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Integrating biological and herbicidal controls to manage salvinia in Kakadu National Park, northern Australia

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Abstract. The salvinia weevil, *Cyrtobagous salviniae*, did not provide adequate control of salvinia, *Salvinia molesta,* in Kakadu National Park during the late 1980s. A three-year study began in 1991 and determined: the main weed-weevil-environment interactions; contributions by the weevil to reducing salvinia; and the reasons for the dramatic crashes in populations of the weevil at the end of each dry season. This information was related to seasonal phenomena to determine why in some years there is an accumulation of salvinia and ineffective biological control. A trial was conducted which indicated that application of the herbicide AF100 could reduce cover and biomass of salvinia when biological control was ineffective. The timing of application of AF100 was important to gain the full benefits of biological control, to conserve resources and to depress regrowth during the following dry-season. A management strategy was devised that included monitoring of the weed, the weevil, the onset-time of the annual monsoonal rains and the flood levels, to determine if and when additional control (application of AF100) was required. This is a rare example of the practical integration of biological and herbicidal controls, particularly in tropical ecosystems, and especially in an important conservation area where the use of herbicides is strictly controlled.

Introduction

Kakadu National Park (KNP), a World Heritage Area, is located in the Northern Territory of Australia, 120 km east of Darwin. It is dominated by two river systems, the East Alligator and South Alligator Rivers, and their associated tributaries comprising seasonally-inundated floodplains and dry-season water-bodies (billabongs). These extensive wetlands are listed under the Ramsar Convention as Wetlands of International Importance. The KNP is a major tourist attraction with most interest being in wetland fauna and flora.

Salvinia, *Salvinia molesta* D.S. Mitchell, was recorded in KNP in September 1983 in the Magela Creek system, a tributary of the East Alligator River. Its spread into swampland suggested that eradication would not be possible and reliance was placed on biological control using the weevil *Cyrtobagous salviniae* Calder and Sands (Julien *et al.* 1987). The weevil was first released in late 1983. In the following few years, damage by *C. salviniae*, in conjunction with the annual monsoonal floods, kept the weed in check. However, during 1987, *S. molesta* increased and covered the water surface of many of the billabongs along Magela Creek. The mats of plants persisted for three years, causing concern about the ecology of the area and concern that the weed would spread to other waterways in the KNP.

To prevent the spread of salvinia, access to the infested areas was restricted. However, in 1990 a new outbreak of the weed was found in swamplands of Nourlangie Creek, a tributary of the South Alligator River system. This, and two other infestations found in 1992 were treated with herbicides, but by 1993 the weed was widespread in the Nourlangie Creek wetlands.

A study by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) was commissioned by the Australian Nature Conservation Agency to determine why biological control of the weed had apparently failed, in contrast to its consistent success in other tropical areas worldwide, and to devise a management strategy for the weed in KNP. An earlier study by Skeat (1990) suggested that the high temperatures experienced in KNP may have adversely affected the weevil. Julien and Storrs (1993) described the CSIRO studies conducted between 1991 and 1993 which determined that: high temperature was not the main factor that restricted weevil populations or limited control; temperatures and nutrients available to the weed were within the normal range for growth; nutrients available to the weevils through the food plant were unlikely to have restricted population increase; and that the weevil populations were not significantly affected by predation or disease. It was also determined that biological control played a major role in restricting growth, biomass and surface-area covered by the weed during most years. However, greater weed-growth occurred in dry seasons that followed poor wet-seasons (when the onset of rains was late or flood heights were low). Under these conditions, the mats of salvinia that were damaged by the weevil were not flushed from the system and nutrients in the water remained at high levels, compared to the levels that remain after 'normal' floods occur. The sequence of poor wet-seasons that occurred between 1987 and 1990 resulted in the development of dense mats of salvinia and other vegetation that covered some billabongs (Julien and Storrs 1993). Salvinia growing in such mats is unsuitable for *C. salviniae*, so the weevils were unable to contribute to control of the weed during this period. The early-season, high floods that occurred during the 1990-1991 wet season flushed the mats from the waterbodies. Subsequently, the interaction of biological control and annual flushing has maintained the weed at low and acceptable levels (Storrs and Julien 1996).

A management strategy was devised that included monitoring weevil-damage and taking note of the time that the monsoon rains occurred, their intensity and the resulting flooding, to predict whether the weevil-damaged salvinia mats might persist from one season to the next. An integrated field-trial, described in this paper, indicated that herbicide could be used to reduce the mats that persist during the later part of the wet season and that application of the herbicide could be timed to integrate with and assist biological control.

Methods

The integrated trial was conducted on a large, elongated billabong with a surface area 0.22 km^2. The billabong was divided into six areas and booms were used to prevent movement of the weed, but not the weevils, between areas. Each area consisted of a 100-m sampling-zone on both sides of the billabong, with buffer zones of at least 25 m between the sampling zone and each boom. There were three treatments, each with two replicates: early-spray; late-spray; and no-spray. The spray treatments superimposed herbicidal control over the on-going biological control activity in the billabong. The no-spray treatment provided a measure of the effect of biological control alone. In the sprayed areas, all salvinia growing as a monoculture between the booms was treated, while salvinia growing amongst the floating mats of native grasses, that grew along the edges of the billabong, was not. Salvinia growing in competition with native grasses persists, but has slow growth-rates and supports low populations of *C. salviniae* (Julien and Storrs 1993).

The herbicide used was AF100, a mixture of JET-A1 ('pure' kerosene) with KEMMAT, a commercial anionic surfactant, at 50:1 (Diatloff *et al.* 1979). According to the Australian Commonwealth Environmental Protection Authority this herbicide constitutes a low threat to the aquatic environment and this was confirmed by independent toxicological studies conducted during these trials (Finlayson *et al.* 1994). AF100 causes salvinia to sink and was used in this trial to reduce weed-cover. Eradication of small areas of salvinia is possible (Miller and Pickering 1988) using herbicides other than AF100. Such herbicides are not acceptable for use in KNP because of likely damage to non-target species.

The trial began on 19 October 1993 when the early-spray treatment was applied, just after salvinia in the billabong had reached its peak biomass. The late-spray was applied on 11 January 1994, when the biomass of salvinia had declined to its lowest level as a result of biological control. The trial was terminated in late April 1994. The herbicide was applied by two-person teams (a boat operator and a spray operator) using small dinghies. A 12-volt electrical motor pumped the AF100 mixture from a 100 l tank along a small-diameter hose to a hand-held spray nozzle with a maximum throw of about 3 m.

Techniques to monitor the abundance of the weevil and the damage they caused to salvinia and the growth, biomass and surface area covered by salvinia are described in Julien and Storrs (1993) and Storrs and Julien (1996).

Results

Changes in biomass of salvinia

The mean wet-weights of salvinia were 12.0 and 14.1 kg m^{-2} for the two replicates in the early-spray treatment, just before the herbicide was applied.

Measurements taken before the late-spray was applied showed that biological control had reduced the biomass considerably, the means were 4.7 and 5.5 kg m^{-2}, respectively. The mean estimated total wet-weights of salvinia that were sprayed were, 5868 kg during the early-spray and 738 kg during the late-spray. Although more salvinia was killed per litre of spray in the early-spray treatment (4.1 and 3.4 kg, compared to 1.9 and 2.8 kg), far less chemical was used during the late-spray (665 l compared to 2521 l) and fewer man-hours were required for its application.

The biomass of salvinia in the no-spray treatment declined as a result of weevil damage and then, after January, increased steadily (Fig. 1a). Biomass was reduced to zero immediately after the early-spray and late-spray applications of herbicide. After each of the applications, there was regrowth of the weed from three sources: from buds that abscised from sunken plants; from plants that were missed during the spray application; and from salvinia plants that were not sprayed among the grass mats. As a result of regrowth following the early-spray treatment, the biomass of salvinia was similar to that in the no-spray treatment by late January and it continued to increase until the end of the trial. Prior to spray application in the late-spray treatment, the biomass of salvinia declined, as a result of biological control, until AF100 was applied in early January and the biomass was reduced to zero. The regrowth after this treatment was at a lower rate than that in the other two treatments over the same period. By the end of the trial, biomass in the late-spray treatment was less than half that of the other treatments (Fig.1a).

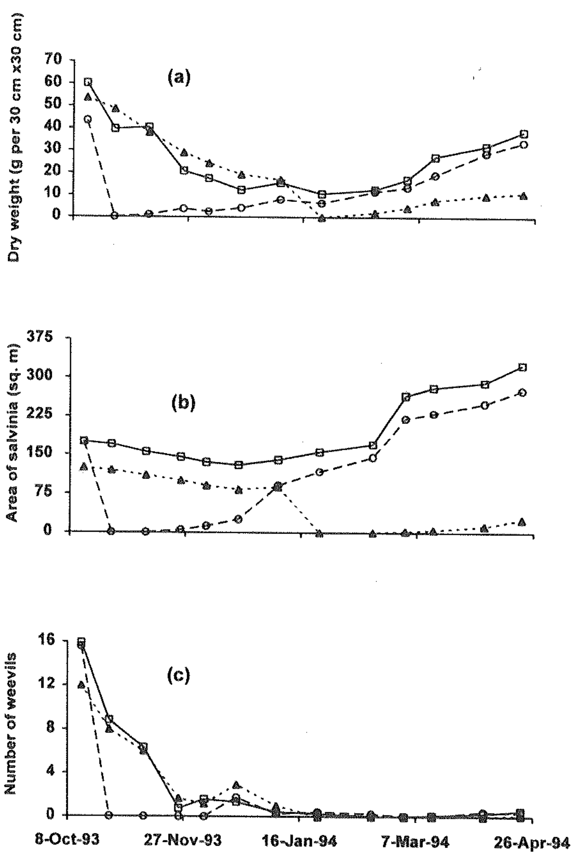

Fig. 1. Changes in: (a) the biomass of salvinia; (b) the surface area covered by salvinia; and (c) the abundance of the biological control agent, *Cyrtobagous salviniae,* for each treatment. Data points are means of two replicates. Open circles - early spray; closed triangles - late spray; open squares - no spray.

Changes in surface area covered by salvinia

The surface-area covered by salvinia declined slightly in the no-spray treatment and then increased so that the area covered by April 1994 was double that at the beginning of the trial (Fig. 1b).

The surface-area covered by free-floating salvinia was reduced to zero immediately after the applications of herbicide. By February, following the early-spray treatment, the weed had regrown to the extent that the area covered approached that of the no-spray treatment. It continued to increase and by April the area covered was about 1.5x that at the beginning of the trial.

In the late-spray treatment, the area covered by salvinia declined until January when application of AF100 reduced it to zero. Regrowth occurred thereafter, but the rate of increase in the area covered was much lower than the rate in the other two treatments over the same period. By late April, the area covered with salvinia in the late-spray treatment was about 10% of that in the other treatments (Fig. 1b).

Weevil abundance

Weevil abundance declined from means of 133, 172 and 178 m^{-2}, respectively, for the three treatments at the beginning of the trials to less than 18 m^{-2} by December in the no-spray treatment (Fig. 1c). After that, abundance fluctuated between zero (i.e. to levels that were undetectable by the sampling technique) and 14 m^{-2}. The applications of herbicide killed the food plant and therefore the weevils. Adults of *C. salviniae* were found on regrowth-plants ten weeks after the early-spray application. The weevils probably colonized the new growth from salvinia plants growing in the adjacent grass mats. The weevils persisted in low numbers, similar to the numbers in the no-spray treatment, until the end of the trial. The application of the late-spray reduced adult numbers to zero and they were not detected again during the trial. Checks of the area one month after the trial, determined that the weevils had reinvaded the late-spray areas before the booms were removed.

Discussion

This and other studies (Storrs and Julien 1996) suggest that a management strategy for salvinia could be developed to be used only when needed, that is, when it seems likely that a poor wet-season would disrupt biological control. Assessment of the monsoonal rain-pattern and rainfall intensity, coupled with the monitoring of salvinia cover and weevil damage, could identify when applications of herbicide would assist with control. The timing of herbicide applications was shown to be important to achieve the best results and to conserve resources. Application should be delayed until late January or February when maximum weed-reduction has been achieved by the weevil and until it seems likely that a poor wet season is occurring. When normal, or greater than normal, wet seasons occur, seasonal flooding will have diluted the nutrients available to the weed and removed salvinia from the water bodies by mid February, in which case herbicide application will not be required.

The application of AF100 during February (late-spray treatment) not only removed salvinia but reduced its rate of regrowth during the period after spray. This limited the increase in biomass and surface-area covered during the early dry-season. It is reasonable to expect that this effect would continue into the middle of the dry season, a critical time when populations of the weevil are reaching the numbers required to control the weed. The overall effect should be less of the weed surviving a poor wet-season and a lower rate of recolonization of the surface of billabongs. In addition, weevil populations will have had time to develop to levels that can begin to exert control, while the surface-area covered by the weed is low. This strategy should prevent the development of high-biomass mats when conditions interrupt the interaction between biological control and annual flushing.

In most years, intervention using AF100 will not be required. In others years, its judicious use could be extremely beneficial. However, the practical and economic aspects of applying herbicides to large wetland systems will limit the use of this strategy. Those responsible for the management of KNP will have to determine which billabongs should be kept as free of the weed as possible. In years following a poor wet-season, billabongs not selected for spraying with AF100 may become covered with salvinia. In many instances, subsequent attack by the weevils will reduce the weed and the remaining weed will be removed by the next floods. Should this not happen because the next wet-season is also a poor one, it would become more critical to undertake spray applications on those billabongs.

The integrated trial was carried out during a period when biological control maintained salvinia at a relatively low level, i.e. at 30% of the surface of Island Billabong. This assisted practical aspects of the trial in that spray treatments could be conducted by boat rather than helicopter, much less herbicide was required and costs were relatively low. The strategy now needs to be tested under an actual management-situation, when the need for intervention has been predicted. The strategy should then be assessed and modified if necessary.

This work has demonstrated that applications of a herbicide can help in the control of a weed when a system that is normally under successful biological control is disrupted. This was achieved by providing control that was additional to that achieved by biological control rather than as an alternative. Another complementary effect was the delayed recovery of the weed, permitting biological control to be restored before the area covered by the weed could increase dramatically. An equally important outcome is that the need for the herbicide can be anticipated rather than having to wait until the problem has increased. This has obvious benefits in conservation and resource management.

Acknowledgement

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