The spread and distribution of terrestrial planarians (Turbellaria: Tricladida: Geoplanidae) within New Zealand

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Abstract: The New Zealand flatworm, *Arthurdendyus triangulatus* (formerly *Artioposthia triangulata*) has become established in the British Isles and the Faroe Islands and its human-mediated spread within Northern Ireland and Scotland is well documented. The geographical distributions within New Zealand of it and two related species, *A. australis* and *A. testacea* have always been assumed to reflect the natural distribution patterns. However, an analysis of the vegetation groups where the flatworms are presently found suggests that within New Zealand the distributions of endemic terrestrial planarians have been extended significantly by human intervention. Delineation of present distribution patterns of these species within New Zealand may lead to a better understanding of their potential distribution in other countries if they ever became established in them. Such extensions of ranges of New Zealand endemics within the country have implications for biodiversity analyses.

Keywords: *Arthurdendyus; Artioposthia;* biodiversity; earthworm; distribution pattern; land planarians; New Zealand flatworm; predator.

Introduction

Interest in the spread and distribution of terrestrial planarians was only of academic interest until it was shown that *Arthurdendyus triangulatus* (Dendy, 1894) (commonly known as the New Zealand flatworm) was responsible for reducing lumbricid earthworm populations below detectable levels under field conditions in Northern Ireland (Blackshaw, 1990). Those adverse impacts on earthworm populations have since been confirmed in horticultural and agricultural establishments in the Faroe Islands (Christensen and Mather, 1995; Mather and Christensen, 1992), Scotland (Boag *et al.*, 1999) as well as Northern Ireland (Blackshaw, 1995). Laboratory experiments (Blackshaw, 1990; Lilico *et al*., 1996) have shown that *A. triangulatus* is a predator of earthworms while Yeates *et al*. (1997) showed that other species within the genus, *A. testaceus* (Hutton, 1880) and an as yet undescribed species, as well as *Australoplana sanguinea* (Moseley, 1877) and another undescribed New Zealand *Australoplana* species, were also predators of European lumbricid earthworms in New Zealand. The indirect impact of *A. triangulatus* on the soil quality and the environment has not been studied in depth. It has been assumed that a decrease in earthworms would have a detrimental impact on soil quality and anecdotal evidence suggests that such changes have occurred e.g. build up of organic matter on the surface of the soil (Blackshaw, 1995). Boag (2000) also found that there was evidence that moles no longer inhabited fields after becoming infested with *A. triangulatus*.

Arthurdendyus triangulatus was first recorded from Northern Ireland in 1963 and from Scotland and England in 1965, although personal reports given to B.B. have indicated that it was probably in both Northern Ireland and Scotland in the 1950s. Answers to a questionnaire associated with a Scottish survey allowed a retrospective picture of its rate of spread in that country (Boag *et al*., 1994). That rate of spread was slow and, at first, *A. triangulatus* was mainly confined to garden centres, nurseries, and botanic gardens. It then became established in domestic gardens and eventually it infested agricultural land (Boag *et al*., 1994). By 1994 its geographical distribution included 91% of the Scottish land area (Boag *et al*., 1997). Application of the CLIMEX model to climatic data from the known distribution of *A. triangulatus* in the Faroe Islands, British Isles and New Zealand (Johns *et al*., 1998) has shown that it could become established in western Europe (Boag *et al*., 1995a) and in other countries throughout the world (Boag *et al*., 1995b).

In New Zealand it is confined to the South Island, where it has been found from north of Kaikoura to Stewart Island (Johns *et al*., 1998). However, DNA

analysis has suggested that *A. triangulatus* may have been spread inadvertently within New Zealand (Dynes *et al*., 2001) as it has in Northern Ireland (Stewart and Blackshaw, 1993).

The purpose of this paper is to identify and map the distribution of *A. triangulatus* in native forest and modified habitats, e.g. gardens, nurseries and agricultural land. The data for *A. triangulatus* are then compared with similar data for another two *Arthurdendyus* species found in New Zealand that have distinctly different distribution patterns. The potential for these other species to become established in countries other than New Zealand and their impact on earthworms are considered.

Materials and methods

Flatworms were collected from throughout New Zealand between 1990 and 2002 by searching under debris which lay on soil. In native forest and shrub vegetation this tended to be logs and stones whereas in nurseries it was usually plant pots, fertiliser bags, and bricks. In agricultural land it was usually logs, derelict fenceposts, boards, stones or polythene sacks. Search time would be approximately half an hour per site but could vary considerably. Also, it was usually far easier to find flatworms in modified habitats than in natural ones. Specimens were identified by either of the authors or people who, reliably, knew these flatworm species.

Sites were usually chosen because they were near a road, easily accessible and represented a habitat where it was felt that flatworms would be present and could be collected. At each site, whether or not flatworms were found, the surrounding vegetation was noted. The position of the site was taken by a postal address or road distance from a signposted locality and more recently by a GPS receiver, the co-ordinates being recorded by latitude and longitude or the New Zealand national map grid references. For the purposes of this paper the vegetation was classified subjectively into three categories, a) natural, relatively undisturbed habitats b) domestic gardens, nurseries and garden centres, roadsides within towns and townships and c) agricultural land and adjoining roadsides. Many modified sites (categories b and c) were also close to or adjacent to native forest. Date, altitude, and collecting and preservation techniques were also noted at each site in preparation for associated taxonomic and histological studies. The distribution maps were plotted using the computer program VisualMap©. Most specimens will be deposited in the Canterbury Museum, Christchurch, and some in the Royal National Museum of Scotland, Edinburgh.

Results

Over the years 1990 to 2002, 563 visits were made to 529 sites (Fig. 1a); fewer sites appear on the maps as many are within the same 10-km grid square and the multiple visits to Cass and Jacksons (both near Arthurs Pass, northwest of Christchurch) and Hinewai, Banks Peninsula, are treated as single visits. All but very few visits provided records of one or more flatworm species. Table 1 shows the numbers of records for each of the three *Arthurdendyus* species in the designated habitat groupings. This shows marked differences in occurrence of the different species; *A. triangulatus* was found at 103 sites, while *A. australis* and *A. testaceus* were recorded from 22 and 71 sites respectively. The relative distribution of the flatworm species between different vegetation types also varies significantly. *Arthurdendyus australis* was usually found in natural habitats, while *A. triangulatus* was more often found in nurseries, garden centres and domestic gardens. This contrasts with *A. testaceus* for which most records were from agricultural land, due perhaps to the intensity of collecting by Boag and Yeates in the lower half of the North Island.

The three species show distinct distribution patterns under natural vegetation. *A. triangulatus* was mainly found in Canterbury (central South Island including the eastern valleys of the mountains) and the four southernmost records were from small natural vegetation reserves surrounded by farmland (Fig. 2a). *A. australis* was found in the south (Fig 3a) and *A. testaceus* was present in the north of the South Island (Fig. 1a). In modified habitats *A. triangulatus* was recorded from north of Kaikoura to Stewart Island and into the eastern valleys of the mountains (Fig. 2b, 2c). Whilst *A. australis* was mainly found in natural habitats south of Dunedin, its distribution in modified

Table 1. Number of records for *Arthurdendyus australis*, *A. testaceus* and *A. triangulatus* in designated habitat groups in New Zealand. (Nurseries includes garden centres, domestic and public gardens and other horticultural establishments).

Flatworm species	Natural habitat	Nurseries	Agricultural land
A. australis	10	6	6
A. testaceus	3	47	21
A. triangulatus	18	63	22

Figure 1. (a) Distribution of 10 km squares examined for flatworms (open squares) and those found positive for *Arthurdendyus testaceus* in natural sites (3 solid squares), and, distribution of 10 km squares containing sites where *A. testaceus* was found in (b) nurseries etc., and (c) in agricultural land.

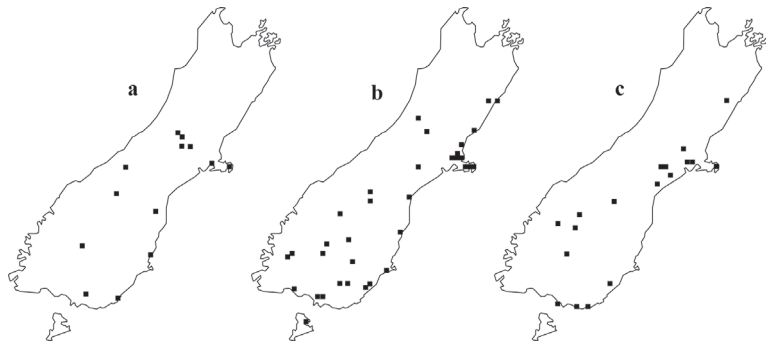

Figure 2. Distribution of 10 km squares containing sites where *A. triangulatus* was found (a) in natural sites, (b) in nurseries etc., and (c) in agricultural land.

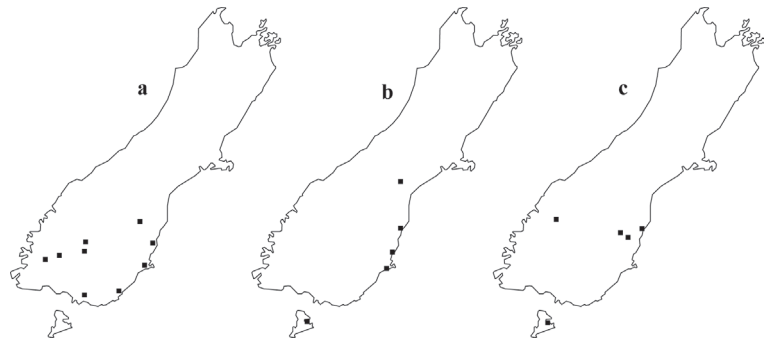

Figure 3. Distribution of 10 km squares containing sites where *A. australis* was found (a) in natural sites, (b) in nurseries etc., and (c) in agricultural land.

habitats, both agricultural and horticultural, extended to include much of the country between Dunedin and Ashburton and across to the valleys on the east side of the Southern Alps (Fig. 3a-3c). This contrasts with the present distribution of *A. testaceus*, which has only been found, and then only as single specimens, in natural habitats at three low-altitude sites in the north of the South Island (Fig. 1a) (although a photograph of what is probably this species was taken in a forest near Wellington in the North Island). South of these "native habitat" sites it has been collected, often abundantly, only in nurseries and gardens (Fig. 1b). North of those three sites it has been taken in agricultural land (Fig. 1c) as well as in nurseries and gardens.

Discussion

The suggestion by Dynes *et al*. (2001), from DNA studies, that *A. triangulatus* has been spread by human activity within New Zealand has been supported by the results of the analysis of the distribution patterns found during the present investigation. A comparison of the natural ranges of the three *Arthurdendyus* species suggests they originally occupied distinct geographic areas of the South Island. However, passive transport by commerce and probably gardeners during the 150 years of colonisation has lead to the present overlap of ranges. In theory, it is possible that *A. triangulatus* always occupied its present distribution and that, apart from the four small, southern sites, the survey did not detect it in natural habitats outside the Canterbury region. However, the fact that many other species, including described and undescribed species of *Arthurdendyus,* were found both south and north of this region, in natural habitats, would suggest this is highly unlikely. The data from *A. australis* again suggest that human means have extended the distribution of this species a considerable distance north of its natural range within the southern part of the South Island and Stewart Island.

Similarly, *A. testaceus* has had its range greatly extended by human means. Its original range is thought to be in the north of the South Island, whereas the present range extends into the southern half of the North Island. It was also found as far south as Stewart Island. Its northern boundary in the North Island presents another biological problem. The greater human population in the North Island and the many garden centres gives higher likelihood of transport for this species. It is yet to be found in the northern half of the island, though many sites have been examined. Other species of *Arthurdendyus* are also uncommon and as most North Island flatworms in other genera occur throughout the island, competition would seem not to be a factor. Other possible population regulators are unknown.

The fact that there are geographically distinct ranges in these soil-inhabiting organisms is not unusual in New Zealand since other animals have been shown to have similar distinct distribution patterns e.g. native earthworms (Lee, 1959), millipedes (Johns, 1979). Two hundred and sixty-nine ecological districts based on the geology, soils and vegetation have already been recognised (Simpson, 1982) and many have endemic species. High diversity within genera and the distribution of species in complex mosaics are common features of the New Zealand endemic fauna. *A. triangulatus* and *A. testaceus* have spread southwards and both species were found in disturbed habitats on Stewart Island. *A. testaceus* was in Dunedin in 1880 (Hutton, 1880), but *A. triangulatus* had not been noted in the south until present collections. Their northern spread seems to have been restricted to approximately 200 km beyond their natural range. *A. testaceus* was present in Wellington also by 1880 (Hutton, 1880). In Canterbury it is known, and that only recently, at only one site, a garden centre in Christchurch. But *A. triangulatus* has long been known in the city. These overlaps north and south are best interpreted as a mosaic rather than sympatry as the two species are seldom found together. In Otago-Southland, of the 70 sites visited, only in 6 were two species cohabiting: three sites for each pair: *A. testaceus-A. australis* and *A. testaceus-A. triangulatus.* All but one of those sites was a garden centre (4) or farmland (1). The exception was in a Scenic Reserve within 200 m of a railway station and township margin (Kingston, Southland). That site is almost certainly a natural one for *A. australis*, but it is thought to be a "new natural site" for *A. triangulatus*. Although present in nearby townships, *A. triangulatus* has not been collected in nearby natural sites as *A. australis* has.

The relative distribution of the three flatworm species between the three habitat groups varied and may reflect differences in their biology or physiology. It would seem that either *A. australis* has not accompanied humans as much as the other species or it is not as tolerant of modified environments as the other species.

Experience with *Arthurdendyus triangulatus* has shown that within Europe it can easily become established in modified environments, especially domestic gardens, nurseries and garden centres (Boag *et al*., 1994). It is less likely to be found in agricultural land at present although it may only be a matter of time before it becomes established throughout much of Northern Ireland and western Scotland (Boag *et al*., 1998a; Murchie *et al*., 2003). In New Zealand it has been found at the edge of agricultural pastures associated with shaded conditions (e.g. agro-forestry sites or wind-breaks) but has not been associated with

significant declines in earthworm numbers. However, such a decline has been seen associated with an undescribed *Arthurdendyus* species under minimal tillage agricultural conditions in New Zealand (Yeates *et al*., 1999). *Arthurdendyus triangulatus* is not having any noticeable effect on the large European earthworm populations in New Zealand (Fraser and Boag, 1998), due probably to conditions in agricultural land, for much of the year, being too hot and dry for the worm to survive (Boag *et al*., 1998a,b).

The northward spread of *A. testaceus* is similar, in distance, to the other two species, but it is also able to survive in Stewart Island over 500 km south of its natural range. As this species is common in nurseries and garden centres it could be a good candidate for accidental spread to other countries if flatworms are indeed spread by international trade in containerised plants, as suggested by Cannon *et al*. (1999). Since *A. testaceus* is found in warmer climatic regions of New Zealand it could become established in warmer climes and countries than those tolerated by *A. triangulatus*. The impact of *A. testaceus* on earthworm populations in such countries would probably be similar to that of *A. triangulatus* in Scotland, the Faroe Islands and Northern Ireland, since laboratory experiments have shown both species feed on earthworms (Yeates *et al*., 1997).

Our data on distribution patterns of three *Arthurdendyus* species in New Zealand suggest that all three species once had three distinct geographic patterns. However, while they now have different distribution patterns, these overlap. We suggest that this overlap is due to human-mediated spread of these species. These species must also have some impact within New Zealand. Beyond their natural sites, they are in effect foreigners in their own country or 'native exotics'. Being outside their natural habitats their presence has created new mosaics of native species since moving into native habitats adjacent to farmland. They could well out-compete or prey upon local natives. The rarity of some native earthworms and snails may be an indication of such impacts. Through the actions of these and perhaps other 'native exotics', biodiversity, in terms of number of species or population counts, could change as much as it has in other lands. New mosaics of native species could also lead to confusion in the interpretation of DNA/RNA phylogenetic relationships that are so useful in the analysis of the New Zealand fauna.

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