2.3a, etc. and then 2.2b, 2.3b etc. for the next pathway.
In this context a pathway is the route or mechanism of entry of the species into the environment.

If there are no active pathways or potential future pathways this should be stated explicitly here, and there is no need to answer the questions 2.2-2.8

Pathway name:

The following active pathways of entry have been identified in the risk assessment area:

a) Hunting (Release in nature)
b) Farmed animals (including animals left under limited control) (Escape from confinement)
c) Botanical garden/zoo/aquaria (excluding domestic aquaria) (Escape from confinement)

The "natural spread" of individuals from neighbouring countries, e.g. Moldova, Russia, Ukraine (Long 2003, Duckworth et al. 2015) is another possibility (but the occurrence of any free-living population in Ukraine and Moldova is considered questionable by Šprem and Zachos 2020). However, as no detailed information is available on the exact location and relevant population size, or the population and expansion trends, this is not considered an active pathway for the time being and the relevant risk cannot be quantified.

a) Hunting (Release in nature)

Qu. 2.2a. Is entry into the environment intentional (e.g. the organism is released for a specific purpose) or unintentional (e.g. the organism escapes from a confinement)?

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[6] https://circabc.europa.eu/sd/a/738e82a8-f0a6-47c6-8f3b-aeddb535b83b/TSSR-2016-010%20CBD%20categories%20on%20pathways%20Final.pdf
[7] https://circabc.europa.eu/sd/a/0aeba7f1-c8c2-45a1-9ba3-bcb91a9f039d/TSSR-2016-010%20CBD%20pathways%20key%20full%20only.pdf

RESPONSE	**intentional** unintentional	CONFIDENCE	low medium **high**

This pathway refers to animals released intentionally into the natural environment to be hunted for food and/or to provide recreational hunting opportunities (including collection of hunting trophies). The release for hunting purpose used to be the main pathway for the species in Europe, as documented in Croatia (Frković 2014; Centore et al. 2018), where several entries into the wild occurred, some of which with successful result (although ultimately only one population has been kept viable until present).

This has been a typical pathway of entry also in other regions, for example in Ukraine (Page et al. 2008), USA (GISD 2015), Argentina (Carpinetti and Merino 2000, Novillo and Ojeda 2008), Andamane Islands (Long 2003, Ali and Pelkey 2013, Banerji 1955), Australia (Massam et al. 2010, Moriarty 2004) and South Africa (https://www.invasives.org.za/legislation/item/709-axis-deer-axis-axis, accessed on 26/07/2019).

Qu. 2.3a. How likely is it that large numbers of the organism will enter into the environment along this pathway from the point(s) of origin over the course of one year?

including the following elements:

- discuss how likely the organism is to get onto the pathway in the first place. Also comment on the volume of movement along this pathway.
- an indication of the propagule pressure (e.g. estimated volume or number of individuals / propagules, or frequency of passage through pathway), including the likelihood of reinvasion after eradication
- if relevant, comment on the likelihood of entry into the environment based on propagule pressure (i.e. for some species low propagule pressure (1-2 individuals) could result in entry whereas for others high propagule pressure (many thousands of individuals) may not).

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

It seems that a very small number of hinds and a few stags is sufficient to found a new population. Despite some uncertainty regarding the outcome of the introduction of axis deer, the propagule size in deer introductions is considered a highly significant predictor of establishment success, as introduction involving four or fewer individuals failed, whereas involving seven or more individuals succeeded (Forsyth et al. 2004).

In Croatia the axis deer population is managed only in the fenced part of the state open hunting ground (number: VIII / 6 - "KALIFRONT") on the island of Rab, where a parental stock of 63 heads and an increase of 15 heads per year is defined by the game management plan (Public Institution National Park Brijuni and Hunting Directorate of the Ministry of

Agriculture, pers. comm. 2020). This population originated from seven axis deer released in 1974 and resulting in a total of 78 animals during the 2015/2016 season, according to Centore et al. (2018). Axis deer in the island of Rab are all kept in a fenced area, but there are also animals reported out of the fence (Nikica Šprem pers. comm. 2020). However, any axis deer out of the enclosure needs to be removed from the wild in accordance to the relevant regulations (Public Institution National Park Brijuni and Hunting Directorate of the Ministry of Agriculture, pers. comm. 2020).

In other introductions occurred in countries outside Europe, the animals were subject to active management (i.e. hunting) therefore the data cannot be considered representative of any specific trend. However, several other introductions occurred in Croatia, although these were unsuccessful (see Qu 1.3a).

Outside the risk assessment area, in the Hawaiian Islands, deer populations flourished on Oahu, Molokai, and Lanai following releases. For example, as reported by Waring (1996) 8 axis deer (3 stags, 4 hinds, and one male fawn) were released in 1868 on Molokai Island where the population increased to 1,000 within 20 years and reached perhaps 7,500 before specific control measures were taken (see also Anderson, 1999). Similar trends were reported in other islands (Anderson 1999). In Queensland (Australia), one herd reported as still present by Bentley (1957) was established about 1866 by the introduction of a stag and two hinds. Similarly, in Rita Island (in Queensland) a population starting in the late 1970s from 20 individuals reached 2,000 or more in 2004 (Jesser 2005). In Ukraine, the number of axis deer increased from 25 individuals to 448 in 15 years (Anderson 1999), but no specific pathways are described. Also in Russia a population of axis deer grew rapidly, from 50 head in 1973 to 109 head in 1989 (Bobrov et al. 2008) but also in this case no specific pathways are described.

Qu. 2.4a. How likely is the organism to enter into the environment within the risk assessment area undetected?

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

The intentional release of the species in the wild for hunting purposes cannot go undetected (although this is valid for authorised releases only, as any illegal introduction would likely go undetected).

Qu. 2.5a. How likely is the organism to enter into the environment during the months of the year most appropriate for establishment?

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

There is no documented evidence about which particular time of the year would be more appropriate for establishment. The diverse diet and habitats requirements along with the aseasonal reproduction patterns may open the window of opportunity for the entry of the species into the environment during most (if not all) months of the year. The likelihood of the animals to enter into the environment during the period most appropriate for establishment along this pathway therefore is high. Moreover, it is likely that hunters will release the animals in the most appropriate time and place, although there is no documented evidence that this has been systematically done (hence the low confidence).

Qu. 2.6a. How likely is the organism to be able to transfer from the pathway to a suitable habitat or host in the environment?

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

Same as in 2.5a.

Qu. 2.7a. Estimate the overall likelihood of entry into the environment within the risk assessment area based on this pathway?

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

The species has already entered the risk assessment area through this pathway, although there is no evidence that this is going to happen regularly.

b) Farmed animals (including animals left under limited control) (Escape from confinement)

Qu. 2.2b. Is entry into the environment intentional (e.g. the organism is released for a specific purpose) or unintentional (e.g. the organism escapes from a confinement)?

RESPONSE	intentional **unintentional**	**CONFIDENCE**	low medium **high**

This pathway refers to the unintentional escape of animals from confinements where they were kept with the primary purpose to provide food, resources and/or as working animals. However, the number of deer farms present in the EU is unknown, and no information is available about the number of axis deer kept in such facilities.

Escapes from farms is a well known risk also in regions other than the EU, e.g. Ukraine (Page et al. 2008). In Australia, axis deer is the most popular farmed species among deer and the most commonly released (Moriarty 2004). According to Massam et al. (2010) escapes occurred since the early 1800s in New South Wales. Also, escapes from private captive facilities are reported in the US, particularly in Texas (Long 2003). In the USA, the origin a population introduced in the 1930s in Volusia County in Florida was caused by the escape from a private collection (Long 2003, Page et al. 2008).

Qu. 2.3b. How likely is it that large numbers of the organism will enter into the environment along this pathway from the point(s) of origin over the course of one year? including the following elements: • discuss how likely the organism is to get onto the pathway in the first place. Also comment on the volume of movement along this pathway. • an indication of the propagule pressure (e.g. estimated volume or number of individuals / propagules, or frequency of passage through pathway), including the likelihood of reinvasion after eradication • if relevant, comment on the likelihood of entry into the environment based on propagule pressure (i.e. for some species low propagule pressure (1-2 individuals) could result in entry whereas for others high propagule pressure (many thousands of individuals) may not).

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

Although there are no specific data for axis deer (with the exception of some generic reference of animals escaped from fenced areas, see Šprem and Zachos 2020), escapes of other species of deer from farms are well known in Europe, as in the case of the sika deer (Bartos 2009). For example, in France an increasing number of small free-living sika deer populations have been reported to enter the wild (and establish) during the last decades, mostly as a result of escapes from deer parks (Baiwy et al. 2013) which share many analogies with deer farms. Also in Germany, according to Bartos (2009), frequent escapes of sika deer from an enclosure near Neuhaus, Möhnesee, occurred (here axis deer were present too, thus showing the inherent risk of entry associated to this pathway). Escapes of sika deer occurred also in Lithuania (Baleišis et al. 2003) and in Poland (Solarz et al. 2018).

Escapes of axis deer from farms are documented in other countries beyond Europe, e.g. in Australia (Jesser 2005). There, axis deer is known to be farmed since 1803, and already 6 years later the escape of 400 animals was recorded (Moriarty 2004).

Qu. 2.4b. How likely is the organism to enter into the environment within the risk assessment area undetected?

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

This is a medium sized deer heavily spotted in all seasons, and although mostly active around dawn and dusk (Wilson and Mittermeier 2011) it may be easily detected by hunters, naturalists, farmers, etc., hence it is unlikely to be introduced in the risk assessment area undetected. Nevertheless, the occurrence of other deer species throughout much of the risk assessment area may allow the entry of axis deer into the wild to go undetected by landowners and the general public not fully familiar with deer species differences.

Qu. 2.5b. How likely is the organism to enter into the environment during the months of the year most appropriate for establishment?

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

There is no documented evidence about which particular time of the year would be more appropriate for establishment, but is can be assumed that it is not during winter months (see for example limiting factors in Qu. 1.3a and 2.3a). The diverse diet and habitats requirements along with the aseasonal reproduction patterns may open the window of opportunity for the entry of escaped animals into the environment during most (if not all) months of the year.

Qu. 2.6b. How likely is the organism to be able to transfer from the pathway to a suitable habitat or host in the environment?

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

The likelihood of the animals to be able to transfer from the pathway to a suitable habitat in the environment through this pathway depends on the actual location of the deer farm. It is considered unlikely because of the lack of documented evidence on this regard, but on the basis of the experience with other deer species, it is not possible to exclude that this may happen.

Qu. 2.7b. Estimate the overall likelihood of entry into the environment within the risk assessment area based on this pathway?

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

The species has not yet entered the wild through this pathway, however, there is some risk for such events to happen as long as animals are kept in such facilities. For example in relation to the population on the island of Rab, as the species is known to be a good swimmer and move across islands by covering also distances of 10 km (see Qu. 4.1). However, the sound assessment of this point is affected by the lack of information about the distribution of deer farms in Europe where the species is held and their biosecurity.

c) Botanical garden/zoo/aquaria (excluding domestic aquaria) (Escape from confinement)

Qu. 2.2c. Is entry into the environment intentional (e.g. the organism is released for a specific purpose) or unintentional (e.g. the organism escapes from a confinement)?

RESPONSE	intentional **unintentional**	**CONFIDENCE**	low medium **high**

This pathway refers to the unintentional escape of animals from facilities such as zoological and deer parks where they are confined within enclosures, displayed to the public, and in which they may also breed. Nevertheless, a part from the number of zoos associated to EAZA, the total number of zoos and deer parks present in the EU is unknown, and no information is available about the number of axis deer kept in such facilities.

In Europe, there is no documented evidence on escapes of the species from captive facilities, except for some general references for the UK (Long 2003), but this possibility cannot be completely ruled out. In fact, escapes from private captive facilities is a well known risk in regions other than Europe, e.g. a release from a zoo in Armenia is reported (Long 2003), and escapes from captive facilities are reported too, e.g. for Ukraine and the US, particularly in Texas (Long 2003). Also the origin of the population introduced during early 1940s to Point Reyes Peninsula (Marin County, California) was the San Francisco Zoo (Long 2003, Page et al. 2008).

Qu. 2.3c. How likely is it that large numbers of the organism will enter into the environment along this pathway from the point(s) of origin over the course of one year?
including the following elements: • discuss how likely the organism is to get onto the pathway in the first place. Also comment on the volume of movement along this pathway. • an indication of the propagule pressure (e.g. estimated volume or number of individuals / propagules, or frequency of passage through pathway), including the likelihood of reinvasion after eradication • if relevant, comment on the likelihood of entry into the environment based on propagule pressure (i.e. for some species low propagule pressure (1-2 individuals) could result in entry whereas for others high propagule pressure (many thousands of individuals) may not).

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

No specific information has been found for axis deer, but it is considered unlikely that large numbers of animals escape from zoos or deer parks within one year.

Escapes of animals from deer farms and deer parks are however well known in Europe, as in the case of the sika deer (Bartos 2009). For example, in France an increasing number of small free-living sika deer populations have been reported during the last decades, mostly as a result of escapes from deer parks (Baiwy et al. 2013). According to Bartos (2009) frequent escapes of sika deer occurred in Germany, from an enclosure near Neuhaus, Möhnesee, where axis deer were present too, thus showing the inherent risk of entry associated to this pathway. Additionally, it is known that some populations of free-ranging fallow deer in Europe derive from escapes from deer parks.

It is however unknown how many axis deer are kept in deer farms and parks in Europe (with the notable exception of the animals kept in EAZA associated facilities (see Qu. 1.2c and 1.3c), and there is no documented evidence on escapes of this species from such facilities. Also in Croatia, the Ministry of Agriculture (responsible for hunting) and the Ministry of Environment and Energy (responsible for nature protection) confirmed that they do not have any data or information on the existence of axis deer populations held in captivity (Public Institution National Park Brijuni and Hunting Directorate of the Ministry of Agriculture, pers. comm. 2020).

Qu. 2.4c. How likely is the organism to enter into the environment within the risk assessment area undetected?

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

This is a medium sized deer heavily spotted in all seasons, and although mostly active around dawn and dusk (Wilson and Mittermeier 2011) it may be easily detected by hunters, naturalists, farmers, etc. hence it is unlikely to enter the wild in the risk assessment area as an escape from a zoo or deer park undetected. Nevertheless, the occurrence of other deer species throughout much of the risk assessment area may allow the entry of axis deer to go undetected by landowners and the general public not fully familiar with deer species differences.

Qu. 2.5c. How likely is the organism to enter into the environment during the months of the year most appropriate for establishment?

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

There is no documented evidence about which particular time of the year would be more appropriate for establishment, but it can be assumed that it is not during winter months (see for example limiting factors in Qu. 1.3a and 2.3a). The diverse diet and habitats requirements along with the aseasonal reproduction patterns may open the window of opportunity for the entry of escaped animals into the environment during most (if not all) months of the year

Qu. 2.6c. How likely is the organism to be able to transfer from the pathway to a

suitable habitat or host in the environment?

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

The likelihood of the animals to be able to transfer from the pathway to a suitable habitat in the environment through this pathway depends on the actual location of the zoological garden or deer park. It is considered unlikely because of the lack of documented evidence on this regard, but on the basis of the experience with other deer species, it is not possible to exclude that this may happen.

Qu. 2.7c. Estimate the overall likelihood of entry into the environment within the risk assessment area based on this pathway?

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

The species has not yet entered the wild through this pathway (as escapee from a zoo or deer park), but some risk for such events to happen exists as long as animals are kept in such facilities. However, the sound assessment of this point is affected by the lack of information about the distribution of zoos and deer parks in Europe where the species is held and their biosecurity.

End of pathway assessment, repeat Qu. 2.2 to 2.7. as necessary using separate identifier.

Qu. 2.8. Estimate the overall likelihood of entry into the environment within the risk assessment area based on all pathways in current conditions and specify if different in relevant biogeographical regions. Provide a thorough assessment of the risk of entry into the environment in relevant biogeographical regions in current conditions.

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

The most likely pathway of axis deer entry into the wild within the EU is the deliberate release for hunting (as it has happened in the Mediterranean biogeographical region in the past) and, less likely, the accidental/deliberate releases of individuals from deer farms and zoological gardens or deer parks.

Qu. 2.9. Estimate the overall likelihood of entry into the environment within the risk assessment area based on all pathways in foreseeable climate change conditions and

specify if different in relevant biogeographical regions. Thorough assessment of the risk of entry in relevant biogeographical regions in foreseeable climate change conditions: explaining how foreseeable climate change conditions will influence this risk, specifically if likelihood of entry is likely to increase or decrease for specific pathways.

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

There is no evidence that climate change will have any effect on the likelihood of entry via the active pathways.

3 PROBABILITY OF ESTABLISHMENT

Important instructions: • For organisms which are already established in parts of the risk assessment area, answer the questions with regard to those areas, where the species is not yet established.

Qu. 3.1. How likely is it that the organism will be able to establish in the risk assessment area based on the history of invasion by this organism elsewhere in the world (including similarity between other abiotic conditions within it and the organism's current distribution)?

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

The only population established in the wild in the EU is in Croatia, on the islands of Brijuni, off Istria (Duckworth et al. 2015). However, environmental conditions similar to those present in the native and alien range of the species are present in other areas of the EU, particularly in the Mediterranean region, therefore it is likely that suitable sites exist elsewhere in all biogeographic regions in the risk assessment area (see Annex VII).

This may be partly confirmed by the fact that before being eradicated the axis deer was considered as successfully introduced also in New Zealand (Forsyth and Duncan 2001), a country partly sharing bio-climatic conditions similar to those found in Europe, as demonstrated by the many successful introductions of alien species of European origin.

Although native to tropical and subtropical areas of the Indian subcontinent, axis deer have adapted well to other ecoclimatic zones, including those present in the EU, such as the Mediterranean, and more continental climates in Russia (and the Ukraine, although the occurrence of any free-living population in this country is considered questionable by Šprem and Zachos 2020).

Qu. 3.2. How widespread are habitats or species necessary for the survival, development and multiplication of the organism in the risk assessment area?

RESPONSE	very isolated isolated moderately widespread **widespread** ubiquitous	**CONFIDENCE**	low **medium** high

Axis deer seem characterised by an extreme degree of flexibility and are well adapted to a wide variety of natural and semi-natural habitats and food, according to availability. Therefore, habitats or species (food sources) necessary for the survival, development and multiplication of axis deer are moderately widespread in the risk assessment area, particularly in the Mediterranean region.

Axis deer occupy a wide range of habitats throughout their native range, and are most commonly associated with a mixture of forest and more open grass-shrub, often avoiding rugged terrain, almost exclusively at lower elevations, below 1000 m a.s.l. (GISD 2015). Axis deer are typically associated with forest and grasslands interfaces but are highly adaptable to a wide range of habitats and changing conditions, including suburban settings (Duckworth et al. 2015). In particular, axis deer are found throughout dry and mixed deciduous forest habitat and secondary forest lands broken by glades, with a presence of understorey of grasses, forbs and tender shoots which supply adequate drinking water and shade. Axis deer consume an extremely wide variety of plants throughout their native and introduced range: about 160–190 of plant species (Duckworth et al. 2015, Sankar and Acharya 2004). Axis deer are predominantly generalist grazers that also browse leaves, flowers, fruits, and seeds, as well as bark when the preferred food items are scarce or during droughts (Anderson, 1999, Long 2003, Wilson and Mittermeier 2011 Duckworth et al. 2015, Schaller 1967), and possibly also during winter. Moreover, when natural forage is insufficient, axis deer forage in cultivated crops and cause economic damage (Anderson 1999). As summarised by Duckworth et al. (2015), axis deer is known to feed on mushrooms, crabs, rubbish and occasionally even human faeces in areas close to human habitation. Moreover, like in other deer species, antler and bone chewing is also common. The need to drink water once a day, more frequently in summer, in general restricts them to forest areas with assured presence of water, even if widely scattered.

However, the species is characterised by flexibility as shown by the significant seasonal changes in temperature and, more significantly, extreme swings in precipitation in their native range. These conditions force the species to deal regularly with long periods of drought and poor forage availability, as well as widespread flooding and lush seasonal growth during the rainy season (GISD 2015, Anderson, 1999). Outside its native range, in Hawaii, for example, axis deer is present from semi-deserts to rainforests (Moe and Wegge 1994).

Qu. 3.3. If the organism requires another species for critical stages in its life cycle then how likely is the organism to become associated with such species in the risk assessment area?

RESPONSE	**N/A** very unlikely unlikely moderately likely likely very likely	**CONFIDENCE**	low medium **high**

No specific organism is required to be associated to axis deer for critical stages in its life cycle.

In their native range, axis deer are known to be associated with other animals, particularly monkeys, which produce alarm sounds on the presence of predators like leopard (*Panthera pardus*) or tiger (*Panthera tigris*) (Dinesan et al. 2006). However, this facilitative/mutualistic relationship is opportunistic and not obligate, and there is no evidence that this is required for critical stages in the life cycle of the species.

Qu. 3.4. How likely is it that establishment will occur despite competition from existing species in the risk assessment area?

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

There is potential for competition with the native red deer (*Cervus elaphus*) and roe deer (*Capreolus capreolus*), as well as other ungulates in the risk assessment area, but as noted for other introduced deer species such competition is unlikely to prevent establishment. However, no specific studies on axis deer exist in the EU on this regard. Studies carried out in regions outside the EU, e.g. in USA (Texas), showed aggressive and dominant behaviour in axis deer toward white-tailed deer (*Odocoileus virginianus*), demonstrating that species coexistence is unlikely, at least at the spatial scale of the study and depending on factors such as population density of the two species and habitat quality (Faas and Weckerly 2010).

Axis deer seem unable to tolerate the presence of feral pigs (Lever 1994), however explicit research on this possible relation is not available.

Qu. 3.5. How likely is it that establishment will occur despite predators, parasites or pathogens already present in the risk assessment area?

RESPONSE	N/A very unlikely unlikely moderately likely **likely** very likely	CONFIDENCE	**low** medium high

The enemies of axis deer in its native range vary from tiger to leopard, wild dog, jackal and python (Dinesan et al. 2006). In particular, jackals may kill fawns (Moe and Wegge 1994). As summarised by Sankar and Acharya (2004) in its native range in India the main cause of death is predation, mostly from tiger (*Panthera tigris*) and leopard (*Panthera pardus*). Outside the native range, predation was thought to limit the spread of axis deer, like in Australia, as a consequence of high density of dingo populations in some areas (Moriarty 2004). Wild boar (*Sus scrofa*) may also predate on axis deer fawns or juveniles, as reported in Argentina (Gürtler et al. 2017). However, the community of predators differ in the risk assessment area and their strategies are presumably different as well (see discussion below).

Other mortality factors in its native range are diseases (e.g. foot and mouth disease). The potential impact of an exotic epidemic like foot and mouth is demonstrated by the 1924 outbreak in California (Clements 2007). Also in Azerbaijan an introduced population was reduced by foot and mouth disease (Long 2003).

The risk assessment area is certainly characterised by the presence of potential predators, parasites or pathogens of axis deer, however there are several species of native and alien deer already occurring, and this does not seem to represent a limiting factor for their populations.

Predation from large carnivores may be less effective in the risk assessment area, given the lack of tigers and leopards, and the potential impact of the large carnivores occurring in Europe is unknown. Therefore, natural enemies and diseases are unlikely to affect the likelihood of species establishment. Moreover, the role of predators in controlling ungulate populations remains uncertain, and is considered not effective, at least in some systems (Côté et al. 2004). The situation may be different in island ecosystems, where ungulates, as a consequence of their co-evolutionary history with large predators, may have very high reproductive rates, causing rapid population growth. For example in Hawaii, in the absence of predators, introduced populations of axis deer exhibit annual population growth rates of 20–30% (Hess 2008). A detailed discussion is beyond the scope of this assessment, and in any case due to the lack of specific data may be too speculative. Moreover, predicting the impact of native predators on axis deer would be a challenging task also because the impact of predators may be sensitive to the composition of the multi-prey species community (e.g. for the wolf see Sand et al. 2016)

Qu. 3.6. How likely is the organism to establish despite existing management practices in the risk assessment area?

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

Deer in Europe are usually subject to hunting and culling, which are regulated by law (see Apollonio et al. 2010). Poaching and overhunting has been a factor which led to the extinction of introduced populations of axis deer, e.g. in Croatia (Frković 2014). However, controlling axis deer may be problematic because it is a charismatic species, and there may be a conflict of interest between sectors obtaining recreational or economic gains from the exploitation of exotic wildlife and sectors promoting the conservation of biodiversity, as reported for Argentina (Gürtler et al. 2017).

Qu. 3.7. How likely are existing management practices in the risk assessment area to facilitate establishment?

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

Usually axis deer populations respond positively to higher levels of protection, water availability, forage quality, flat terrain and low predation, factors that are relatively widespread in the risk assessment area, although poaching and livestock grazing may be limiting factors (Duckworth et al. 2015). The availability of food and cover, which is usually provided to deer in game management reserves or in protected areas (where hunting may be forbidden, depending on the national legislation) may certainly favour the species establishment. Axis deer may benefit from water troughs established for cattle plus water sources on golf courses and homesites, as reported in Texas (Waring 1996). Also habitat restoration measures (i.e., prescribed burns and opening of fire breakers offering permanent pastures) may benefit axis deer (Gürtler et al. 2017). In addition, reducing competition (and perhaps predation) from wild boar due to its heavy hunting in the risk assessment area, may lead to an increase of axis deer abundance, as shown by a study assessing the result of a control program targeting both species in Argentina (Gürtler et al. 2017), which would increase the chance of successful establishment.

Qu. 3.8. How likely is it that biological properties of the organism would allow it to survive eradication campaigns in the risk assessment area?

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

There is no information for the risk assessment area, but overhunting has been a clear factor which led to the extinction of introduced populations (see for example Frković 2014). Nevertheless it is interesting to consider a long-term study of hunted axis deer in the introduced range in Argentina (for detail see Gürtler et al. 2017), which showed that contrary to park managers' expectations, the control program failed to reduce the axis deer population over a 10-year period despite increasing shooting effort and increasing deer harvest. Failure to reduce deer abundance may be explained by the combined effects of several putative processes: (1) population growth of axis deer over nearly two decades; (2) deer range expansion in the region leading to increasing immigration to the park; (3) sex- and stage-biased hunting mortality which kept per capita deer recruitment rates at sub-maximal levels, and (4) release from the pressure of wild boar (which was also a target of the control program) as a competitor (and perhaps as a predator).

Overall, the success of an eradication programme may depend on several factors, including the population size and the availability of resources. For example, in Russia the axis deer population of the Prioksko-Terrasny Nature Reserve (5,000 hectares) was reduced from 109 heads in 1989 to 5 in 2006 due to a control program (Bobrov et al. 2008).

Qu. 3.9. How likely are the biological characteristics of the organism to facilitate its establishment in the risk assessment area?

including the following elements:

- a list and description of the reproduction mechanisms of the species in relation to the environmental conditions in the Union
- an indication of the propagule pressure of the species (e.g. number of gametes, seeds, eggs or propagules, number of reproductive cycles per year) of each of those reproduction mechanisms in relation to the environmental conditions in the Union.

If relevant, comment on the likelihood of establishment based on propagule pressure (i.e. for some species low propagule pressure (1-2 individuals) could result in establishment whereas for others high propagule pressure (many thousands of individuals) may not.

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

	likely very likely		

Key biological characteristic which may facilitate the establishment of axis deer in the risk assessment area are the behavioural variability, opportunism and the species' extreme adaptability to changing circumstances (Anderson, 1999). As summarised by Duckworth et al. (2015) and references therein, the axis deer is a prolific breeder, which is documented by several empirical studies of the speed of increase by newly introduced subpopulations or in those where a factor restraining subpopulations was removed. For example, the population explosion in the Andaman Islands is considered a consequence of a series of factors (beside the presence of good vegetation) such as fast maturity, high annual pregnancy rate, low fawn mortality (Sivakumar 2003). In Bhadra, India, following the departure from the park of human settlements and consequent removal of anthropogenic pressures on axis deer and habitats, axis deer populations bounced back by nearly seven times in less than four years (Duckworth et al. 2015).

In the wild, axis deer are characterised by an aseasonal reproduction pattern (Centore 2016, Graf and Nichols 1966). The reproductive cycle of individual stags is not synchronised with that of other stags in the herd, hence they are found in rutting conditions throughout the year, do not retain harems and mate with hinds in more herds as they become receptive (GISD 2015). Hinds also experience non-synchronised oestrous cycles, with each cycle lasting about 3 weeks, and typically produce one fawn per pregnancy after a 210-238 days gestation period (Davis and Schmidly 1997).

Qu. 3.10. How likely is the adaptability of the organism to facilitate its establishment?

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

The diverse diet requirements and the ecological flexibility which characterise the axis deer, along with the aseasonal reproduction patterns may facilitate the establishment of the species. Several other features of the species biology may explain the invasion success of the axis deer within the many introductions which occurred worldwide. For example, it is known to be a gregarious species, found in herds ranging from a few animals to 100 or more. In its native range, population densities fall within three to 50 animals per km^2 in India, up to around 200 axis deer per km^2 in Nepal (Duckworth et al. 2015). In Hawaii a herd as large as 300 was reported (Hess 2008). Natural lifespan of the species is 9-13 years, although zoo animals may reach 18-22 years (Davis and Schmidly 1997, Page et al. 2008).

Qu. 3.11. How likely is it that the organism could establish despite low genetic diversity in the founder population?

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

Apparently, a very small number of hinds and a few stags seems sufficient to fund a new population (which may show the negligible impact of genetic diversity), although no data on the impact of low genetic diversity in the founder population are available. See also **Qu. 2.3a.**

Qu. 3.12. If the organism does not establish, then how likely is it that casual populations will continue to occur?
Consider, for example, a species which cannot reproduce in the risk assessment area, because of unsuitable climatic conditions or host plants, but is present because of recurring introduction, entry and release events. This may also apply for long-living organisms.

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

It is likely that high number of individuals are still kept and bred in captivity in the risk assessment area, which leads to a certain risk of some being intentionally or accidentally released in the wild, building up casual occurrences. The overall likelihood of casual population to occur seems low, but no sufficient data are available to support any statement on this regard.

Qu. 3.13. Estimate the overall likelihood of establishment in the risk assessment area based on the similarity between climatic conditions within it and the organism's current distribution under current climatic conditions. In addition, details of the likelihood of establishment in relevant biogeographical regions under current climatic conditions should be provided.
Thorough assessment of the risk of establishment in relevant biogeographical regions in current conditions: providing insight in the risk of establishment in (new areas in) the Union.

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

Providing that sufficient founder individuals are encountered (see point 2.3.a), the axis deer is likely to establish self-sustaining populations in almost all EU Member States (with the exception of Estonia and Finland, see Annex VII) because appropriate climatic conditions, habitats and food are present and local natural enemies and diseases are unlikely to affect establishment.

Qu. 3.14 Estimate the overall likelihood of establishment in the risk assessment area under foreseeable climate change conditions. In addition, details of the likelihood of establishment in relevant biogeographical regions under foreseeable climate change conditions should be provided.
Thorough assessment of the risk of establishment in relevant biogeographical regions in

foreseeable climate change conditions: explaining how foreseeable climate change conditions will influence this risk. With regard to climate change, provide information on • the applied timeframe (e.g. 2050/2070) • the applied scenario (e.g. RCP 4.5) • what aspects of climate change are most likely to affect the likelihood of establishment (e.g. increase in average winter temperature, increase in drought periods) The thorough assessment does not have to include a full range of simulations on the basis of different climate change scenarios, as long as an assessment of likely establishment within a medium timeframe scenario (e.g. 30-50 years) with a clear explanation of the assumptions is provided. However, if new, original models are executed for this risk assessment, the following RCP pathways shall be applied: RCP 2.6 (likely range of 0.4-1.6°C global warming increase by 2065) and RCP 4.5 (likely range of 0.9-2.0°C global warming increase by 2065). Otherwise, the choice of the assessed scenario has to be explained.

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

Providing that sufficient founder individuals are encountered (see point 2.3.a), the axis deer is likely to establish self-sustaining populations in all EU Member States (see Annex VII) because appropriate climatic conditions, habitats and food are likely to be widespread (even more than in current conditions) and local natural enemies and diseases are unlikely to affect establishment.

4 PROBABILITY OF SPREAD

Important instructions:

- Spread is defined as the expansion of the geographical distribution of an alien species within the risk assessment area.
- Repeated releases at separate locations do not represent continuous spread and should be considered in the probability of entry section. In other words, intentional anthropogenic “spread” via release or escape (“jump-dispersal”), should be dealt within the entry section. However, as repeated releases contribute to the spread of the target organism in the risk assessment area, the relevant pathway(s) should be briefly discussed here too, with an explicit reference to the entry section for additional details.

Qu. 4.1. How important is the expected spread of this organism within the risk assessment area by natural means? (List and comment on each of the mechanisms for natural spread.)

including the following elements:

- a list and description of the natural spread mechanisms of the species in relation to the environmental conditions in the risk assessment area.
- an indication of the rate of each of those spread mechanisms in relation to the environmental conditions in the Union.

The description of spread patterns should include elements of the species life history and behavioural traits able to explain its ability to spread, including: reproduction or growth strategy, dispersal capacity, longevity, dietary requirements, environmental and climatic requirements, specialist or generalist characteristics.

RESPONSE	**minimal** minor moderate major massive	CONFIDENCE	low **medium** high

The potential of axis deer to spread within the risk assessment area by natural means is likely to be minimal, but there are no data about the rate of spread of individuals in Europe (which may vary depending on the extent of deer management and disturbance, as well as habitat availability and connectivity, appropriate food resources, presence of other species acting as competitor/predators etc.). For example, Okarma et al. (2018) pointed out that current information based on the lack of success of previous introductions in Europe and on biological characteristics of the species (size, life history, fertility, behaviour) allow to consider the spread rate of the population rather small.

Studies on spacing behaviour and habitat use in other parts of their native and alien range, show that animals are mostly sedentary and with small home ranges, usually between 180-890 ha (Long 2003, Moe and Wegge 1994), depending on resource availability (Waring 1996). Herds travel slowly at some 0.5 km/hour (Schaller 1967), but occasionally axis deer may make long trips to reach feeding grounds and water sources, for example during the dry season, and daily movements of up to 8 km for water have been reported (Graf and Nichols

1966). In Russia, the species was introduced approx. 100 km south of Moscow, in the Serpukhovskoe Hunting Reserve, and dispersed in about 10 years spontaneously to the Prioksko-Terrasnyi Biosphere Reserve through the Oka valley, just a few kilometres from the release site (Bobrov et al. 2008). In Queensland, although much of the area appears climatically suited to the species, axis deer were mostly concentrated surrounding their original release point, although drought may lead to wider dispersals of the animals (Jesser 2005).

Isolation of the axis deer in a small island, may not prevent the species from spreading. Axis deer are capable swimmers (Nowak 1991), and have been observed to swim fairly long distances between islands, i.e. about 3 km in Croatia (Šprem and Zachos 2020) and about 10 km in the Andaman Islands (Ali 2004, Ali and Pelkey 2003). In Brazil, the species is supposed to have reached the country from Uruguay by crossing the Uruguay River at the border between the two countries (Sponchiado et al. 2011).

Qu. 4.2. How important is the expected spread of this organism within the risk assessment area by human assistance? (List and comment on each of the mechanisms for human-assisted spread and provide a description of the associated commodities.)

including the following elements:

- a list and description of the anthropogenic spread mechanisms of the species in relation to the environmental conditions in the Union.
- an indication of the rate of each of those spread mechanisms in relation to the environmental conditions in the Union.

RESPONSE	**minimal** minor moderate major massive	CONFIDENCE	**low** medium high

The main (potential) pathway of spread is the natural dispersal across borders.

Otherwise axis deer were reportedly translocated and released intentionally in the risk assessment area for hunting purposes, e.g. in Croatia (Frković 2014). Moreover, the potential for spread after escapes from deer farms and deer parks should not be underestimated. The relevant introduction and entry pathways are already discussed in the corresponding sections above.

Qu. 4.2a. List and describe relevant pathways of spread. Where possible give detail about the specific origins and end points of the pathways. For each pathway answer questions 4.3 to 4.9 (copy and paste additional rows at the end of this section as necessary). Please attribute unique identifiers to each question if you consider more than one pathway, e.g. 4.3a, 4.4a, etc. and then 4.3b, 4.4b etc. for the next pathway.

including the following elements:

- a list and description of pathways with an indication of their importance and associated risks (e.g. the likelihood of spread in the Union, based on these pathways; likelihood of survival, or reproduction, or increase during transport and storage; ability and likelihood of transfer from the pathway to a suitable habitat or host).

Where possible details about the specific origins and end points of the pathways shall be included. • an indication of the propagule pressure (e.g. estimated volume or number of specimens, or frequency of passage through pathway), including the likelihood of reinvasion after eradication. • All relevant pathways should be considered. The classification of pathways developed by the Convention of Biological Diversity shall be used.

Natural dispersal across borders of invasive alien species that have been introduced through pathways 1 to 5.

Qu. 4.3a. Is spread along this pathway intentional or unintentional (e.g. the organism is a contaminant of translocated goods within the risk assessment area)?

RESPONSE	intentional **unintentional**	**CONFIDENCE**	low medium **high**

This pathway is unintentional, as it depends on the dispersal capacities of the species. It is facilitated by the habitat conditions which characterise the area (including, for instance, the forest management regime and the recreational hunting practices, the extent of suitable ecological corridors etc.).

Qu. 4.4a. How likely is it that a number of individuals sufficient to originate a viable population will spread along this pathway from the point(s) of origin over the course of one year? including the following elements: • an indication of the propagule pressure (e.g. estimated volume or number of specimens, or frequency of passage through pathway), including the likelihood of reinvasion after eradication • if appropriate, indicate the rate of spread along this pathway • if appropriate, include an explanation of the relevance of the number of individuals for spread with regard to the biology of species (e.g. some species may not necessarily rely on large numbers of individuals).

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

No specific information is available on this regard. However as discussed in the sections above (see for example point 1.3a), it seems that in general a very small number of hinds and a few stags are sufficient to found a new population.

Qu. 4.5a. How likely is the organism to survive, reproduce, or increase during transport

and storage along the pathway (excluding management practices that would kill the organism)?

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

The likelihood of the animals to survive, reproduce, or increase during spread (there is no transport and storage as such along this pathway) will vary depending on the extent of deer management and disturbance in the area (for examples in relation to land use practices, hunting, and other pressures).

Qu. 4.6a. How likely is the organism to survive existing management practices during spread?

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

The likelihood of the animals to survive existing management practices during spread will vary depending on the extent of deer management and disturbance in the area (for examples in relation to the hunting regime for ungulates).

Qu. 4.7a. How likely is the organism to spread in the risk assessment area undetected?

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

This is a medium sized deer heavily spotted in all seasons, and although mostly active around dawn and dusk (Wilson and Mittermeier 2011) it may be easily detected by hunters, naturalists, and farmers; hence it is unlikely to be spreading in the risk assessment area undetected. Nevertheless, the occurrence of other deer species throughout much of the risk assessment area may allow the spread of axis deer to go undetected by landowners and the general public not fully familiar with deer species differences.

Qu. 4.8a. How likely is the organism to be able to transfer from the pathway to a suitable habitat or host during spread? (including, where possible, details about the specific origins and end points of the pathway)

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

	likely **very likely**		

No information available on this regard. Based on information from similar species, animals dispersing through natural spread are highly likely to find suitable habitats for survival throughout the risk assessment area, except in areas devoid of any woodland (see GB Non-Native Species Secretariat 2011). The species would not spread by natural means along unsuitable habitats.

Qu. 4.9a. Estimate the overall potential rate of spread within the Union based on this pathway? (please provide quantitative data where possible).

RESPONSE	very slowly **slowly** moderately rapidly very rapidly	**CONFIDENCE**	**low** medium high

Overall, natural spread from localised population is likely to be slow, but there are no data about the rate of spread of individuals in Europe (which may vary depending on e.g. the extent of deer management and disturbance).

End of pathway assessment, repeat Qu. 4.3 to 4.9. as necessary using separate identifiers.

Qu. 4.10. Within the risk assessment area, how difficult would it be to contain the organism in relation to these pathways of spread?

RESPONSE	very easy easy **with some difficulty** difficult very difficult	**CONFIDENCE**	low **medium** high

Effective containment measures to prevent the spread of axis deer through the pathway above are the same as those to control/eradicate the species (see for example discussion on **Qu. 3.8.)**, hence their applicability is context dependent, and depends on the size of the population and the invasion stage.

Qu. 4.11. Estimate the overall potential rate of spread in relevant biogeographical regions under current conditions for this organism in the risk assessment area (indicate any key issues and provide quantitative data where possible). Thorough assessment of the risk of spread in relevant biogeographical regions in current conditions, providing insight in the risk of spread into (new areas in) the Union.

RESPONSE	very slowly **slowly** moderately rapidly	**CONFIDENCE**	**low** medium high

	very rapidly		

See Qu. 4.9a.

Qu. 4.12. Estimate the overall potential rate of spread in relevant biogeographical regions in foreseeable climate change conditions (provide quantitative data where possible). Thorough assessment of the risk of spread in relevant biogeographical regions in foreseeable climate change conditions: explaining how foreseeable climate change conditions will influence this risk, specifically if rates of spread are likely slowed down or accelerated.

RESPONSE	very slowly **slowly** moderately rapidly very rapidly	**CONFIDENCE**	**low** medium high

No information has been found.

5 MAGNITUDE OF IMPACT

Important instructions: • Questions 5.1-5.5 relate to biodiversity and ecosystem impacts, 5.6-5.8 to impacts on ecosystem services, 5.9-5.13 to economic impact, 5.14-5.15 to social and human health impact, and 5.16-5.18 to other impacts. These impacts can be interlinked, for example a disease may cause impacts on biodiversity and/or ecosystem functioning that leads to impacts on ecosystem services and finally economic impacts. In such cases the assessor should try to note the different impacts where most appropriate, cross-referencing between questions when needed. • Each set of questions starts with the impact elsewhere in the world, then considers impacts in the risk assessment area (=EU excluding outermost regions) separating known impacts to date (i.e. past and current impacts) from potential future impacts (including foreseeable climate change). • Only negative impacts are considered in this section (socio-economic benefits are considered in Qu. A.7)

Biodiversity and ecosystem impacts

Qu. 5.1. How important is the impact of the organism on biodiversity at all levels of organisation caused by the organism in its non-native range excluding the risk assessment area? including the following elements: • Biodiversity means the variability among living organisms from all sources, including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems • impacted chemical, physical or structural characteristics and functioning of ecosystems

RESPONSE	minimal minor **moderate** major massive	**CONFIDENCE**	low medium **high**

Axis deer may cause significant direct impacts on native vegetation, e.g. through browsing and bark stripping, and may have a number of indirect effects on fauna and ecosystem processes. In general their impact (as an invasive alien species) is similar to that of other native deer, however it could amplify the pressure caused by ungulates on the natural environment. The impact may be even more sever where also other alien ungulates occur.

As summarised by Page et al. (2008) axis deer can feed on many species of native plants, as documented in the Hawaiian Islands (Hess 2008). Negative impact on natural regeneration of the native forests is also reported (Novillo and Ojeda 2008). In the Andaman Islands, where axis deer feed on over 70 different plant species (Sivakumar 2003), a negative impact on seedling and sapling survival, as well as on forest regeneration and forest structure is documented (Ali 2004; Ali and Pelkey 2013). In northern Patagonia, Argentina, introduced deer (among which axis deer) cause significant modification of the forest understory and impair the regeneration of canopy tree species (Veblen et al. 1989, Veblen et al. 1992), which seemed to negatively affect also the endemic conifer *Austrocedrus chilensis* (Relva and Veblen 1998).

Significant impact to individual trees which may limit the forests renewal is known to occur during the rut (reproductive season) when stags rub and wipe the antlers against the bark, frequently causing secondary infections, which may lead to the death of the trees, for example in Hawaii (Anderson 1999). Additionally, in extreme drought conditions (and possibly in winter) axis deer may feed on the bark of trees (Anderson 1999).

Another threat to the habitat and native vegetation may be caused by the deer trampling behaviour, which may lead to the creation of trails and increasing erosion and runoff (Hess et al. 2015, Page et al. 2008), for example in the Hawaiian Islands (Anderson 1999, Hess 2008). As summarised by GISD (2015) this results in a loss of the stability that vegetation provides, with resulting destabilisation of stream banks, subsequent changes in stream flow and increasing erosion and sedimentation of streams, ponds and rivers. When deer populations become very large, their trailing behaviour creates dirt paths even through the thickest of vegetation. These trails can lead to significant erosion and, in wet forest areas, increase runoff by decreasing the moss layer from soil that would normally retain water (Centore 2016, Anderson 1999). Soil erosion induced by the species leading to consequent siltation of offshore coral reefs is reported in Hawaii (Lever 1994).

Additionally, by opening up of habitat or by selective browsing of understory vegetation, axis deer could help in the spread and establishment of alien, and probably invasive, plants (Mohanty et al. 2016). Anecdotal observations exist that high axis deer densities lead to exposing bare ground, e.g. by removing the vegetation, which in turn may increase light levels and disrupt moisture dynamics, hence facilitating the invasion of exotic weeds (Jesser 2005, Davis et al. 2016). An example is the parthenium (*Parthenium hysterophorus*), a native to the New World accidentally introduced into several countries, including Australia, where it is flourishing in areas where axis deer are not adequately controlled (Jesser 2005).

Axis deer may also have a potential for endozoochoric dispersal of native and exotic plants, as documented in the case of the exotic hog deer (*Axis porcinus*) in south-eastern Australia (Davis et al. 2010).

Competitive displacement of native deer is another (potential) impact, as reported in Argentina (Novillo and Ojeda 2008). Axis deer is a generalist species, and scarcity of forage in the dry (or cold) season may lead to niche overlap with other cervids (Bhattarai 2019). For example, axis deer outcompeted white-tailed deer (*Odocoileus virginianus*) in experimental enclosures over an eight-year follow-up in Texas (Anonymous 2016). This study was within enclosures, where by definition competition may be enhanced because there is no opportunity to avoid competition through niche differentiation or use of species-specific refugia, therefore the results are only indicative (but may reflect situations in closed environment, e.g. small islands). Another research conducted in Texas showed aggressive and dominant behaviour in axis deer toward white-tailed deer, which subsequently modified the habitat selection and feeding patterns (Faas and Weckerly 2010). Axis deer may have a competitive advantage over white-tailed deer for being less specialized in food requirements, while the role played by the different susceptibilities to parasitic disease (Richardson and Demarais 1992). Another study carried out in an enclosure (although about the size of a small island or a small protected area) demonstrates that coexistence of these two species is unlikely, at least at the spatial scale of the studies and in any case depending on factors such as population density of each species and habitat quality (Faas and Weckerly 2010). Ferretti and Lovari (2014) stressed the difficulty to use an experimental approach in field conditions, but pointed out that evidence on overlap in the use of resources, opposing trends in population size, and behavioural interactions support the hypothesis of competition between alien ungulates and native ones. This however needs to be evaluated on a case by case.

Indirect effects on native biodiversity by altering ecosystem processes may be more subtle and affect also animals other than ungulates. For example, a study showed that in the Andaman archipelago axis deer depressed the abundance of forest floor and semi arboreal lizards approximately five-fold, by reducing vegetative cover in the understory (Mohanty et al. 2016).

Detrimental effects of axis deer are reported from outside the risk assessment area in relation to the conservation status of threatened species at the global level. This is mostly as a consequence of the habitat degradation, as documented by the IUCN Red List, in this case with examples limited to the situation in the Hawaii (BirdLife International 2016a, 2016b, 2016c, 2016d, 2018a, 2018b, 2018c, Bruegmann and Caraway 2003, Heddle 2004). For instance, this is deemed to affect four species that are considered Critically endangered (CR): the Pacific Lacefern (*Ctenitis squamigera*), the Olomao (*Myadestes lanaiensis*), the Maui Parrotbill (*Pseudonestor xanthophrys*) and the Ou (*Psittirostra psittacea*). Two additional species, the Maui Alauahio (*Paroreomyza montana*) and the Fabulous Green Sphinx Moth (*Tinostoma smaragditis*), are considered Endangered (EN). Because of its burrows trampled by axis deer and other ungulates, the Hawaiian Petrel (*Pterodroma sandwichensis*) is considered Vulnerable (VU). Axis deer also contributed to the destruction of the habitats of two extinct Hawaiian species (EX), the Black Mamo (*Drepanis funereal*) and the Bishop's Oo (*Moho bishop*).

Overabundant deer may apparently exert cascading effects on other animals by competing directly for resources with other herbivores and omnivores and by indirectly modifying the composition and physical structure of habitats of both invertebrates and vertebrates (Côté 2005). High deer abundance resulting from the introduction of alien deer species, may have strong indirect effect on forest birds through their impact on vegetation and associated insects. For example, as documented by Allombert et al. (2005) overabundance of white-tailed deer (*Odocoileus virginianus*) populations in North America, resulted in a decrease in songbird habitat quality through decreased food resources and nest site quality and may partly explain continental-scale decreases in songbird populations. An introduced herbivore may even lead to the indirect extirpation of an abundant large carnivore, as documented in a large island in Canada, where the near eradication of shrubs producing berries by introduced white-tailed deer (*O. virginianus*) was considered as the main cause of the extirpation of black bears (*Ursus americanus*) within approximately 50–70 years (Côté 2005). As a remark, the examples above pertain to other deer species in countries other than the EU, and as such do not necessarily apply to axis deer in particular, especially if those deer are not at high densities. However, the information was deemed indicative for the purpose of this assessment, to show the diversity of impacts potentially emerging from the introduction of a new deer species in the EU.

Qu. 5.2. How important is the current known impact of the organism on biodiversity at all levels of organisation (e.g. decline in native species, changes in native species

communities, hybridisation) in the risk assessment area (include any past impact in your response)? Discuss impacts that are currently occurring or are likely occurring or have occurred in the past in the risk assessment area. Where there is no direct evidence of impact in the risk assessment area (for example no studies have been conducted), evidence from outside of the risk assessment area can be used to infer impacts within the risk assessment area.

RESPONSE	minimal minor **moderate** major massive	**CONFIDENCE**	**low** medium high

No direct evidence of impact in the risk assessment area exists other than what is reported for the presence of the species in Croatia.

As reported by the Public Institution National Park Brijuni and Hunting Directorate of the Ministry of Agriculture (pers. comm. 2020) it is difficult to say how much impact the axis deer itself has on the biodiversity of Brijuni National Park, but it is certain that mouflon and deer species significantly affect the biodiversity of Veliki Brijun islands (where axis deer, mouflon and fallow deer are present). In the past, axis deer dominated over the other two species, but due to one harsh winter in the past many died and fallow deer has since prevailed. As the Public Institution National Park Brijuni has been reducing the number of deer specimens in recent years, currently mouflons are predominant. All three species together have a great impact on grasslands and forests of the island Veliki Brijun. Browsing and grazing of large herbivores that live on the island without natural predators affect lower layers of forests causing a problem for the natural reforestation and affect biodiversity of grassland allowing plants that the animals avoid (for example the Spanish oyster thistle *Scolymus hispanicus*) to overly spread. According to the few available data from literature, in the island of Brijuni, axis deer are known to feed on grasses and ash (*Fraxinus ornus*) leaves and holm oak (*Quercus ilex*) leaves and acorns, and sometimes browse the leaves of myrtle (*Myrtus communis*), new stems of blackberry (*Rubus* spp.), mosses growing on rocks, and cedar (*Cedrus* spp.) seeds (Šprem et al. 2008). No information on the type and scale of impact is available. It must be noted that the island of Brijuni is characterised by a very intense human use, limiting the possibility of observing impacts on natural ecosystems of the axis deer.

A couple of studies were carried out in the hunting reserve in the Island of Rab (Krapinec 2002a, 2002b), but their results may be of limited applicability for the assessment of impacts in the wild, because the location was inside an actively managed forest in a fenced area.

Based on evidence from outside the risk assessment area it can be expected that overabundant deer may have a substantial impact on woodland vegetation (modifying patterns of relative abundance and vegetation dynamics), and play a significant role in woodland ecosystem function. In case axis deer would get established on islands, the impacts on the local ecosystems as well as on some bird species (e.g. petrels) could be severe. In the absence of control (either by predators or humans), deer populations can rise to very high densities. This may be further facilitated by human management of forests providing ideal habitats. Vegetation changes brought about by browsing and trampling axis deer are detrimental to other deer species as well as other vertebrate and invertebrate species (see note by Gill 2000). Cascading effects on other species may extend to insects, birds, and other vertebrates. Hence, axis deer may tip forest ecosystems toward alternative states by acting as "ecosystem engineers" or "keystone herbivores", as generally noted for deer (Côté et al. 2004).

According to Okarma et al. (2018) in the worst case axis deer may locally cause hardy reversible changes in ecosystem functioning. According to Okarma et al. (2018) it can therefore be assumed that in the event of spreading in Poland, the impact could lead to serious decreases in the population size of some native protected species. In Poland, it can be expected that axis deer may exert a certain negative impact on native deer species, as also remarked by the Council of Europe (2002) for Croatia. The potential for competition with native deer may be particularly strong because such species have not shared a common evolutionary history. Additionally, some possible competition with European bison (*Bison bonasus*) may be expected in Poland, should axis deer become established and widespread in this country (Okarma et al. 2018).

Qu. 5.3. How important is the potential future impact of the organism on biodiversity at all levels of organisation likely to be in the risk assessment area?

See comment above. The potential future impact shall be assessed only for the risk assessment area.

RESPONSE	minimal minor **moderate** major massive	**CONFIDENCE**	**low** medium high

In the event of substantial spread and increase in numbers of axis deer to new parts of the risk assessment area, the impact may be expected to increase accordingly, even despite the possible presence of predators. However, there are no elements to foresee that the impact would lead to any irreversible change, therefore the risk is considered "moderate". Because there is no documented evidence the confidence is low.

Qu. 5.4. How important is decline in conservation value with regard to European and national nature conservation legislation caused by the organism currently in the risk assessment area?

including the following elements:

- native species impacted, including red list species, endemic species and species listed in the Birds and Habitats directives
- protected sites impacted, in particular Natura 2000
- habitats impacted, in particular habitats listed in the Habitats Directive, or red list habitats
- the ecological status of water bodies according to the Water Framework Directive and environmental status of the marine environment according to the Marine Strategy Framework Directive

RESPONSE	minimal minor **moderate** major	**CONFIDENCE**	**low** medium high

	massive		

The axis deer may represent a potential threat for a series of species and habitats protected by the Birds and Habitats directives, as well as a number of IUCN red-listed species, as shown in countries outside the risk assessment area. The effect of axis deer on protected species of plants and relevant habitats would reflect its browsing habits and diet, as well as the ability of the plants to withstand damage (including from trampling, etc.). Therefore, several plants may be susceptible to axis deer impact, not to consider the cascading effects that overabundant axis deer populations may apparently exert on other ungulates (see for the possible competition with *Bison bonasus*, which could occur if the species were to establish in Poland, Qu. 5.2) and other groups of animals as well, including birds on islands.

Qu. 5.5. How important is decline in conservation value with regard to European and national nature conservation legislation caused by the organism likely to be in the future in the risk assessment area?

including the following elements:

- native species impacted, including red list species and species listed in the Birds and Habitats directives
- protected sites impacted, in particular Natura 2000
- habitats impacted, in particular habitats listed in the Habitats Directive, or red list habitats
- the ecological status of water bodies according to the Water Framework Directive and environmental status of the marine environment according to the Marine Strategy Framework Directive

RESPONSE	minimal minor **moderate** major massive	**CONFIDENCE**	**low** medium high

In the event of substantial spread and increase in numbers of axis deer to new parts of the risk assessment area, the impact may be expected to increase accordingly. In case of a future expansion of the species range, other native species may be affected. While there is no documented evidence of the species being able to cause the extinction of any native species, the level of risk is assessed as being “moderate” also in the future.

Ecosystem Services impacts

Qu. 5.6. How important is the impact of the organism on provisioning, regulating, and cultural services in its non-native range excluding the risk assessment area?

- For a list of relevant services use the CICES classification V5.1 provided as an annex.
- Impacts on ecosystem services build on the observed impacts on biodiversity (habitat, species, genetic, functional) but focus exclusively on reflecting these changes in relation to their links with socio-economic well-being.
- Quantitative data should be provided whenever available and references duly reported.

- In absence of specific studies or other direct evidences this should be clearly stated by using the standard answer "No information has been found on the issue". This is necessary to avoid confusion between "no information found" and "no impact found".

RESPONSE	minimal minor **moderate** major massive	**CONFIDENCE**	**low** medium high

Axis deer may affect several ecosystem services, not only through the discussed impacts on biodiversity, but also due to the impacts documented on ornamental plants and agricultural crops through browsing and bark stripping, for example in the Hawaiian Islands (Hess 2008). The erosion caused by the trampling behaviour associated with the death of trees caused by the habit to wipe their antlers on the barks, may results in destabilisation of stream banks, changes in stream flow and increased erosion and sedimentation of waterways (Anderson 1999, GISD 2015). Additionally, it is known that the trailing behaviour has caused erosion and damage to a variety of culturally or archaeologically significant sites in Hawaii (Anderson 1999). The role of axis deer in the regulation of zoonosis, because of its pathogens and parasites, is another possible threat to both wildlife and livestock, and to humans (Okarma et al. 2018).

Here follows a list of potential impacts on ecosystem services (based on the CICES classification V5.1):

Provisioning (Biomass)
- Cultivated terrestrial plants
- Reared animals
- Wild plants (terrestrial and aquatic)
- Wild animals (terrestrial and aquatic)

Regulation & Maintenance (Regulation of physical, chemical, biological conditions)
- Baseline flows and extreme event regulation
- Lifecycle maintenance, habitat and gene pool protection
- Pest and disease control
- Soil quality regulation
- Water conditions

Cultural (Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting)
- Physical and experiential interactions with natural environment
- Intellectual and representative interactions with natural environment

Qu. 5.7. How important is the impact of the organism on provisioning, regulating, and cultural services currently in the different biogeographic regions or marine sub-regions where the species has established in the risk assessment area (include any past impact in your response)?

- See guidance to Qu. 5.6.

RESPONSE	minimal minor moderate major massive	**CONFIDENCE**	low medium high

No information has been found. It is worth mentioning that the value of hunting provided by game species can be an argument for introducing, translocating and preserving populations of these species, e.g. the fallow deer (*Dama dama*) in the risk assessment area. However, only little information is available for the target species (see point A13).

Qu. 5.8. How important is the impact of the organism on provisioning, regulating, and cultural services likely to be in the different biogeographic regions or marine sub-regions where the species can establish in the risk assessment area in the future?

- See guidance to Qu. 5.6.

RESPONSE	minimal minor **moderate** major massive	**CONFIDENCE**	**low** medium high

In the event of substantial spread and increase in numbers of axis deer to new parts of the risk assessment area, the impact may be expected to increase accordingly (at the moment there is no evidence of impact, but should the population grow and spread, the impact may become evident). As there is no documented evidence of the species being able to cause other types of impact, the level of risk can be expected to be "moderate" in the future. However, because of paucity of information, confidence of this assessment is low.

Economic impacts

Qu. 5.9. How great is the overall economic cost caused by the organism within its current area of distribution (excluding the risk assessment area), including both costs of / loss due to damage and the cost of current management.

- Where economic costs of / loss due to the organism have been quantified for a species anywhere in the world these should be reported here. The assessment of the potential costs of / loss due to damage shall describe those costs quantitatively and/or qualitatively depending on what information is available. Cost of / loss due to damage within different economic sectors can be a direct or indirect consequence of the earlier-noted impacts on ecosystem services. In such case, please provide an indication of the interlinkage.

RESPONSE	minimal minor **moderate** major massive	**CONFIDENCE**	low medium **high**

As pointed out by Page et al. (2008), the species is capable of having an impact on sheep, cattle, cereal grain, grain legumes, and other fruit (pineapple) commodities. Crop damages by axis deer, particularly when other available forage is scarce, have been described in both the native and the introduced range (Anderson 1999, Hess et al. 2015, GISD 2015, Page et al. 2008). For example, in Hawaii severe and extensive damage to the pineapple industry on Lānai was reported (Lever 1994, Hess et al. 2015). In Maui, more specifically, deer were blamed to be responsible of an estimated $35,000 to $55,000 in crop losses to Maui Pineapple Co., and one farmer claimed about 40 deer caused US $20,000 in fence and corn crop damage in one night (Kubota 2001).

When overgrazing occurs, axis deer are known to compete with livestock and native wildlife (Long 2003). Being primarily grazers, axis deer compete for food mainly with domestic cattle and sheep (Lever 1994). In particular, direct competition for forage with cattle is reported in both California and in Texas (Anderson 1999). In California, in Point Reyes National Seashore, the cost to the park for staff, equipment, vehicles and supplies to monitor and manage non-native deer (both axis deer and fallow deer) was approximately $140,000, or 2.5% of the park annual budget (GISD 2015, National Park Service 2004). In Argentina, although regularly hunted, axis deer populations have increased in some provinces, interfering with livestock production (Flueck 2009).

Deer may transmit infectious diseases directly to livestock (as well as to other deer and to humans), especially if deer density is high (Côté et al. 2004). In particular, axis deer have been shown to carry and transmit bovine tuberculosis (*Mycobacterium bovis*) and several other diseases in both the native range, i.e. in India (Schaller 1967) and the introduced range. For example, in Hawaii, bovine tuberculosis was found in five percent of deer from Molokai, posing an ongoing threat to cattle trade throughout the islands (Hess et al. 2015). In California, in addition to carrying several livestock and wildlife diseases, a small percentage of axis deer also harboured Johne's disease (*Mycobacterium paratuberculosis*), a contagious bacterial disease of the small intestines of ruminants (Hess et al. 2015). In Russia, the species was considered responsible for the introduction of the deer louse fly (*Lipoptena cervi*) (Bobrov et al. 2008), although this parasite is considered native to the region. However, some studies suggest that the indigenous parasite fauna of small founder populations of introduced exotic ungulates, such as the axis deer in Hawaii, frequently does not persist in their free-ranging progeny and that subsequent parasite communities acquired from sympatric ungulates are of limited diversity and comprised primarily of species exhibiting a broad host range (McKenzie and Davidson 1989).

Besides carrying parasites and pathogens, axis deer are responsible for a number of deer-vehicle collisions, as regularly documented on Molokai, Hawaii (Anderson 1999, Page et al. 2008), however the economic impact is not quantified.

Qu. 5.10. How great is the economic cost of / loss due to damage (excluding costs of management) of the organism currently in the risk assessment area (include any past costs in your response)?

- Where economic costs of / loss due to the organism have been quantified for a species anywhere in the EU these should be reported here. Assessment of the potential costs of damage on human health, safety, and the economy, including the cost of non-action. A full economic assessment at EU scale might not be possible, but qualitative data or different case studies from across the EU (or third countries if relevant) may provide useful information to inform decision making. In absence of specific studies or other direct evidences this should be clearly stated by using the standard answer "No information has been found on the issue". This is necessary to avoid confusion between "no information found" and "no impact found". Cost of / loss due to damage within

different economic sectors can be a direct or indirect consequence of the earlier-noted impacts on ecosystem services. In such case, please provide an indication of the interlinkage.

RESPONSE	minimal **minor** moderate major massive	CONFIDENCE	**low** medium high

No direct evidence of impact in the risk assessment area exists other than what is reported in Croatia. For example, in the island of Cres, the axis deer inflicted damage to vineyards and households (Frković 2014). No economic damage was recorded in the Island of Rab in a study aimed at the analysis of the feeding activities of axis deer and mouflon (*Ovis ammon*) in an actively managed (fenced) forest community of holm oak and manna ash (*Fraxino orni-Quercetum ilicis*) (Krapinec 2002a).

Okarma et al. (2018) considered that in case the species established in Poland, the impact of the species on crops would be "medium".

Qu. 5.11. How great is the economic cost of / loss due to damage (excluding costs of management) of the organism likely to be in the future in the risk assessment area? • See guidance to Qu. 5.10.

RESPONSE	minimal minor **moderate** major massive	CONFIDENCE	**low** medium high

In the event of substantial spread and increase in numbers of axis deer to new parts of the risk assessment area, the impact may be expected to increase accordingly.

Overabundant deer are known to inflict major economic losses in forestry, agriculture, and transportation and contribute to the transmission of several animal and human diseases (Côté et al. 2004). See also comments in **Qu. 5.19** and **Qu. 5.10**.

Qu. 5.12. How great are the economic costs / losses associated with managing this organism currently in the risk assessment area (include any past costs in your response)? • In absence of specific studies or other direct evidences this should be clearly stated by using the standard answer "No information has been found on the issue". This is necessary to avoid confusion between "no information found" and "no impact found".

RESPONSE	minimal minor moderate major massive	CONFIDENCE	low medium high

No information has been found.

Qu. 5.13. How great are the economic costs / losses associated with managing this organism likely to be in the future in the risk assessment area? • See guidance to Qu. 5.12.

RESPONSE	minimal minor moderate **major** massive	**CONFIDENCE**	**low** medium high

In the event of substantial spread and increase in numbers of axis deer to new parts of the risk assessment area, the costs may be expected to increase accordingly. If the species spreads and is to be managed, some costs are bound to be incurred, even if there is no info on what these costs are currently. But it is not possible to estimate the monetary value, as it depends on deer management systems and policies involved, which vary considerably across the different countries of Europe depending on species present, legislation, cultural tradition and the status of deer as *res nullius* or *res communis*.

Social and human health impacts

Qu. 5.14. How important is social, human health or other impact (not directly included in any earlier categories) caused by the organism for the risk assessment area and for third countries, if relevant (e.g. with similar eco-climatic conditions). The description of the known impact and the assessment of potential future impact on human health, safety and the economy, shall, if relevant, include information on • illnesses, allergies or other affections to humans that may derive directly or indirectly from a species; • damages provoked directly or indirectly by a species with consequences for the safety of people, property or infrastructure; • direct or indirect disruption of, or other consequences for, an economic or social activity due to the presence of a species. Social and human health impacts can be a direct or indirect consequence of the earlier-noted impacts on ecosystem services. In such case, please provide an indication of the interlinkage.

RESPONSE	minimal **minor** moderate major massive	**CONFIDENCE**	low **medium** high

Deer may transmit infectious diseases directly to humans (as well as to other deer and to livestock), especially if deer density is high (Côté et al. 2004). The axis deer, as other ungulates (hence similar to native species), can be a carrier of a number of diseases and parasites that may be harmful to humans. For example, they carry common parasites that may directly affect humans, i.e. if droppings enter freshwater systems (GISD 2015). Parasitic zoonoses harbored by the species include: leptospirosis, cryptosporidiosis, and strains of *Escherichia coli* (Anderson 1999). A potential role of axis deer and their associated ticks (e.g. *Ixodes pacificus*) in the ecology of the Lyme disease spirochete, *Borrelia burgdorferi*, was evidenced through a study in California, USA (Lane and Burgdorfer 1986, Page et al. 2008). However the relationship between density of deer (and other large herbivores) in the environment and environmental tick burden is controversial, with different studies coming to different conclusions, hence the information above should be considered only indicative.

Overall, as pointed out for alien mammals in general (Capizzi et al. 2018), axis deer can act as vectors of both alien and native pathogens, and as host of either native or alien parasites (which in turn can be acting as vectors of either native or alien pathogens). In this way axis deer may either introduce new pathogens, alter the epidemiology of local pathogens, become reservoir hosts, and increase disease risk for humans, along with other species (e.g. by introducing changes in the vector-host-parasite relationship). However, we could not find any evidence of the species hosting new alien species, or increasing the rate or intensity of infections of pathogens.

In addition to carrying diseases that can infect humans, axis deer may cause road collisions, e.g. as reported in the Hawaiian Islands (Hess 2008). On Maui roads, for example, at least 36 motor vehicle collisions with axis deer occurred during an 18-month period between 1999 and 2000, see http://archives.starbulletin.com/2001/08/28/news/story8.html).

An indirect human health issue that deer axis pose in Hawaii is the potential for stray bullets to hit people as poaching increases (Anderson 1999). In any case shooting for managing the species is considered potentially dangerous and has led to complaints as it may represent a safety risk for residents, e.g. mostly because is conducted at night, as reported in Australia (Mitchell 2015).

Axis deer is an animal that is unlikely to make an unprovoked attack but such attacks can cause serious injury (requiring hospitalisation) or fatality if animals are cornered or handled (Page et al. 2008).

Qu. 5.15. How important is social, human health or other impact (not directly included in any earlier categories) caused by the organism in the future for the risk assessment area.

- In absence of specific studies or other direct evidences this should be clearly stated by using the standard answer “No information has been found on the issue”. This is necessary to avoid confusion between “no information found” and “no impact found”.

RESPONSE	minimal minor **moderate** major massive	**CONFIDENCE**	**low** medium high

In the event of substantial spread and increase in numbers of axis deer to new parts of the risk assessment area, the impact may be expected to increase accordingly.

Other impacts

Qu. 5.16. How important is the impact of the organism as food, a host, a symbiont or a vector for other damaging organisms (e.g. diseases)?

RESPONSE	minimal minor **moderate** major massive	**CONFIDENCE**	**low** medium high

Deer, in general, may transmit infectious diseases directly to other species of deer (as well as to livestock, and to humans), especially if their density is high (Côté et al. 2004). The axis deer, as other ungulates, can be a carrier of a number of diseases and parasites that may be harmful to native species. For example, this species is involved in the transmission of bovine tuberculosis (Anderson 1999, Schaller 1967), which is a deadly disease for native ungulates, including the European bison (*Bison bonasus*), as pointed out by Okarma et al. (2018). Other diseases transmitted by axis deer in their native range are leptospirosis and cryptosporidiosis (Anderson 1999, Schaller 1967). The species may also act as a new host for native parasites, as in the case of the tick *Amblyomma dubitatum* found on axis deer in northern Argentina, and this interrelationship may have potential deleterious effects on the native fauna, due to acquisition and amplification of the native parasite by an introduced host (Debárbora et al. 2012).

Qu. 5.17. How important might other impacts not already covered by previous questions be resulting from introduction of the organism?

RESPONSE	minimal minor moderate major massive	**CONFIDENCE**	low medium high

No information has been found.

Qu. 5.18. How important are the expected impacts of the organism despite any natural control by other organisms, such as predators, parasites or pathogens that may already be present in the risk assessment area?

RESPONSE	minimal minor **moderate** major massive	**CONFIDENCE**	**low** medium high

As described in Qu.3.5 the risk assessment area is certainly characterised by the presence of potential predators, parasites or pathogens of axis deer. However, there are several species of native and alien deer already occurring here, and this does not seem to represent a limiting factor for the relevant populations (predation from the large carnivores may be less effective than in the native range, given the lack of tigers and leopards). In fact, the role of predators in controlling ungulate populations remains uncertain as pointed out by Côté et al. (2004), and is considered not effective, at least in some ecosystems.

The situation may be different in island ecosystems, where ungulates, as a consequence of their co-evolutionary history with large predators, may have very high reproductive rates, causing rapid population growth in the absence of predators. For example, in Hawaii, introduced axis deer exhibit annual population growth rates of 20–30% (Hess 2008).

Qu. 5.19. Estimate the overall impact in the risk assessment area under current climate conditions. In addition, details of overall impact in relevant biogeographical regions should be provided.

Thorough assessment of the overall impact on biodiversity and ecosystem services, with impacts on economy as well as social and human health as aggravating factors, in current conditions.

RESPONSE	minimal minor **moderate** major massive	**CONFIDENCE**	**low** medium high

The species is known to exert a multifaceted impact on both biodiversity and ecosystem services, by feeding on native vegetation and contributing to the loss of habitat structure and function (hence indirectly affecting other species, including birds, reptiles, invertebrates, etc.). Competition with other ungulates is documented. The species is known to contribute to the spread of diseases and pathogens affecting both livestock and humans. It can also damage crops and compete with livestock. It can be a threat in relation to possible deer/vehicle collisions. No documented exists to provide discuss in details the overall impact in the biogeographical regions.

Qu. 5.20. Estimate the overall impact in the risk assessment area in foreseeable climate change conditions. In addition, details of overall impact in relevant biogeographical regions should be provided.

Thorough assessment of the overall impact on biodiversity and ecosystem services, with impacts on economy as well as social and human health as aggravating factors, under future conditions.

RESPONSE	minimal minor **moderate** major massive	**CONFIDENCE**	**low** medium high

In foreseeable climate change conditions, the area suitable for the species in the risk assessment area may increase (see Annex VII), and the impact may be expected to increase accordingly. For example, in case of a future expansion of the species range, other native species may be affected. No documented evidence exists to discuss in details the overall impact in the biogeographical regions.

RISK SUMMARIES			
	RESPONSE	**CONFIDENCE**	**COMMENT**
Summarise Introduction*	very unlikely unlikely **moderately likely** likely very likely	low medium **high**	The species is already present in the risk assessment area (in the wild and in confinements). Further introductions for hunting, farming or exhibitions are considered possible.
Summarise Entry*	very unlikely unlikely **moderately likely** likely very likely	low medium **high**	Releases or escapes from captive facilities have been documented in the past in the risk assessment area and may take place again.
Summarise Establishment*	very unlikely unlikely moderately likely **likely** very likely	low medium **high**	Axis deer, although native to tropical and subtropical areas of the Indian subcontinent, has the ability to establish in other ecoclimatic zones, including those present in the EU, such as the Mediterranean. In Croatia it is currently established. The species life-history, available habitat conditions and management practices in the EU offer the potential to support self-sustaining populations of axis deer also in other countries and biogeographical regions.
Summarise Spread*	very slowly **slowly** moderately rapidly very rapidly	**low** medium high	The species has a sedentary habit, but is also known to spread over some distance in specific circumstances (e.g. suitability of habitat, lack of predators), including across islands given the good swimming skills.
Summarise Impact*	minimal minor **moderate** major massive	**low** medium high	The species is known to exert a multifaceted impact on both biodiversity and ecosystem services, by feeding on native vegetation and contributing to the loss of habitat structure and function (hence indirectly affecting other species, including birds, reptiles, invertebrates, etc.). Competition with other

			ungulates is documented. The species is known to contribute to the spread of diseases and pathogens affecting both livestock and humans. It can also damage crops and compete with livestock. It can be a threat in relation to possible deer/vehicle collisions.
Conclusion of the risk assessment (overall risk)	low **moderate** high	low **medium** high	The axis deer represents a potential threat in the risk assessment area, given the ability to establish in the wild, the potential for spread, and the documented impact in other parts of the introduced range. Further warming of the climate due to climate change may increase impacts by increasing the amount of suitable habitat.

*in current climate conditions and in foreseeable future climate conditions

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Distribution Summary

Please answer as follows:

Yes if recorded, established or invasive
– if not recorded, established or invasive
? Unknown; data deficient

The columns refer to the answers to Questions A5 to A12 under Section A.
For data on marine species at the Member State level, delete Member States that have no marine borders. In all other cases, provide answers for all columns.

Member States and the United Kingdom

	Recorded	Established (currently)	Possible establishment (under current climate)	Possible establishment (under foreseeable climate)	Invasive (currently)
Austria			Yes	Yes	
Belgium			Yes	Yes	
Bulgaria			Yes	Yes	
Croatia	Yes	Yes	Yes	Yes	Yes
Cyprus			Yes	Yes	
Czech Republic	Yes		Yes	Yes	
Denmark			Yes	Yes	
Estonia				Yes	
Finland				Yes	
France	Yes		Yes	Yes	
Germany			Yes	Yes	
Greece			Yes	Yes	
Hungary			Yes	Yes	
Ireland	Yes		Yes	Yes	
Italy			Yes	Yes	
Latvia			Yes	Yes	
Lithuania			Yes	Yes	
Luxembourg			Yes	Yes	
Malta			Yes	Yes	
Netherlands			Yes	Yes	
Poland			Yes	Yes	
Portugal			Yes	Yes	
Romania			Yes	Yes	
Slovakia			Yes	Yes	
Slovenia	Yes		Yes	Yes	
Spain			Yes	Yes	
Sweden			Yes	Yes	
United Kingdom	Yes		Yes	Yes	

Biogeographical regions of the risk assessment area

	Recorded	Established (currently)	Possible establishment (under current climate)	Possible establishment (under foreseeable climate)	Invasive (currently)
Alpine	Yes		Yes	Yes	
Atlantic			Yes	Yes	
Black Sea			Yes	Yes	
Boreal			Yes	Yes	
Continental	Yes		Yes	Yes	
Mediterranean	Yes	Yes	Yes	Yes	Yes
Pannonian			Yes	Yes	
Steppic			Yes	Yes	

ANNEX I Scoring of Likelihoods of Events

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

Score	**Description**	**Frequency**
Very unlikely	This sort of event is theoretically possible, but is never known to have occurred and is not expected to occur	1 in 10,000 years
Unlikely	This sort of event has not occurred anywhere in living memory	1 in 1,000 years
Moderately likely	This sort of event has occurred somewhere at least once in recent years, but not locally	1 in 100 years
Likely	This sort of event has happened on several occasions elsewhere, or on at least one occasion locally in recent years	1 in 10 years
Very likely	This sort of event happens continually and would be expected to occur	Once a year

ANNEX II Scoring of Magnitude of Impacts

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

Score	**Biodiversity and ecosystem impact**	**Ecosystem Services impact**	**Economic impact (Monetary loss and response costs per year)**	**Social and human health impact, and other impacts**
	Question 5.1-5	*Question 5.6-8*	*Question 5.9-13*	*Question 5.14-18*
Minimal	Local, short-term population loss, no significant ecosystem effect	No services affected[8]	Up to 10,000 Euro	No social disruption. Local, mild, short-term reversible effects to individuals.
Minor	Some ecosystem impact, reversible changes, localised	Local and temporary, reversible effects to one or few services	10,000-100,000 Euro	Significant concern expressed at local level. Mild short-term reversible effects to identifiable groups, localised.
Moderate	Measureable long-term damage to populations and ecosystem, but reversible; little spread, no extinction	Measureable, temporary, local and reversible effects on one or several services	100,000-1,000,000 Euro	Temporary changes to normal activities at local level. Minor irreversible effects and/or larger numbers covered by reversible effects, localised.
Major	Long-term irreversible ecosystem change, spreading beyond local area	Local and irreversible or widespread and reversible effects on one / several services	1,000,000-10,000,000 Euro	Some permanent change of activity locally, concern expressed over wider area. Significant irreversible effects locally or reversible effects over large area.
Massive	Widespread, long-term population loss or extinction, affecting several species with serious ecosystem effects	Widespread and irreversible effects on one / several services	Above 10,000,000 Euro	Long-term social change, significant loss of employment, migration from affected area. Widespread, severe, long-term, irreversible health effects.

[8] Not to be confused with “no impact”.

ANNEX III Scoring of Confidence Levels

(modified from Bacher et al. 2017)

Each answer provided in the risk assessment must include an assessment of the level of confidence attached to that answer, reflecting the possibility that information needed for the answer is not available or is insufficient or available but conflicting. The responses in the risk assessment should clearly support the choice of the confidence level.

Confidence level	**Description**
Low	There is no direct observational evidence to support the assessment, e.g. only inferred data have been used as supporting evidence *and/or* Impacts are recorded at a spatial scale which is unlikely to be relevant to the assessment area *and/or* Evidence is poor and difficult to interpret, e.g. because it is strongly ambiguous *and/or* The information sources are considered to be of low quality or contain information that is unreliable.
Medium	There is some direct observational evidence to support the assessment, but some information is inferred *and/or* Impacts are recorded at a small spatial scale, but rescaling of the data to relevant scales of the assessment area is considered reliable, or to embrace little uncertainty *and/or* The interpretation of the data is to some extent ambiguous or contradictory.
High	There is direct relevant observational evidence to support the assessment (including causality) *and* Impacts are recorded at a comparable scale *and/or* There are reliable/good quality data sources on impacts of the taxa *and* The interpretation of data/information is straightforward *and/or* Data/information are not controversial or contradictory.

ANNEX IV Ecosystem services classification (CICES V5.1, simplified) and examples

For the purposes of this risk assessment, please feel free to use what seems as the most appropriate category / level / combination of impact (Section – Division – Group), reflecting information available.

Section	Division	Group	Examples (i.e. relevant CICES "classes")
Provisioning	**Biomass**	**Cultivated *terrestrial* plants**	Cultivated terrestrial plants (including fungi, algae) grown for nutritional purposes; Fibres and other materials from cultivated plants, fungi, algae and bacteria for direct use or processing (excluding genetic materials); Cultivated plants (including fungi, algae) grown as a source of energy *Example: negative impacts of non-native organisms to crops, orchards, timber etc.*
		Cultivated *aquatic* plants	Plants cultivated by in- situ aquaculture grown for nutritional purposes; Fibres and other materials from in-situ aquaculture for direct use or processing (excluding genetic materials); Plants cultivated by in- situ aquaculture grown as an energy source. *Example: negative impacts of non-native organisms to aquatic plants cultivated for nutrition, gardening etc. purposes.*
		Reared animals	Animals reared for nutritional purposes; Fibres and other materials from reared animals for direct use or processing (excluding genetic materials); Animals reared to provide energy (including mechanical) *Example: negative impacts of non-native organisms to livestock*
		Reared *aquatic* animals	Animals reared by in-situ aquaculture for nutritional purposes; Fibres and other materials from animals grown by in-situ aquaculture for direct use or processing (excluding genetic materials); Animals reared by in-situ aquaculture as an energy source *Example: negative impacts of non-native organisms to fish farming*
		Wild plants (terrestrial and aquatic)	Wild plants (terrestrial and aquatic, including fungi, algae) used for nutrition; Fibres and other materials from wild plants for direct use or processing (excluding genetic materials); Wild plants (terrestrial and aquatic, including fungi, algae) used as a source of energy *Example: reduction in the availability of wild plants (e.g. wild berries, ornamentals) due to non-native organisms (competition, spread of disease etc.)*
		Wild animals (terrestrial and aquatic)	Wild animals (terrestrial and aquatic) used for nutritional purposes; Fibres and other materials from wild animals for direct use or processing (excluding genetic materials); Wild animals (terrestrial and aquatic) used as a source of energy *Example: reduction in the availability of wild animals (e.g. fish stocks, game) due to non-native organisms (competition, predations, spread of disease etc.)*
	Genetic material from all biota	**Genetic material** from plants, algae or fungi	Seeds, spores and other plant materials collected for maintaining or establishing a population; Higher and lower plants (whole organisms) used to breed new

			strains or varieties; Individual genes extracted from higher and lower plants for the design and construction of new biological entities *Example: negative impacts of non-native organisms due to interbreeding*
		Genetic material from animals	Animal material collected for the purposes of maintaining or establishing a population; Wild animals (whole organisms) used to breed new strains or varieties; Individual genes extracted from organisms for the design and construction of new biological entities *Example: negative impacts of non-native organisms due to interbreeding*
	Water[9]	**Surface water** used for nutrition, materials or energy	Surface water for drinking; Surface water used as a material (non-drinking purposes); Freshwater surface water, coastal and marine water used as an energy source *Example: loss of access to surface water due to spread of non-native organisms*
		Ground water for used for nutrition, materials or energy	Ground (and subsurface) water for drinking; Ground water (and subsurface) used as a material (non-drinking purposes); Ground water (and subsurface) used as an energy source *Example: reduced availability of ground water due to spread of non-native organisms and associated increase of ground water consumption by vegetation.*
Regulation & Maintenance	**Transformation** of biochemical or physical inputs to ecosystems	**Mediation of wastes or toxic substances** of anthropogenic origin by living processes	Bio-remediation by micro-organisms, algae, plants, and animals; Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals *Example: changes caused by non-native organisms to ecosystem functioning and ability to filtrate etc. waste or toxics*
		Mediation of nuisances of anthropogenic origin	Smell reduction; noise attenuation; visual screening (e.g. by means of green infrastructure) *Example: changes caused by non-native organisms to ecosystem structure, leading to reduced ability to mediate nuisances.*
	Regulation of physical, chemical, biological conditions	**Baseline flows and extreme event** regulation	Control of erosion rates; Buffering and attenuation of mass movement; Hydrological cycle and water flow regulation (Including flood control, and coastal protection); Wind protection; Fire protection *Example: changes caused by non-native organisms to ecosystem functioning or structure leading to, for example, destabilisation of soil, increased risk or intensity of wild fires etc.*
		Lifecycle maintenance, habitat and gene pool protection	Pollination (or 'gamete' dispersal in a marine context); Seed dispersal; Maintaining nursery populations and habitats (Including gene pool protection) *Example: changes caused by non-native organisms to the abundance and/or distribution of wild pollinators; changes to the availability / quality of nursery habitats for fisheries*
		Pest and disease control	Pest control; Disease control

[9] Note: in the CICES classification provisioning of water is considered as an abiotic service whereas the rest of ecosystem services listed here are considered biotic.

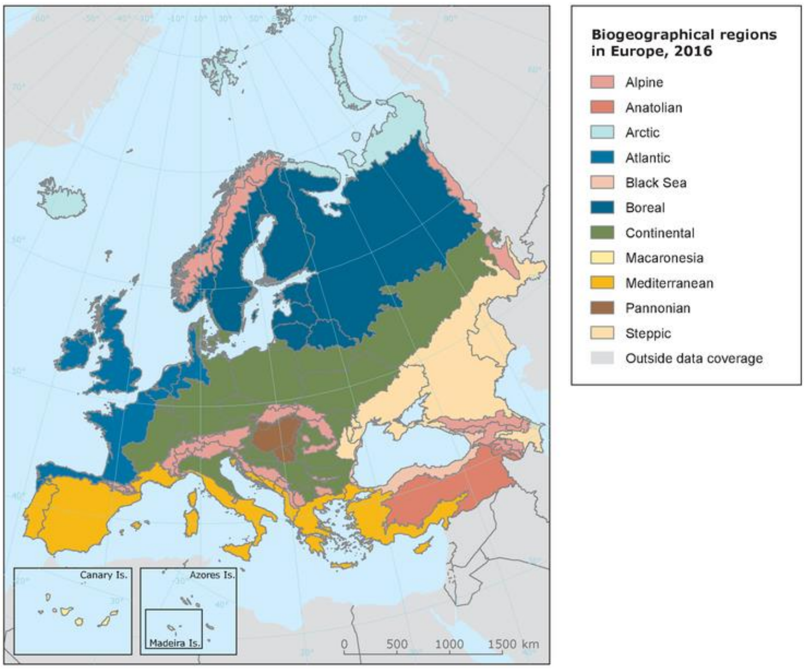
			Example: changes caused by non-native organisms to the abundance and/or distribution of pests
		Soil quality regulation	Weathering processes and their effect on soil quality; Decomposition and fixing processes and their effect on soil quality *Example: changes caused by non-native organisms to vegetation structure and/or soil fauna leading to reduced soil quality*
		Water conditions	Regulation of the chemical condition of freshwaters by living processes; Regulation of the chemical condition of salt waters by living processes *Example: changes caused by non-native organisms to buffer strips along water courses that remove nutrients in runoff and/or fish communities that regulate the resilience and resistance of water bodies to eutrophication*
		Atmospheric composition and conditions	Regulation of chemical composition of atmosphere and oceans; Regulation of temperature and humidity, including ventilation and transpiration *Example: changes caused by non-native organisms to ecosystems' ability to sequester carbon and/or evaporative cooling (e.g. by urban trees)*
Cultural	**Direct, in-situ and outdoor interactions** with living systems that depend on presence in the environmental setting	**Physical and experiential** interactions with natural environment	Characteristics of living systems that that enable activities promoting health, recuperation or enjoyment through active or immersive interactions; Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions *Example: changes caused by non-native organisms to the qualities of ecosystems (structure, species composition etc.) that make it attractive for recreation, wild life watching etc.*
		Intellectual and representative interactions with natural environment	Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge; Characteristics of living systems that enable education and training; Characteristics of living systems that are resonant in terms of culture or heritage; Characteristics of living systems that enable aesthetic experiences *Example: changes caused by non-native organisms to the qualities of ecosystems (structure, species composition etc.) that have cultural importance*
	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	**Spiritual, symbolic** and other interactions with natural environment	Elements of living systems that have symbolic meaning; Elements of living systems that have sacred or religious meaning; Elements of living systems used for entertainment or representation *Example: changes caused by non-native organisms to the qualities of ecosystems (structure, species composition etc.) that have sacred or religious meaning*
		Other biotic characteristics that have a **non-use value**	Characteristics or features of living systems that have an existence value; Characteristics or features of living systems that have an option or bequest value *Example: changes caused by non-native organisms to ecosystems designated as wilderness areas, habitats of endangered species etc.*

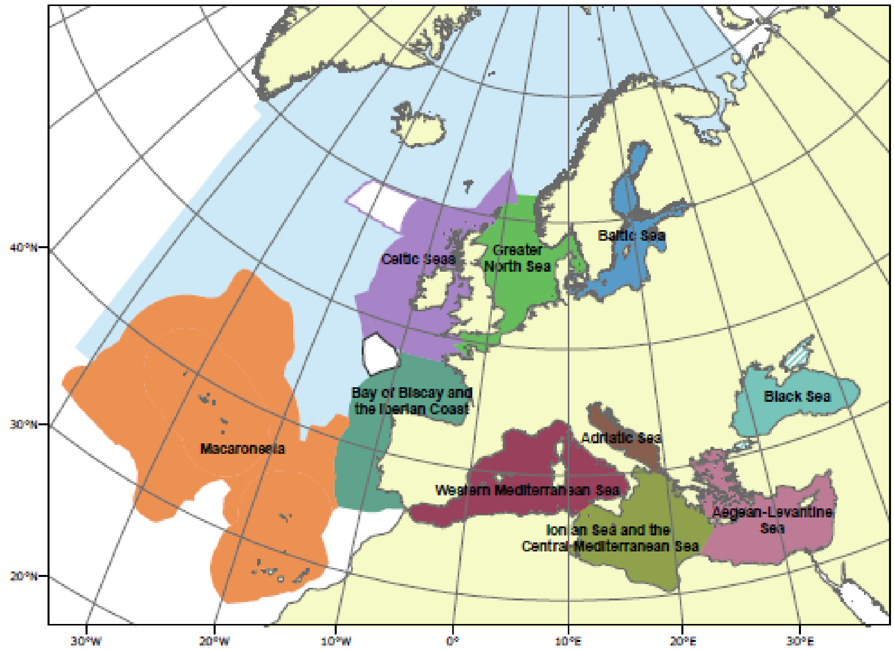
ANNEX V EU Biogeographic Regions and MSFD Subregions

See https://www.eea.europa.eu/data-and-maps/figures/biogeographical-regions-in-europe-2 , http://ec.europa.eu/environment/nature/natura2000/biogeog_regions/

and

https://www.eea.europa.eu/data-and-maps/data/msfd-regions-and-subregions-1/technical-document/pdf





ANNEX VI Delegated Regulation (EU) 2018/968 of 30 April 2018

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

ANNEX VII Projection of climatic suitability for *Axis axis* establishment

Björn Beckmann, Riccardo Scalera, Beth Purse and Dan Chapman

30 October 2019

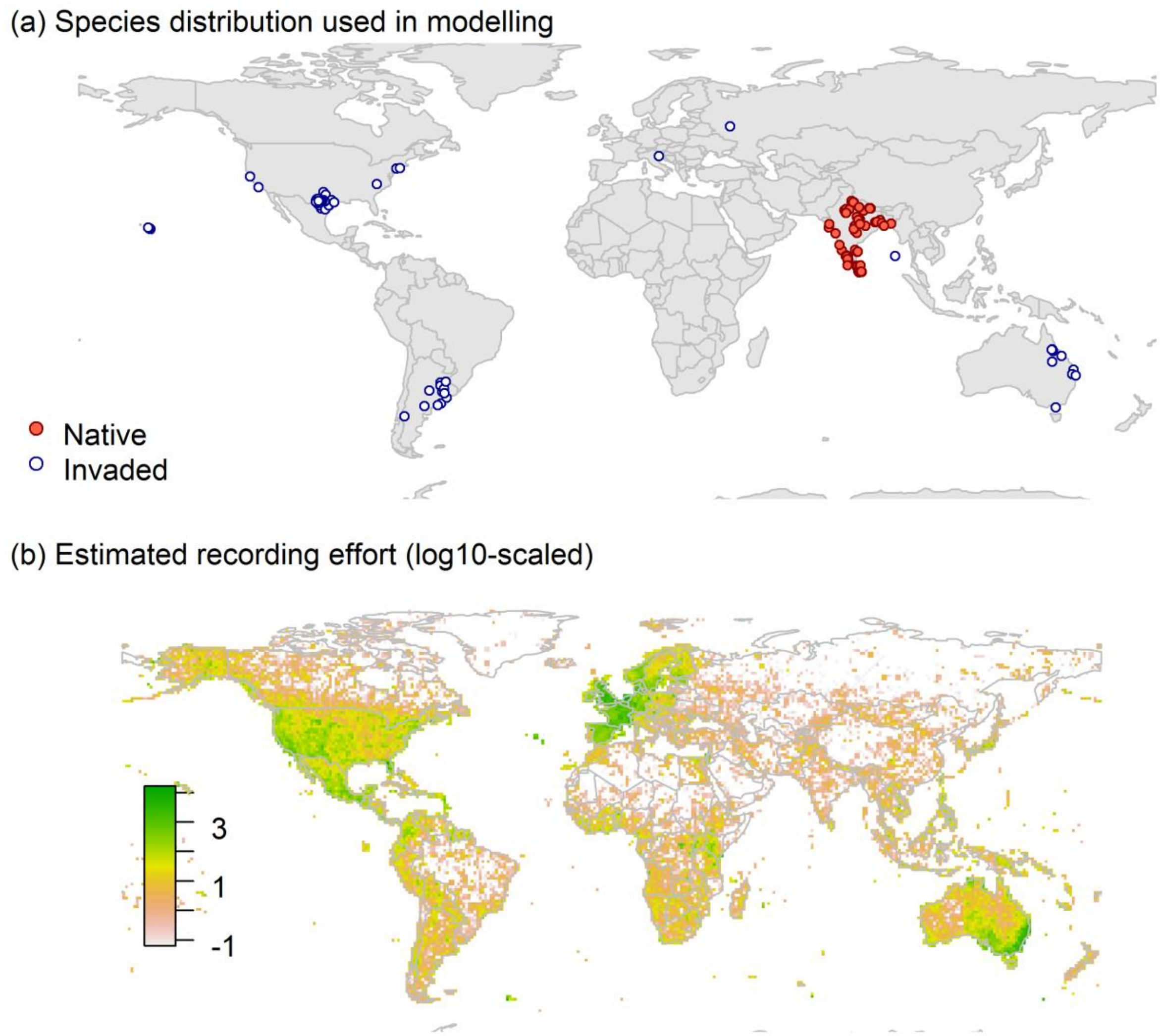
Aim

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

Data for modelling

Species occurrence data were obtained from the Global Biodiversity Information Facility (GBIF) (394 records), the Biodiversity Information Serving Our Nation database (BISON) (85 records), the Atlas of Living Australia (19 records), the Integrated Digitized Biocollections (iDigBio) (8 records), and a small number of additional records from the risk assessment team. We scrutinised occurrence records from regions where the species is not known to be established and removed any dubious records (e.g. fossils, captive records) or where the georeferencing was too imprecise (e.g. records referenced to a country or island centroid) or outside of the coverage of the predictor layers (e.g. small island or coastal occurrences). The remaining records were gridded at a 0.25 x 0.25 degree resolution for modelling, yielding 156 grid cells with occurrences (Figure 1a). As a proxy for recording effort, the density of Mammalia records held by GBIF was also compiled on the same grid (Figure 1b).

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



Climate data were selected from the 'Bioclim' variables contained within the WorldClim database (Hijmans et al., 2005), originally at 5 arcminute resolution (0.083 x 0.083 degrees of longitude/latitude) and aggregated to a 0.25 x 0.25 degree grid for use in the model.
Based on the biology of *Axis axis*, the following climate variables were used in the modelling:

- Minimum temperature of the coldest month (Bio6)
- Mean temperature of the warmest quarter (Bio10)
- Annual precipitation (Bio12)

To estimate the effect of climate change on the potential distribution, equivalent modelled future climate conditions for the 2070s under the Representative Concentration Pathways (RCP) 2.6 and 4.5 were also obtained. There represent low and medium emissions scenarios, respectively. The above variables were obtained as averages of outputs of eight Global Climate Models (BCC-CSM1-1, CCSM4, GISS-E2-R, HadGEM2-AO, IPSL-CM5A-LR, MIROC-ESM, MRI-CGCM3, NorESM1-M), downscaled and calibrated against the WorldClim baseline (see http://www.worldclim.org/cmip5_5m).

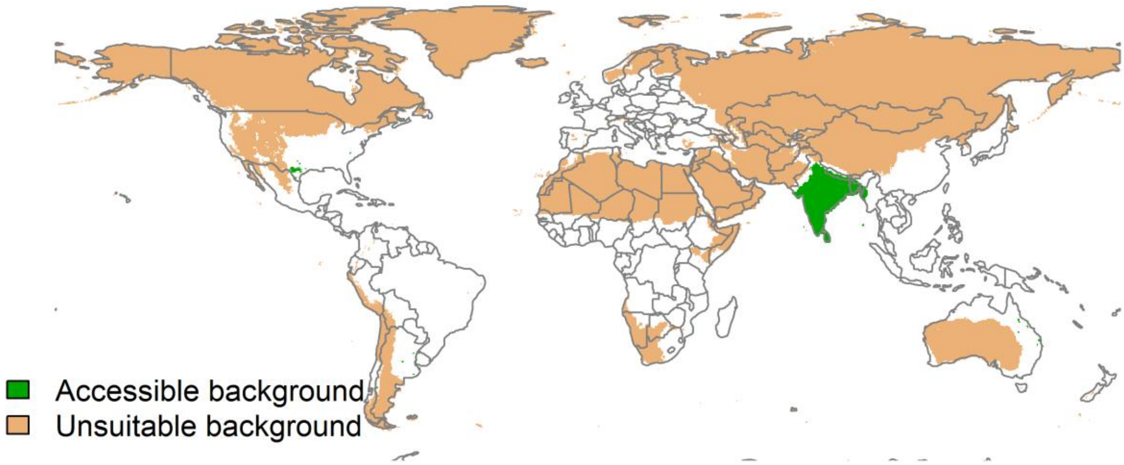
Species distribution model

A presence-background (presence-only) ensemble modelling strategy was employed using the BIOMOD2 R package v3.3-7.1 (Thuiller et al., 2019, Thuiller et al., 2009). These models contrast the environment at the species' occurrence locations against a random sample of the global background environmental conditions (often termed 'pseudo-absences') in order to characterise and project suitability for occurrence. This approach has been developed for distributions that are in equilibrium with the environment. Because invasive species' distributions are not at equilibrium and subject to dispersal constraints at a global scale, we took care to minimise the inclusion of locations suitable for the species but where it has not been able to disperse to (Chapman et al. 2019). Therefore the background sampling region included:

- The area accessible by native *Axis axis* populations, in which the species is likely to have had sufficient time to disperse to all locations. Based on presumed maximum dispersal distances, the accessible region was defined as a 300km buffer around the native range occurrences; AND
- A 30km buffer around the non-native occurrences, encompassing regions likely to have had high propagule pressure for introduction by humans and/or dispersal of the species; AND
- Regions where we have an *a priori* expectation of high unsuitability for the species so that absence is assumed irrespective of dispersal constraints (see Figure 2). The following rules were applied to define a region expected to be highly unsuitable for *Axis axis* at the spatial scale of the model:
  - Minimum temperature of the coldest month (Bio6) < -12°C
  - Mean temperature of the warmest quarter (Bio10) < 11°C
  - Annual precipitation (Bio12) < 6 (i.e. < 403mm, as the Bioclim variable is on a natural log scale)

Altogether, only 0.6% of occurrence grid cells were located in the unsuitable background region. Within the background region, 10 samples of 5000 randomly sampled grid cells were obtained, weighting the sampling by recording effort (Figure 2).

Figure 2. The background from which pseudo-absence samples were taken in the modelling of *Axis axis*. Samples were taken from a 300km buffer around the native range and a 30km buffer around non-native occurrences (together forming the accessible background), and from areas expected to be highly unsuitable for the species (the unsuitable background region). Samples were weighted by a proxy for recording effort (Figure 1(b)).



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

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

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

Model predictive performance was assessed by the following three measures:

- AUC, the area under the receiver operating characteristic curve (Fielding & Bell 1997). Predictions of presence-absence models can be compared with a subset of records set aside for model evaluation (here 20%) by constructing a confusion matrix with the number of true positive, false positive, false negative and true negative cases. For models generating non-dichotomous scores (as here) a threshold can be applied to transform the scores into a dichotomous set of presence-absence predictions. Two measures that can be derived from the confusion matrix are sensitivity (the proportion of observed presences that are predicted as such, quantifying omission errors), and specificity (the proportion of observed absences that are predicted as such, quantifying commission errors). A receiver operating characteristic (ROC) curve can be constructed by using all possible thresholds to classify the scores into confusion matrices, obtaining sensitivity and specificity for each matrix, and plotting sensitivity against the corresponding proportion of false positives (equal to 1 - specificity). The use of all possible thresholds avoids the need for a selection of a single threshold, which is often arbitrary, and allows appreciation of the trade-off between sensitivity and specificity. The area under the ROC curve (AUC) is often used as a single threshold-independent measure for model performance (Manel, Williams & Ormerod 2001). AUC is the probability that a randomly selected presence has a higher model-predicted suitability than a randomly selected absence (Allouche et al. 2006).

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

An ensemble model was created by first rejecting poorly performing algorithms with relatively extreme low AUC values and then averaging the predictions of the remaining algorithms, weighted by their AUC. To identify poorly performing algorithms, AUC values were converted into modified z-scores based on their difference to the median and the median absolute deviation across all algorithms (Iglewicz & Hoaglin, 1993). Algorithms with $z < -2$ were rejected. In this way, ensemble projections were made for each dataset and then averaged to give an overall suitability, as well as its standard deviation. The projections were then classified into suitable and unsuitable regions using the 'minimum ROC distance' method, which minimizes the distance between the ROC plot and the upper left corner of the plot (point (0,1)), i.e. which maximises both sensitivity (correctly classified presences) and specificity (correctly classified absences).

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

Results

The ensemble model suggested that suitability for *Axis axis* was most strongly determined by Annual precipitation (Bio12), accounting for 45.9% of variation explained, followed by Minimum temperature of the coldest month (Bio6) (35.1%) and Mean temperature of the warmest quarter (Bio10) (19%) (Table 1, Figure 3).

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

					variable importance (%)		
Algorithm	AUC	Kappa	TSS	Used in the ensemble	Annual precipitation (Bio12)	Minimum temperature of the coldest month (Bio6)	Mean temperature of the warmest quarter (Bio10)
GLM	0.984	0.653	0.948	yes	47	35	18
GAM	0.982	0.668	0.949	yes	43	40	18
ANN	0.982	0.648	0.949	yes	44	37	19
GBM	0.977	0.671	0.946	no	45	33	22
MARS	0.981	0.660	0.950	yes	42	40	18
RF	0.978	0.639	0.938	yes	54	23	23
Maxent	0.976	0.675	0.943	no	46	32	22
Ensemble	**0.983**	**0.655**	**0.952**		**46**	**35**	**19**

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

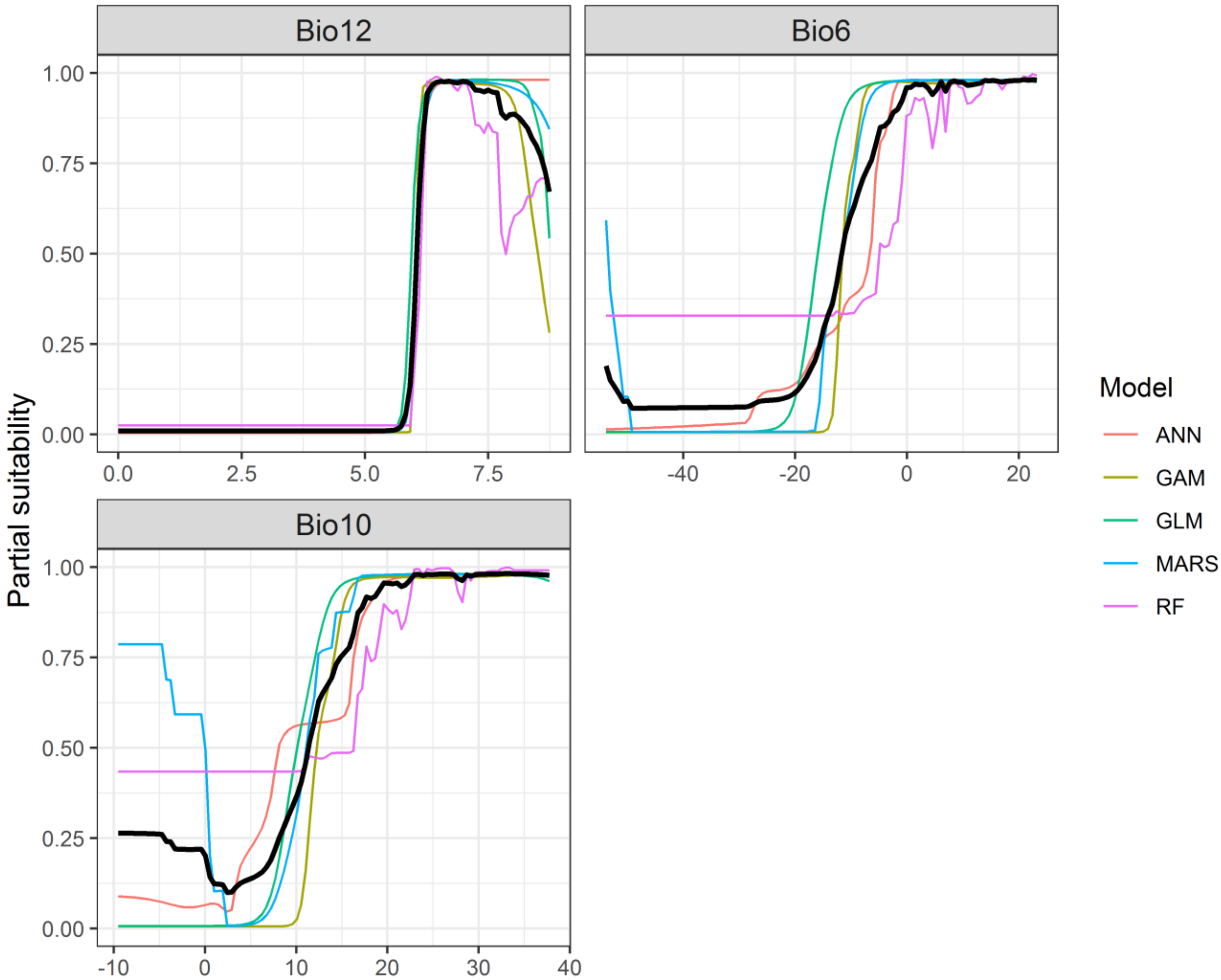


Figure 4. (a) Projected global suitability for *Axis axis* establishment in the current climate. For visualisation, the projection has been aggregated to a 0.5 x 0.5 degree resolution, by taking the maximum suitability of constituent higher resolution grid cells. Values > 0.45 may be suitable for the species ('minimum ROC distance' threshold at which both correctly classified presences and correctly classified absences are maximised). Grey areas have climatic conditions outside the range of the training data and were excluded from the projection. (b) Uncertainty in the ensemble projections, expressed as the among-algorithm standard deviation in predicted suitability, averaged across the 10 datasets.

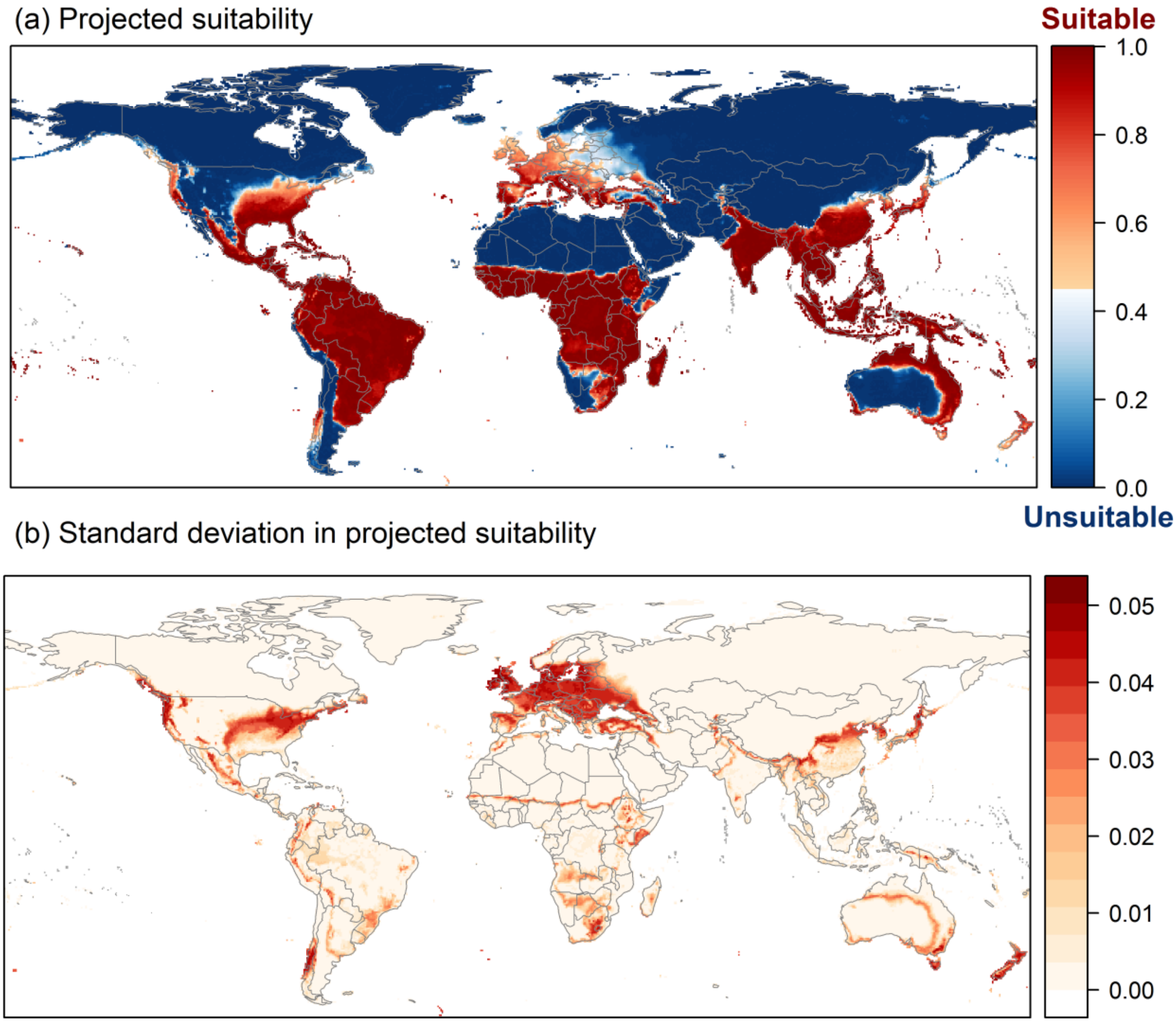


Figure 5. (a) Projected current suitability for *Axis axis* establishment in Europe and the Mediterranean region. Values > 0.45 may be suitable for the species ('minimum ROC distance' threshold at which globally both correctly classified presences and correctly classified absences are maximised). Grey areas have climatic conditions outside the range of the training data and were excluded from the projection. (b) Uncertainty in the ensemble projections, expressed as the among-algorithm standard deviation in predicted suitability, averaged across the 10 datasets.

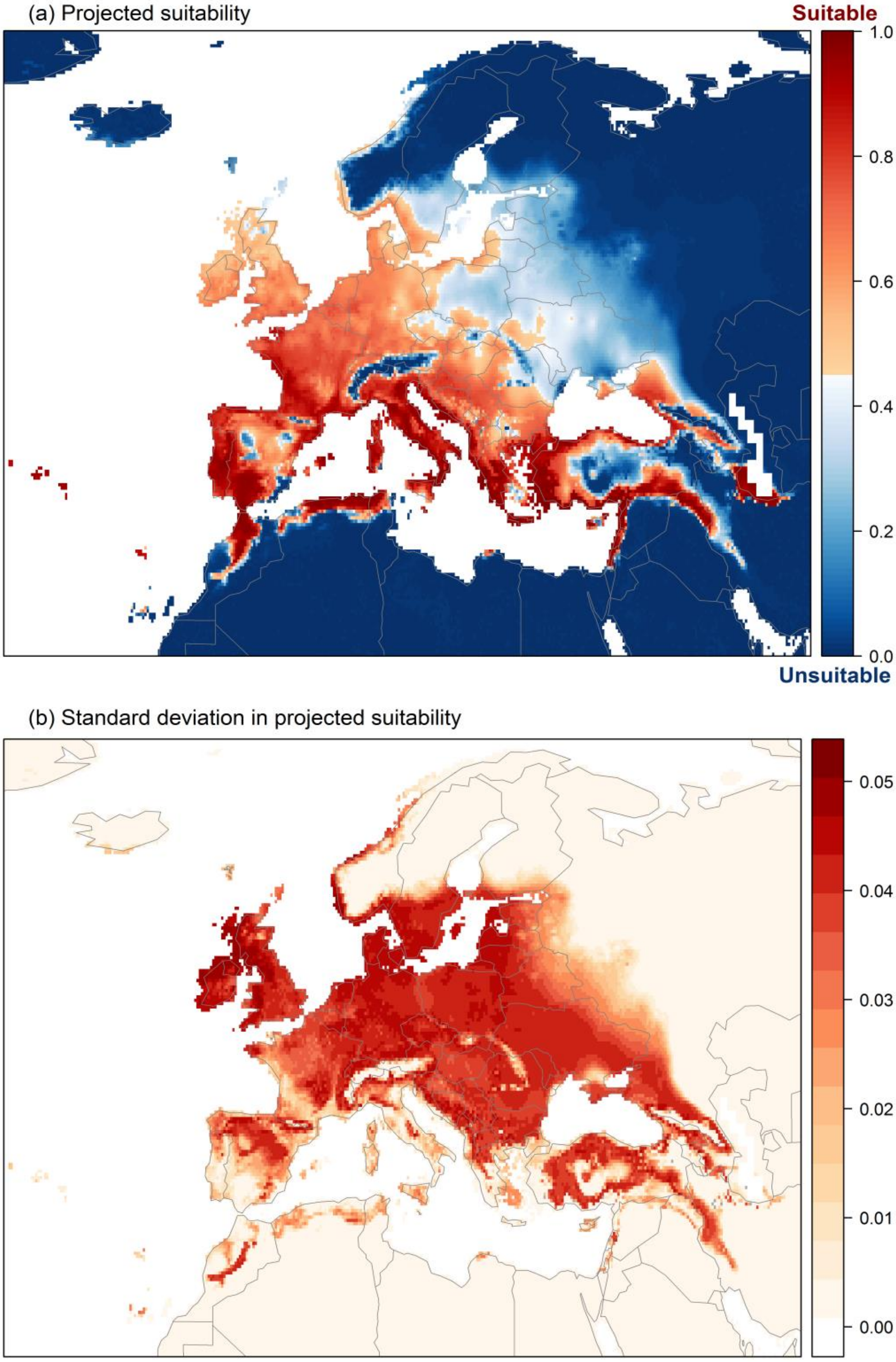


Figure 6. The most strongly limiting factors for *Axis axis* establishment estimated by the model in Europe and the Mediterranean region in current climatic conditions.

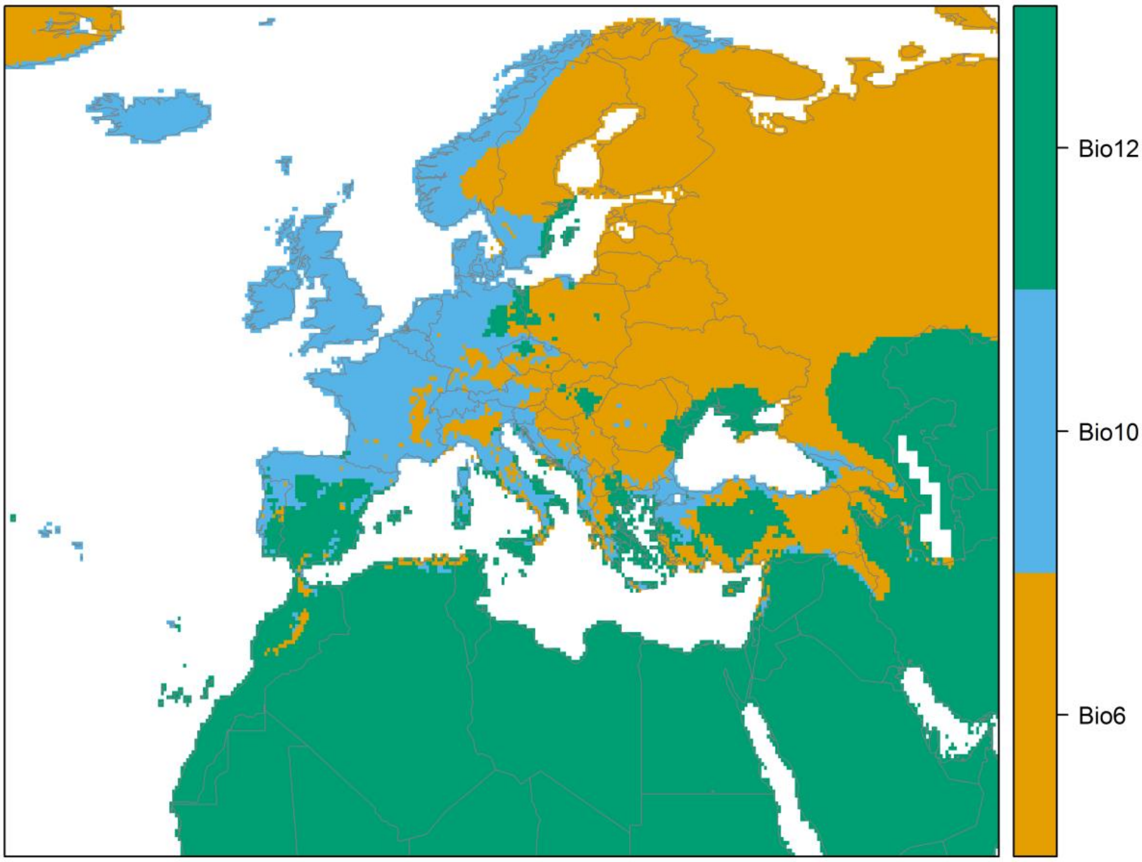


Figure 7. (a) Projected suitability for *Axis axis* establishment in Europe and the Mediterranean region in the 2070s under climate change scenario RCP2.6, equivalent to Figure 5. Values > 0.45 may be suitable for the species ('minimum ROC distance' threshold at which globally both correctly classified presences and correctly classified absences are maximised). Grey areas have climatic conditions outside the range of the training data and were excluded from the projection. (b) Uncertainty in the ensemble projections, expressed as the among-algorithm standard deviation in predicted suitability, averaged across the 10 datasets.

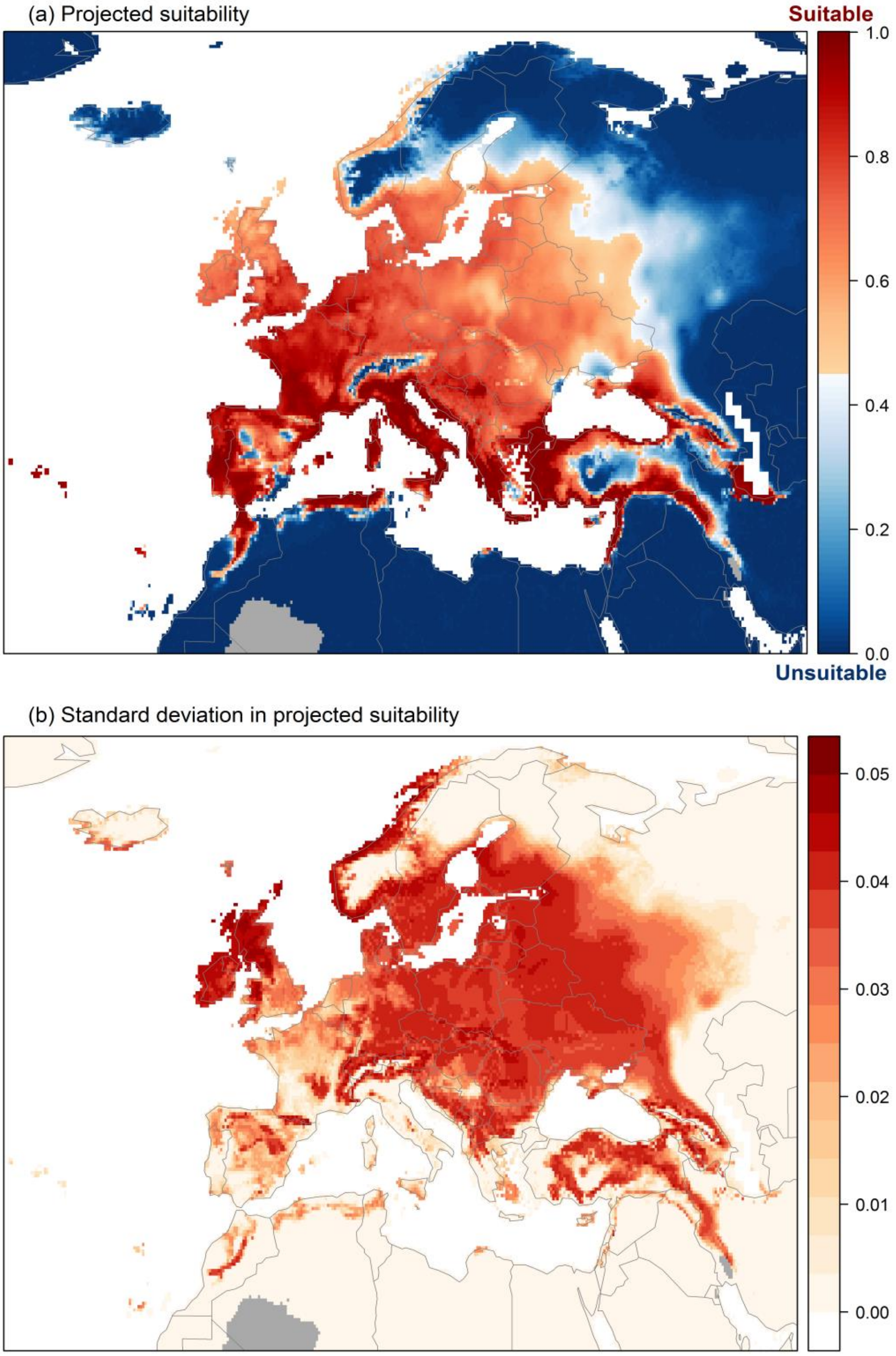


Figure 8. (a) Projected suitability for *Axis axis* establishment in Europe and the Mediterranean region in the 2070s under climate change scenario RCP4.5, equivalent to Figure 5. Values > 0.45 may be suitable for the species (‘minimum ROC distance’ threshold at which globally both correctly classified presences and correctly classified absences are maximised). Grey areas have climatic conditions outside the range of the training data and were excluded from the projection. (b) Uncertainty in the ensemble projections, expressed as the among-algorithm standard deviation in predicted suitability, averaged across the 10 datasets.

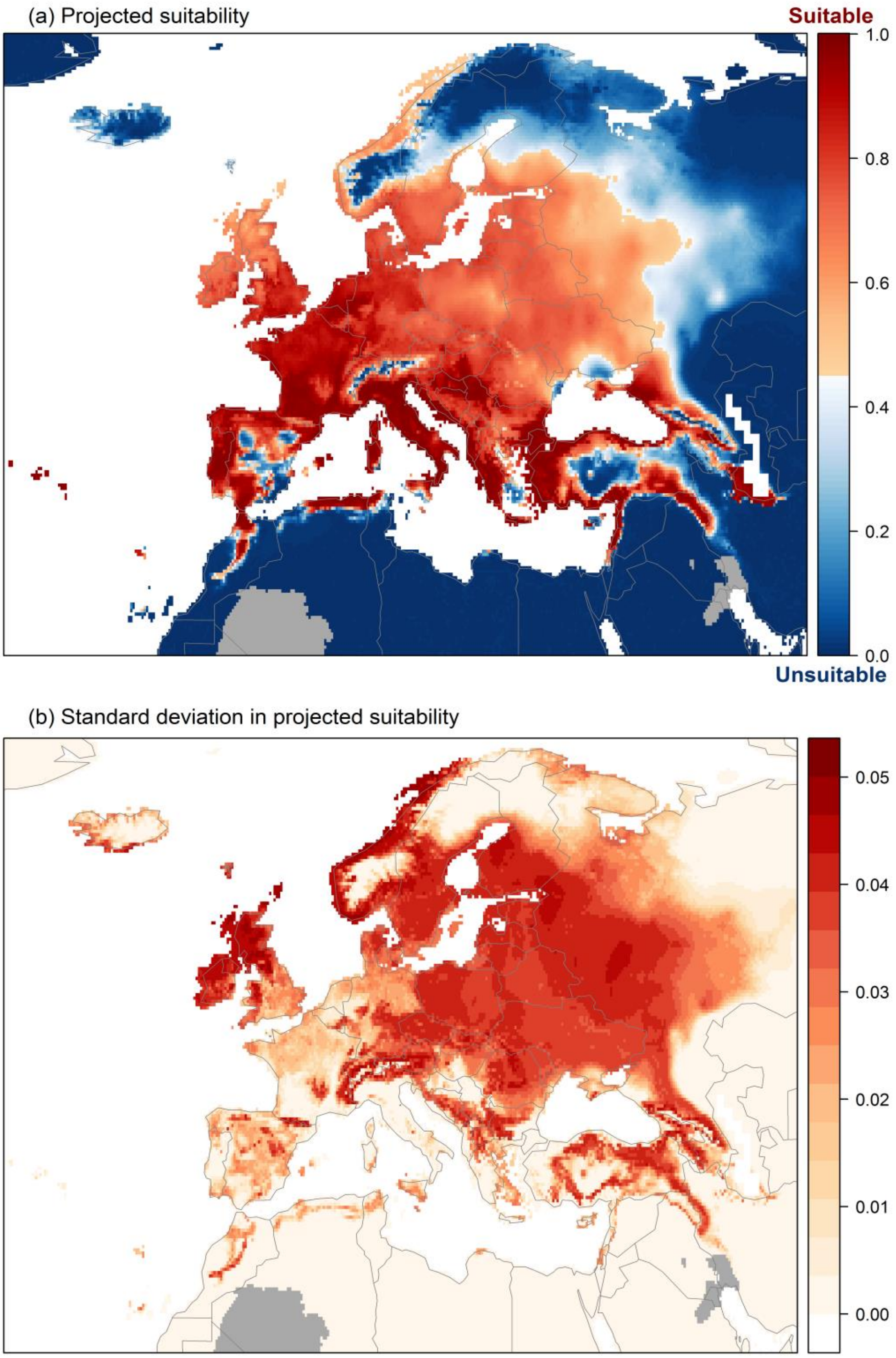


Figure 9. Variation in projected suitability for *Axis axis* establishment among Biogeographical regions of Europe (https://www.eea.europa.eu/data-and-maps/data/biogeographical-regions-europe-3)). The bar plots show the proportion of grid cells in each region classified as suitable in the current climate and projected climate for the 2070s under two RCP emissions scenarios. The classification threshold is the same as in Figures 4, 5, 7 and 8 above (minimum ROC distance), i.e. the bars in the below diagram show the proportion of each Biogeographical region that is coloured in a shade of red in the above figures. The location of each region is also shown. The Arctic and Macaronesian biogeographical regions are not part of the study area, but are included for completeness.

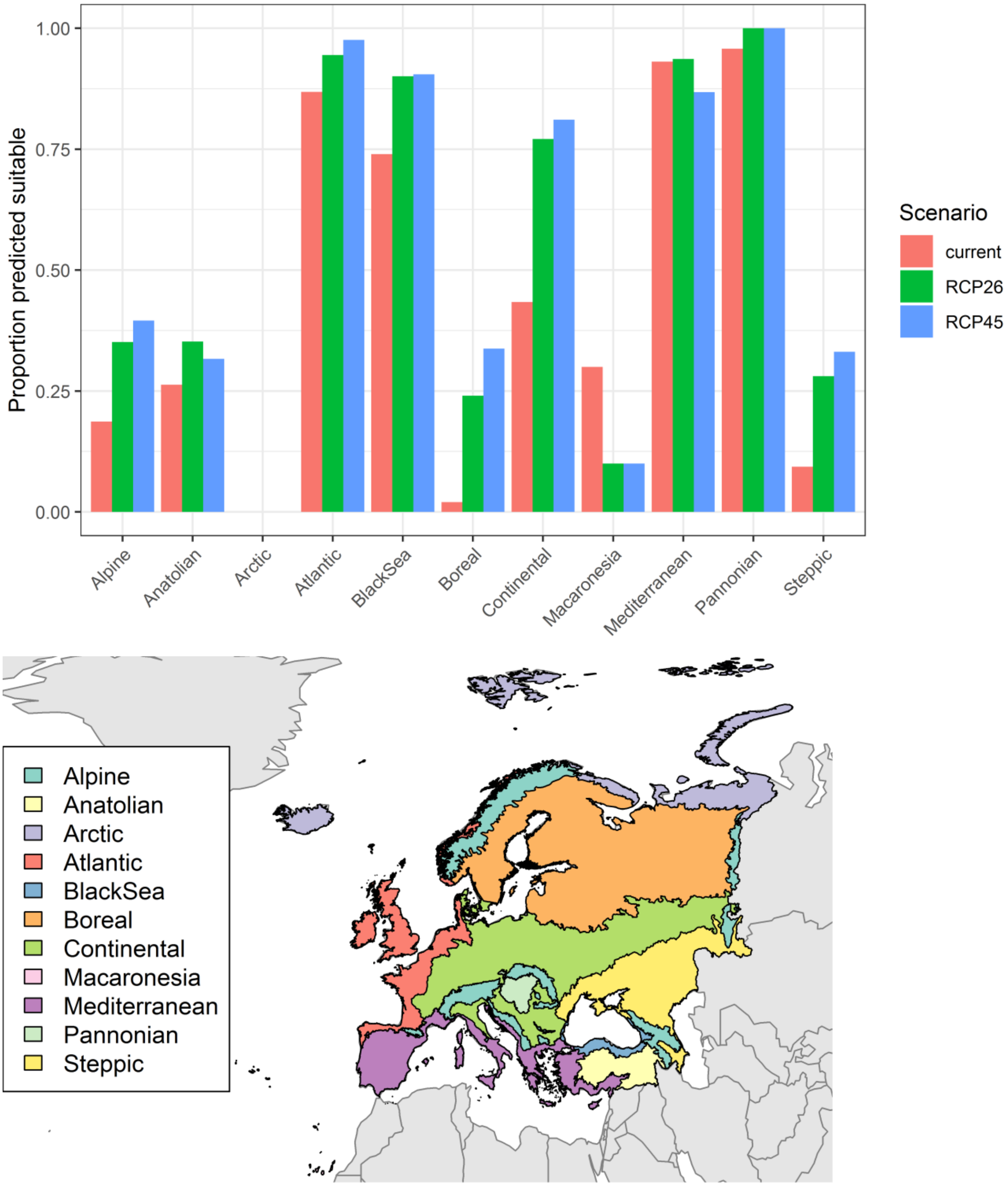
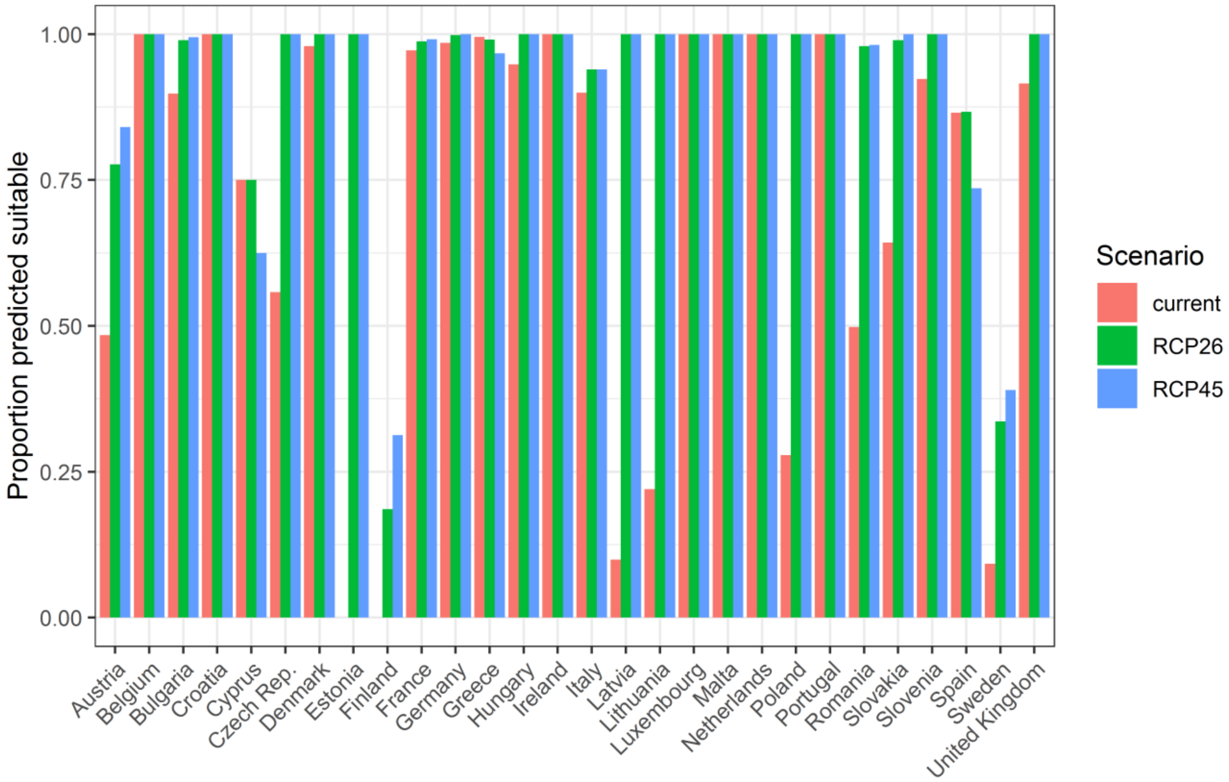


Figure 10. Variation in projected suitability for *Axis axis* establishment among European Union countries. The bar plots show the proportion of grid cells in each country classified as suitable in the current climate and projected climate for the 2070s under two RCP emissions scenarios. The classification threshold is the same as in Figures 4, 5, 7 and 8 above (minimum ROC distance), i.e. the bars in the below diagram show the proportion of each country that is coloured in a shade of red in the above figures.



Caveats to the modelling

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

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

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