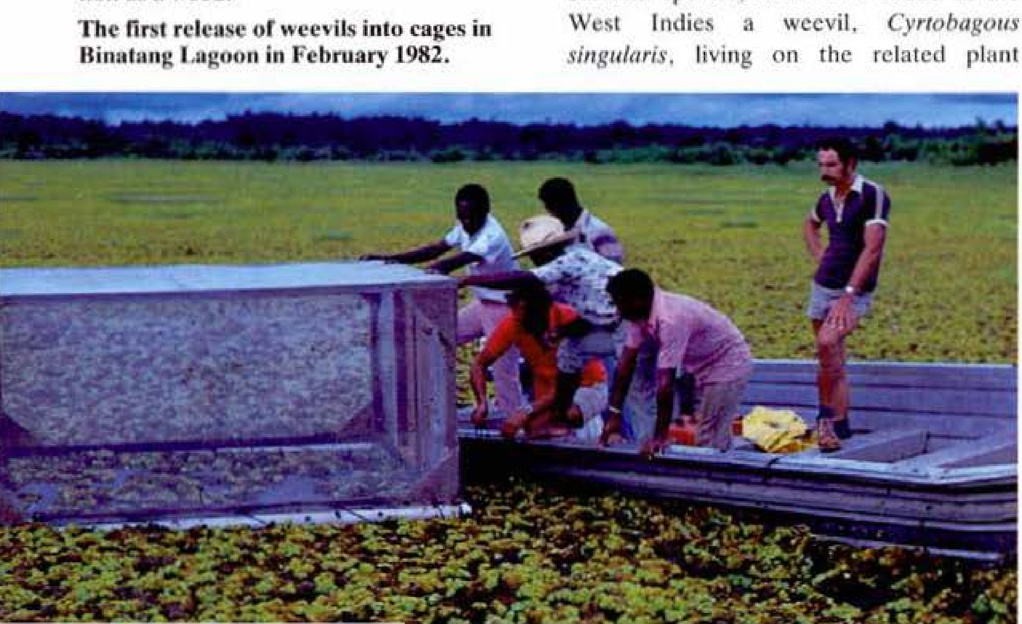
Weevils take on the water weeds

As city-dwellers, most of us tend to think of water weeds as aesthetically pleasing clumps of greenery that grace home aquaria or ornamental ponds. But in many tropical and subtropical regions, including northern Australia, weeds like salvinia and water hyacinth have a devastating effect, proliferating rapidly to suffocate water bodies.

In Papua–New Guinea, lakes and rivers choked by salvinia have disrupted local transport and communication, prevented villagers from gathering traditional foods, and obstructed access to hospitals and schools.

The main elements that add up to salvinia's success are easy to explain. Salvinia (*Salvinia molesta*) is a fern, a more primitive relative of flowering plants. The plant is sterile and reproduces by budding off new plants. Under optimal conditions, a group of plants may double in size within two days. Because it spreads quickly in environments where its natural enemies are absent, the plant has earned its notorious reputation as a weed.

The first release of weevils into cages in Binatang Lagoon in February 1982.



Salvinia's introduction as an aquarium plant to areas outside its natural home in Brazil and subsequent attempts to control its spread were described in *Ecos* 20. Briefly, during the past 30 years man served as the 'vector' of infestation, and early attempts to control the weed with herbicides or by harvesting proved unsuccessful.

In the 1970s, the Commonwealth Institute for Biological Control (CIBC) decided to see whether the plant's predators in its native range in South America could serve as biological control agents. However, *S. molesta* was not then known to be a separate species, different from other *Salvinia* species, and CIBC found in the West Indies a weevil, *Cyrtobagous singularis*, living on the related plant

An adult salvinia weevil.

S. auriculata. Predator–host relations are often very specific, and this weevil had little impact on the pest species *S. molesta* in Africa and Fiji.

Salvinia molesta was recognized as a distinct species in 1972, and in 1979 Dr Ken Harley and Dr Wendy Forno, of the CSIRO Division of Entomology, working at the Organization's former biological research station at Curitiba in southern Brazil, discovered its native range. There they found that three agents — a weevil, a moth, and a grasshopper — kept the plant in check. Dr Forno, Dr Don Sands, and Mr Bill Sexton tested the weevil, which was first thought to be a strain of *C. singularis*, for its host specificity, to ensure that the insect would not attack native Australian plants and economically important species. Dr Peter Room then let the weevil loose on Lake Moondarra, Mt Isa's salvinia-infested water supply reservoir.

The rest of that story, told in *Ecos* 32, is history. Within 10 months, the weevils had disposed of the 50 000 or so tonnes of salvinia that had carpeted the lake.

Dr Sands has since identified the weevil as a new, undescribed species. He is completing a taxonomic description of it and mapping its known distribution.

The subsequent battle against salvinia in Australia will be described later. First — an account of the most recent salvinia-control success.

Salvinia in the Sepik

Papua–New Guinea's largest river, the Sepik, meanders through an extensive flood-plain, and over the centuries has pinched off a series of about 200 large billabongs or ox-bow lakes. These form as the river short-cuts through old U-bends in its course. Most of the lakes support wide mats of salvinia, which has been spread by man and by seasonal flooding. Huge agglomerations of the weed also get swept out to sea, where they die (they are later washed up as debris along the coastline, west of the Sepik delta).

Salvinia doesn't pose much of a problem in the river itself, where powerful currents prevent it accumulating. But on the ox-bow lakes and side-channels, sites of many villages, the weed has affected more than 500 sq. km of water. It has completely covered 200 sq. km of the water surface.

This situation is disastrous to a population dependent on water transport for food, communication, health care, and trade. People living in the Sepik area use canoes for harvesting sago palm, their staple food; for fishing; and for access to markets, hospitals, and other facilities. Roads are non-existent in most of the region because of the extensive swamps and annual flooding in the area.

The Papua–New Guinea government approached the United Nations Development Program (UNDP) to help them eradicate the weed from the Sepik. A collaborative UNDP–Papua–New Guinean salvinia control project was set up and a co-ordinator, Mr Phil Thomas, was appointed. Part of the project involved training Papua–New Guinean staff.

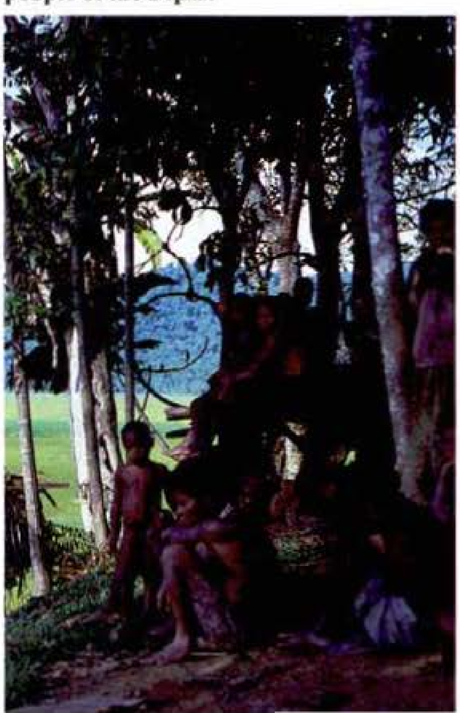
At first, the team used control measures such as herbicide (paraquat) and floating booms. In the Sepik lakes, the plant was doubling every 8–9 days, making these methods completely uneconomic for long-term control. Following the Lake Moondarra success, the UNDP group decided that biological control was their only hope, and in 1982 Dr Peter Room of the Division of Entomology's group at CSIRO's Long Pocket Laboratories in Brisbane visited the Sepik River area to initiate the current project.

The Sepik River and some of its ox-bow lakes.

The control team, led by Dr Room and Mr Thomas, established bases at either end of the badly affected section of the Sepik. They released the weevil in two floating 'cages', each 4 sq. m in area, on Binatang Lagoon near Angoram in the eastern Sepik region. On checking the progress of the weevils 7 months (about four weevil generations) later, they discovered that, instead of thriving, the weevil population had dropped from 600 to 40. What had happened?

A group of plants may double in size within two days.

When they released the insects, the scientists noticed that the salvinia in the lagoon appeared yellowish — a sign of nutrient deficiency. To confirm this, they hung a pierced plastic bag, containing 2 kg of nitrogen–phosphorus–potassium fertilizer, just below water level in each cage, where it acted as a slow-release nutrient dispenser.



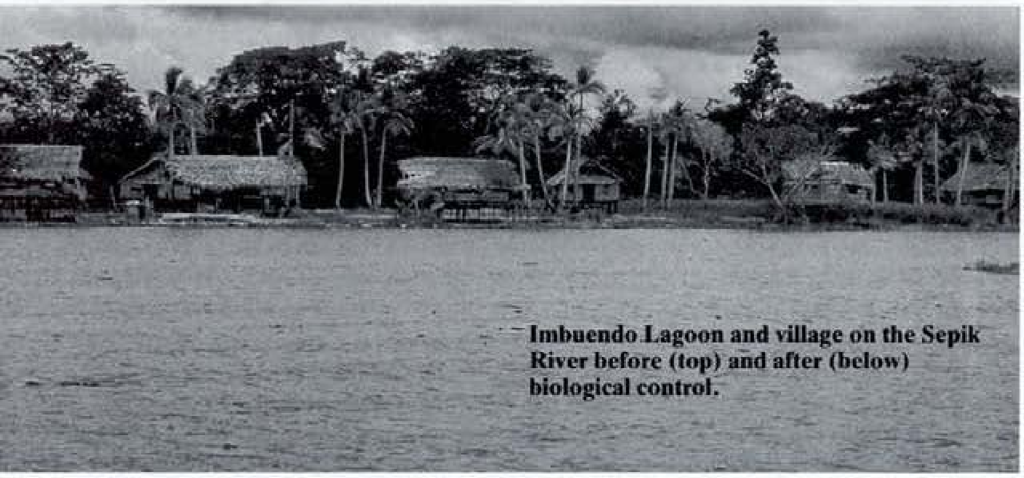
Salvinia has caused many problems for the people of the Sepik.

Among the disappearing insect populations in the cages, most of the survivors clustered around the bags of fertilizer. Dr Room's analysis of the salvinia plants showed that the original nitrogen levels in the Sepik lagoon were much lower than those at Lake Moondarra, while phosphorus levels were higher. Support for the conclusion that salvinia's predators can be restricted by low nitrogen levels came from studies by Dr Sands and his co-workers, who showed that nitrogen in salvinia affected larval development and damage to the weed.

The CSIRO–UNDP team introduced a new supply of weevils into Binatang Lagoon, and this time sprayed the weed inside the cages with urea, a nitrogenous fertilizer. Two months later, the weevil populations had doubled and 90% of the salvinia buds had been damaged. The added nitrogen had enabled the weevils to breed rapidly.

Spraying the whole Sepik River lagoon system with expensive nitrogen fertilizer appeared an impossible solution. However, when the scientists released the weevils from the cages, the population unexpectedly shot up, despite the low concentrations of nitrogen in the surrounding salvinia.

The explanation for the successful release ironically appears to be that, by damaging its host, the weevil improves the quality of the host plant as food. The adult weevil attacks the growing buds of salvinia, leaving the roots, which continue to take up nitrogen, intact. Consequently, the remaining buds and leaves receive proportionately more nitrogen. In addition, the dead and dying plant matter releases nitrogen back to the roots for further redistribution.



Imbuendo Lagoon and village on the Sepik River before (top) and after (below) biological control.

Dr Room and Mr Thomas have proposed that a 'critical' population density of the insect exists for particular combinations of population density and nitrogen content of salvinia; below this critical density, the insect population declines, and above it the population increases.

The Sepik trial is the first recorded case of a fertilizer aiding the introduction of a biological control agent for water weeds. Dr Room believes that the results also suggest a reason why some biological control programs elsewhere have failed — nutritional inadequacy of the host plant leading to failure of the agents to establish.

Since the Binatang trial, the salvinia control team has introduced weevils into 40 other lagoons in the middle and lower (eastern) Sepik area. The insects have established viable populations at 30 of these; 10 sites are showing signs of severe damage to the weed and three are effectively cleared. Of the 15 lagoons in the upper Sepik region where weevils have been released, at least four have a firmly established weevil population. By transporting damaged weed along the river, the people living along the

Biological control of water weeds

All things are relative, and weed growth is no exception. Weeds are frequently plants that, although inconspicuous in their home range, proliferate excessively after being introduced to a new region, free from their natural predators. Biological control programs seek to re-establish the balance between a plant and its predators.

In Australia, most of the more destructive aquatic weeds are introduced plants. Free from their enemies, they overwhelm native aquatic plants (and hence native wildlife), limit the use of water and water bodies, reduce water quality, block pumps, encourage mosquito breeding, increase health hazards, increase water loss through the process of evapotranspiration, and increase silting and the severity of flooding.

Insects have been used to control land-living weeds for more than a century. But not until 1964, when the alligator weed flea-beetle was released in the United States, were insects used against water weeds. Overseas, the United States Department of Agriculture (USDA) and the Commonwealth Institute for Biological Control (CIBC) have been particularly active in research. USDA has focused on alligator weed (*Alternanthera philoxeroides*) and water hyacinth (*Eichhornia crassipes*). The British unit has studied water hyacinth and salvinia(*Salvinia molesta*).

These efforts influenced the establishment of CSIRO's biological weed control program in Australia. The Division of Entomology began work on water hyacinth in 1975, alligator weed in 1976, and salvinia and water lettuce in 1978. All of these weeds originated in South America. The Division's Biological Control Unit in Curitiba, Brazil, combed the region for control agents for these weeds.

Although the concept of biological control is simple, the practice is far more complicated. Most importantly, any natural enemies introduced must be tested for host-specificity — that is, they must not be capable of attacking non-target native or introduced vegetation. Further, the insect or plant pathogen introduced must be free of its own natural enemies.

The Division of Entomology's Dr Ken Harley, a veteran of aquatic weed control programs, has outlined the procedure for introducing and maintaining a biological control agent. Firstly, scientists have to establish the taxonomic position of the weed and define its native and adopted ranges and the ecological conditions under which it grows. Natural enemies are then selected and their identity, biology, and host-specificity studied. Using quarantine facilities, scientists test 'starter colonies' of the control agent from the native range and eliminate any parasites, predators, or disease.

Carefully selected agents are finally released from quarantine and mass produced for field trials. The next important step is monitoring for establishment, spread, and effectiveness of the agent against the weed. An entire program may require up to 10 years to complete.

Researchers need to consider possible effects of weeds on each other. For example, the progressive control of water hyacinth in some areas of Australia may merely open up the same areas to salvinia invasion. This is why Dr Harley initiated programs against water hyacinth, alligator weed, salvinia, and water lettuce within a short period of time.

Water hyacinth occurs along the eastern coast from Sydney to southern Cape York Peninsula, on western Cape York Peninsula, inland near Moree and Mt Isa, and near Darwin and Perth. Work on its biological control began with the introduction of a South American weevil, *Neochetina eichhorniae*, from the USDA laboratories in Florida. Since its release in Australia in 1975, this weevil has become established on numerous weed infestations along the eastern coast.

Mr Samson Laup of the PNG Department of Primary Industry counting the weevils in a sample.

Sepik are now involved in the process of spreading the control agent.

Dr Room believes that most of the salvinia will be destroyed within the next 2 years. The plant–weevil system should reach an equilibrium, leaving fragments of salvinia and small numbers of weevils to contain excess growth.

In Papua–New Guinea outside the Sepik area, scientists have released weevils on a weed-infested natural lake near Port Moresby, which happens to form part of the capital's sewage-treatment system.

In a project supported by the Australian Centre for International Agricultural Research (ACIAR), the weevil is to be introduced in Sri Lanka to control salvinia infestations there. And across the Indian Ocean, Dr Sands visited the African countries of Botswana and Zimbabwe in October 1984, also supported by ACIAR, to monitor the effect of the weevil there. Its progress is being compared with that of the unsuccessful weevil species, *C. singularis*, which CIBC had released into the swampy waterlogged Capriwi Strip.

Nitrogen and temperature

Together with nitrogen availability, temperature is an important factor controlling the growth of both salvinia and its natural enemies. Once an agent achieves control of a weed, different combinations of climate and nutrition can change the relations between weed and insect.

Since its release in Australia on Lake Moondarra, the salvinia weevil has become established at Lake Julius (also near Mt Isa), at Darwin and Nhulunbuy in the Northern Territory, and at sites along the eastern coast including the Atherton Tableland, Ingham, Cairns, Townsville (where the weevil is being released in the Ross River), Rockhampton, and Nambour. The CSIRO scientists are also monitoring weevils released near Sydney, where low winter temperatures are slowing their growth.

Most salvinia infestations occur east of the Great Dividing Range between Newcastle (33°S) and Cairns (17°S) with isolated infestations in, or near, Sydney, Melbourne, Perth, Darwin, Nhulunbuy, and Mt Isa. Dr Room believes that chemical analyses of both infested and uninfested waters west of the Great Dividing Range, carried out by the Queensland Department of Primary Industries, suggest that the weed has yet to reach its ecological limits in Australia.

Dr Forno and Dr Sands have been studying factors that affect the activity of the weevil in the laboratory. Dr Sands found that it required certain minimum temperatures for various developmental stages:

At Cattle Creek near Ingham, Qld, a low bridge over swampland was, until 1980, in danger of being swept away by the pile-up of water hyacinth during floods. After the beetle's introduction, the water eventually cleared and the area has now been recolonized by water-lilies.

The CSIRO team selected the moth *Sameodes albiguttalis* as a second control agent in Australia, and this too established itself successfully. However, the beetle has been the most damaging agent and water hyacinth is now under control in most areas of northern Queensland and, to a lesser extent, further south.

Dr Sands and Mr Richard Kassulke of the Division of Entomology have studied the biology and host-specificity of another moth, *Acigona infusella*, in quarantine in Australia. In starvation tests — in which they kept the moths on test plants until the insects either ate or died — the moths only developed completely on water hyacinth and the related pickerel weed.

As with the salvinia moth, *A. infusella* is prone to infection, in this case by a parasitic protozoan microsporidian. When Dr Sands and Mr Kassulke eliminated the pathogen from the quarantine sample, the moth's larval mortality decreased and its egg-mass size increased, suggesting that these insects should perform more effectively as biological control agents in Australia than in South America.

Dr Sands believes that tunnelling by larvae of the water hyacinth moth should complement damage by the two agents already established here. *Acigona infusella* was first released at two localities near Brisbane in September 1981, but its establishment has not been confirmed. Its effect may have been masked by the intervention of the 1982–83 drought. Mr Tony Wright of the Division is currently assessing the results of field trials.

Dr Forno studied the life history and biology of yet another water hyacinth moth at the CSIRO field station in Curitiba. Its potential as a biological control agent remains to be evaluated.

Another South American import is alligator weed, which takes root in the banks of lakes, streams, and canals. Alligator weed has a limited distribution near Newcastle, Liverpool, and Albury, in New South Wales. In the right conditions, it grows outwards onto the water forming a thick, floating mat, which is replaced rapidly if swept away by floods or killed by herbicides.

Researchers from CSIRO began the biological control of alligator weed in 1977, with the release of the South American alligator weed flea-beetle *Agasicles hygrophila* from the USDA laboratories in Florida. A second insect introduced for control is the moth *Vogtia malloi*. Although these insects appear to be able to keep the floating mat at an acceptably low level, they can't control the weed growing on dry land.

The other water weed of South American origin subject to research at the Division's laboratories is water lettuce, *Pistia stratiotes*. A weevil, *Neohydronomus pulchellus*, has been released and has thinned out water lettuce at several sites. Strangely enough, the moth *Samea multiplicas*, a control agent for salvinia, appears to be a promising weapon in the battle against water lettuce.

Acigona infusella (Walker) (Lepidoptera: Pyralidae), an agent for biological control of water hyacinth (*Eichhornia crassipes*) in Australia. D.P.A. Sands and R.C. Kassulke. *Bulletin of Entomological Research*, 1983, **73**, 625–32.

Life history and biology of a water hyacinth moth, *Argyractis subornata* (Lepidoptera: Pyralidae, Nymphulinae). I.W. Forno. *Annals of the Entomological Society of America*, 1983, **76**, 624–7.

Biological control. K.L.S. Harley. In 'Water Plants of New South Wales', ed. G.R. Sainty and S.W.L. Jacobs. (Water Resources Commission of N.S.W.: Sydney, 1981.)

Samea multiplicalis (Lep.: Pyralidae), for biological control of two water weeds, *Salvinia molesta* and *Pistia stratiotes* in Australia. D.P.A. Sands and R.C. Kassulke. *Entomophaga*, 1984, **29** (in press).

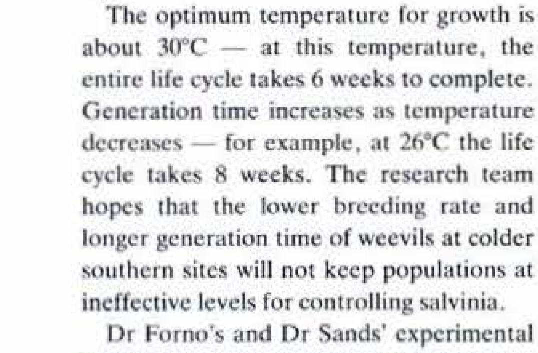
Locations in Papua–New Guinea and northern Australia where the salvinia weevil has become established. The green section marked on the Sepik River is the area in which the insect has been released.

19°C for egg hatch; 16°C for larval development; 20°C for pupal development; 13°C for adult feeding; and 21°C for egg-laying.

The optimum temperature for growth is about 30°C — at this temperature, the entire life cycle takes 6 weeks to complete. Generation time increases as temperature decreases — for example, at 26°C the life cycle takes 8 weeks. The research team hopes that the lower breeding rate and longer generation time of weevils at colder southern sites will not keep populations at ineffective levels for controlling salvinia.

Dr Forno's and Dr Sands' experimental studies have identified the secret of the salvinia weevil's success — its mode of attack. Salvinia forms colonies of individual plants, each held together by a single, usually branched, horizontal 'stem' or rhizome. Each plant consists of three leaves, a growing bud, and several dormant buds. Two of the leaves are green and float on the surface of the water; the frond of the third leaf is split and hangs down in the water like a root.

A yellow-brown weevil larva tunnels inside a salvinia rhizome.



A rhizome of salvinia rotting after an attack by a weevil larva.

Adult weevils feed on the emerging buds of new clusters, suppressing growth and branching of the weed, while the weevil larvae tunnel through rhizomes, especially the younger sections. So, as well as literally nipping the weed in the bud, the weevil destroys the vascular bundles — which transfer water, carbohydrates, and nutrients throughout the plant — at the core of the rhizome. The rhizome also contains air-filled tissue that buoys up the plant. Eventually, the salvinia rots and sinks to the bottom. Other species, like *Cyrtobagous singularis*, feed mainly on other parts of the plant, leaving more of the growing buds and rhizomes intact.

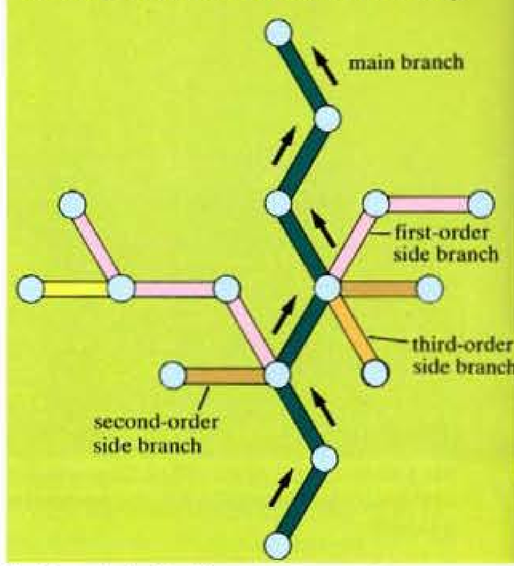
The preference of larvae for young rhizome sections may be tied up with the species' demonstrated nitrogen requirement — newly grown rhizome sections in salvinia contain higher levels of nitrogen than older ones.

Modelling the problem

Dr Room has used computer models in his study of salvinia to determine the significance of the plant's arrangement of rhizomes in its population ecology. In a 1983 paper, he presented a model he had developed relating rhizome growth to the production of side branches.

New colonies of salvinia, rather than growing from single plants, begin when the oldest rhizome segments of existing colonies break. Within the colony, the growing bud of each plant usually develops to extend its parent branch with a new one, while lateral buds may develop into the beginnings of side branches. The emerging plants and lateral buds alternate from side to side along a branch, producing a zig-zag pattern that enables growths to be traced and side branches to be distinguished from their parent branches.

Nutrient availability determines the extent of side branch formation. In



Each node in the diagram represents a group of fronds; the growth of the main branch is indicated by the arrows. Side branches continue to follow a zig-zag growth pattern and form new side branches. Nutrients determine the extent of side branch formation, with an abundance stimulating second- and third-rank growth.

nutrient-poor water, plants may not produce side branches at all, and they may obtain the nutrients that are in short supply from old, dying branches. But abundance of nutrients may stimulate so-called second- and third-rank lateral buds to develop. In most inland areas of Australia and Papua–New Guinea, waters are intermediate in nutrient richness, and occasional inflows of

How would two control organisms interact if released together?

nutrient-rich run-off result in short periods when all first- and some second-rank lateral buds develop. Third-rank side branches are commonly found only in colonies growing in nutrient-rich sewage-treatment lagoons.

The model reflects the way salvinia's branching system responds to resource availability, increasing its growth rate when nutrients are readily available. In 'average' waters, plants retain the potential for regrowth should any of their buds be destroyed.

Dr Room has used the model to examine the amount of damage weevils need to inflict to control salvinia. The model suggests that about half of the developing buds alone need to be destroyed to control weed populations. In some situations, damage may stimulate compensatory growth in the weed. Dr Room and Mr Mic Julien are evaluating how compensatory growth by the plant, combined with behavioural flexibility in the weevil, alter the effects of damage predicted by the model.

The model can be used to estimate the time taken for initial infestations to become economic problems, assuming a range of growth rates and areas of water. Salvinia generally reaches 'nuisance level' when plants loosely cover the water at a population density of about 1500 per sq. m.

What about the moth and grasshopper?

The other salvinia insects identified by the CSIRO team in Brazil have yet to match the performance of the voracious weevil. Dr Forno and Mr Martin Taylor at CSIRO are studying one of the them, the moth *Samea multiplicalis*, to see why it is not as effective as the weevil.

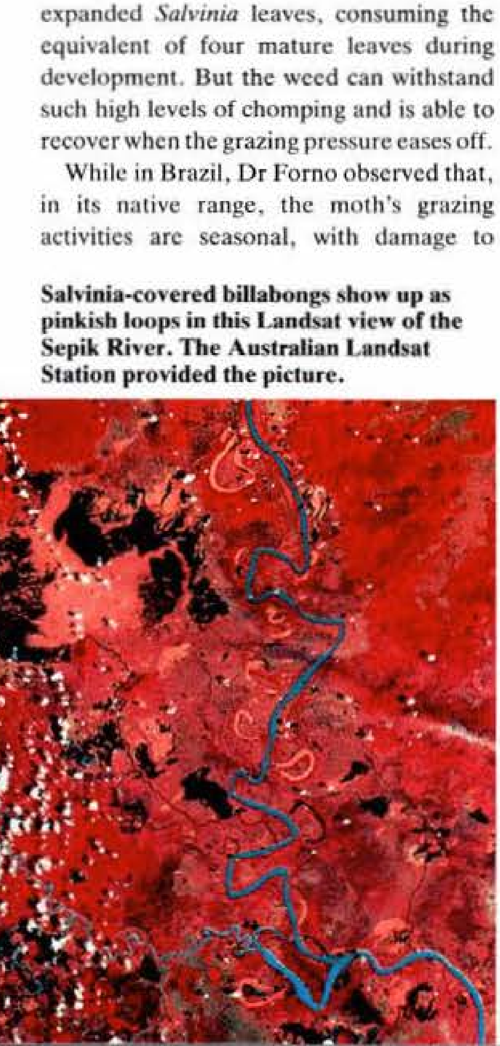
Dr Room released the moth at Lake Moondarra and then at the neighbouring Lake Julius. He also set 1000 of the insects loose at Ingham on the northern Queensland coast. Moth populations developed at all three sites, as well as spreading about 2000 km north and south within a few years.

However, while the weevil inhibited weed growth at most of its release sites, the moth did not achieve control at any of them.

The scientists conclude that the weevil's relative success is due to its strategy of attacking rhizomes and growing buds. The moth mainly damages larger fronds: its caterpillars chew holes through the expanded *Salvinia* leaves, consuming the equivalent of four mature leaves during development. But the weed can withstand such high levels of chomping and is able to recover when the grazing pressure eases off.

While in Brazil, Dr Forno observed that, in its native range, the moth's grazing activities are seasonal, with damage to

Salvinia-covered billabongs show up as pinkish loops in this Landsat view of the Sepik River. The Australian Landsat Station provided the picture.



The weevil on the road to success; it has turned this salvinia brown.

leaves increasing in spring and early summer. Further experimental work by Mr Taylor indicated that the optimum temperature for the moth's development is about 30°C, at which the life cycle takes about 24 days to complete. Increases in nitrogen content of the plant accelerate the larval development rate.

Although the moth can cause some damage to salvinia infestations, the weed regrows as soon as the insect population declines. Two things seem to cause population crashes of the moth — periods of high temperature, and infection by endemic parasites of similar native Australian moths.

The team hopes that the salvinia moth may prove more successful in the cooler, more southerly regions of Australia than in the tropics.

At Lake Moondarra, the increase in the moth population was stopped by the effects of the salvinia weevil, which had been released 6 months earlier. One of the problems facing scientists at the moment is predicting how the two control organisms would interact if released together.

At high population densities, the salvinia moth and grasshopper would probably compete for leaves, and the effect of these leaf-feeders would interact with damage caused to buds and rhizomes by the weevil. But would such interaction enhance control or would the insects interfere with each other?

An experiment is in progress in which the weevil and moth are being released separately, into two cages each, at each of three sites separated by 600 km on a north–south transect. The salvinia in one of each pair of cages is being fertilized with urea, and the scientists hope to gain useful information on the effects of climate and nutrition on interactions between the plant and its grazers. Results to date indicate that urea can greatly increase the rates of population growth of the plant and of both insects.

The grasshopper will not be released in Australia unless an evaluation of the other two species suggests that it could improve the degree of control achieved.

The results of further studies will be used to extend the existing models of weed growth to include the effects of interactions between the insects. The team plans to use the models to predict the geographical limits of the insects and the degree of control that could be established in different environments.

Mary Lou Considine

More about the topic

Establishment in Australia of insects for biological control of the floating weed *Salvinia molesta* Mitchell. P.M. Room, I.W. Forno, and M.F.J. Taylor. *Bulletin of Entomological Research*, 1984, **74** (in press).

A summary of research into biological control of salvinia in Australia. P.M. Room, D.P.A. Sands, I.W. Forno, M.F.J. Taylor, and M.H. Julien. *Proceedings, Sixth International Symposium on Biological Control of Weeds, Vancouver, 1984.*

Distribution, biology and host specificity of *Cyrtobagous singularis* Hustache (Coleoptera: Curculonidae) for the biological control of *Salvinia molesta*. I.W. Forno, D.P.A. Sands, and W. Sexton. *Bulletin of Entomological Research*, 1983, **73**, 85–95.

The feeding characteristics and development of larvae of a salvinia weevil *Cyrtobagous* sp. D.P.A. Sands, M. Schotz, and A.S. Bourne. *Entomologia Experimentalis Applicata*, 1983, **34**, 291–6.

'Falling apart' as a lifestyle; the rhizome architecture and population growth of *Salvinia molesta*. P.M. Room. *Journal of Ecology*, 1983, **71**, 349–65.

Samea multiplicalis (Guenee) (Lepidoptera: Pyralidae), for biological control of two water weeds, *Salvinia molesta* and *Pistia stratiotes* in Australia. D.P. Sands and R.C. Kassulka. *Entomophaga*, 1984, **29** (in press).