The potential detrimental impact of the New Zealand flatworm to Scottish islands

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Abstract: The New Zealand flatworm, *Arthurdendyus triangulatus*, is an alien invasive species in The British Isles and the Faroes. It was probably first introduced after WWII and is an obligate predator of our native earthworms. It was initially considered a curiosity until observations in the 1990s in Northern Ireland found it could significantly reduce earthworm numbers. In 1992, it was scheduled under the Countryside and Wildlife Act 1981 then transferred to the Wildlife and Natural Environment (Scotland) Act in 2011 which makes it an offence to knowingly distribute the flatworm. A retrospective survey in Scotland showed that it was detected in botanic gardens, nurseries and garden centres in the 1960s but then spread to domestic gardens then finally to farms in the 1990s. Although the geographical distribution of *A. triangulatus* was initially confined to mainland Scotland it was subsequently found established on 30 Scottish Islands. Most of the islands are to the north and west of Scotland and have cool damp climates which are favoured by the New Zealand flatworm. These islands also generally have relatively poor soils that support grassland farming systems. Evidence from both Northern Ireland and Scotland suggests anecic species of earthworm which occur predominantly in grassland, which help drainage and are a source of food for both animals and birds are at particular risk from the flatworm. The detrimental impact of the flatworm on soil processes and wildlife has yet to be quantitatively evaluated but unlike many other invasive species there is currently no known means of control. The precautionary principle must be therefore applied wherever possible and every opportunity taken to stop its further spread.

Keywords: *Arthurdendyus triangulatus*, earthworms, invasive alien species, predator, Scotland

INTRODUCTION

Many of the Scottish islands have impoverished acidic soils (Boyd, 1957; Glentworth, 1979; Hudson, et al., 1982) which have been improved in the past by the addition of seaweed, lime or occasionally imported soil (Magnusson, 1997; Entwhistle, et al., 2000). Wind-blown calcareous sandy soils with a high shell content occurring in the north and west of Scotland, known as "machair" (Angus, 2001), are characterised with a defined flora and low input agriculture (Hudson, et al., 1982) and is a fragile ecosystem listed under the EU Habitats Directive Annex 1. Earthworms prefer soils with a near neutral pH and are therefore typically found in improved soils compared with those with a pH levels< 4 (Guild, 1951; Edwards & Bohlen, 1996). Boyd (1956, 1957) surveyed earthworms in the Hebrides and recorded a complex of 15 species from the machair, dominated by *Lumbricus rubellus, Aporrectodea caliginosa* and *Dendrobaena octaedra*. This contrasted with only six species under acidic heather soils, the dominant species being *L. rubellus and D. octaedra.* The genus of one of the recorded species, *Bimastos,* has since been removed from the British list (Sims & Gerard, 1985).

Stop-Bowitz (1968), suggested that in Norway some species e.g. *D. octaedra* and *L. rubellus* could have survived the Quaternary ice age and this may also have occurred in Scotland. However, many of the other recorded earthworm species were probably introduced by man to enhance the productivity of the land as occurred in New Zealand where productivity was increased significantly by the addition of European earthworm species (Stockdill, 1982). The only other place in the world where the New Zealand flatworm has become established is the Faroe Islands where earthworms have been found in closed association with human settlements possibly due to the inhabited areas being on fertile land (Enckell & Rundgren, 1988).

The New Zealand flatworm (*Arthurdendyus triangulatus*) was probably first accidentally introduced into the British Isles just after WWII but not officially recorded in Scotland until 1965 when it was considered a curiosity (Wakeman & Vickerman, 1979). However, Blackshaw (1990) reported that the presence of the New Zealand flatworm was associated with a decline in earthworm populations to below detectable levels in Northern Ireland. The results of a survey undertaken in Scotland during 1991–1992 (Boag, et al., 1994) indicated that the New Zealand flatworm was initially confined to botanic gardens, garden centres and nurseries but then spread to domestic gardens in the 1970s and finally to farms in the 1980s. It also showed that by 1992 it had spread to many parts of Scotland including the islands of Skye and Orkney. In the last 30 years the flatworm has been recorded from several other islands off the west and north coast of Scotland.

Further research indicated that the presence of the New Zealand flatworm reduced the abundance of anecic earthworm species (Jones, et al., 2001), populations of which were unlikely to fully recover (Murchie & Gordon, 2013). Anecic earthworm species are those which make vertical burrows and consume dead organic matter on the soil surface (Fraser and Boag, 1998), thus play a key role in soil nutrient processes and are considered ecosystem engineers (Lavelle, et al., 1997; Blouin, et al., 2013). Furthermore, they are also a major component of food for some mammals and birds (Boag & Neilson, 2006).

The New Zealand flatworm prefers cool damp conditions to survive (Boag, et al., 1998a) and this may have contributed to it being a problem predominantly in the north and west of Scotland, Ireland and the Faroe Islands compared with the east of Scotland and England (Jones & Boag, 1996). The flatworm is also dependent on the presence of earthworms which potentially restricts its distribution in Scotland as earthworms rarely occur in soils with a pH < 4 (Boag, et al., 1998b).

The aim of the present paper is to document the extent to which the New Zealand flatworm has become established in the Scottish islands and to consider the detrimental impact its presence might, in the future, have on island agriculture and wildlife.

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MATERIAL AND METHODS

The data used for this paper were the records of where the New Zealand flatworms were found by the general public in their gardens, parks etc. and these records over time have also shown how it spread. The New Zealand flatworm can easily be recognised by the general public as different from earthworms as it is flat, covered by a sticky mucus and pointed at both ends. Initially the records were collated by the National Museum of Scotland until this was taken over by the senior author after a survey financed by the Scottish Government (Boag, et al., 1994) and a 1995 BBC TV survey (Jones & Boag, 1996). Subsequent records have continued to be collected by staff at the James Hutton Institute and submitted to and curated by the National Biodiversity Network from where three additional island records were gleaned for this paper. More recently The Open Air Laboratory (OPAL) has run a citizen science survey for the New Zealand flatworm (<https://www.opalexplorenature.org>). The records are stored by the National Biodiversity Network and the senior author is the national expert on this species and verifies all records.

RESULTS

Most flatworm records were from individual households with a few from farms, garden centres and schools. Scotland has 790 offshore islands of which 95 are inhabited of which 30 islands recorded New Zealand flatworm (Table 1). These were distributed from Arran in the south of Scotland to Shetland in the north. Many of the infested islands had few inhabitants, but in general the number of flatworm records reflected the population size (Table 1).

This was demonstrated across the Orkney archipelago (Fig. 1) where there were 41 flatworm records, from a population > 17,000 on mainland Orkney compared with the outlying islands of Burray, Egilsay, Hoy, North Ronaldsay, Rousay and South Ronaldsay which had a combined population of > 1,700 and had only seven flatworm records. The Orkney mainland had the most records of all Scottish Islands even though it has a smaller land area than Skye, Shetland, Mull or Lewis. Of these larger islands Orkney is by far the most fertile with a large proportion covered with arable crops or permanent pasture (Dry & Robertson, 1982). Most island records only reported the presence of the flatworm but others reported a reduction or absence of native earthworms while others reported that large numbers of flatworms had been collected e.g. a householder from Baleshare killed 1,445 flatworms over a period between May 2015 and January 2016. Another householder from Skye regularly killed 20-40 flatworms daily with a reported maximum of 150, and an estimated total kill of 15,000 over a period of one year.

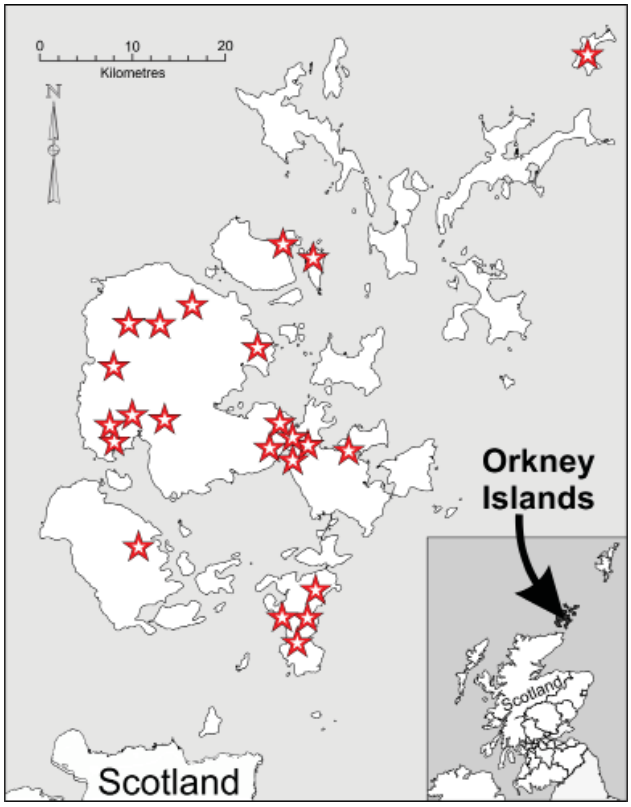

Fig. 1 Distribution of records of *Arthurdendyus triangulatus*, the New Zealand flatworm, in Orkney.

Table 1 Scottish islands infested with *Arthurdendyus triangulatus,* the New Zealand flatworm: the number of records; the human population and; area of the islands.

Island	No of records	Population	Hectares
Arran	5	5,058	43,201
Baleshare	1	58	910
Barra	3	1,078	5,875
Bressay	4	360	2,805
Burray	1	409	903
Bute	13	7,228	12,217
Coll	1	164	7,685
Easdale	1	59	25
Egilsay	1	26	650
Eriskay	1	143	703
Fair Isle	1	55	768
Gigha	3	110	1,305
Greater Cumbrae	2	1,376	1,168
Harris	3	1,916	50,119
Hoy	1	272	14,320
Iona	1	120	877
Islay	2	3,228	61,956
Isle of Seil	1	21	1,329
Lewis	14	18,500	163,695
Lismore	4	146	2,351
Mull	6	2,667	87,535
North Ronaldsay	1	72	690
North Uist	1	1,271	30,305
Orkney Mainland	41	17,162	52,325
Rousay	1	26	4,860
Shetland	13	22,000	96,879
Skye	12	10,008	165,625
South Ronaldsay	1	909	4,980
South Uist	1	1,754	32,026
Whalsay	1	14	1,970

DISCUSSION

The records received over the last 25 years show that the New Zealand flatworm is now widely distributed in the Scottish islands. Since it is an obligate feeder on earthworms, the presence of the flatworm also indicates that these islands must have had an abundance of earthworms. A possible reason for Orkney having a disproportionately greater number of New Zealand flatworm records compared with Lewis, Skye, Mull or Shetland is probably the fact that Orkney is formed from sedimentary rock while the others are igneous or metamorphic in origin (Dry & Robertson, 1982) thus more conducive to earthworm establishment and survival.

The New Zealand flatworm is known to have a deleterious impact on earthworms in mainland Scotland and Ireland (Jones, et al., 2001; Murchie & Gordon, 2013) and it can probably be assumed that is also the case on these islands. Apart from earthworms playing an important role in delivering soil function and ecosystem services (Lavelle, et al., 1997; Blouin, et al., 2013) they are an important constituent of the diets of some mammals and birds which live in the islands and are, in some cases, declining in number e.g. the lapwing (*Vanellus vanellus*). To help revive the decrease in lapwing numbers it has been proposed that lime should be added to increase the soil pH and hence encourage the build-up of earthworms upon which lapwing feed (McCallum, et al., 2015). Studies have also shown that earthworms are a major constituent of the diet of chough (*Pyrrhocorax pyrrhocorax*) (Meyer, 1990), a rare breeding corvid found on Islay and Colonsay with an estimate of c. 50 breeding pairs in 2014 (https://scotlandsnature.wordpress.com/2014/09/25/good-news-from-islay-as-population-grows/). It is therefore concerning that flatworms have been recorded from Islay as this may confound the conservation of chough on the island.

Apart from the direct impact of New Zealand flatworm on wildlife it has been estimated that it could have a potential detrimental economic effect on agriculture (Boag & Neilson, 2006). This is particularly relevant to small holdings with tight farm unit margins such as crofts. Circumstantial evidence from an area north of Dunoon infested with flatworm suggested that in addition to an accumulation of dead organic matter on the soil surface, undesirable plants such as rushes became established as a result of frequent flooding after rainfall events. The New Zealand flatworm may also become a problem where there are large amounts of arable land and permanent grassland which occurs in mainland Orkney. Agricultural land in Scotland can have a wide range of earthworm species including the anecic species which would be particularly at risk (Boag, et al., 1997).

No investigations have been undertaken to ascertain the actual impact of the New Zealand flatworm on either wildlife or agricultural production in the Scottish islands. Assumptions on the detrimental impact of the New Zealand flatworm must therefore be made based on the knowledge gleaned from the literature on the benefits that earthworms have on agricultural production and wildlife (Schmidt & Curry, 1999; Bartlett, et al., 2010). Unlike many other invasive plants and animals which have been successfully removed from Scottish islands e.g. mink from the Uists and rats from Canna (Bell, et al., 2011; Roy, et al., 2015) there are no prospects of the New Zealand flatworm being controlled on the Scottish islands once it has become established. Given the only mechanism known to spread the New Zealand flatworm is the human mediated movement of plant material every effort must be made to stop infested material reaching the islands by informing the general public of the threat that New Zealand flatworm poses.

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