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THE INVASION OF NEW ZEALAND FLATWORMS

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ABSTRACT

New Zealand flatworms were first recognised in Scotland (Edinburgh) in the early 1960s, shortly after being found in Northern Ireland, though it has recently been reported that they were seen in Edinburgh in the late 1950s. It is supposed that they were transported, either as adults or as egg capsules, by means of potted plants. In New Zealand they have a scattered distribution in the South Island. They are thought to feed exclusively on earthworms, and though initially they were regarded as curiosities in the UK, their subsequent spread and local abundance has raised concerns about reduced earthworm populations and consequent effects on soil structure and fertility and on wildlife. The biology, distribution and possible effects of the flatworm are summarised. Large, deep-burrowing species of earthworm may be particularly affected and this could have consequences on soil drainage, though more research is required. We consider the likelihood of other species of land planarian becoming a problem in the British Isles.

HISTORICAL INTRODUCTION

In 1885, Arthur Dendy graduated in Zoology from the University of Manchester. He went initially to the University of Melbourne and then in 1894 moved to the University of Canterbury, Christchurch, New Zealand. In both Australia and New Zealand he described several new species of land planarians, most of them on external characters only (no anatomical details). One of these from the vicinity of Christchurch he named *Geoplana triangulata*. It was described in two papers by Dendy (1894; 1895) as follows (1895 additions are in parentheses below, comments in italics are by HDJ).

"This is a large species, commonly about 5 inches (*about 13 cm*) long when crawling and rather broad. There is a very broad band of a dark purplish-brown tint, occupying the middle two thirds or thereabouts of the dorsal surface. Outside this band the margins of the body are thin and translucent, and of a pale yellowish colour peppered with minute specks of dark grey. (The anterior tip is pale pinkish yellow. Eyes numerous, but very small, and rarely in more than a single series; continued round the horse-shoe-shaped anterior tip.) The ventral surface is pale yellowish, thickly peppered with minute grey specks.

(The peripharyngeal aperture (*mouth*) is situate at about the junction of the middle and posterior thirds, and the genital aperture is somewhat nearer to it than to the posterior extremity.) *Note: this is typical of many land planarians.*

The name *triangulata* is given on account of the presence, under certain conditions, of a strongly-marked median dorsal ridge....

This worm is very common in gardens round Christchurch. It feeds upon earthworms and is frequently dug up with the spade. It is also found under old wood etc. as usual."

Graff (1899) partially described the internal anatomy and transferred it to the genus *Artioposthia* which was defined by the presence of adenodactyls (accessory glandular structures of uncertain function) in the copulatory apparatus. Fyfe (1937) gave a thorough description of the internal anatomy. It has since been transferred to (and is type species of) the genus *Arthurdendyus* Jones and Gerard (1999). The main generic character is that the ovaries are lateral to the copulatory apparatus, rather than being anterior as in most land planarians. Its current scientific name is thus *Arthurdendyus triangulatus* (Dendy, 1894).

Land flatworms are triclad turbellarians, or planarians, belonging to the phylum Platyhelminthes. Planarians lack a circulatory system. This restricts their thickness as oxygen has to diffuse to all parts. The gut has one opening only and three major branches, one anterior and two posterior (triclad), each with side branches which reach all parts of the body. All land planarians are hermaphrodite. There is a variously complex copulatory apparatus and the reproductive opening (gonopore) is posterior to the mouth. Large egg capsules are laid through the gonopore or by dorsal

fission. Each capsule hatches after several weeks and contains several young.

INITIAL IDENTIFICATION IN UK

New Zealand flatworms were first recognised in Northern Ireland in 1963 though must have been present for some time previously (Willis and Edwards, 1977). The initial identification was made by Stephen Prudhoe of the British Museum (Natural History). One of the first specimens in Northern Ireland was found in a toilet bowl (Willis and Edwards, 1977). Who knows what the finder thought! The first apparent record in Scotland was in 1965 at the Royal Botanic Gardens (RBG), Edinburgh (Wakelin and Vickerman, 1979). However, one of us (BB) has been told by a then trainee gardener at RBG, Edinburgh, Mr Les Bisset, that he recalls noticing it in the late 1950s. Whenever they first got here, it is presumed that they were accidentally transported to the UK in soil or plant pots as part of the horticultural trade, either as adults, juveniles or egg capsules.

NEW ZEALAND

Studies in New Zealand (Johns *et al.*, 1998) have shown that *A. triangulatus* is confined there to scattered localities in the South Island. It can be quite abundant locally in some mountain valleys and at horticultural sites (Christensen and Mather, 1998), though it seems to have little impact on earthworm populations (Fraser and Boag, 1998). In horticultural sites, regular irrigation leads to ideal moist conditions for both flatworms and their earthworm prey. Agricultural regions have a water deficit for most of the year though there is occasional irrigation. Earthworms can be quite abundant in fields but flatworms are not, perhaps because it is too dry for some of the year.

Several European earthworm species have been deliberately introduced to New Zealand in attempts to improve pasture and arable land (Fraser and Boag, 1998). Native New Zealand earthworms are of a different family (Megascolecidae) to European earthworms (Family Lumbricidae). Megascolecid earthworms are much more vigorous (wriggling violently, even jumping) when disturbed or attacked than are lumbricid species. One factor in the apparent success of New Zealand flatworms in the British Isles may be that European earthworms are more susceptible to flatworm predation than the New Zealand species which have co-evolved with the predation.

THE SITUATION IN SCOTLAND

Before 1991, records of distribution of the New Zealand flatworm in Scotland had been collected by a number of people or organisations such as the Royal Scottish Museum, Edinburgh. In 1991 recording was centralised via the Biological Recording in Scotland Campaign, but several organisations were involved. A "Wanted dead or Alive" campaign was launched. The Scottish Office Agriculture and Fisheries Department (SOAFD) commissioned SCRI to make an objective assessment of its distribution and possible impact (Boag *et al.*, 1994). Results showed that flatworms are widespread in Scotland and particularly abundant in the Edinburgh area. Subsequently, all Scottish records are sent (whoever collected them) to Brian Boag.

Scotland, of course, has high rainfall, over 2 m annually in the parts of west, less in the east. Thus large parts of Scotland have ideal moist conditions for both flatworms and for their earthworm prey and it is little wonder that they have become well established.

THE PROBLEM

Dendy (1894) in his initial description noted that *A. triangulatus* fed on earthworms. Subsequent studies suggest that it is apparently an obligate feeder on earthworms. Until the mid-1980s not much notice was taken of this species in the British Isles. But, by then it had become widespread across Northern Ireland and in parts of Scotland. Since then it has become even more widespread and even abundant in some parts of both Ireland and Scotland, and occurs in scattered locations in England (Jones and Boag, 1996; Cannon *et al.*, 1999). It also occurs in the Faeroe Islands (Mather and Christensen, 1992) where the particular method of potato cultivation (cut and inverted turf) would seem particularly suited to flatworm survival.

Blackshaw (1989; 1990), in Northern Ireland, was the first to correlate the presence of *A. triangulatus* with a reduction in earthworm numbers. There is evidence from Northern Ireland (Blackshaw, 1989), Scotland (Lillico *et al.*, 1996) and the Faeroe Islands (Christensen and Mather, 1995) that earthworms may be temporarily eliminated soon after flatworm invade an area in any numbers. An adult flatworm will catch and consume earthworms larger than themselves, taking about half an hour to consume an earthworm. They eat about 1.4 *Eisenia fetida* a week (Blackshaw and Stewart, 1992). Given a free choice, *A. triangulatus* shows little preference for particular UK earthworm species (Lillico *et al.*, 1996). However, flatworms apparently feed on the soil surface at night and earthworm species which do likewise may be more vulnerable to predation by flatworms (Blackshaw, 1990; Alford, 1998; Cannon *et al.*, 1999). Earthworms have long been

recognised as being beneficial to soils (Darwin, 1881; Edwards and Bohlen, 1996). Any reduction in earthworms is possibly detrimental to soil fertility and their burrows aid soil drainage. The long-term effect on earthworm populations will be considered later. These concerns led to considerable publicity and media interest, and to questions in the House of Lords. They also led to appeals for more information by various organisations, such as the Royal Horticultural Society and gardening magazines. In 1992, *A. triangulatus* was added to Part 1, Schedule 9 of the Wildlife and Countryside Act 1981. This made it an offence for anyone to release it or to allow it to escape into the wild. MAFF introduced a Code of Practice (Anon, 1996), giving advice on control and preventative methods. Several EU states have threatened to boycott certain UK produce, mainly potatoes, because of possible spread of *A. triangulatus*.

LONG-TERM EFFECTS OF NEW ZEALAND FLATWORMS

Blackshaw (1995) noted that, after initial reduction, earthworm populations could at least partially recover. In 1998-9 earthworm populations were recorded in two pasture fields at a farm near Dunoon in which New Zealand flatworm were abundant (Jones, Santoro, Boag and Neilson, 2001). These results are compared with data from 48 uninfected pasture fields in the west of Scotland surveyed by Boag *et al.* (1997). Results (Table 1) show that overall earthworm numbers in one of the infected fields were similar to uninfected fields, but that in the other they were reduced to about one sixth. Three species of earthworm were reduced in both infected fields, *Aporrectodea caliginosa*, *A. longa*, and *Lumbricus terrestris*. The first is particularly beneficial to grass growth (Syers and Springett, 1983). The latter two are the only deep burrowing and long-lived (anecic) earthworm species in Britain and are particularly important in maintaining soil drainage. Their reduction in the infected fields may have led to waterlogging and growth of rushes. Conversely, poor drainage, lack of ploughing and high rainfall in recent years could have led to waterlogging, in turn causing a reduction in the numbers of earthworms.

The ultimate test of the effect of flatworm predation on earthworms would be to know if crop production was affected. Such information would be expensive and laborious to obtain.

IMPACT ON WILDLIFE

Any reduction of earthworms is considered to be detrimental, not only to soils but also to vermivorous wildlife such as moles, hedgehogs, badgers and birds (Alford, 1998; *Cannon et al.*, 1999), though no-one has suggested eliminating any of them in an effort to conserve earthworms!

Table 1. Numbers of each earthworm species and ecotype totals (mean per square metre ± SD) for the Paddock (8 samples) and Hayfield (5 samples) near Dunoon, both infected with New Zealand flatworm, and uninfected pasture fields in the west of Scotland. P is the Mann-Whitney U probability (and * indicate P < 0.05 and < 0.01 respectively, thus significant differences). "P v U" is for the Paddock against the uninfected fields; "H v U" is for the Hayfield against the uninfected fields. (After Jones, Santoro, Boag and Neilson, 2001.)**

Species and **ecotype (bold)**	Paddock (n = 8)	Hayfield (n = 5)	Uninfected fields (n = 48)	P v U *P*	H v U *P*
Allolobophora chlorotica	0.95±1.24	0.64±1.04	5.33±8.15	0.224	0.203
Aporrectodea caliginosa	3.75±5.13	1.28±1.21	18.82±15.19	0.002**	0.001**
Aporrectodea limicola	2.05±3.24	1.12±1.56	0	0.023*	0.153
Aporrectodea nocturna	0	0	0.08±0.34	0.792	0.825
Aporrectodea rosea	2.60±3.61	0.48±1.07	2.40±3.36	0.991	0.119
Octolasion t. tyrtaeum	0.55±1.26	0.16±0.36	0	0.272	0.486
Octolasion cyaneum	0.20±0.56	0	1.05±2.64	0.512	0.333
Endogeic species	**10.1±9.15**	**3.68±3.9**	**27.68±21.86**	**0.018***	**0.001****
Dendrobaena octaedra	0	0	0.02±0.11	0.936	0.941
Dendrodrilus rubidus	0	0	0.30±1.08	0.589	0.668
Lumbricus castaneus	0	0	0.15±0.48	0.654	0.712
Lumbricus festivus	1.45±1.28	0.16±0.36	1.05±3.17	0.011*	0.712
Lumbricus rubellus	19.7±13.88	4.64±4.97	4.52±7.44	0.000**	0.626
Satchellius mammalis	0	0	0.18±0.84	0.722	0.779
Epigeic species	**21.15±14.56**	**4.8±5.21**	**6.22±10.13**	**0.001****	**0.965**
Aporrectodea longa	0.30±0.85	0.48±1.07	16.73±17.0	0.000**	0.000**
Lumbricus terrestris	4.70±3.22	0.80±0.8	7.17±6.42	0.454	0.010**
Anecic species	**5.00±3.17**	**1.28±0.91**	**23.90±20.51**	**0.000****	**0.000****
Total individuals	36.25±18.56	9.76±8.11	57.80±36.99	0.095	0.000**
Number of species	5.75±1.90	3.60±2.07	5.83±1.57	0.845	0.026*

It is feared that garden birds may be reduced in number in areas where flatworm are present and the British Trust for Ornithology in its Garden Birds Survey is collecting data on presence or absence of flatworms. To date there have been insufficient returns to allow any conclusions to be drawn (Andrew Cannon, pers. comm.). There is evidence to suggest that in the Dunoon area, where *A. triangulatus* is common, moles have been eradicated (Boag, 2000). A comparison of old, dated photographs of fields with molehills may be of interest if they should be available. (There are no moles in Ireland.)

PREVENTION

The MAFF Code of Practice (Anon, 1996) is aimed at commercial growers. It lists several "Things to do" many of which apply as much to domestic gardeners:

- Inspect incoming consignments of plants carefully
- Maintain good hygiene
- Check regularly under matting or pots standing directly on the ground for flatworms or their egg capsules
- Lift plants from their pots frequently to check for the presence of flatworms or their egg capsules
- 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
- Inspect all outgoing consignments of plants carefully whether for export or not
- If you suspect that you have discovered a flatworm, do not kill it but send it for identification.

The Royal Horticultural Society (Anon, undated) suggests that you should immerse plant pots in water overnight to expel flatworm, but this will not affect eggs. Otherwise put down traps as above and kill the worms by squashing or by putting them in a tightly sealed container of salt solution. Additionally, anyone moving plants to a garden should find out if the suppliers (whether commercial, friend or relative) have flatworms. If so then extreme precautions, such as above should be taken. If in doubt, don't transport. If flatworms are not present there is no need to worry.

Care should be taken if obtaining hay or straw bales or plastic-wrapped silage bales from an infected area, since both are ideal refuges for flatworms (Boag *et al.*, 1999).

ELIMINATION

In heavily infested areas such as Edinburgh or the Dunoon area, it is impractical and probably too late to eliminate the New Zealand flatworm. There are just too many in too many places. However, in isolated infestations (single gardens) it might be possible. One of us (HDJ) has been told of a domestic garden near Winchester in which flatworms were recorded in 1995, but they had gone by 2000. This is without taking any special measures. Presumably the initial inoculant was too small and maybe the climate of the area helped.

Removal trapping (placing refuges and searching them regularly) has been suggested as a means of elimination. This may work in small, isolated infestations, but Blackshaw *et al.* (1996) concluded that it was impractical in larger areas.

Several things can be used to kill flatworms. Salt sprinkled on the live worms will kill them. They can be hand collected (use a stick or gloves) and placed in salt solution, diluted bleach, Jeyes Fluid, or 1 part Armillatox to 100 parts of water (precautions are necessary with the latter ones). Egg capsules should be squashed.

Is there anything that eats New Zealand flatworms? There are few natural predators, either in New Zealand or the UK. Gibson *et al.* (1996) noted that adult and larval beetles will attack New Zealand flatworm, but it seems unlikely that these would have a significant effect on the population. We have seen farmyard ducks and geese eating uncovered New Zealand flatworms. Given the nocturnal habit of flatworms and the diurnal habit of birds, it is unlikely that this would significantly reduce flatworm numbers. There are certainly plenty of flatworms in the farm where this was observed.

OTHER LAND FLATWORM SPECIES

There are only three probable native species in the UK. They are quite widespread (Jones, 1988), but none is particularly abundant. They seem to feed mainly on dead soil animals such as slugs or earthworms. They are ecologically insignificant, that is their effect on the population of other organisms is minimal.

Over 1100 species of land planarian are known world-wide. The total of native species for each continent is estimated as follows (figures in parentheses are introduced species). Europe 10 (12), Africa 47 (4), North America 0 (12), Central and South America 442 (6), Asia 208 (?), Australia 300 (9), New Zealand >100 (6) (Johns, 1998; Jones, 1998; Kawakatsu and Ogren 1998; Ogren

and Kawakatsu, 1998; Winsor, 1998a). Most species are quite small and their prey unknown. Most probably they eat soil arthropods, slugs or carrion (squashed slugs, woodlice or earthworms are good bait for some species). But several of the New Zealand species are large and eat earthworms. In addition to *A. triangulatus*, three other vermivorous species have already been found in the UK, *A. albidus* (probably from New Zealand), *A. australis* (from New Zealand) and *Australoplana sanguinea alba* (from either Australia or New Zealand), as well as 8 other alien species. Most have few records and very limited distribution, but *A. sanguinea alba* (the "Australian flatworm") is widely distributed in the British Isles and particularly common in the south and west of England (Jones and Boag, 1996). It can occur in large numbers. In one domestic garden as many as 400 can be collected in one month (Jones *et al.*, 1998; Jones, Green, Harrison and Palin, 2001). It can lead to temporary elimination of earthworms, but they seem to recover and stabilise (Santoro and Jones, 2001). Some alien species are found only in hothouses in the UK (Jones, 1988; 1998). One of the UK hothouse species, *Bipalium kewense*, is also vermivorous and has been found in many countries. In warmer countries it lives outdoors and in Australia and the southern USA it is a pest of earthworm farms (Winsor, 1998b).

CONCLUSION

The main problem is that the trade in horticultural and garden plants is not only local (between friends and relatives and commercial) but also international. Preventative legislation exists and quarantine and import controls are theoretically in place (Manchester and Bullock, 2000), but given the ease and amount of local and international travel and trade, and the practical difficulties of policing and inspection, further introductions of alien species (not just of flatworms) are probably inevitable. For example, in September 2000 a single yellow land flatworm with a brownish head was found on an imported Australian tree fern in Penzance (HDJ). Another example was the use of mature decorative trees, with large soil balls, that were grown in the Netherlands and imported for the 2001 Chelsea Flower Show (BBC TV Gardener's World). We have no idea what quarantine precautions were taken in either case, and flatworm introduction is unlikely from the Netherlands (there are very few records or species), but is it any wonder that introductions of these and other organisms continue? Unfortunately it is the gardening and horticulture trades that have ultimately caused the introduction of land flatworms, and many other organisms. It is gardeners (amateur and professional) who have spread the New Zealand flatworm throughout the British Isles. It is probably too late to do much about it.

Arthurdendyus triangulatus can be considered as New Zealand's revenge for the thistle, gorse (whins) and many other things!

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