The key to success: an investigation into oviposition of the salvinia weevil in cool climate regions

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Summary In cooler climates of Australia, where salvinia (*Salvinia molesta* D.S.Mitchell (Pteridophyta: Salviniales) is rapidly becoming a major problem, long-term establishment of the salvinia weevil (*Cyrtobagous salviniae* Calder and Sands (Coleoptera: Curculionidae)) has not yet been achieved. Biological control appears to offer the only cost-effective and long-term solution to salvinia but until the agent is successfully established, ongoing use of expensive chemical and mechanical control methods are required.

The reasons that the salvinia weevil is failing to establish in cool climates are not fully understood. This paper describes preliminary studies on oviposition of the salvinia weevil at low temperatures as part of an investigation into the breeding ability of the weevil in temperate zones.

The effect of air and water temperatures on the oviposition of the weevil in climate-controlled cabinets, and a glasshouse has been investigated and results are discussed.

In understanding cool temperature effects on oviposition of the weevil, a significant contribution could be made towards the long-term management of salvinia in temperate climates.

Keywords Salvinia, biological control, *Cyrtobagous salviniae*, weevil, temperate, climate.

INTRODUCTION

Salvinia invades both temperate and tropical waterways in Australia. The spread of salvinia, since its introduction to Australia in the early 1950s, is directly linked to human activities, particularly through the aquarium industry.

Salvinia is a free-floating, sterile, aquatic fern, which reproduces by vegetative growth and fragmentation (Loyal and Grewal 1966). In its native range, it is often part of a mixed community of floating and emergent plants and is kept under control through a balance between the plant and its natural enemies (Forno and Bourne 1988). Elsewhere, salvinia forms dense monocultures and kills submerged plants by preventing light from entering the water. In its optimum temperature and nutrient range, salvinia has the ability to grow rapidly and double its biomass in two days (Parsons and Cuthbertson 1992). Salvinia is most amenable to establishing in still or slow-moving water that has resulted from reduced flows and water control structures such as dams (Mitchell 1972). The optimum growth rate of the weed occurs at a temperature range between 20–30°C, but plants can cope with short periods above 43°C and light frosts of −3°C (Room and Julien 1995). Based on temperature tolerance of salvinia all areas of Australia have climatic conditions that favour the growth of salvinia.

Mechanical and chemical controls can provide some immediate short-term options but, where water is used for drinking, recreation and fishing, the only environmentally-friendly and safe tool is biological control which can offer sustainable and economical control of salvinia. The discipline of biological control of weeds has made significant contributions to the knowledge of plant-insect interactions.

In many tropical and subtropical regions, salvinia has been controlled by the introduction of the salvinia weevil (Room 1986, Room *et al.* 1981 and Thomas and Room 1986). Although the release of the salvinia weevil in tropical and subtropical areas was carried out with minimal pre-release studies based on host specificity, it showed consistent success (Thomas and Room 1986). The weevil has been successful as a biological control agent in at least 11 countries worldwide (Julien *et al*. 2002).

While a range of relevant post-release research has been carried out on the biology of the salvinia weevil for tropical and subtropical climates there is a lack of both field trial experience and experimental evidence for weevil behaviour in temperate climates.

Releases of the salvinia weevil were made in the Hawkesbury-Nepean River System in October 2004 by the NSW Department of Primary Industries and monitoring is still being carried out by this paper's second author. This research, along with the present study, will help to clarify the requirements and limitations of the weevil in this environment. Preliminary results from these field trials that indicate the salvinia weevil is able to overwinter and has the ability to control salvinia at several sites in the Hawkesbury (pers. obs.) are encouraging. It has also been reported that the weevil survived temperatures as low as −9°C in the USA (Tipping and Center 2004).

Thomas and Room (1986) suggested that temperature, one of the major factors influencing the development of the weevil, was likely to be the most important factor in determining the success or failure of the salvinia weevil in controlling salvinia. The optimum temperature for an aquatic insect is defined as that at which the insect's fecundity is maximised (Vannote and Sweeney 1980).

At constant temperatures, Forno *et al*. (1983) reported maximum numbers of eggs at 23°C or 27°C and negligible egg-laying below 21°C (0.041 at 21°C and 0.019 eggs per day at 19°C). This leads to the assumption that the weevil might not be suitable for temperate climates. This study used weevils that had been reared at 27°C and transferred to cooler experimental temperatures.

This paper provides preliminary data on the ability of the female weevil to lay eggs at lower temperatures than previously demonstrated when brought from a cooler temperature up to the experimental temperature. These findings are discussed with regard to the question of whether the salvinia weevil represents a viable option as a biological control agent of salvinia in temperate climates.

MATERIALS AND METHODS

New plant colonies were grown from collected material from the Hawkesbury River in an insect proof glasshouse. Salvinia colonies consist of ramets interconnected with branching rhizomes (Room 1983). New growth occurs at terminals on the main branch and on side branches. For the experiments fresh terminal growth of secondary stage salvinia (Mitchell and Thomas 1992) was used, containing at least two floating leaves and a third leaf, which is submerged in the form of a root-like structure. Each plant used contained two growing tips or buds, which the weevils favour for feeding (Forno and Bourne 1985). The design of the experiment followed the design of Forno *et al.* (1983). Oviposition in regard to low temperatures was investigated in controlled environmental cabinets at constant temperatures. Newly-emerged adults were maintained at 27°C for 14 days to mate. Female weevils were then selected by isolating individual weevils on a single plant each in their own container and then examining each plant microscopically for eggs after 24–48 hours. Actively laying females were divided into two groups of 14 and 15 weevils. The first group was placed in a cabinet at 27°C and the second at 13°C for 4 days (to acclimatise weevils to warm or cold conditions). Groups of five weevils (one group of four) were then placed in constant temperatures of 17°C, 18°C and 19°C, with one group from the cold and one from the warm treatment at each temperature. After eight days with scarcely any eggs laid, it was decided to transfer all the weevils to 19°C. All weevils were then kept at 19°C for a further 27 days, and regular counts of eggs laid were made. A control group of five weevils was placed at 27°C for the duration of the experiment.

Temperatures were monitored using Hastings Dataloggers, and all air temperatures were within + or −0.5°C and water temperatures were generally 1°C lower than the air temperature.

RESULTS

Including the total number of eggs laid per female over the duration of the experiment; there is no significant difference between the cold and warm treatment groups. If the eggs laid during the first four days of cold or warm treatment are discounted, the mean number of eggs laid per female transferred from cold to warm (see Figure 1) was 3.5 eggs per female (or 0.13 per day), while the mean number of eggs laid by weevils that were moved from warm to cold (see Figure 2) was 1.1 egg per female, or 0.04 per day. There was in this case

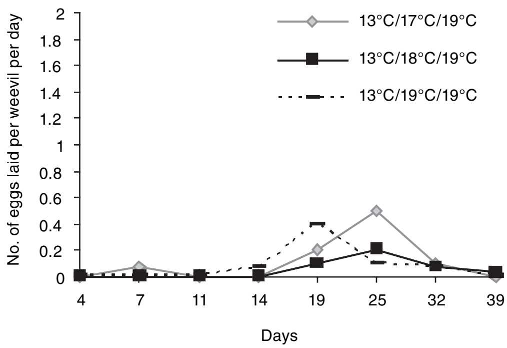

Figure 1. Egg laying pattern of weevils taken from cold to warm constant temperatures.

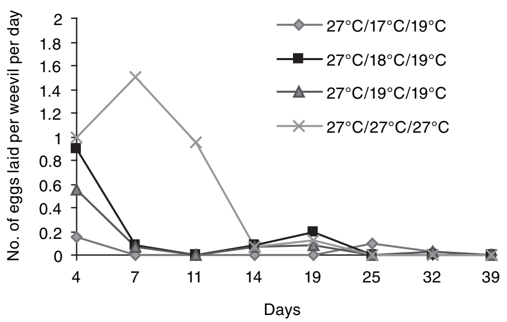

Figure 2. Egg laying pattern of weevils taken from warm to cold constant temperatures.

a significant difference between the two treatments. These eggs were laid over a period of 27 days.

During the last week of the experiment only one egg was laid by a weevil in the cold treatment group.

The weevils which had been exposed to 27°C for the first four days laid 64% of their eggs during those days and laid the remaining 35% of eggs sporadically over the next 27 days.

The cold treatment weevils, in contrast, laid no eggs for the first four days, and began laying their eggs 16 days after removal from 13°C. Once they had started laying eggs the cold treatment group laid eggs at a rate of 0.25 per day for 13 days. The control group, which remained at 27°C for the whole duration of the experiment, laid an average of 0.45 eggs per day per female, but the eggs were all laid during the first 12 days of the experiment.

DISCUSSION

The results confirm the hypothesis that weevils will lay more eggs at a lower temperature if previously exposed to a cool treatment. This is in line with work on other aquatic insects that show that insects respond to accumulation of heat units (usually referred to as degree days) as well as absolute temperatures (Ward and Stanford 1982).

The results suggest that in previous experiments weevils had laid all their eggs at 27°C before being transferred to cooler temperatures. Those exposed to cold treatment laid all their eggs at 19°C although it took 16 days for them to begin laying. Further experimentation is required to ascertain whether, if enough time were given, weevils would indeed begin to lay at temperatures even lower than 19°C.

The cold temperature weevils, once laying, laid 0.25 eggs per day, which seems a small number until compared with the maximum number of eggs achieved by Forno *et al*. (1983), which was 0.59 eggs per day at 23°C.

It appears that, at least under experimental conditions at constant temperatures, female salvinia weevils do not lay large numbers of eggs. The design of the experiment where each weevil is kept on a single plant, to reduce time spent dissecting and counting eggs, means that food and space for laying eggs is reduced. It is possible that in the field, with unlimited food, and at fluctuating temperatures many more eggs may be laid.

The fact that weevils have been shown to lay eggs at 19°C, at least two degrees lower than previously believed is an encouraging sign for biological control of salvinia in temperate areas.

It had been thought that low temperatures would limit the weevil as a viable control option in temperate climates but the fact that the optimum temperature for salvinia growth is 20°C and above (Room and Julien 1995) means that it is not essential for the weevil to be reproducing much below this temperature.

These results were achieved under constant temperatures and current investigations are under way on fluctuating temperatures. Studies on other aquatic insects suggest that oviposition and egg hatch may occur at lower temperatures when experienced as part of a fluctuating as opposed to constant temperature regime and that female fecundity may also be greater under fluctuating temperatures, which are closer that those experienced in the natural environment (Baskerville and Emin 1968, Vannote and Sweeney 1980 and Ward and Stanford 1982).

In the meantime, these results from constant temperature trials are significant for biological control of salvinia and support anecdotal reports that the salvinia weevil has had some success in the Sydney region.

Further study is needed on the complete life-cycle of the salvinia weevil at its lower temperature limits, in constant and fluctuating temperatures as well as analysis of the actual temperatures experienced by the weevil in the field in temperate climates.

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