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Population studies on the land planarian *Artioposthia triangulata* (Dendy) at natural and horticultural sites in New Zealand

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Abstract

Morphometric data and general observations of habitat conditions are presented for populations of the land planarian *Artioposthia triangulata* at natural and horticultural sites in New Zealand. A considerable variation in size structure was apparent, the overall weight range for egg capsules being 86 and 396 mg fwt (up to a 4-fold difference), and that for flatworms being 28–2316 mg fwt (juveniles to adults). The number of hatchlings emerging per egg capsule ranged from 1–14. Densities as high as 16 flatworms m^{-2} and 70 egg capsules m^{-2} could be found in natural areas beneath pine logs felled just one year previously. Densities of 6 flatworms m^{-2} and 25 egg capsules m^{-2} occurred at a horticultural site in Christchurch. The mean individual weights of both egg capsules and flatworms were significantly greater at natural sites than horticultural sites, this being related to habitat conditions (prey availability and micro-climate) and the associated age structure of the population. Prey availability appears to be the main factor regulating population density. Many similarities between indigenous *A. triangulata* populations in New Zealand and populations resulting from accidental introduction in north-west Europe are revealed. Although this species is not considered a problem in its native land, owing to passive spread via horticultural trade and thereby introduction to high suitability habitats, it is likely to prove a threat to introduced European lumbricid populations in gardens and agricultural areas in New Zealand, so having implications for soil quality. © 1998 Elsevier Science B.V.

Keywords: *Artioposthia triangulata*; Land planarian; New Zealand flatworm; Lumbricid earthworms; Horticultural sites; Natural sites

1. Introduction

New Zealand probably has over a hundred species of land planarians (Platyhelminthes; Tricladida), most of which await identification (P. Johns, pers. comm.). Little is known of their general biology other than their habit of preying on soil invertebrates. Due to increasing world-wide horticultural trade, it is not surprising that some terrestrial flatworm species have been accidentally exported with plant material to non-native areas.

One such species is the so-called 'New Zealand flatworm' *Artioposthia triangulata* (Dendy) which was first described in its native land in 1894 (Dendy, 1894), being widespread in gardens in Christchurch (Dendy, 1895). The flatworm was first recorded outside its native land over 30 years ago, reports coming from Northern Ireland and Scotland (Anon, 1964; Willis and Edwards, 1977). Originally of curiosity value only, *A. triangulata* is now proving to have considerable ecological significance in north-west

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Europe due to being a voracious and obligatory predator of lumbricid earthworms (Blackshaw, 1990; Blackshaw and Stewart, 1992; Mather and Christensen, 1992; Christensen and Mather, 1995). Negative impacts on these beneficial soil organisms result in detrimental changes to the environment, directly via food webs and species diversity, and indirectly via soil structure and fertility.

Apart from Dendy's (1894) observation that *A. triangulata* is a predator of earthworms, studies of this flatworm in New Zealand have focused upon species distribution (Boag et al., 1995a, b). The few population studies available have all been conducted on accidentally introduced colonies in Northern Ireland (Blackshaw, 1995) and the Faroe Islands (Mather and Christensen, 1992; Christensen and Mather, 1995, 1997). We here present the first study of native *A. triangulata* populations, and provide morphometric data for flatworms and egg capsules, along with other general observations.

2. Materials and methods

During a general survey of flatworms in New Zealand (October/November 1995, i.e. spring-time), the authors found specimens of *A. triangulata* at a number of localities on the South Island, particularly around the area of Christchurch on the east coast. Colonies of this species were studied at five sites, two being characterised by a lesser degree of human interference ('natural sites') and three having a high degree of human impact ('horticultural sites'). The two natural areas comprised grassland bordering native *Nothofagus* forest at Hinewai Nature Reserve on the Banks Peninsula, and grassland (forest clearance) at Cass near Arthur's Pass National Park in the Southern Alps. The other three sites were Parkland near Spencerville to the north of Christchurch, a larger garden centre in Christchurch and a smaller one in Alexandra (a town located in the centre of the Southern Island).

Daytime observations revealed numerous *A. triangulata* flatworms and egg capsules beneath objects lying on the soil surface, including logs, stones, concrete slabs, wooden planks, plant containers and plastic sheeting. Specimens were usually found at the interface between the overlying object and soil surface or within the top layer of soil. Shortly after collection from the field, fresh weight of flatworms and egg capsules was measured (±1 mg), as was egg capsule length and width (±0.1 mm).

3. Results

At natural sites, *A. triangulata* was found to congregate especially under pine logs. At Cass, for example, beneath logs felled just one year previously estimated densities were as high as 16 flatworms m^{-2} (4 individuals m^{-2} with signs of egg capsule development) and 70 egg capsules m^{-2} (hatched+non-hatched). Here, the habitat comprised a rich organic soil with grass roots and decomposing bark, moist conditions and temperatures of ca. 12°C. The colony was associated with numerous slime trails, mucus-lined resting sites and excretion sites. One large log (also felled the previous year) was remarkable in having over 150 hatched egg capsules m^{-2}. All flatworms had the purplish-brown dorsal coloration with speckled buff margin and venter, typical of the species. Very few earthworms were apparent, the few observed being introduced lumbricid species; one dead specimen had recently been preyed upon.

At horticultural sites, *A. triangulata* was found beneath plant containers and black plastic sheeting, particularly in areas with daily irrigation. At the Christchurch garden centre, for example, estimated densities m^{-2} were 6 flatworms and 25 egg capsules (hatched+non-hatched). Flatworms ranged from larger pigmented reproductive adults to cream/yellow coloured hatchlings, and an incidence of egg capsule hatching was also observed. Slime trails, resting sites and excretion sites were evident. The occasional lumbricid earthworm was also seen.

Mean weights and ranges for *A. triangulata* egg capsules and flatworms collected from the various sampling sites are presented in Tables 1 and 2, respectively. As no differences between samples from the two natural sites were apparent, nor between samples from the three horticultural sites (Mann-Whitney *U*-test; $P>0.05$), data were subsequently pooled to allow comparison of the two categories of habitat.

The weight distributions of egg capsules and flatworms for the two habitat categories are shown in Figs. 1 and 2. The flatworm sample from horticultural

Table 1
Mean weights and ranges for *A. triangulata* egg capsules from the various sites

Site	Mean weight (±SE) (mg fwt)		Sample size	Weight range (mg fwt)
Hinewai	237.2	(23.44)	6	134–307
Cass	203.7	(8.09)	35	86–300
Spencerville	153.8	(11.95)	9	122–246
Christchurch	187.9	(15.15)	19	97–396
Alexandra	155.9	(10.84)	15	97–233
Natural sites	208.6	(7.81)	41	86–307
Horticultural sites	169.6	(8.31)	43	97–396

Table 2
Mean weights and ranges for *A. triangulata* flatworms from the various sites

Site	Mean weight (±SE) (mg fwt)		Sample size	Weight range (mg fwt)
Hinewai	726.0	(146.39)	14	125–1563
Cass	1175.1	(83.70)	34	378–2245
Spencerville	487.9	(57.50)	14	189–863
Christchurch	484.5	(66.14)	50	28–2316
Alexandra	564.6	(74.18)	11	192–972
Natural sites	1044.1	(78.10)	48	125–2245
Horticultural sites	496.9	(46.47)	75	28–2316

sites comprised a higher proportion of smaller/younger individuals, whereas at natural sites specimens weighing <100 mg fwt could not be found. A comparison of the two habitat categories indicates that the mean individual weights of egg capsules and flatworms are significantly greater at natural sites (Mann-Whitney *U*-test; $P<0.01$).

Mean lengths and widths, plus corresponding ranges, for egg capsules collected from natural and horticultural sites are presented in Table 3. The significant difference in egg capsule size between the two habitat categories is also expressed with respect to linear measurements (Mann-Whitney *U*-test; $P<0.01$). For the entire sample of egg capsules (all sites), the relationship between length and width is given in Fig. 3(a). The linear regression equation indicates that most egg capsules were ovoid in form. Regarding the relationship between egg capsule weight and dimensions (Fig. 3(b)), the best linear fit was achieved by considering a prolate spheroidal volume which was derived by incorporating measurements for length and width into the formula $4/3\ \pi ab^2$ (where a and b are the major and minor semi-axes of the spheroid).

Table 3
Linear dimensions for *A. triangulata* egg capsules collected from the two habitat categories

Site	Mean length and width (mm)		Sample size	Weight range (mm)
Natural sites	8.6	(0.13)	41	7.1–11.0
	6.5	(0.09)		5.0–7.6
Horticultural sites	8.1	(0.14)	42	6.0–10.4
	6.1	(0.11)		5.0–8.5

Standard errors for mean lengths and widths are given in brackets.

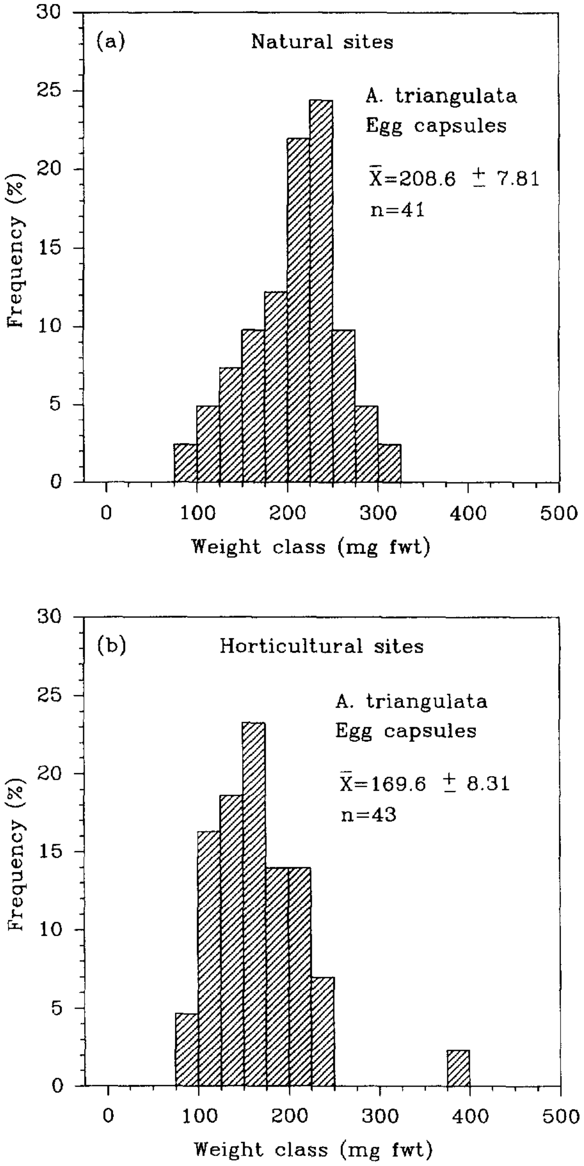

Fig. 1. Weight distribution of *A. triangulata* egg capsules at natural and horticultural sites.

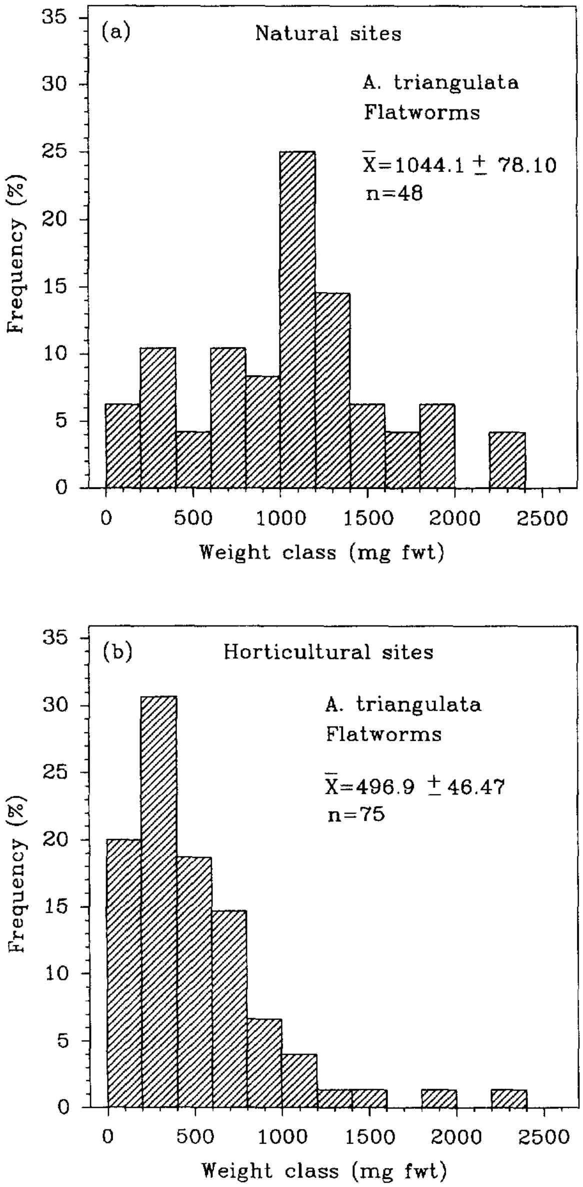

Fig. 2. Weight distribution of *A. triangulata* flatworms at natural and horticultural sites.

Based upon a random sample of 29 egg capsules from all sites, the number of hatchlings per egg capsule was found to range from 1–14, the mean being 7.0 (±0.55 SE). A random sample of these hatchlings gave a mean individual weight of 9.1 mg fwt (±0.48 SE; n=41). No inter-site differences for these two parameters were apparent.

4. Discussion

Population studies of *A. triangulata* in the Faroe Islands have demonstrated that habitats with conditions favourable for lumbricid earthworms promote the build-up of high density flatworm populations. For example, during late spring flatworms and egg cap-

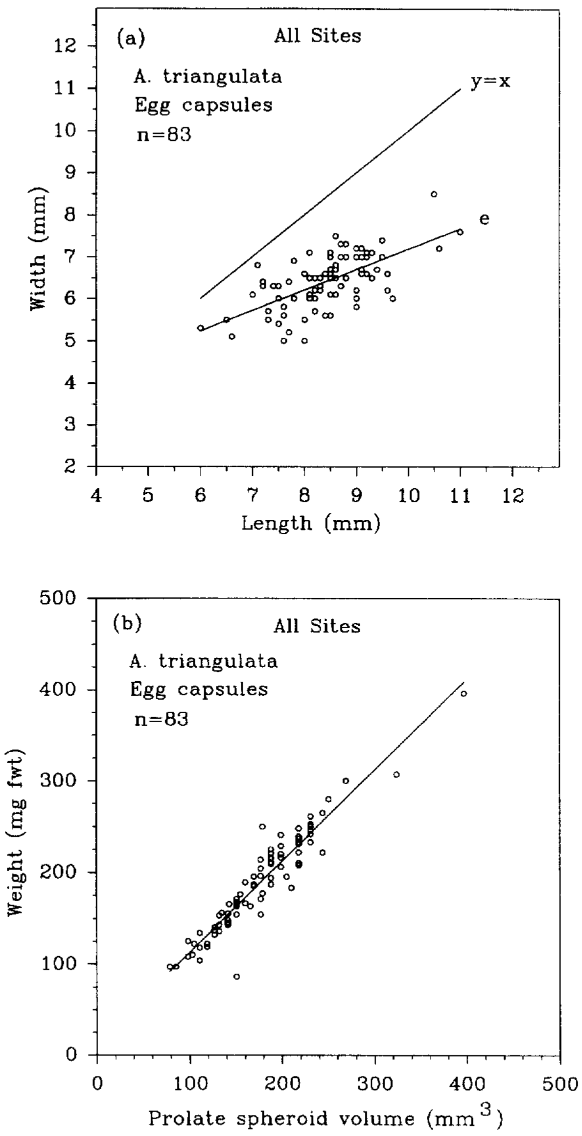

Fig. 3. The relationships between length, width, volume and weight of *A. triangulata* egg capsules. (a) The linear regression equation (e) is y=2.31+0.49x; r^2=0.42. The line y=x is given for comparison. (b) Spheroidal volume was derived by incorporating measurements for length (a) and width (b) into the formula 4/3 πab^2. The linear regression equation is y=13.02+0.99x; r^2=0.90.

sules can be found at densities of up to 10 and 78 m^{-2}, respectively, at horticultural areas (Christensen and Mather, 1995), and up to 40 and 60 m^{-2}, respectively, in potato fields involving 'reimavelta' practice (inverted grass sward) (Mather and Christensen, 1992). Similarly, the present study of *A. triangulata* in its native land during spring has revealed that high densities of flatworms and their egg capsules can be found in pockets at natural sites (e.g. beneath logs), viz. 16 and 70 m^{-2}, respectively, and horticultural sites (e.g. beneath plant containers), viz. 6 and 25 m^{-2}, respectively.

Considerable variation in size structure of both egg capsule and flatworm samples was apparent for the various sites in New Zealand. Concerning the two habitat categories, egg capsules showed a similar 3- to 4-fold difference in individual weight, the overall range being between 86 and 396 mg fwt. For comparison, for *A. triangulata* at a horticultural site in the Faroes, a 7-fold difference in egg capsule weight has been found, specimens ranging from 40–271 mg fwt, though for 80% of the population the size difference was likewise 4-fold (Christensen and Mather, 1995). Regarding flatworm samples in New Zealand, the overall range in individual weight was 28–2316 mg fwt, including recent hatchlings, juveniles and adults. For the Faroese horticultural site, a similar wide range in flatworm body weight was also evident, i.e. 21–2334 mg fwt (Christensen and Mather, 1995).

With regard to the number of hatchlings emerging per egg capsule, the range of 1–14 observed in the present New Zealand study extends those previously reported for Northern Ireland (i.e. 2–5, Willis and Edwards 1977; 2–10, Blackshaw and Stewart 1992) but equals that found in the Faroe Islands (Christensen and Mather, 1997).

Interestingly, the present study indicates major differences in the mean individual weights of both egg capsules and flatworms at natural versus horticultural sites, both life stages being larger at the former. The 20% larger egg capsules at natural sites (cf. Fig. 1(a)) is most likely related to a larger size of reproductive adults (cf. Fig. 2(a)). A direct association between egg capsule size and flatworm size has been observed in the Faroes, this being linked to earthworm prey availability (Christensen and Mather, 1995). Particularly favourable habitat conditions would appear to exist for *A. triangulata* at horticultural sites owing to regular irrigation and increased abundance of shelter sites as well as earthworm prey (cf. Mather and Christensen, 1996). These conditions enhance flatworm reproduction and recruitment of juveniles, so lowering the population mean for flatworm weight (cf. Fig. 2).

Studies of *A. triangulata* in the Faroes have revealed that 'larder-type' (high prey density) habitats such as potato fields and garden centres can result in a flatworm population explosion such that lumbricid earthworms become depleted within a year (Christensen and Mather, 1995). A similar situation almost certainly exists at horticultural sites elsewhere. The present study reveals a similar phenomenon also occurring in natural areas in New Zealand, flatworm populations reaching high densities within twelve months, with few lumbricids subsequently evident (cf. pine log habitats). On the other hand, in native *Nothofagus* forest where *A. triangulata* probably evolved, only isolated specimens could be found by the authors; this infers low density populations which possibly relate to low densities of indigenous earthworm species. Thus, a relatively stable predator/prey equilibrium appears to exist in the *Nothofagus* forest ecosystem. Prey availability therefore seems to be the main factor regulating densities of *A. triangulata* populations.

The present study highlights many similarities between the *A. triangulata* situation in north-west Europe and that in New Zealand. Horticultural activities in particular promote both high density populations and passive spread to other habitats, after which active migration into the surrounding countryside may result in the establishment of new colonies (cf. Mather and Christensen, 1996). Although *A. triangulata* is currently considered not to be a problem in its native land, we propose that high density flatworm populations in gardens and agricultural areas can pose a threat to local earthworm populations also in New Zealand. The flatworm thus has the potential to counter the beneficial effects of introduced lumbricids, eventually leading to soil impoverishment.

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