Further monthly records (1994 to 2000) of size and abundance in a population of the "Australian" flatworm, *Australoplana sanguinea alba* in the U.K.

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ABSTRACT. Collections of the "Australian" flatworm, *Australoplana sanguinea alba*, have been made in one garden in the UK three times a week from February 1995 to September 2000. All specimens seen were placed in 70% alcohol, one jar each month. Flatworms were counted but not collected for some months from March 1992. The first flatworm was seen in December 1991. Rainfall, soil moisture and air and soil temperature (and latterly, the depth of the water table) were recorded. All specimens (5121) were weighed and measured. For some years the maturity of each specimen was also determined. Fewest flatworms are found in July and most in November. Seasonal variation is probably related to soil moisture content. Relatively low rainfall in the winter of 1995-6 apparently led to low numbers of flatworms the following winter. Average size of flatworms is smallest in July and largest in March. Apparent hatchlings are most abundant August to October. 80% of the specimens were mature. Immature flatworms form the majority only between July and October. Specimens as small as 9.5 mm long are mature. Only four egg capsules have been seen over eight years. Flatworms have been observed undergoing fission and it is suspected that fission may be the main method of reproduction in this population. Body weight varies with the square of body length (exponent = 2.093).

KEY WORDS: Platyhelminthes, Tricladida, *Australoplana sanguinea var. alba*; *Geoplana sanguinea*; reproduction; growth; allometry.

INTRODUCTION

The "Australian" flatworm, *Australoplana sanguinea* var. *alba* (Jones, 1981) was probably introduced into the British Isles sometime around the early 1970's, and is now distributed widely, mainly in the south and west of Great Britain (Jones & Boag, 1996). It feeds exclusively on earthworms and is thus perceived as undesirable by gardeners and farmers.

In December 1991 two specimens were found in a domestic garden near Southport, the first at that site. Numbers of flatworms were recorded at regular intervals over 1992 and sporadically in 1993 and 1994. From February 1995 to the present (September 2000) flatworms have been systematically collected, weighed and measured, along with rainfall and soil and air temperature records. Soil moisture is presumed to be the most significant factor in determining the number of flatworms collected. At any time, this is likely to be the result of recent rainfall and current temperature (and plant transpiration). Thus flatworm numbers are compared with rainfall (including totals of previous months) and air and soil temperature, as well as with soil moisture. Jones et al (1998) reported a partial analysis of the data based on collections to December 1997. This paper reports on collections of flatworms to September 2000 and further analyses the data.

MATERIAL AND METHODS

The garden covers an area about 198 m^2 of which about 70 m^2 is covered by lawn and paving, the rest is cultivated as flower borders or for vegetables. Paving stones are inset or round the edge of the lawn, and planks were placed on bare soil in the cultivated part of the garden. The soil is sandy and drains rapidly, though the water table is only 1 to1.5 m below the surface, varying seasonally. Flatworms were collected from beneath the same paving stones and planks three times a week. All flatworms seen were collected and placed in a jar of 70% industrial methylated spirits, one jar per calendar month (except for 11 specimens found between July and October

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1996 which were preserved together). In December 1997 illness prevented collection for the second half of the month – the number of flatworms has been doubled for inclusion. Daily records are kept of rainfall (from December 1995) and maximum and minimum air temperature. Rainfall records for previous years at Southport (5 km distant) were kindly provided by Sefton Borough Council. From December 1995, soil temperature at 10 cm depth and soil moisture (using a proprietary soil moisture meter with an arbitrary scale of 0-10 of unknown manufacture obtained from a garden centre) were also recorded on each collection date. From May 1999, the depth of the water table in a well in the centre of the garden has been recorded.

All specimens (5121) were individually weighed and length and width (to 0.5 mm accuracy) measured. Jones et al (1998) showed that preserved weight is 91.4% of live weight. Specimens from February 1995 to February 1999 were individually examined externally for the presence of the gonopore. Ones with no gonopore visible were cleared in cedarwood oil to see if there was any development of the copulatory apparatus. An arbitrary scale of maturity, 0-3, was used: 0 = immature; copulatory organs (and sometimes the pharynx) absent due to recent fission or breakage. 1 = immature; no development of the copulatory organs visible after clearing. 2 = partially mature; copulatory organs visible after clearing, but gonopore not open. 3 = mature; gonopore open.

RESULTS

Flatworm numbers – temporal variation

Flatworm numbers clearly fluctuate seasonally. In most years, and on average, numbers are highest in November (Figs1 & 2), averaging 215±122 SD (7 yr data). Numbers decline from November to July when they are at their lowest, averaging 3.29±4 SD (8 yr data). Numbers climb rapidly through the autumn months (Fig. 2). September appears to be the most variable month. Flatworm numbers are obviously correlated with rainfall (however totalled) and negatively correlated with temperature (Table1; Fig. 1).

TABLE 1

Spearman's rank correlation coefficient of the number of flatworms each month against the given factor. * - P = 0.05-0.01; ** - P <0.01. N = 89 months unless otherwise stated.

	Spearman's Rho
Rain, same month	0.284**
Smoothed (*4253H, twice*) rainfall	0.330**
Rain previous 2 months total	0.542**
Rain previous 3 months total	0.551**
Daily maximum air temperature (n = 58)	-0.733**
Soil temperature (n = 58)	-0.679**
Soil moisture (n = 58)	0.601**
Water table (n = 17)	-0.533*

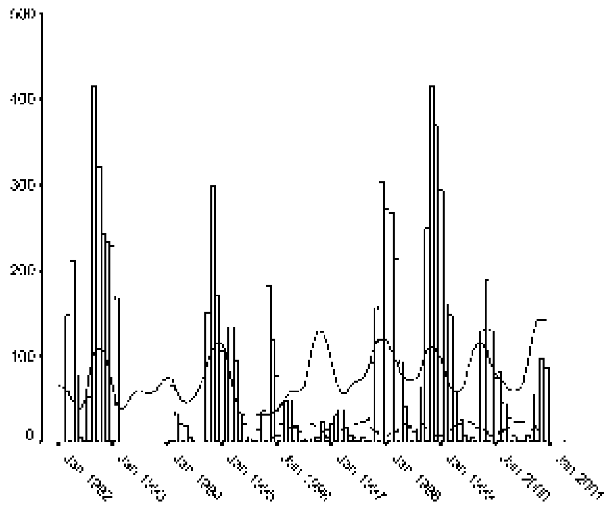

Fig. 1. – Number of flatworms (bars), smoothed rainfall (mm, continuous line) and maximum daily air temperature (°C, dashed line) each month. From March 1992 to January 1995 flatworm numbers were recorded but not collected (except from March 1993 to January 1994 and from July to September 1994 – no data). After February 1995 flatworms were collected. Monthly rainfall has been smoothed using *4253H, twice* smoother in SPSS.

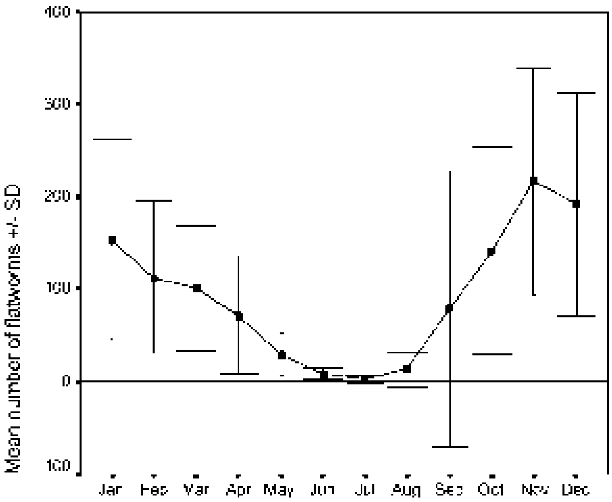

Fig. 2. – Mean (±confidence interval) monthly (a) worm numbers and (b) rainfall (mm). All data included from 1992.

Flatworm numbers vary between years (Fig. 1). The autumn-winter of 1992-3 and of 1998-9 showed the highest numbers. Over the autumn-winter of 1996-7 numbers were extremely low. In most years there was a clear autumn-winter peak in rainfall (Fig. 1). However, rainfall over the autumn-winter of 1996-7 was not particularly low, but that of previous summer, autumn and winter, 1995-6, was (Fig. 1) and 1995 was the hottest summer for 200 years. There is a striking parallel between the low rainfall of autumn-winter 1995-6 and the low flatworm numbers of the following autumn-winter, 1996-7.

Monthly size-frequency

For all years combined, flatworms are heaviest in March (Fig. 3). Weight is particularly variable between May and September. Weight-frequency for each month (all years combined) is shown in Fig. 4.

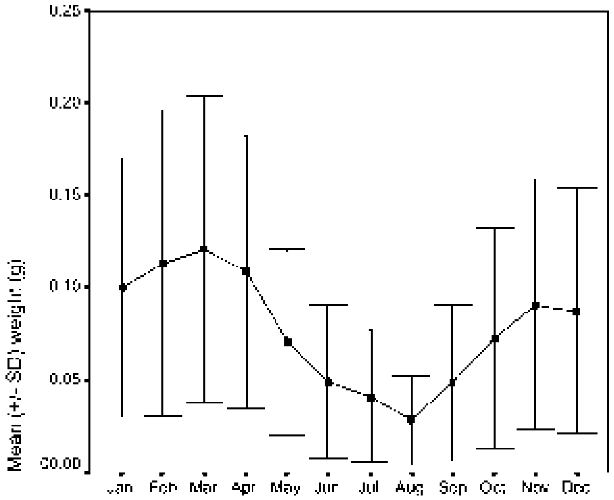

Fig. 3. – Mean (± 95% confidence interval) weight (g) of collected flatworms from February 1995 to September 2000.

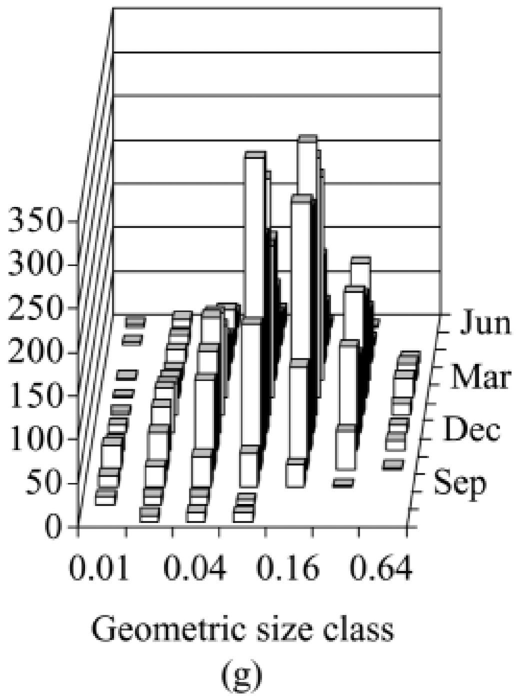

Fig. 4. – Weight frequency (geometric size class) of flatworms collected for each calendar month. All data from February 1995 to September 2000 pooled.

Maturity

Fig. 5 illustrates the proportion of mature specimens for each month from February 1995 to February 1999. Specimens as small as 9.5 mm long are mature. 80% of the specimens examined possessed an open gonopore and were judged to be mature. Partially mature and immature specimens appear to be in the majority August to October 1995, August to October 1997 and July 1998 (1996 data was pooled over these months). This suggests that partially mature and immature specimens may predominate between July and October.

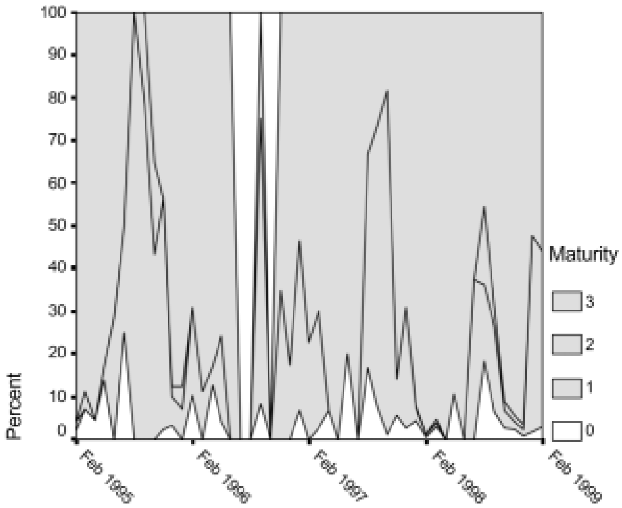

Fig. 5. – The proportion of mature specimens in each monthly collection between February 1995 and February 1999. See *Materials and Methods* for explanation of the assessment.

Allometry

Fig. 6 shows the relationship between body length and weight. Correlation equations are given in the legend. Body width varies against body length as follows: width = 1.415 (±0.033 SE) + 0.0089 (±0.001 SE) length, r = 0.761.

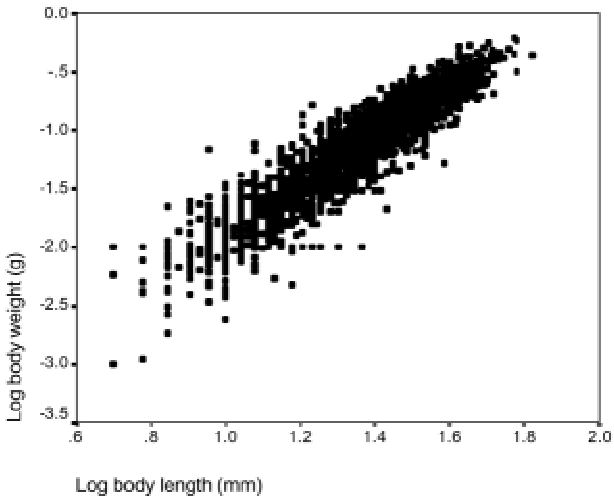

Fig. 6. – Scattergraph of $\log_{10}$ body length (mm) against $\log_{10}$ body weight (g). Regression equation: log weight = 2.093(±0.012 SE) log length – 3.961(±0.016 SE).

DISCUSSION

There is a clear autumn-winter peak in flatworm numbers each year. The population grows from a seasonal low in July to a seasonal maximum in November. From 1992 to 1997, though the data are incomplete, seasonal maximum numbers declined each year. We suggested then (JONES et al. 1998) that the flatworm population might have reached a low level after an initial population explosion, a feature common with introduced species. Numbers since 1997 have been high each winter (Fig. 1) which tends to negate that suggestion.

The low flatworm numbers of autumn-winter 1996-7 followed the low rainfall of the previous autumn-winter (Fig. 1). There has not been another such a dry winter over the recording period, but it is suggested that the latter was a major cause of the former. Subsequent winters have been as wet or wetter than usual and flatworm numbers have been high.

The regular collection of flatworms might itself affect numbers. However, in recent years, numbers have remained high in winter months even though they have been regularly collected over nearly six years. Clearly the reproductive capacity of the flatworm is capable of keeping pace with regular collection.

JONES et al (1998) concentrated on rainfall as the factor likely to be most significant in affecting the number of flatworms found, though acknowledging that other factors such as the summer rise in temperature and soil moisture deficit were probably involved. The initial data suggested that flatworm numbers correlated best with the previous 2 months rainfall (JONES et al., 1998). The longer data set presented here shows that flatworm numbers correlate positively with rainfall (with a slight lag, the peak in flatworm numbers is a month or two after maximum rainfall, Fig. 1) and soil moisture, and negatively with soil and air temperature (Table 1). Surely a combination of moisture and temperature is the ultimate factor in determining how many flatworms are found under objects resting on the soil surface. The low numbers in May, June, July and August are probably the result of surface dryness and lowered water table resulting from increased temperature, transpiration and reduced rainfall.

Mean size of flatworms is minimal in August (though variable) and then increases (with a slight decline in December) to a maximum in March (Figs 3 & 4). Thus growth of flatworms takes place over autumn, winter and early spring. The appearance of relatively large specimens, as well as small ones, in September and October (Fig. 4) suggests that flatworms may have been residing at some depth in the soil over the dryer period. Numbers of small individuals (probable hatchlings) are at a maximum between July and October (Fig. 4), even though absolute numbers are small, and immature specimens are most abundant between July and October (Fig. 5). All this suggests that juveniles appear in the population roughly between July and October. This provides some confirmation of the suggestion by JONES et al. (1998) that the flatworms may breed and lay egg capsules in the late Spring (April, May, June) as soil dries out, and that they hatch as conditions (soil wetness) improve in October. This is despite the fact that over the entire period of observations only four egg capsules have been found. (On 31 July 2000 a hatching egg capsule, only the fourth capsule to be found at the site, was found, photographed and preserved.) If egg capsules are being laid, then clearly most are not being laid near the surface or more would have been recorded. Asexual fission has been observed occurring during the winter when conditions are benign. JONES et al (1998) proposed that a cycle of reproduction occurs: sexual when conditions deteriorate, asexual when conditions are benign. MATHER & CHRISTENSEN (1996) found that egg capsules of this species were abundant at a location in New Zealand.

The data have been collected over eight and a half years. Any one year's data, though giving some indications, is unlikely to show typical cycles, particularly so soon after the initial infestation in December 1991. The data illustrate value of a long term and continuing data set in population studies.

The weight of most organisms showing isometric growth increases in proportion to the cube of length, giving a log:log slope (exponent) of 3. The log:log slope in this case is 2.093 (Fig. 6) which, though statistically different from 2, indicates that body weight increases as the square of length rather than the cube. This is to be expected in flattened animals such as these. As the slope is 2.093 rather than 2, a slight dorso-ventral thickening may take place as size increases. In Platyhelminthes generally, the lack of a circulatory system particularly limits growth in the third dimension. Body width in this species varies as 0.088 of the body length.

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