Study on Invasive Alien Species – Development of risk assessments to tackle priority species and enhance prevention

Contract No 07.0202/2016/740982/ETU/ENV.D2

Final Report

Annex 10: Risk Assessment for *Arthurdendyus triangulatus* (Dendy, 1894) (Jones & Gerard, 1999)

Risk assessment template developed under the "Study on Invasive Alien Species – Development of risk assessments to tackle priority species and enhance prevention" Contract No 07.0202/2016/740982/ETU/ENV.D2

Based on the Risk Assessment Scheme developed by the GB Non-Native Species Secretariat (GB Non-Native Risk Assessment - GBNNRA)

Name of organism: New Zealand flatworm *Arthurdendyus triangulatus*

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Risk Assessment Area: The territory of the European Union (excluding the outermost regions)

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This risk assessment has been peer-reviewed by four independent experts and discussed during a joint expert workshop. Details on the review and how comments were addressed are available in the final report of the study.

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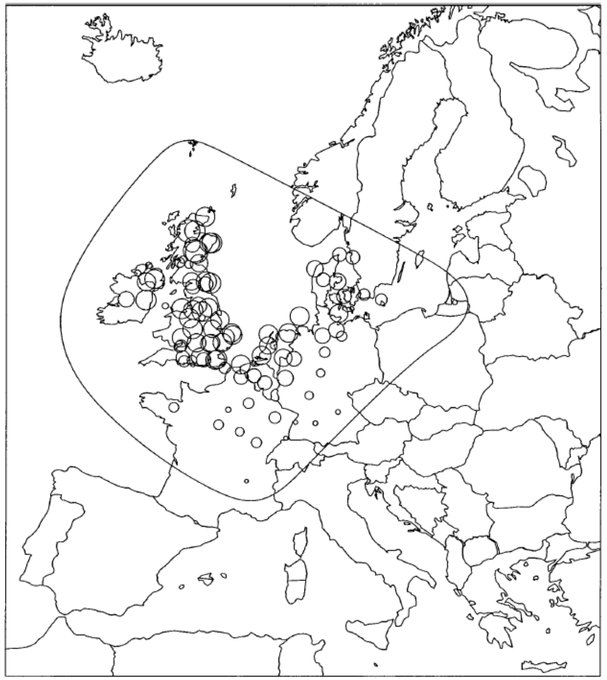
Approved by the IAS Scientific Forum on 16/10/2018

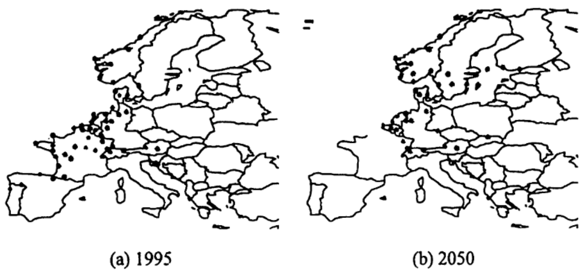
RISK SUMMARIES			
	RESPONSE	**CONFIDENCE**	**COMMENT**
Summarise Entry	**very likely**	**high**	*Arthurdendyus triangulatus* is present within the EU in the UK and Ireland. There is genetic evidence of more than one introduction (Dynes *et al.*, 2001) and there are at least 20 other non-indigenous terrestrial flatworms established in the UK and some more in Europe, which implies that there are viable pathways for entry of terrestrial flatworms.
Summarise Establishment	**very likely**	**high**	*Arthurdendyus triangulatus* seems ideally suited to the mild maritime climates of Northern Ireland, Scotland and the Faroe Islands. However, even within the relatively small geographical range of the UK and Ireland, the distribution in the south is less widespread than in northern parts of the British Isles. Various studies have examined the climatic preferences of *A. triangulatus* and made predictions of its potential establishment, mainly based on climate matching approaches. These were criticised as not taking sufficient cognisance of the specific eco-climatic requirements of *A. triangulatus*. It may well be that *A. triangulatus* has a narrower range of eco-climatic requirements than previously thought. Yet, even with this, there are likely to be coastal regions of continental Europe in the Atlantic and Continental biogeographical regions at risk of *A. triangulatus* establishment.
Summarise Spread	**Moderately likely**	**medium**	*Arthurdendyus triangulatus* is mainly spread by man's activities, such as the movement of ornamental plants, topsoil or agricultural produce. Within the British Isles, it has established on many offshore islands that it could not have spread to by any natural means. This means that the spread of the flatworm within a region is not on a continuous front but sporadic and unpredictable. Following anthropogenic spread, *A. triangulatus* moves into the adjoining habitat by natural dispersal at a much slower rate. Boag *et al.* (1994) suggested a period of 15 years from establishment (normally in gardens) to infestation of agricultural land.
Summarise Impact	**major**	**medium**	*Arthurdendyus triangulatus* is a predator of earthworms. It has a differential impact on earthworm species with anecic species

			such as *Lumbricus terrestris* most severely affected. In a replicated field experiment, earthworm biomass was reduced by 20% but that of *L. terrestris* by 75% (Murchie & Gordon, 2013). The threat posed therefore by *A. triangulatus* is that it may severely impact on anecic earthworm species but sustain populations by feeding on smaller earthworms, thus circumventing normal predator-prey dynamics. This could potentially lead to severe local reductions of of anecic species which may never fully recover in the presence of *A triangulatus*. Decline in earthworm species will affect grassland productivity, with a predicted reduction in grass yield of 6.8% and major economic costs. Earthworms are also an important food source for many indigenous birds and mammals (Alford *et al.*, 1995; Alford, 1998). A significant decline in earthworms would have severe knock-on effects for species that rely on earthworms for food, even if only at certain times in their lifecycle (e.g. chicks) or at times when other sources of food are scarce.
Conclusion of the risk assessment	**high**	**medium**	*Arthurdendyus triangulatus* is an invasive species that reduces earthworm populations and by association biodiversity where it has established. This has knock-on effects on grassland productivity and indigenous wildlife. First officially recorded outside of its native New Zealand in Belfast in 1963, the flatworm is now widespread in Ireland and Scotland. Despite being present in the UK and Ireland for at least 54 years, it has not established in continental Europe so far. Either *A. triangulatus* has not been introduced to continental Europe or the conditions are not conducive for establishment. Yet in both cases, there is evidence of significant risk, in terms of 1) sufficient pathways for introduction and 2) suitable conditions and earthworm prey for establishment. The most likely explanation would seem that *A. triangulatus* has not yet been introduced to areas that would support its establishment.

EU CHAPEAU		
QUESTION	**RESPONSE**	**COMMENT**
Ch1. In which EU biogeographical region(s) or marine subregion(s) has the species been recorded and where is it established?	*Arthurdendyus triangulatus* has been recorded and is established in the Atlantic biogeographical region.	
Ch2. In which EU biogeographical region(s) or marine subregion(s) could the species establish in the future under current climate and under foreseeable climate change?	According to a CLIMEX model, the potential distribution of *A. triangulatus* under current climate includes the Atlantic and Continental biogeographical regions, as well as marginally reaching the Alpine and Boreal biogeographical regions (Boag & Yeates, 2001). Note, use of climate matching was critiqued by Cannon et al. (1999) who considered it of insufficient precision to predict *A. triangulatus* microhabitat preferences and potential geographical distributions. Predictions suggest that its distribution will move further north into the southern areas of the Boreal biogeographical region, in particular southern Norway and Sweden (Evans & Boag, 1996).	

	 Taken from Boag & Yeates (2001): The outer line encompasses the area where it is considered *A. triangulatus* could become established under current climate. The larger the inner circle size, the closer the climate is to that in Edinburgh.	
Ch3. In which EU member states has the species been recorded? List them with an indication of the timeline of observations.	United Kingdom – first recorded outside of New Zealand in Belfast in 1963 (Anon, 1963). Records from Scotland (1965) and England (1965) (Willis & Edwards, 1977). Anecdotal evidence of earlier presence in Scotland, possibly dating back to the 1950s (Jones & Boag, 2001). Established. Republic of Ireland – first record in Donegal in 1984 (Anderson, 1986). Established.	

	[Denmark – Faroe Islands only. Note the Faroe Islands are not part of the EU. First record from the downpipes of the parliament building in Tórshavn (Bloch, 1992). Established.] Iceland - there is one report of a flatworm in a glasshouse in Iceland (Bloch, 1992), but there are no records of establishment .	
Ch4. In which EU member states has this species established populations? List them with an indication of the timeline of establishment and spread.	United Kingdom – widespread in Northern Ireland (Moore *et al.*, 1998), the central belt of Scotland, (roughly in a horizontal band between Glasgow and Edinburgh) and northern England (Boag *et al.*, 1994). Less common in southern England and Wales (Boag & Neilson, 2014). Republic of Ireland – predominantly found in the North but recorded across the island down to south Cork. Fewer records in central Ireland (National Biodiversity Datacentre maps (http://maps.biodiversityireland.ie/#/Map/NbdcTerrestrial/Species/187040) [Denmark – Faroe Islands only. Note the Faroe Islands are not part of the EU. Widespread, having spread to all the major islands (except Sandoy) (Christensen & Mather, 1998).]	
Ch5. In which EU member states could the species establish in the future under current climate and under foreseeable climate change?	Current climate Modelling studies have predicted that *A. triangulatus* could establish in large tracts of north-western Europe, including: Sweden, Poland, Germany, Denmark, Belgium, The Netherlands, Luxembourg, and France and marginally reaching Austria, Czech Republic, Latvia, and Lithuania (reviewed in Boag & Yeates, 2001). The fact that it has not been reported in any of these countries so far despite being present in the British Isles since at least the early 1960s suggests that it may have comparatively	

	narrow eco-climatic limitations (Murchie, 2010) or that its preferred pathways and association with commodities (see Qu. 1.1) are very specific and provide less opportunities of introduction and entry. Though not in the EU, according to models, the species could establish in southwestern parts of Norway and in Switzerland under current conditions (Boag & Yeates, 2001). Climate change Predictions based on 1991 Department of the Environment (UK) climate change scenarios suggest that *A. triangulatus* distribution will move further north, becoming progressively less common in the British Isles but increasingly threatening Scandinavian countries, particularly southern Norway and Sweden (Evans & Boag, 1996).  Taken from Evans & Boag (1996): European locations (excluding the UK) that have climates that match with Dunoon (Scotland) at a level of 50 or above under the current climate (a) and that projected for 2050 under the climate change scenario (b).	

Ch6. In which EU member states has this species shown signs of invasiveness?	United Kingdom Republic of Ireland [Denmark (Faroe Islands only - note the Faroe Islands are not part of the EU)] For reviews see Blackshaw & Stewart (1992), Canon et al. (1999) and Boag & Yeates (2001). Despite its arrival in the 1960s the species was only found occasionally until the 1990s when it was recorded frequently	
Ch7. In which EU member states could this species become invasive in the future under current climate and under foreseeable climate change?	The species could become invasive under current climate and under foreseeable climate change wherever it is able to establish (Evans & Boag, 1996 (see Qu. Ch5), particularly Denmark, western Norway and southern Sweden are likely to be at increased threat following climate change	

Distribution Summary (for explanations see EU chapeau):

Member States

	Recorded	Established (currently)	Established (future)	Invasive (currently)
Austria	–	–	?	–
Belgium	–	–	Yes	–
Bulgaria	–	–	–	–
Croatia	–	–	–	–
Cyprus	–	–	–	–
Czech Republic	–	–	?	–
Denmark	Faroe Isl.	Faroe Isl.	Yes	Faroe Isl.
Estonia	–	–	–	–
Finland	–	–	–	–

France	–	–	Yes	–
Germany	–	–	Yes	–
Greece	–	–	–	–
Hungary	–	–	–	–
Ireland	Yes	Yes	Yes	Yes
Italy	–	–	–	–
Latvia	–	–	?	–
Lithuania	–	–	?	–
Luxembourg	–	–	Yes	–
Malta	–	–	–	–
Netherlands	–	–	Yes	–
Poland	–	–	Yes	–
Portugal	–	–	–	–
Romania	–	–	–	–
Slovakia	–	–	–	–
Slovenia	–	–	–	–
Spain	–	–	–	–
Sweden	–	–	Yes	–
United Kingdom	Yes	Yes	Yes	Yes

EU biogeographical regions

	Recorded	Established (currently)	Established (future)
Alpine	–	–	?
Atlantic	Yes	Yes	Yes
Black Sea	–	–	–
Boreal	–	–	Yes
Continental	–	–	?
Mediterranean	–	–	–
Pannonian	–	–	–
Steppic	–	–	–

SECTION A – Organism Information and Screening		
Organism Information	**RESPONSE**	**COMMENT**
A1. Identify the organism. Is it clearly a single taxonomic entity and can it be adequately distinguished from other entities of the same rank?	The organism is a single taxonomic entity. There are no known varieties, breeds or hybrids. *Arthurdendyus triangulatus* (Dendy, 1894) (Jones & Gerard, 1999) Synonyms: *Artioposthia triangulata* (Dendy, 1894) *Geoplana triangulata* Dendy, 1894 Class: Turbellaria Order: Tricladida Suborder: Continenticola Superfamily: Geoplanoidea Family: Geoplanidae Subfamily: Rhynchodeminae	
A2. Provide information on the existence of other species that look very similar	*Arthurdendyus triangulatus* is a fairly distinctive species but could be confused with other flatworms. It is usually larger that the native *Microplana* flatworms in Europe (bearing in mind that flatworm body size is variable) (Mateos *et al.*, 2017). The 'Australian flatworm', *Australoplana sanguinea* is found in the same habitats in the British Isles and has a similar body shape but is orange and usually smaller. There are other non-indigenous species in the British Isles (Boag & Yeates, 2001; Boag *et al.*, 2010; Jones & Sluys, 2016; Sluys, 2016; Fenwick, 2017): <u>Native</u> • *Microplana humicola*	

	• *Microplana groga* • *Microplana kwiskea* • *Microplana scharffi* • *Microplana terrestris* • *Rhynchodemus sylvaticus* (possibly introduced) Non-indigenous • *Arthurdenyus albidus* • *Arthurdendyus australis* • *Arthurdendyus triangulatus* • *Artioposthia exulans* • *Australopacijca coxii* • *Australoplana sanguinea* • *Bipalium kewense* • *Caenoplana coerulea* • *Dolichoplana striata* • *Kontikia andersoni* • *Kontikia ventrolineata* • *Marionfyfea adventor* • *Rhynchodemus hallezi* • *Obama nungara* is a polyphagous predator of invertebrates, including earthworms and snails. Native to Brazil, this species has since been found in Guernsey, the Channel Islands, Italy, France and the UK (Kent and Oxfordshire). *Platydemus manokwari* (New Guinea Flatworm) is an invasive predator of snails and has been recorded in France (Justine *et al.*, 2014). Knowledge of the Europe-wide terrestrial flatworm fauna is fragmentary (Sluys *et al.*, 2016) but the species count is probably around 20 (Jones pers comm.). As with	

	the British Isles, interest in terrestrial flatworms has been stimulated by the discovery of non-native and invasive species. For example, in the Iberian peninsula, at least ten non-native species, compared to 15 native, have been recorded (Álvarez-Presas *et al.*, 2017). Some of these non-natives are large enough to be mistaken for *A. triangulatus* but their colourations are different. Terrestrial leeches also have a cursory similarity to *A. triangulatus* but are segmented.	
A3. Does a relevant earlier risk assessment exist? (give details of any previous risk assessment and its validity in relation to the EU)	Alford *et al.* (1995) assessed the potential impact of *A. triangulatus* on agriculture and the environment in England and Wales. A specific pest risk analysis on *A. triangulatus* was produced in 1995 and updated 1997 (Mather & Christensen, 1997). This PRA's summary is as follows: "This terrestrial planarian and earthworm predator native to New Zealand, has been accidentally introduced to north-western Europe. The long-distance displacement from its native land probably occurred due to trade in antipodean plant material. Since the first European observations in Northern Ireland and Scotland during the early. 1960's, the flatworm has become common and widespread in these countries, and has also become established in the Republic of Ireland and the Faroe Islands. Horticultural trade is the main route of passive dispersal and dissemination to domestic gardens. The flatworm can then actively migrate from such sites into surrounding fields and forests, where satellite colonies may establish. The potential for active migration is apparent from crawling speeds, adults moving at relatively fast rates of up to 17 metres per hour. The ecological significance of this particular species is due to resulting negative effects on European lumbricid earthworms, *A. triangulata* having depleted populations	

	of these beneficial soil organisms as well as causing a reduction in earthworm species number at certain sites. Depletion of lumbricid populations can lead to negative impacts on wildlife, soil structure and fertility, plant production and horticultural/ agricultural trade. Records indicate that the species' geographical range in Europe is expanding. Modelling predicts that other regions in Europe and the rest of the world are potentially at risk with regard to flatworm establishment. Currently, there are no feasible control options." Anon. (2000) provided an assessment of biological unknowns (including experiments to address these) for a comprehensive pest risk assessment for the UK. All information given in these assessments and factsheets is still valid in relation to the EU.	
A4. Where is the organism native?	*Arthurdendyus triangulatus* is native and widespread in the South Island of New Zealand (Blackshaw & Stewart, 1992; Johns *et al.*, 1998). Although found throughout the South Island it probably originated in the Canterbury region (Jones & Boag, 2003). It was then spread by man to other parts of the South Island. The climate of the South Island is largely temperate (compared to the north Island which is sub-tropical) with a mean annual temperature of 10°C and 600 - 1600 mm of rainfall, although the central Southern Alps mountain range bisects the island creating different climatic zones in the east and west. The native habitat of *A. triangulatus* is probably *Nothofagus* forests (Christensen & Mather 1998a), although, even within its native range, it is closely associated with disturbance (Dynes *et al.*, 2001; Johns & Boag, 2003); hence the impact of climate change is difficult to separate from other human activities (e.g. habitat alteration).	

A5. What is the global non-native distribution of the organism (excluding the Union, but including neighbouring European (non-Union) countries)?	The global non-native range of *Arthurdendyus triangulatus* encompasses the UK, Ireland and the Faroe Islands. There is one report of a flatworm in a glasshouse in Iceland (Bloch, 1992) but there are no records of establishment.	
A6. Is the organism known to be invasive (i.e. to threaten organisms, habitats or ecosystems) anywhere in the world?	*Arthurdendyus triangulatus* is invasive in the UK, Ireland and the Faroe Islands. .	
A7. Describe any known socio-economic benefits of the organism in the risk assessment area.	At present, there are no known socio-economic benefits of *A. triangulatus* within Europe. However, it has been postulated that *A. triangulatus* could be used for earthworm control in bowling green lawns, golf courses or even to control invasive earthworms but such actions are not recommended due to the generally beneficial effects of earthworms on the wider environment and crop yield. The main earthworm species affected by *A. triangulatus* is *Lumbricus terrestris*, which, although an important beneficial species in its native range, is ironically considered an invasive species itself in some regions (notably North America) (CABI, 2016). The flatworm has a range of anti-microbial peptides (McGee *et al.*, 1998), which could feasibly be utilised for novel antibiotics, although this has not been investigated.	

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."
- For detailed explanations of the CBD pathway classification scheme consult the IUCN/CEH guidance document.
- With regard to the scoring of the likelihood of events or the magnitude of impacts see Annex.
- With regard to the confidence levels, see Annex.

PROBABILITY OF INTRODUCTION and ENTRY

Important instructions:

- Introduction is the movement of the species into the EU.
- Entry is the release/escape/arrival in the environment, i.e. occurrence in the wild. Not to be confused with spread, the movement of an organism within Europe.
- For organisms which are already present in Europe, 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 introduction and entry.

QUESTION	RESPONSE [chose one entry, delete all others]	CONFIDENCE [chose one entry, delete all others]	COMMENT
1.1. How many active pathways are relevant to the potential entry of this organism? (If there are no active pathways or potential future pathways respond N/A and move to the Establishment section)	**few**	**medium**	The main pathway is importation of ornamental plants, especially containerised plants, e.g. *Dicksonia* tree ferns. It has also been found in a rhododendron nursery which exports plants to the UK
1.2. List relevant pathways through which the organism could enter. Where possible give detail about the specific	TRANSPORT – CONTAMINANT: 1) Contaminant nursery material		*Arthurdendyus triangulatus* is thought to have been introduced to the British Isles inadvertently with ornamental plants (Willis & Edwards, 1977; Blackshaw & Stewart, 1992). There a number of early records associated with botanic gardens,

origins and end points of the pathways as well as a description of the associated commodities. For each pathway answer questions 1.3 to 1.10 (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. 1.3a, 1.4a, etc. and then 1.3b, 1.4b etc. for the next pathway.	(trade in ornamental plants, particularly potted plants)		garden centres and nurseries (Boag & Yeates, 2001). It is thought that the Faroe Islands became colonised by *A. triangulatus* from Scotland, although direct transmission from New Zealand via arboretum plants cannot be discounted (Mather & Christensen, 1992). The organism can be carried along as egg or adult in parts of the plants (e.g. bulbs, rhizomes, leaves), but also in growing medium accompanying plants or in rootballs. The flatworm has a sticky body and readily adheres to farm machinery, plastic wrapped silage bales and even livestock but these are only hypothetical pathways of introduction (Moore et al., 1998; Boag et al., 1999).
Pathway name:	Contaminant nursery material		
1.3. Is entry along this pathway intentional (e.g. the organism is imported for trade) or accidental (the organism is a contaminant of imported goods)? (If intentional, only answer questions 1.4, 1.9, 1.10, 1.11)	**unintentional**	**very high**	Contaminant in imported plants and associated rootballs.
1.4. How likely is it that large numbers of the organism will travel along this pathway from the point(s) of origin over the course of one year? Subnote: In your comment discuss how likely the organism is to get onto the pathway in the first place. Subnote: In your comment discuss the volume of movement along this pathway.	**unlikely**	**high**	Interceptions of *A. triangulatus* in imported materials are relatively rare. However, as an example, 22 live flatworms (though not *A. triangulatus*) were found at UK borders within a *Dicksonia antarctica* (tree fern) from Australia (Parker *et al.*, 2005). Large numbers of *D. antarctica* tree ferns are imported from Australia and New Zealand to Europe potentially containing a whole range of non-indigenous invertebrates (Cannon & Baker, 2007). Following the 2004-5 interceptions, DEFRA (UK) requested that Australian and New Zealand exporters adhered to European Commission Directive 92/103/EEC requirements, including production in registered nurseries and ensuring that plants were free from pests and diseases (Ashby, 2005) (www.agriculture.gov.au/export/controlled-goods/plants-plant-products/ian/05/01). *Artioposthia exulans*, first found in the UK in 2016, also appears to be associated with imported nursery stock from

			New Zealand, particularly New Zealand flax (*Phormium* spp.) and *Astelia* spp. (Fenwick, 2017). *Arthurdendyus albidus* was first described in 1999 from Scotland and was a similar size to *A. triangulatus* and fed on earthworms. Another site was found within a year but both sites have been flatworm free after 17 years and it could be concluded that its establishment and spread has been stopped. Flatworms are known to be associated with the horticultural trade, with plant pots and plastic sheeting providing ideal refugia and hence a means of transport. The likelihood of reinvasion after eradication will be identical to the likelihood of first introduction in the nursery plant trade.
1.5. How likely is the organism to survive during passage along the pathway (excluding management practices that would kill the organism)? Subnote: In your comment consider whether the organism could multiply along the pathway.	**moderately likely**	**high**	*Arthurdendyus triangulatus* is transported as free-living flatworms and egg capsules, both of which are likely to be embedded in moist soil or plant materials. Survival is dependent on the flatworms being kept moist and cool. Comparatively low temperatures (e.g. 30°C for 20 minutes) will kill adult *A. triangulatus* (Murchie & Moore, 1998). It is considered that the temperature tolerances of egg capsules will be similar (AK Murchie unpublished) but this has not been fully tested. Flatworms are unlikely to reproduce in transit due to lack of earthworm prey, although previously fertilised adults may deposit egg capsules.
1.6. How likely is the organism to survive existing management practices during passage along the pathway?	**moderately likely**	**very high**	*Arthurdendyus triangulatus* is susceptible to raised temperatures and if this method is used as a phytosanitary procedure then it is unlikely that flatworms would survive the treatment, providing the whole of the substrate is sufficiently heated. For example, flower bulbs, a potential pathway (Willis & Edwards, 1977), may be treated by temperatures above 40°C to prevent transfer of stem and bulb nematode pests, e.g. *Ditylenchus dipsaci* on narcissi and tulips (Decker, 1989). However, it may be difficult to target *A. triangulatus*, in the soil bulk, compared to nematodes within defined bulbs.

			Fumigation of imported plant material is problematic because of the withdrawal of methyl bromide. In addition, the impact of fumigants on *A. triangulatus* has not been investigated. Greater restrictions on movement of soil in root balls will aid in preventing transmission of this pest species. Nonetheless the flatworm continues to spread along these pathways unhindered.
1.7. How likely is the organism to enter Europe undetected?	**Very likely**	**high**	*Arthurdendyus triangulatus* is a cryptic soil dwelling species. It can shelter within root balls in containerised plants or possibly within plant material itself, e.g. *Dicksonia* tree ferns (Jones & Boag, 2001; Parker *et al.*, 2005). Furthermore, the flatworm can shrink in size by reabsorbing tissues if starved (Blackshaw, 1992; Boag & Yeates, 2001; Baird *et al.*, 2005b), meaning both adult and egg capsules sizes are highly variable (Baird *et al.*, 2005a). New records of terrestrial planarians are continuing to be found c.f. Carbayo et al. 2016
1.8. How likely is the organism to arrive during the months of the year most appropriate for establishment?	**very likely**	**medium**	Importation of ornamental plants occurs year-round but is most likely to coincide with the start of the growing season in the host country (e.g. spring in Europe). *Arthurdendyus triangulatus* show a seasonal cycle, related to soil conditions. They are most abundant at the soil surface in the British Isles in spring and late-autumn/winter, with greatest numbers of egg capsules produced mid-March to mid-July (Blackshaw, 1997). Flatworm numbers found at the soil surface decrease during mid-summer as soil temperatures increase and moisture levels fall.
1.9. How likely is the organism to be able to transfer from the pathway to a suitable habitat or host?	**very likely**	**high**	Flatworms can transfer with ease from containerised ornamental plants to the soil, whereupon they prey on native earthworm species. Normally, this occurs in a garden or nursery but thereafter natural dispersal of the flatworms allows them to colonise the surrounding habitats.
1.10. Estimate the overall likelihood of entry into Europe based on this pathway?	**moderately likely**	**high**	Analysis of *A. triangulatus* population genetic structure in the UK and New Zealand suggested several introductions (Dynes *et al.*, 2001). This contention was supported by the number of other non-indigenous flatworms that have entered and established in British Isles, presumably via the ornamental

			plant trade given their association with botanic gardens and hothouses. Of the probable 21 species of terrestrial flatworms recorded in the British Isles (Boag pers comm) only four, possibly five, are native, with the rest aliens (Jones, 2005; Boag *et al.*, 2010). Similarly in the Iberian peninsula, ten non-native species and 15 native have been recorded (Álvarez-Presas et al., 2017). In France, much press attention has focussed on *P. manokwari* and *O. nungara* (Sluys, 2016). It is likely that the wider European situation is similar to that of the British Isles but that flatworms have been under-recorded (Sluys, 2016).
End of pathway assessment, repeat as necessary.			
1.11. Estimate the overall likelihood of entry into Europe based on all pathways in relevant biogeographical regions in current conditions (comment on the key issues that lead to this conclusion).	**moderately likely**	**high**	*Arthurdendyus triangulatus* has established in the Atlantic biogeographic region on the British Isles and Faroe Islands. It has not established in the Continental region on continental Europe despite being present in the British Isles for over 50 years. There are two possible reasons for this: 1) there have been few introductions to continental Europe; or 2) *A. triangulatus* may have relatively narrow eco-climatic requirements, with the mild maritime climate of Northern Ireland, Scotland and the Faroe Islands proving ideal (Murchie, 2010). On one hand the main plant trade hub in Europe is the Netherlands but on the other, the UK has historic trade links with the Commonwealth (Blackshaw & Stewart, 1992) and is the main importer of live plants from New Zealand (Unger, 1998; Dynes *et al.*, 2001; Matthews, 2005; Fountain-Jones *et al.*, 2012).
1.12. Estimate the overall likelihood of entry into Europe based on all pathways in relevant biogeographical regions in foreseeable climate change conditions?	**moderately likely**	**high**	As by far the most likely pathway is trade in ornamental plants, the likelihood of entry into the EU (beyond the British Isles) is not in itself affected by climate change. It is possible that changing climate within the EU may lead to greater or lesser imports of certain ornamental plants as garden conditions alter.

PROBABILITY OF ESTABLISHMENT			
Important instructions: • For organisms which are already established in parts of the Union, answer the questions with regard to those areas, where the species is not yet established. If the species is established in all Member States, continue with Question 1.16.			
QUESTION	**RESPONSE**	**CONFIDENCE**	**COMMENT**
1.13. How likely is it that the organism will be able to establish in the EU based on the similarity between climatic conditions in Europe and the organism's current distribution?	**very likely**	**very high**	*Arthurdendyus triangulatus* has established in the UK and Ireland and in addition on the Faroe Islands. Despite the potential limitations of previous studies, the climates of areas where *A. triangulatus* has established are likely to be similar to at least some areas of continental Europe, even if these are not as widespread as previous models predicted. Soil temperature and moisture are most likely to restrict the establishment of *A. triangulatus*, with soil temperatures greater than 20°C limiting *A. triangulatus* survival (Blackshaw & Stewart, 1992) and consistent low temperatures of -2°C causing 100% mortality after 3 days (Anon., 2000) .The requirement of refugia at the soil surface is not fully known but anyway likely the same between gardens, horticultural sites and agricultural land in the British Isles and continental Europe.
1.14. How likely is it that the organism will be able to establish in the EU based on the similarity between other abiotic conditions in Europe and the organism's current distribution?	**likely**	**high**	Other abiotic soil conditions, such as soil type or pH, are most likely to affect *A. triangulatus* indirectly by governing the presence of earthworm prey. The flatworm has been found in a range of soil types, although it has been suggested that the flatworm favours heavier clay

			soils rather than sandy soils (Willis & Edwards, 1977; Boag *et al.*, 1998b).
1.15. How likely is it that the organism will become established in protected conditions (in which the environment is artificially maintained, such as wildlife parks, glasshouses, aquaculture facilities, terraria, zoological gardens) in Europe? Subnote: gardens are not considered protected conditions	**likely**	**medium**	*Arthurdendyus triangulatus* has been associated with horticultural sites in New Zealand that are irrigated (Jones & Boag, 2001), and this could have implications for establishment in irrigated sites in Europe (Boag *et al.*, 1995b; Evans & Boag, 1996). In Scotland the flatworm is found mainly in domestic gardens, nurseries and garden centres. There is one report of a flatworm in a glasshouse in Iceland (Bloch, 1992).
1.16. How widespread are habitats or species necessary for the survival, development and multiplication of the organism in Europe?	**widespread**	**high**	Preferred habitats are gardens, margins of agricultural land, and pastures (CABI 2014), all of which very widespread in the EU. In Scotland they have been found to a lesser extent but also in woodland and more natural habitats and these are very widespread indeed. Another limiting factor is the availability of earthworm prey. Earthworm densities in the UK, Ireland and the Faroe Islands can be high and comparable densities are found in other north-western European states, particularly those with coastal boundaries, e.g. northern France, the Netherlands, Belgium, Denmark, northern Germany (Rutgers *et al.*, 2016). Though variable, numbers range for example, from 40-160 m^{-2} in arable soils in Denmark (Boström, 1988)
1.17. 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 Europe?	**very likely**	**very high**	*Arthurdendyus triangulatus* is an obligate predator of earthworms. Earthworms are ubiquitous in many wild and agricultural ecosystems in temperate EU countries, occurring in gardens lawns and pasture at densities of c. 200-400 per m^2 (Edwards & Bohlen, 1996).
1.18. How likely is it that establishment will occur despite competition from existing species in Europe?	**very likely**	**very high**	There are no known specialist competitors to *A. triangulatus* in EU member states. Given the comparatively high densities of earthworms combined with the lack of terrestrial flatworm fauna in Europe, it may be that *A. triangulatus* is utilising an

			underdeveloped predatory niche (Boag & Yeates, 2001; Boag *et al.*, 2010). Interactions between *A. triangulatus* and other earthworm predators / parasites such as ground beetles (Carabidae) and cluster flies (*Pollenia* spp.) or earthworm diseases have not been investigated but are unlikely to prevent establishment.
1.19. How likely is it that establishment will occur despite predators, parasites or pathogens already present in Europe?	**very likely**	**very high**	Predatory ground beetles (Carabidae and Staphylinidae) prey on *A. triangulatus* (Blackshaw, 1996; Gibson *et al.*, 1997) but it is unlikely their impact will be sufficient to prevent establishment. Similarly, some birds and other generalist worm predators such as shrews will eat flatworms (Cannon *et al.*, 1999). However, it would seem that flatworms are not choice prey and are distasteful to most predators (Cannon *et al.*, 1999). Ducks, geese and a stoat have been seen to eat NZ flatworm and hens have been reported to consume them (B. Boag pers comm) Whether there are diseases infecting *A. triangulatus* and if such diseases are important remains to be documented.
1.20. How likely is the organism to establish despite existing management practices in Europe?	**likely**	**medium**	Management practices in Europe are designed to prevent the establishment and spread of *A. triangulatus*. These are mainly governed through the Plant Health Directive (2000/29/EC). Although much debated, *A. triangulatus* is not listed in schedules 1 or 2 of the Plant Health Orders, nor is it on the corresponding EPPO A1 and A2 lists of species recommended for regulation as quarantine pests (Murchie, 2010). Instead, specific EPPO guidelines on *A. triangulatus* were produced. These guidelines are: • Import requirements concerning *Arthurdendyus triangulatus* (EPPO, 2001a) • Nursery inspection, exclusion and treatment for *Arthurdendyus triangulatus* (EPPO, 2001b). However, these are unlikely to be 100% effective

1.21. How likely are existing management practices in Europe to facilitate establishment?	**very unlikely**	**medium**	The management practises as stipulated in the EPPO guidelines (EPPO, 2001a/b) are specifically designed to limit the establishment and spread of *A. triangulatus* but are unlikely to be 100% effective.
1.22. How likely is it that biological properties of the organism would allow it to survive eradication campaigns in Europe?	**very likely**	**medium**	*Arthurdendyus triangulatus* is a cryptic soil dwelling species. Once established in the wild there are no control measures capable of eradication.
1.23. How likely are the biological characteristics of the organism to facilitate its establishment?	**likely**	**high**	*Arthurdendyus triangulatus* is hermaphrodite and, although mating has not been observed, the reproductive organs indicate sexual reproduction by copulation (Baird *et al.*, 2005b). Reproduction by fission does not appear to take place in *A. triangulatus* and they are susceptible to mechanical damage. *Arthurdendyus triangulatus* produces shiny black ovoid egg capsules extruded through the dorsal surface or the ventral gonopore (Blackshaw & Stewart, 1992). In the British Isles, egg capsules are most commonly found at the soil surface March to July, with a smaller peak in August to September. Each egg capsule contains 1-14 juveniles, with an average of six (Blackshaw & Stewart, 1992; Christensen & Mather, 1997). Under laboratory conditions, flatworms were capable of producing one egg capsule every two weeks for a period of 16 weeks (Baird *et al.*, 2005a). Combining the number of egg capsules produced and an estimate of the number of young therein, gave the figure of c. 40 juvenile flatworms per reproductive adult per year (Blackshaw, 1997; Baird *et al.*, 2005a) In the absence of food, *A. triangulatus* can shrink or degrow, surviving by utilising body tissues for respiration. This allows the flatworm to survive up to a year without food (Blackshaw, 1992; Christensen & Mather, 2001; Baird *et al.*, 2005b). An ability that could

			be an important attribute to its survival and spread (Boag *et al.*, 2010).
1.24. How likely is the capacity to spread of the organism to facilitate its establishment?	**likely**	**high**	*Arthurdendyus triangulatus* is mostly spread by anthropogenic activities. Within the British Isles this is exemplified by the spread of *A. triangulatus* to many off-shore islands, including the inner and outer Scottish Hebrides, the Shetlands, the Orkneys and the Isle of Man (Jones & Boag, 1996). Notwithstanding the introduction of *A. triangulatus* to the Faroe Islands. In addition to movement of infested plant material, the flatworm has a sticky body and readily adheres to farm machinery, plastic wrapped silage bales and even livestock (Moore *et al.*, 1998; Boag *et al.*, 1999).
1.25. How likely is the adaptability of the organism to facilitate its establishment?	**likely**	**medium**	Boag *et al.* (2010) listed attributes that made *A. triangulatus* a successful invasive species, including: • Ability to survive for prolonged periods without food • Egg capsules with multiple young and hermaphroditic reproduction Added to this would be largely indiscriminate earthworm feeding. The association of *A. triangulatus* with man-altered habitats and propensity for sheltering under plastic and other debris on the soil surface is likely to aid in its establishment.
1.26. How likely is it that the organism could establish despite low genetic diversity in the founder population?	**likely**	**low**	*Arthurdendyus triangulatus* produces egg capsules with 1-14 young inside. Hermaphroditic reproduction means that a single egg capsule could form a founder population. Although not observed, reproduction by copulation, rather than self-fertilisation, seems most likely, although the latter cannot be discounted (Baird *et al.*, 2005a). The potential impact of limited genetic diversity on the fitness of the population is not known.

			However, in a study of fission and self-fertilisation in freshwater flatworms, marked inbreeding depression occurred (Benazzi & Forli, 2009). On the other hand in an exclusively self-fertilising flatworm, no effect was found on fitness (Benazzi, 1991).
1.27. Based on the history of invasion by this organism elsewhere in the world, how likely is it to establish in Europe? (If possible, specify the instances in the comments box.)	**moderately likely**	**medium**	*Arthurdendyus triangulatus* has already established in the UK and Ireland and in addition on the Faroe Islands. However, establishment in continental Europe is less certain and considered only moderately likely. The main reason for this assessment is that *A. triangulatus* has been present in GB and Ireland since the 1960s, e.g. for over 50 years, and has not yet established in continental Europe, when in the past there were fewer restrictions on potential pathways. The counter argument is that there is now greater global trade, increasing the risk of spread, but even so, it is still surprising that *A. triangulatus* distribution has not extended beyond the British Isles and Faroe Islands.
1.28. If the organism does not establish, then how likely is it that casual populations will continue to occur? Subnote: Red-eared Terrapin, a species which cannot re-produce in GB but is present because of continual release, is an example of a transient species.	**unlikely**	**very high**	Casual populations are unlikely as if soil conditions are not suitable the flatworms will die. On the other hand, if eco-climatic conditions are favourable to allow *A. triangulatus* to survive, there are unlikely to be barriers to reproduction and spread.
1.29. Estimate the overall likelihood of establishment in relevant biogeographical regions in current conditions (mention any key issues in the comment box).	**very likely**	**medium**	*Arthurdendyus triangulatus* has established and spread in the Atlantic biogeographic region in the UK and Ireland and in addition on the Faroe Islands. It has been introduced and established on a diverse group of islands signifying relative ease of secondary man-made movements in a region. Yet, despite being present in the British Isles for over 50 years, it has not been found in continental Europe. Many climate matching studies would suggest that establishment would be probable and there are likely to

			be coastal regions that have virtually identical microclimatical characteristics to infested areas in the UK. At the present level of knowledge, the most plausible explanation is that there are regions of continental Europe that could support *A. triangulatus* establishment but that these are smaller than previously predicted and that *A. triangulatus* has simply not arrived there yet.
1.30. Estimate the overall likelihood of establishment in relevant biogeographical regions in foreseeable climate change conditions	**very likely**	**low**	Climate change predictions of increasing summer and winter temperatures and increased summer / winter rainfall give that *A. triangulatus* potential distribution will move northwards with greater threat to Scandinavian countries (Evans & Boag, 1996). However, as pointed out by Cannon *et al.* (1999), lack of data on species responses make such predictions difficult. It may be that milder, wetter winters could benefit *A. triangulatus*, whilst the flatworm could survive higher summer temperature by aestivation in cells in the soil (Willis & Edwards, 1977).

PROBABILITY OF SPREAD

Important notes:

- Spread is defined as the expansion of the geographical distribution of an alien species within the assessment area.
- Repeated releases at separate locations do not represent spread and should be considered in the probability of introduction and entry section.

QUESTION	RESPONSE	CONFIDENCE	COMMENT
2.1. How important is the expected spread of this organism in Europe by natural means? (Please list and comment on each of the mechanisms for natural spread.)	**moderate**	**high**	*Arthurdendyus triangulatus* is a soil-dwelling species that moves by contraction/extension of its creeping sole. Under laboratory conditions, it can move 17 m per hour on wet plastic sheeting (Mather & Christensen, 1995). By tracking the spread of established populations in transects of traps, Boag & Neilson (2014) gave a maximum rate of movement in the wild as 15 m in 7 days or 2.14 m per day. Gibson & Cosens (1998) found the flatworm to disperse 17 m in 30 days. Natural spread is therefore slow compared to anthropochorous dispersal. It is possible *A. triangulatus* could be moved by floodwater but this is not considered a major mechanism for dispersal. Invasion of agricultural land in Northern Ireland went from 4% in 1991 to 70% in 1998/1999, probably through a combination of local man-made transfer followed by natural dispersal by the flatworm (Murchie *et al.*, 2003).
2.2. How important is the expected spread of this organism in Europe by human assistance? (Please list and comment on each of the mechanisms for human-assisted spread) and provide a description of the associated commodities.	**major**	**very high**	*Arthurdendyus triangulatus* is principally spread by human activities. The main mechanisms are: • Trade in horticultural products, particularly potted plants • Domestic transfer of garden plants • Movement of topsoil or farmyard manure

			• Movement of farm goods such as plastic-wrapped silage bales Other transfer may occur via: • Sticking to livestock or pets • Sticking to farm machinery • Sticking to plastic sheeting or tarpaulins and tent groundsheets • Attachment to the fur of domestic pets • Rivers (they have been found in kick samples) The nature of horticultural trade, gardening and agricultural production varies with environmental conditions across the EU. For example, production of baled silage is predominantly in more temperate regions with livestock production. In regions that are mostly arable, mechanical disturbance of the soil will limit spread of *A. triangulatus* by agricultural goods. Invasion of agricultural land in Northern Ireland went from 4% in 1991 to 70% in 1998/1999, probably through a combination of local man-made transfer followed by natural dispersal by the flatworm (Murchie *et al.*, 2003).
2.2a. 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 2.3 to 2.9 (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. 2.3a, 2.4a, etc. and then 2.3b, 2.4b etc. for the next pathway.	TRANSPORT – CONTAMINANT: 1) Contaminant nursery material 2) Transportation of habitat material (soil, vegetation,…)		Based on the natural dispersal capacity (see Qu. 2.1) the pathway “Unaided (Natural dispersal across borders)” is regarded here as not of sufficient relevance to be considered.
Pathway name:	**Contaminant nursery material**		

2.3a. Is spread along this pathway intentional (e.g. the organism is released at distant localities) or unintentional (the organism is a contaminant of imported goods)?	**unintentional**	**very high**	
2.4a. How likely is it that large numbers of the organism will spread along this pathway from the point(s) of origin over the course of one year?	**likely**	**high**	The main source of *A. triangulatus* was considered to be infested garden centres and nurseries. However, after publicity and dissemination of management guidelines (MAFF, 1996; EPPO, 2001b), increased consumer awareness of this pest and corresponding reputational damage to outlets meant that spread from commercial producers seemed to decrease (Boag & Neilson, 2014). However, there is still evidence of significant transfer of *A. triangulatus* by movement of plants amongst amateur gardeners (A Murchie pers. comm.). Where *A. triangulatus* has colonised farmland, movement of goods and machinery from field-to-field will easily spread the flatworm (A Murchie pers. comm).
2.5a. How likely is the organism to survive during passage along the pathway (excluding management practices that would kill the organism)? Subnote: In your comment consider whether the organism could multiply along the pathway.	**likely**	**very high**	Although *A. triangulatus* is susceptible to mechanical damage, evidence from infested regions indicates that they survive transport in soil, providing it is sufficiently moist. The flatworm is unlikely to reproduce during transit due to lack of earthworm prey; however previously fertilised individuals may lay egg capsules.
2.6a. How likely is the organism to survive existing management practices during spread?	**likely**	**high**	If specific management practices are implemented fully and extensively, then *A. triangulatus* could be prevented from spreading along this pathway. This would largely involve heat treatments to kill *A. triangulatus* in rootballs or composts. The problem is that these treatments are unlikely to be applied within a country or region, as opposed to transnational boundaries.
2.7a. How likely is the organism to spread in Europe undetected?	**likely**	**high**	Although adults are readily identifiable with the naked eye, and often seen on the soil surface under plastic, stones or other shelters, *A. triangulatus* is a soil-dwelling cryptic species, with a significant proportion (c. 50%), and including

			egg capsules, of its population at depth in the soil (Murchie & Harrison, 2004).
2.8a. How likely is the organism to be able to transfer to a suitable habitat or host during spread?	**very likely**	**very high**	If transported in potted plants or topsoil, *A. triangulatus* will be introduced directly to a suitable habitat. In the areas affected, this has typically been a step-wise process from gardens to surrounding fields. In Northern Ireland, where this invasion process is most advanced, the majority of land is under agricultural production.
2.9a. Estimate the overall likelihood of spread into or within the Union based on this pathway?	**very likely**	**very high**	If *A. triangulatus* established in continental Europe then it will almost certainly spread through anthropochorous dispersal within the Union. The colonisation of many British islands would support this contention.
End of pathway assessment, repeat as necessary.			
Pathway name:	**Transportation of habitat material/ adherent surfaces (soil, vegetation, agricultural plastic)**		
2.3b. Is spread along this pathway intentional (e.g. the organism is released at distant localities) or unintentional (the organism is a contaminant of imported goods)?	**unintentional**	**very high**	
etc. …			
2.4b. How likely is it that large numbers of the organism will spread along this pathway from the point(s) of origin over the course of one year?	**likely**	**high**	Local spread by movement of topsoil and agricultural products, such as plastic-wrapped baled silage has been reported on several occasions (Moore *et al.*, 1998; Boag *et al.*, 1999). The flatworm is common on pasture in Northern Ireland and the central belt of Scotland. The farming systems in these regions are mostly livestock based, so movement of fodder such as baled silage is commonplace.
2.5b. How likely is the organism to survive during passage along the pathway (excluding management practices that would kill the organism)?	**likely**	**very high**	Provided the flatworm is moved along this pathway during damp weather conditions and avoids direct mechanical damage, survival rates are likely to high. It is very unlikely to reproduce while in transit but egg capsules could hatch and pregnant flatworms give birth

Subnote: In your comment consider whether the organism could multiply along the pathway.			
2.6b. How likely is the organism to survive existing management practices during spread?	**likely**	**high**	Small quantities of top soil or compost may be heat-treated by placing in glasshouse during the summer, which could kill the flatworm if temperature are sufficiently high. For baled silage, there are no management practices associated with this pathway.
2.7b. How likely is the organism to spread in Europe undetected?	**likely**	**high**	Farmers move products such as baled silage with machinery (e.g. tractors with bale spikes) and are viewing the product from tractor cabs. It is difficult to detect the dark-coloured flatworm from distance against typically black plastic, mud or soil.
2.8b. How likely is the organism to be able to transfer to a suitable habitat or host during spread?	**likely**	**very high**	The flatworms can be moved around agricultural fields in this manner and will likely colonise fields in which they are placed. Some agricultural land is in close proximity to natural habitats and the flatworm can spread into these by natural movement.
2.9b. Estimate the overall likelihood of spread into or within the Union based on this pathway?	**moderately likely**	**high**	The likelihood of spread by agricultural products is dependent on the farming system in the EU country. In cattle / dairy rearing areas with pasture, spread by flatworms adhering to the bottom of baled silage would be likely. Topsoil is commonly moved around countries for landscaping gardening purposes so, if from an infested locality, it will be a likely internal pathway.
End of pathway assessment, repeat as necessary.			
2.10. Within Europe, how difficult would it be to contain the organism?	**very difficult**	**high**	Other than heat treatment, there are no means to control *A. triangulatus* once it has established in the wild.
2.11. Based on the answers to questions on the potential for establishment and spread in Europe, define the area endangered by the organism.	*Arthurdendyus triangulatus* has already established and spread in the UK	**medium**	See Questions 3, 4 of the Chapeau (Ch3, Ch4).

	and Ireland and in addition on the Faroe Islands. Other areas at risk include the coastal regions of northern Germany, the Netherlands, Denmark and southern Sweden as well as the thin coastal strip in the south of Norway which although outside the EU could act as a route into Europe		
2.12. What proportion (%) of the area/habitat suitable for establishment (i.e. those parts of Europe were the species could establish), if any, has already been colonised by the organism?	**0-10%**	**low**	*Arthurdendyus triangulatus* is mainly found in gardens, parks or pasture. In Northern Ireland, an estimated 70% of pasture is colonised by *A. triangulatus* (Murchie *et al.*, 2003). Ireland is predominantly pasture-based agriculture. In Scotland and northern England, *A. triangulatus* is still mostly found in gardens (Boag & Neilson, 2014). A similar level of infestation seems likely in the Faroe Islands. None of mainland Europe has been infested and probably only a small % of the potential area Scotland and Northern England has flatworms
2.13. What proportion (%) of the area/habitat suitable for establishment, if any, do you expect to have been invaded by the organism five years from now (including any current presence)?	**0-10%**	**low**	*Arthurdendyus triangulatus* will continue to spread in Scotland, Ireland and northern England to colonise agricultural pasture. In Northern Ireland, it is now virtually ubiquitous in domestic gardens around the major areas of population and is widespread in pasture. The situation would appear similar in the Faroe Islands, with the exception of Sandoy, which had not been colonised - at least up until 1998 (Christensen & Mather, 1998).

2.14. What other timeframe (in years) would be appropriate to estimate any significant further spread of the organism in Europe? (Please comment on why this timeframe is chosen.)	**20 years**	**high**	Once established *A. triangulatus* can spread fairly rapidly through anthropochorous dispersal. Twenty years has been chosen as a significant time period as this pest is comparatively well publicised in the UK and Ireland and the major colonisation process has taken place. The next phase of dispersal is through active movement by the flatworm into surrounding pasture. This is a slower process but a 20 year time period will likely demonstrate significant spread into agricultural fields (Boag *et al.*, 1994). The number of plant health interceptions of flatworms in the UK is comparatively low compared to insect pests. Nevertheless in a European context more flatworms are establishing (Boag & Yeates, 2001; Justine *et al.*, 2014; Sluys, 2016). It seems that at least once in 20 years would be a reasonable time period for an *A. triangulatus* importation event to occur in continental Europe.
2.15. In this timeframe what proportion (%) of the endangered area/habitat (including any currently occupied areas/habitats) is likely to have been invaded by this organism?	**10-33**	**medium**	The proportion of the endangered area is likely to increase in the UK and Ireland and in addition on the Faroe Islands through local dispersal of *A. triangulatus*, particularly from gardens into surrounding farmland and wild habitats within the next 20 years. If *A. triangulatus* establishes in continental Europe then we will see a proportionally greater expansion of areas affected as the flatworm goes through the initial colonisation and expansion phases of invasion.
2.16. Estimate the overall potential for spread in relevant biogeographical regions under current conditions for this organism in Europe (using the comment box to indicate any key issues).	**moderately**	**very high**	*Arthurdendyus triangulatus* will continue to spread in the UK and Ireland and in addition on the Faroe Islands through natural movement from infested gardens to surrounding farmland and other areas. There is also likely to be a continuation of anthropochorous movement via farm goods (such as plastic wrapped silage), which is very hard to prevent. For ornamental plants bought from garden centres and nurseries, awareness of the flatworm has increased in this affected area and this pathway for spread should largely be under control. Movement by domestic gardeners or

			topsoil for landscaping is unregulated but publicity campaigns about the flatworm have increased awareness, although inadvertent transfer will still occur. Examples include https://www.opalexplorenature.org/nzflatworm, http://www.nonnativespecies.org/downloadDocument.cfm?id=1001 If *A. triangulatus* establishes in continental Europe, it is likely the pattern of spread will follow that of the UK and Ireland, although increased awareness of the flatworm (given the UK/Ireland experience) would hopefully aid in increasing awareness and promoting best practice management.
2.17. Estimate the overall potential for spread in relevant biogeographical regions in foreseeable climate change conditions	**moderately likely**	**medium**	The response of *Arthurdendyus triangulatus* to climate change is likely to be mixed. Milder wetter winters will benefit the flatworm, whilst hotter summer temperatures will have a negative effect on their populations. Boag *et al.* (1998b) contended that temperature was less important than relative humidity in determining *A. triangulatus* spread, albeit prolonged temperatures at freezing or above 20^o C were likely to be fatal. This meant that in the British Isles, where climate is moderated by the Gulf stream, temperature itself was unlikely to be restrictive. Despite this, the concentration of *A. triangulatus* densities in the central belt of Scotland and Northern Ireland and not in England or the Republic of Ireland might suggest relatively subtle eco-climatic requirements. Although climate change models have suggested a northward movement in *A. triangulatus* distribution in response to increased temperatures (Evans & Boag, 1996), the interplay between soil temperature, moisture and relative humidity may be less straightforward than previously considered.

MAGNITUDE OF IMPACT

Important instructions:

- Questions 2.18-2.22 relate to environmental impact, 2.23-2.25 to impacts on ecosystem services, 2.26-2.30 to economic impact, 2.31-2.32 to social and human health impact, and 2.33-2.36 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 above starts with the impact elsewhere in the world, then considers impacts in Europe separating known impacts to date (i.e. past and current impacts) from potential future impacts (including foreseeable climate change).
- Assessors are requested to use and cite original, primary references as far as possible.

QUESTION	RESPONSE	CONFIDENCE	COMMENTS
Biodiversity and ecosystem impacts			
2.18. How important is impact of the organism on biodiversity at all levels of organisation caused by the organism in its non-native range excluding the Union?	**major**	**high**	*Arthurdendyus triangulatus* has not established outside of its native range (South Island of New Zealand) other than in the European Union (UK, Ireland) and the Faroe Islands. In the Faroe Islands, *A. triangulatus* has achieved very high densities (40 flatworms per m^2) in the 'reimavelta' potato cultivation system, which resulted in local depletion of earthworm populations (Christensen & Mather, 1998). Experiments suggest that the impact is greatest on *Lumbricus terrestris* and, to a lesser extent, *Aporrectodea longa* and is believed to pose a serious risk to *L. terrestris* populations, with implications for soil functioning and indigenous earthworm-feeding wildlife (Murchie & Gordon, 2013) The Faroe Islands seem to provide an ideal habitat for *A. triangulatus*. Depletion of earthworms will likely impact on soil functioning and food supply for native wildlife. The islands have a unique fauna including a subspecies of starling (*Sturnus vulgaris faroensis*) whose diet likely includes earthworms (see Alford *et al*., 1995). In short *A triangulatus* poses a serious risk to *L. terrestris* populations, with implications for soil functioning and indigenous earthworm-feeding wildlife

2.19. How important is the impact of the organism on biodiversity at all levels of organisation (e.g. decline in native species, changes in native species communities, hybridisation) currently in the different biogeographic regions or marine sub-regions where the species has established in Europe (include any past impact in your response)?	**major**	**medium**	*Arthurdendyus triangulatus* is a predator of earthworms. In a replicated field experiment, *A. triangulatus* reduced earthworm biomass by 20 % at densities that were comparable to those in colonised pasture (0.8 flatworms per m^2) (Murchie & Gordon, 2013). However, the impact on the larger anecic species such as *Lumbricus terrestris* was more severe with a reduction in biomass of 75%. Flatworm predation at densities greater than 1 flatworm per m^2, would eradicate anecic earthworm populations. This statistically significant finding supports observations by others, that *A. triangulatus* has a disproportionately greater impact on anecic earthworms than epigeic or endogeic species (Blackshaw & Stewart, 1992; Fraser & Boag, 1998; Jones *et al.*, 2001). Thus is poses a serious threat to these key species. Earthworms are a major component of the diet of many birds and mammals (Alford *et al.*, 1995). There have been few studies looking at the knock-on effects of a decline in earthworms. However, there was a clear dissociation between the colonization of fields in Scotland by *A. triangulatus* and the presence of moles (*Talpa europaea*) (Boag, 2000). Earthworms perform important ecosystem functions within the soil including: • decomposition of plant material and livestock dung, • subsequent recycling of nutrients, • the mixing of soil horizons, • by burrowing, aeration and drainage of the soil. Possible effects of depleted earthworm populations include soil structural degradation, increased waterlogging and build-up of thatch at the soil surface (Haria, 1995; Murchie & Mac An tSaoir, 2006). There are anecdotal reports of poorer soil drainage and increased prevalence of *Juncus* in pastures colonized by *A. triangulatus* (Jones *et al.*, 2001). Although the precise functions of individual earthworm species are not well known, anecic species such as *Lumbricus*

			terrestris have been termed 'ecosystem engineers' because of their key role in soil processes. The effects of *A. triangulatus* on earthworm species will vary with the species present and the nature of the soil. The most affected earthworm species, *L. terrestris*, is widespread across Europe (Fraser & Boag, 1998; CABI, 2016), so impact on this species and associated soil effects will likely be similar. See Qu. 2.18.
2.20. How important is the impact of the organism on biodiversity at all levels of organisation likely to be in the future in the different biogeographic regions or marine sub-regions where the species can establish in Europe?	**major**	**medium**	If *A. triangulatus* becomes established in regions of continental Europe, then it is likely to have a similar impact on earthworm species as it has had in the British Isles and these will be both on agricultural land and on biodiversity. See Qu. 2.18.
2.21. How important is decline in conservation value with regard to European and national nature conservation legislation caused by the organism currently in Europe?	**moderate**	**high**	Most of the work on *A. triangulatus* has concerned its spread in domestic gardens and impact on agricultural pasture. The British Isles are depauperate in earthworm species compared to Europe and there is no red list for earthworms. The species most affected is *Lumbricus terrestris* and to a lesser extent *Aporrectodea longa*. Murchie & Gordon (2013) found a 75% depletion of these species biomass in the presence of *A. triangulatus*; with potential for local extinction if flatworm densities exceeded 1 per m^2. In a long-term monitoring study, Blackshaw (1995) compared earthworm and flatworm numbers over 8 years at two sites in Belfast. At both sites, the number of earthworm species declined from 6–7 to two. Another major impact is likely to be on native competitors of *A. triangulatus*, e.g. other species for which earthworms are a major component of their diet. A comprehensive list of potentially affected vertebrate species in the British Isles was given by Alford (1995), including: Mammals / *Erinaceus europaeus* / Hedgehog / *Talpa europaea* / Mole

	Soricidae	Shrews
	Meles meles	Badger
	Mustela erminea	Stoat
Birds	*Gallinula chloropus*	Moorhen
	Haematopus ostralegus	Oystercatcher
	Pluvialis apricaria	Golden Plover
	Vanellus vanellus	Lapwing
	Gallinago gallinago	Snipe
	Burhinus oedicnemus	Stone Curlew
	Scolopax rusticola	Woodcock
	Athene noctua	Little Owl
	Turdus merula	Blackbird
	Turdus iliacus	Redwing
	Turdus torquatus	Ring Ouzel
	Turdus philomelos	Song Thrush
	Corvus frugilegus	Rook

Three of these bird species (oystercatcher, lapwing and redwing) are listed as vulnerable on the EU Red List for Birds. Recent research has highlighted the importance of earthworms in the biology of some birds and the mitigating effort proposed to protect them by increasing earthworm numbers (McCallum *et al* 2016)

For invertebrates, shelled slugs (*Testacella* spp.) are potentially vulnerable (Alford, 1998), as these are specialist earthworm predators. Predatory ground beetles (Carabidae and Staphylinidae) feed on earthworms, although these are considered largely polyphagous there is a lack of information on the effects of earthworm depletion on these groups or their conservation status. This point was also made with respect to autochthonous populations of terrestrial flatworms, as knowledge of these species on a European scale is scarce (Álvarez-Presas et al., 2017).

2.22. 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 Europe?	**moderate**	**medium**	The potential impact of *A. triangulatus* on the wider earthworm fauna is unknown. Fraser and Boag (1998) considered that *A. triangulatus* posed a potential risk to rare earthworm species in Europe, but did not specify species. The impact of *A. triangulatus* as a competitor to other earthworm feeding wildlife has not been assessed for Europe as a whole beyond Alford (1995, 1998) for the British Isles. It is however likely that a greater subset of earthworm-feeding species could potentially be at risk. (MacDonald 1983)
Ecosystem Services impacts			
2.23 How important is the impact of the organism on provisioning, regulating, and cultural services in its non-native range excluding the Union?	**major**	**medium**	Please see below for details of the impact of the organism on ecosystem services provided by earthworms in the Faroe Islands (the only area affected by *A. triangulatus* outside of the EU). This will be broadly similar to the impact on the British Isles.
2.24. 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 Europe (include any past impact in your response)?	**major**	**medium**	*Arthurdendyus triangulatus* is a predator of earthworms and in particular significantly reduces populations of anecic earthworms such as *L. terrestris*. Earthworms provide the below ecosystem services, which will all be adversely impacted by the presence of *A. triangulatus* Provisioning>Nutrition>Biomass>Cultivated crops. Earthworm activities generally increase crop yield. This is through recycling nutrients, including interactions with the soil microbiota, to provide nutrients in a form available for plant uptake. Provisioning>Nutrition>Biomass> Wild animals and their outputs. Earthworms form the basis of the food chain for many familiar birds and mammals (section 2.21), some of which are of game value (e.g. snipe and woodcock) Regulating> Mediation of waste, toxics and other nuisances> Mediation by biota>Bio-remediation by micro-organisms, algae, plants, and animals.

			Earthworms are an important part of the decomposer community within the soil. They break down and recycle dead plant material and animal dung. Regulating>Mediation of flows>Liquid flows>Hydrological cycle and water flow maintenance. Earthworm burrows create channels in the soil that increase soil porosity, permit water permeation and aid drainage. Maintenance of physical, chemical, biological conditions>Pest and disease control>Disease control. Earthworms, by removal of fallen leaves, reduce apple scab (*Venturia inaequalis*) infection rates in apple orchards (de Jager & Heijne, 2004). Maintenance of physical, chemical, biological conditions >Soil formation and composition > Decomposition and fixing processes.Earthworms are important decomposer organisms within European soils. Through feeding on dead plant material and soil micro-organisms they physically break down structures and regulate microbial decomposition. Earthworms are arguably the most important component of the soil fauna for soil formation and fertility (Edwards, 2004). Maintenance of physical, chemical, biological conditions > Lifecycle maintenance, habitat and gene pool protection > Pollination and seed dispersal *Lumbricus terrestris* has been termed an 'ecosystem engineer', in part because of its ability to influence floral composition through the movement of seeds from the seedbank (Milcu *et al.*, 2006). Cultural. There is anecdotal evidence of a decline in earthworms used for angling where *A. triangulatus* has established. In general, earthworms are some of

			the commonest and most-easily encountered soil organisms. An earthworm survey undertaken by Boag et al., 1997 found *Lumbricus terrestris* in 94% of the farms they surveyed and they are often included in primary school curricula on 'minibeasts' studies.
2.25. 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 Europe in the future?	**major**	**medium**	The ecosystem services provided by earthworms are likely to be generally constant across the EU, e.g. recycling nutrients, maintenance of soil fertility, aeration and drainage of the soil and provision of food for indigenous wildlife. Depletion of earthworms due to *A. triangulatus* could therefore have similar negative effects, where the flatworm establishes.
Economic impacts			
2.26. How great is the overall economic cost caused by the organism within its current area of distribution, including both costs of damage and the cost of current management	**major**	**high**	*Arthurdendyus triangulatus* does not cause economic damage in its native range (Boag & Yeates, 2001). Earthworms provide economically-important ecosystem services in both agricultural and natural habitats. These are summarised by Blouin *et al.* (2013) as: • pedogenesis • development of soil structure • water regulation • nutrient cycling • primary production • climate regulation • pollution remediation • cultural services Quantifying economic externalities such as ecosystem services is immensely difficult due to the lack of data. Estimates for Ireland for the totality of ecosystem services provided by earthworms are in the region of € 1 billion per annum (Bullock *et al.*, 2008). Earthworm presence aids plant growth and consequently enhances crop yield (van Groenigen *et al.*, 2014). The

			mechanisms for this include: improved soil structural stability and soil porosity, nutrient cycling and enhanced microbial activity (Bertrand *et al.*, 2015). In agricultural land, *A. triangulatus* has mostly colonised pasture and not arable areas, as cultivation leads to mechanical damage for both flatworms and their earthworm prey. *Arthurdendyus triangulatus* records from public sightings in Northern Ireland gave 79.5% from domestic gardens, 6.6% from grassland, 1.5% from arable crops, 1.5% from forestry and 0.8% from golf courses (Moore *et al.*, 1998). <u>Example of economic impact in pasture</u> In Northern Ireland, grass is the predominant crop, underpinning the dairy and beef industries. Combining published values for the contribution of earthworms on plant growth with the prevalence and impact of *A. triangulatus* is admittedly simplistic but gives a rough estimated economic impact: • Contribution of earthworms to ryegrass aboveground biomass = 34% (van Groenigen *et al.*, 2014) • Reduction in earthworm biomass with presence of *A. triangulatus* at 0.8 flatworms per m^2 = 20% (Murchie & Gordon, 2013) • Presence of *A. triangulatus* will reduce ryegrass biomass production by 6.8% (34% x 20%) As grass is used directly as on-farm as fodder, calculating the value of the crop is not straightforward. • In Northern Ireland, 800,000 ha are under grass (DAERA, 2017b) • Grass silage = 287,000 ha • Production = 8,660,000 tonnes • Silage variable costs = £19.62 per tonne (DAERA, 2017a) • Value of silage = £170 million

			• Grazing variable costs (stocking density =1.8 cow equivalents per ha) = £147 per ha • Value of grazing = £75 million Total value of grass = £245 million. Note, if the value of grass is calculated as a concentrate-saving feed, then the value is much greater (c. £660 million). Estimated percentage of grassland with *A. triangulatus* in Northern Ireland = 70% (Murchie *et al.*, 2003). Impact of *A. triangulatus* in Northern Ireland = 6.8% x 70% x £245 million = £11.7 million. These calculations assume 0.8 flatworms per m^2 in 70% of grassland in NI based on upper estimates in Murchie *et al.* (2003). In intensive trapping studies in a grassland field, Murchie & Harrison (2004) estimated 2.4 flatworms per m^2 from direct counts. So a density of 0.8 flatworms per m^2 would seem a reasonable population estimate where the flatworm has established. A national impact of £11.7 million on grass production is equivalent to an average loss of £15 per ha. Boag (2000) gave predicted losses due to *A. triangulatus* as between £7–£42 per ha, with the comment that more work was required to provide a meaningful estimate But extrapolations from known data estimated annual potential losses of £17m in Scotland. As grass is an extensive crop, yield losses due to *A. triangulatus*, causing a decline in earthworm numbers, is a hidden problem. Farmers are more likely to associate reductions in grass yield with weather and fertiliser problems, rather than loss of earthworms. However, farmers have commented on a reduction in earthworm numbers where flatworms are found, along with increased compaction and waterlogging.

			Impact of *A. triangulatus* on the horticultural trade is largely unquantified. However, adverse publicity caused by a flatworm infestation at a garden centre or nursery will impact on sales. Measures to reduce the likelihood of flatworm transfer will also have an economic burden (Alford, 1998; Unger, 1998). Similarly, the impact of *A. triangulatus* on international trade has not been economically assessed. Generic plant health legislation, such as restrictions on the movement of soil, designed to prevent importation of many pests and diseases will likely restrict *A. triangulatus* importation from outside the EU (Unger, 1998). The DEFRA (UK) ban on importation of *Dicksonia* tree ferns imposed in 2005 due to infestation of non-indigenous invertebrates (including flatworms) had negative economic effects on exporters but also on specialist importers within Europe (Anon, 2005).
2.27. How great is the economic cost of damage* of the organism currently in the Union (include any past costs in your response)? *i.e. excluding costs of management	**major**	**very high**	In Scotland, Ireland and England/Wales, the economic impact of *A. triangulatus* is likely to be the same in infested pasture as Northern Ireland (see Qu. 2.26), i.e. a reduction in grass yield of 6.8% with comparable loss of £15 per ha. At the moment, although *A. triangulatus* is widely distributed in Scotland, the extent of infestation of pasture has not been quantified (Boag & Neilson, 2014), similarly in England / Wales.
2.28. How great is the economic cost of damage* of the organism likely to be in the future in the Union? *i.e. excluding costs of management	**major**	**very high**	Extrapolating losses of 12% in earthworm populations to a national scale in Scotland, the detrimental impact on grass production by *A. triangulatus* was estimated as £16–17 million (Boag & Neilson, 2006). If *A. triangulatus* colonised 100% of grass pasture in Northern Ireland, then using the figures in 2.18, the economic impact would be £18 million.
2.29. How great are the economic costs associated with managing this organism currently in the Union (include any past costs in your response)?	**minor**	**medium**	The economic costs associated with managing *A. triangulatus* relate purely to horticultural guidelines (e.g. MAFF, 1996). There are no practical control measures currently used to limit this species in agricultural land (Blackshaw, 1996; Boag & Neilson, 2006).

2.30. How great are the economic costs associated with managing this organism likely to be in the future in the Union?	**moderate**	**low**	The main economic threat of *A. triangulatus* is likely to be to grassland productivity. Grass is an extensive and, per ha, a low value crop compared to horticultural or arable production. Furthermore, *A. triangulatus* is not an easy pest to control as it is soil dwelling and measures directed against it could easily affect earthworms in the same habitat. If control measures were implemented on a widespread scale, probably cultural control would be most the practicable set of methods, for example, crop rotation (cultivation sufficient to disrupt the flatworm without affecting earthworms) combined with methods to enhance earthworm populations (e.g. input of farmyard manure or fertiliser). Such an approach would have other benefits as well as mitigating against flatworm damage so is difficult to quantify.
Social and human health impacts			
2.31. How important is social, human health or other impact (not directly included in any earlier categories) caused by the organism for the Union and for third countries, if relevant (e.g. with similar eco-climatic conditions).	**minor**	**high**	*Arthurdendyus triangulatus* secretes digestive enzymes (e.g. collagenase) and neuropeptides and these may cause skin irritation if the flatworm is handled (Blackshaw & Stewart, 1992), although in most cases this is felt as a mild dermabrasion. Soil biodiversity, which is likely to reduce, plays an important part in maintaining human health. It suppresses disease-causing soil organisms and provides clean air, water and food (Wall et al., 2015)
2.32. 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 Union.	**minor**	**high**	There are unlikely to be any substantial increases in the social or human health impacts of *A. triangulatus*. Although a fascinating creature scientifically, the flatworm is often regarded with repulsion by gardeners and infestation can cause personal distress.
Other impacts			
2.33. How important is the impact of the organism as food, a host, a symbiont or a vector for other damaging organisms (e.g. diseases)?	**minimal**	**high**	There are no known harmful organisms associated with this species (as food, host, symbiont or vector), although its microbiota has not been investigated.
2.34. How important might other impacts not already covered by previous questions be resulting from	**moderate**	**low**	Some potential indirect impacts of *A. triangulatus* are: • Increased water-logging and local flooding • Poor soil drainage leading to increased incidence of liver fluke

introduction of the organism? (specify in the comment box)			• Greater leaching of fertilisers and pesticides into local watercourses • Unforeseen changes in flora and floral succession as earthworm biodiversity alters (Alford *et al.*, 1995; Alford, 1998; Haria *et al.*, 1998)
2.35. 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 Europe?	**major**	**high**	Although generalist predators such as predatory beetles, shrews and some birds will feed on *A. triangulatus* (Blackshaw, 1996; Gibson *et al.*, 1997; Cannon *et al.*, 1999) it is not a palatable prey item due to distasteful mucus (McGee *et al.*, 1998). The impact of indigenous predators may slow the rate of population increase but is unlikely to prevent the damaging effects of *A. triangulatus*.
2.36. Indicate any parts of Europe where any of the above impacts are particularly likely to occur (provide as much detail as possible).	Anywhere that the flatworm is able to establish is likely to be vulnerable to some or all of the impacts recorded above dependent on ecosystem invaded and earthworm biodiversity and prevalence therein. This would include all susceptible habitats in the coastal regions of northern Germany, the Netherlands,	**medium**	

	Denmark and southern Sweden.		

ADDITIONAL QUESTIONS - CLIMATE CHANGE			
3.1. What aspects of climate change, if any, are most likely to affect the risk assessment for this organism?	[temperature]	**high**	Data from an unpublished SEERAD report in 2002 (Flexible Fund project No. CSL/002/96) gives the temperature requirements for the survival of the New Zealand flatworm and coupled with data from Evan &Boag (1996) suggests that milder wetter winters have the potential to benefit *A. triangulatus* establishment and spread, whereas hotter summers will reduce their survival.
3.2. What is the likely timeframe for such changes?	**50**	**medium**	
3.3. What aspects of the risk assessment are most likely to change as a result of climate change?	[establishment]	**high**	The potential for *A. triangulatus* establishment will be most affected by climate change.
ADDITIONAL QUESTIONS – RESEARCH			
4.1. If there is any research that would significantly strengthen confidence in the risk assessment please summarise this here.	[physiology, management, impact]	**high**	• Eco-climatic limitations to *A. triangulatus* establishment and how this relates to continental Europe. • The effectiveness of thermal treatment to prevent transference of *A. triangulatus*. • The contribution of native earthworm ecotypes (particularly anecic) to grassland productivity and the resulting impact if declining.

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ANNEX I: Scoring of Likelihoods of Events

(taken 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
Possible	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**
	Question 2.18-22	*Question 2.23-25*	*Question 2.26-30*	*Question 2.31-32*
Minimal	Local, short-term population loss, no significant ecosystem effect	No services affected[1]	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 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.

[1] Not to be confused with „no impact“.

ANNEX III: Scoring of Confidence Levels

(modified from Bacher et al. 2017)

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.
Very high	There is direct relevant observational evidence to support the assessment (including causality) from the risk assessment area *and* Impacts are recorded at a comparable scale *and* There are reliable/good quality data sources on impacts of the taxa *and* The interpretation of data/information is straightforward *and* Data/information are not controversial or contradictory.

ANNEX IV: Ecosystem services classification (CICES V4.3) and examples

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

Section	Division	Group	Class	Examples
Provisioning	Nutrition	Biomass	Cultivated crops	Cereals (e.g. wheat, rye, barely), vegetables, fruits etc.
			Reared animals and their outputs	Meat, dairy products (milk, cheese, yoghurt), honey etc.
			Wild plants, algae and their outputs	Wild berries, fruits, mushrooms, water cress, salicornia (saltwort or samphire); seaweed (e.g. Palmaria palmata = dulse, dillisk) for food
			Wild animals and their outputs	Game, freshwater fish (trout, eel etc.), marine fish (plaice, sea bass etc.) and shellfish (i.e. crustaceans, molluscs), as well as equinoderms or honey harvested from wild populations; Includes commercial and subsistence fishing and hunting for food
			Plants and algae from in-situ aquaculture	In situ seaweed farming
			Animals from in-situ aquaculture	In-situ farming of freshwater (e.g. trout) and marine fish (e.g. salmon, tuna) also in floating cages; shellfish aquaculture (e.g. oysters or crustaceans) in e.g. poles
		Water	Surface water for drinking	Collected precipitation, abstracted surface water from rivers, lakes and other open water bodies for drinking
			Ground water for drinking	Freshwater abstracted from (non-fossil) groundwater layers or via ground water desalination for drinking
	Materials	Biomass	Fibres and other materials from plants, algae and animals for direct use or processing	Fibres, wood, timber, flowers, skin, bones, sponges and other products, which are not further processed; material for production e.g. industrial products such as cellulose for paper, cotton for clothes, packaging material; chemicals extracted or synthesised from algae, plants and animals such as turpentine, rubber, flax, oil, wax, resin, natural remedies and medicines (e.g. chondritin from sharks), dyes and colours, ambergris (from sperm whales used in perfumes); Includes consumptive ornamental uses.
			Materials from plants, algae and animals for agricultural use	Plant, algae and animal material (e.g. grass) for fodder and fertilizer in agriculture and aquaculture
			Genetic materials from all biota	Genetic material from wild plants, algae and animals for biochemical industrial and pharmaceutical processes e.g. medicines, fermentation, detoxification; bio-prospecting activities e.g. wild species used in breeding programmes etc.

		Water	Surface water for non-drinking purposes	Collected precipitation, abstracted surface water from rivers, lakes and other open water bodies for domestic use (washing, cleaning and other non-drinking use), irrigation, livestock consumption, industrial use (consumption and cooling) etc.
			Ground water for non-drinking purposes	Freshwater abstracted from (non-fossil) groundwater layers or via ground water desalination for domestic use (washing, cleaning and other non-drinking use), irrigation, livestock consumption, industrial use (consumption and cooling) etc.
	Energy	Biomass-based energy sources	Plant-based resources	Wood fuel, straw, energy plants, crops and algae for burning and energy production
			Animal-based resources	Dung, fat, oils, cadavers from land, water and marine animals for burning and energy production
		Mechanical energy	Animal-based energy	Physical labour provided by animals (horses, elephants etc.)
Regulation & Maintenance	Mediation of waste, toxics and other nuisances	Mediation by biota	Bio-remediation by micro-organisms, algae, plants, and animals	Bio-chemical detoxification/decomposition/mineralisation in land/soil, freshwater and marine systems including sediments; decomposition/detoxification of waste and toxic materials e.g. waste water cleaning, degrading oil spills by marine bacteria, (phyto)degradation, (rhizo)degradation etc.
			Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals	Biological filtration/sequestration/storage/accumulation of pollutants in land/soil, freshwater and marine biota, adsorption and binding of heavy metals and organic compounds in biota
		Mediation by ecosystems	Filtration/sequestration/storage/accumulation by ecosystems	Bio-physicochemical filtration/sequestration/storage/accumulation of pollutants in land/soil, freshwater and marine ecosystems, including sediments; adsorption and binding of heavy metals and organic compounds in ecosystems (combination of biotic and abiotic factors)
			Dilution by atmosphere, freshwater and marine ecosystems	Bio-physico-chemical dilution of gases, fluids and solid waste, wastewater in atmosphere, lakes, rivers, sea and sediments
			Mediation of smell/noise/visual impacts	Visual screening of transport corridors e.g. by trees; Green infrastructure to reduce noise and smells
	Mediation of flows	Mass flows	Mass stabilisation and control of erosion rates	Erosion / landslide / gravity flow protection; vegetation cover protecting/stabilising terrestrial, coastal and marine ecosystems, coastal wetlands, dunes; vegetation on slopes also preventing avalanches (snow, rock), erosion protection of coasts and sediments by mangroves, sea grass, macroalgae, etc.
			Buffering and attenuation of mass flows	Transport and storage of sediment by rivers, lakes, sea

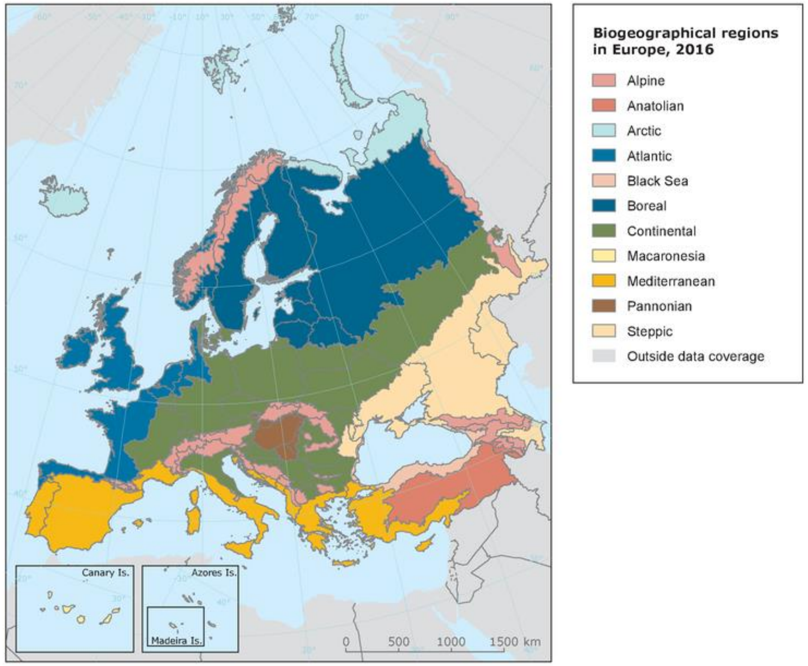
		Liquid flows	Hydrological cycle and water flow maintenance	Capacity of maintaining baseline flows for water supply and discharge; e.g. fostering groundwater; recharge by appropriate land coverage that captures effective rainfall; includes drought and water scarcity aspects.
			Flood protection	Flood protection by appropriate land coverage; coastal flood prevention by mangroves, sea grass, macroalgae, etc. (supplementary to coastal protection by wetlands, dunes)
		Gaseous / air flows	Storm protection	Natural or planted vegetation that serves as shelter belts
			Ventilation and transpiration	Natural or planted vegetation that enables air ventilation
	Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Pollination and seed dispersal	Pollination by bees and other insects; seed dispersal by insects, birds and other animals
			Maintaining nursery populations and habitats	Habitats for plant and animal nursery and reproduction e.g. seagrasses, microstructures of rivers etc.
		Pest and disease control	Pest control	Pest and disease control including invasive alien species
			Disease control	In cultivated and natural ecosystems and human populations
		Soil formation and composition	Weathering processes	Maintenance of bio-geochemical conditions of soils including fertility, nutrient storage, or soil structure; includes biological, chemical, physical weathering and pedogenesis
			Decomposition and fixing processes	Maintenance of bio-geochemical conditions of soils by decomposition/mineralisation of dead organic material, nitrification, denitrification etc.), N-fixing and other bio-geochemical processes;
		Water conditions	Chemical condition of freshwaters	Maintenance / buffering of chemical composition of freshwater column and sediment to ensure favourable living conditions for biota e.g. by denitrification, re-mobilisation/re-mineralisation of phosphorous, etc.
			Chemical condition of salt waters	Maintenance / buffering of chemical composition of seawater column and sediment to ensure favourable living conditions for biota e.g. by denitrification, re-mobilisation/re-mineralisation of phosphorous, etc.
		Atmospheric composition and climate regulation	Global climate regulation by reduction of greenhouse gas concentrations	Global climate regulation by greenhouse gas/carbon sequestration by terrestrial ecosystems, water columns and sediments and their biota; transport of carbon into oceans (DOCs) etc.

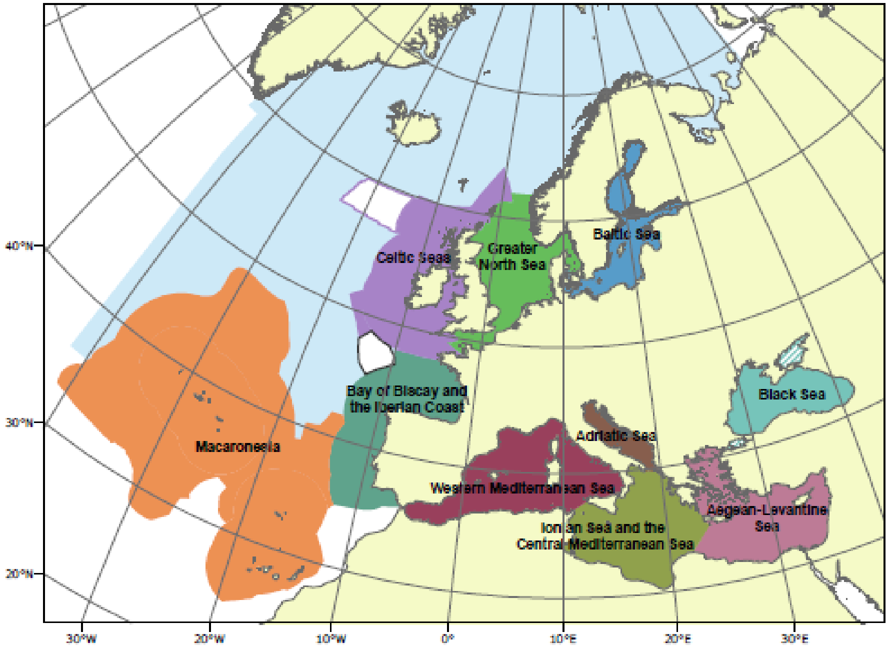
			Micro and regional climate regulation	Modifying temperature, humidity, wind fields; maintenance of rural and urban climate and air quality and regional precipitation/temperature patterns
Cultural	Physical and intellectual interactions with biota, ecosystems, and land-/seascapes [environmental settings]	Physical and experiential interactions	Experiential use of plants, animals and land-/seascapes in different environmental settings	In-situ whale and bird watching, snorkelling, diving etc.
			Physical use of land-/seascapes in different environmental settings	Walking, hiking, climbing, boating, leisure fishing (angling) and leisure hunting
		Intellectual and representative interactions	Scientific	Subject matter for research both on location and via other media
			Educational	Subject matter of education both on location and via other media
			Heritage, cultural	Historic records, cultural heritage e.g. preserved in water bodies and soils
			Entertainment	Ex-situ viewing/experience of natural world through different media
			Aesthetic	Sense of place, artistic representations of nature
	Spiritual, symbolic and other interactions with biota, ecosystems, and land-/seascapes [environmental settings]	Spiritual and/or emblematic	Symbolic	Emblematic plants and animals e.g. national symbols such as American eagle, British rose, Welsh daffodil
			Sacred and/or religious	Spiritual, ritual identity e.g. 'dream paths' of native Australians, holy places; sacred plants and animals and their parts
		Other cultural outputs	Existence	Enjoyment provided by wild species, wilderness, ecosystems, land-/seascapes

			Bequest	Willingness to preserve plants, animals, ecoystems, land-/seascapes for the experience and use of future generations; moral/ethical perspective or belief

ANNEX V: EU Biogeographical Regions and MSFD Subregions

See https://www.eea.europa.eu/data-and-maps/figures/biogeographical-regions-in-europe-2
and https://www.eea.europa.eu/data-and-maps/data/msfd-regions-and-subregions/technical-document/pdf





Annex VI: Evidence on measures and their implementation cost and cost-effectiveness

Species (common name)	**'New Zealand flatworm'**
Species (scientific name)	***Arthurdendyus triangulatus***
Date Completed	**22 September 2017**
Authors	**Archie K. Murchie**
Version	**Final**

	Description of measures[1]	**Assessment of implementation cost and cost-effectiveness (per measure)[2]**	**Level of confidence[3]**
Methods to achieve prevention [4]	The main invasion pathway for *Arthurdendyus triangulatus* is through importation of containerised plants. Prevention of invasion is therefore by managing this pathway (Alford 1998; EPPO 2001a; Unger 1998). Regular plant health inspections and surveillance are necessary	The burden for implementing pathway management will largely fall on the exporting nursery. In areas where flatworm infestation is prevalent these would be considered good practice anyway to prevent local spread (MAFF 1996). Inspection for flatworms should form part of ongoing inspection routines for pests and	Low

	to prevent establishment (Shrader and Unger 2003). Unfortunately, this is difficult with a cryptic pest that may be hidden in the soil. UK government guidelines (MAFF 1996) for nurseries and garden centres suggest the following methods: 1) Check regularly under matting or pots standing directly on the ground for flatworms or their egg capsules. 2) Lift plants from their pots frequently to check for the presence of flatworms or their egg capsules. 3) Set traps along the edges of your holding especially where it adjoins private gardens. Regularly check these for the presence of flatworms or their egg capsules. 4) Inspect all outgoing consignments of plants carefully whether for export or not. European and Mediterranean Plant Protection Organization (EPPO) guidelines	disease in the crop. More specific measures such as growing plants on raised beds or thermal treatment will impose a cost consideration. This will vary from nursery to nursery and depend on existing facilities (glasshouses, temperature controlled water baths) and the tolerance requirements of many different plant species. Consequently, there are no published data available on costs of pathway management for flatworms or its effectiveness. In general though, as controls are physical such measures will be publically acceptable, relatively immediate, have minimal health and safety issues, require no special licensing and have no wider environmental impacts. However, new alien terrestrial flatworm are continuing to enter the country despite these controls	

	specify and/or combinations of the below requirements for export of plants: 1) The plants are grown on raised slatted or open meshed benches. 2) The consignment must come from a place of production found free from *A. triangulatus*. 3) Representative samples of the consignment have been examined and found free from *A. triangulatus*. 4) The consignment has been subjected to a disinfestation treatment to eliminate *A. triangulatus* (EPPO 2001b). The inspection and disinfection process are given in a separate guideline (EPPO 2001c). Possible disinfestation procedures are: 1) Repotting. 2) Immersing the pot, tray or other container and root ball in warm water (> 34 ^{o}C) for a minimum of 10 min (alternatively > 30 ^{o}C for 40 min) (cf. Murchie and Moore 1998). 3) Placing the plants in a warm environment (at least 26.5 ^{o}C for 24 h or 30 ^{o}C for 12 h). Please note that this method		

	of control is particular to *A. triangulatus*. There are several other species of invasive flatworms that survive well in hothouses, for example *Bipalium kewense* and *Platydemus manokwari*, in temperate regions (Sluys, 2016).		
Methods to achieve eradication [5]	No widespread eradication measures against *A. triangulatus* have been attempted. Removal trapping of *A. triangulatus* has been suggested as a means of eradication (Cannon et al. 1999) but was tested by Blackshaw et al. (1996) and found to be ineffective at a commercial scale. *Arthurdendyus triangulatus* is susceptible to heat and physical damage so **removal of refuges, scorching and turning the soil** could eradicate the flatworm at the very early stages of infestation. However, Murchie and Harrison (2004) estimated from mark-release-recapture studies that 44% of the flatworm population was hidden in the soil, rather than at the soil surface. Once, the flatworm has got into the soil, the only	Eradication has not been attempted for *A. triangulatus* or similar flatworm species, so implementation cost and cost-effectiveness have not been evaluated. Digging up and scorching or heating soil would require mechanised diggers and be feasible only for a small area. It would be costly in terms of implementation (hire of digger, manpower, heating / scorching equipment, etc.) but also dependent on surrounding structures. The flatworm can shelter in the soil down the side of walls, posts and other structures. If *A. triangulatus* were to be eradicated from a nursery by this means, it would disrupt the commercial activities of the nursery, possibly requiring the dismantling of benches and polytunnels. On the positive side, the comparatively slow rate of natural dispersal of the flatworm (compared to say flying insects) would make the treatment area	Low

	feasible means of eradication would be to dig the soil up and heat it to temperatures above 30°C. No chemical measures are available to target the flatworm in the soil.	limited, although this would depend on the length of time the flatworm had been established. Such an approach would be limited to the infested area, likely to be publically acceptable, have no unusual health and safety requirements and require no special licences. The methods used (digging and heating) are readily available although untested for flatworm eradication. Their impact would be immediate. Waterlogging could be an option for some sites based on observations in a market garden following a flooding event when hundreds of flatworms were driven to the surface (B. Boag pers obs.)	
Methods to achieve man agement [6]	Blackshaw (1996) reviewed possible control measures for *A. triangulatus*. These were: 1) cultural control in terms of removal trapping, hot-water treatment and soil cultivation; 2) chemical control with pesticides;	*Arthurdendyus triangulatus* is not managed on a widespread or commercial scale. Individual gardeners and nursery owners do implement some management. For nurseries, this is principally to prevent spreading the flatworm and the corresponding damaging impact this would have on their reputation. Their methods normally follow those for prevention, i.e. vigilance, repotting, use of raised benches and thermal treatment (EPPO 2001c; MAFF 1996).	Low

	3) biological control by natural enemies or classical biological control.		
	Removal trapping was tested and whilst some population reduction was observed, the authors concluded that the method was too labour intensive for commercial control (Blackshaw et al. 1996).	Removal trapping was too labour intensive to be considered a viable means of large-scale control. It may be of value as part of an integrated pest management approach (see below).	Low
	Chemical control of *A. triangulatus* is problematic because the flatworms are hidden under refuges on the soil surface or buried in the soil itself. In addition, the proximity of flatworms to their earthworm prey increases the likelihood of negative effects on earthworms. Some pesticides have been tested against *A. triangulatus*, but only gamma-hexachlorocyclohexane (gamma-HCH or lindane) affected *A. triangulatus* without killing the test earthworm species (*Eisenia fetida*) (Blackshaw 1996; Murchie 2010). Gamma-HCH is no longer approved for agricultural use in the EU along with other chemicals which were previously found to be effective against NZ flatworm.	No pesticides are available for control of *A. triangulatus*. It is difficult to target *A. triangulatus* in the soil without having a deleterious effect on earthworms. However at some nurseries removal trapping has been superseded by putting down slug pellets under the traps and when the flatworms use them as refugia they are killed surface (B. Boag pers obs.)	Low

	For **biological control** it is recognised that predatory beetles (Carabidae and Staphylinidae) will feed on *A. triangulatus* (Blackshaw 1996; Gibson et al. 1997) and could have a moderating influence on their populations. However, this has not been tested. There is a single record of a parasitoid attacking terrestrial flatworms (Hickman 1965). *Planarivora insignis* Hickman (Diptera: Keroplatidae) is a small fly, whose larvae are parasitic on terrestrial flatworms (*Geoplana* spp.) in Tasmania. Beyond the original paper describing the species and its biology, no other work has been conducted on this species. Slug parasitic nematodes (*Phasmarhabditis hermaphrodita*) had no affect on *A. triangulatus* (Rae et al. 2005).	Predatory beetles are commonly found alongside *A. triangulatus* under refuges on the soil surface in gardens and agricultural habitats. Their impact on flatworm populations is not known. Classical biological control using a specialist parasitoid such as *P. insignis* remains a possibility (Blackshaw 1996; Blackshaw and Stewart 1992; Cannon et al. 1999) but the parasitoid species and its relationship with flatworms remains under-researched. It is not known, for example, whether *P. insignis* is capable of parasitizing *A. triangulatus*. There are also other flatworms which prey on other flatworms in New Zealand but little more is known (B. Boag Pers. comm.). Another possible control strategy would be to identify how the New Zealand flatworm recognises earthworms and disrupt this mechanism but again no work has been done on this subject.	Low
	Mitigation measures, including an integrated pest management approach, are probably the best way to manage *A. triangulatus*	Currently, the most practical solution is to mitigate against *A. triangulatus* predation by enhancing earthworm populations, coupled with an integrated pest management approach that seeks to disadvantage flatworm populations whilst having minimal effects on earthworms. There has	Low

		been no direct research on this but a hypothetical approach on farmland would involve: 1) Combinations of tillage and minimum till sufficient to physically damage *A. triangulatus* but with sufficient time intervals to allow earthworm populations to recover post-cultivation; 2) Input of fertilisers, such as farm-yard manure, to enhance earthworm populations; 3) Habitat manipulation to encourage predation by predatory beetles and/or other natural enemies/ or discourage flatwork colonisation e.g by drying out The above approach is long-term and likely to be publically acceptable, with no health and safety or special licensing implications. The effectiveness is unknown and will depend on the location, crop and surrounding habitat.	

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