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Biological Control of *Salvinia molesta* in Sri Lanka: An Assessment of Costs and Benefits

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Foreword

A number of ACIAR research projects have moved into a development/implementation phase and are now impacting on the economies of the collaborating countries. One such project is the biological control of the water weed, salvinia, in Sri Lanka.

This report by J.A. Doeleman (Department of Economics, University of Newcastle, Newcastle NSW 2308, Australia) presents an impact assessment (or economic evaluation) of the project. While the full impact of the project has not yet occurred, sufficient information is available to enable a confident conclusion that the project is providing an excellent economic return on the investment.

The costs of the Sri Lankan project represent a relatively small component of the total Australian research effort into biological control on salvinia. Indeed, it was this fact which provided the motivation for ACIAR involvement. By building a low-cost, add-on component to an existing Australian research effort, disproportionately high benefits can be obtained. At the same time, the ACIAR financial contribution can modestly assist the core research effort in Australia.

Biological pest control research provides an excellent example of the rationale for public investment in research. The products of the research are virtually impossible to commercialise, and therefore biological control research does not attract private sector funding. Without public sector funding, the economic benefits of biological control research on salvinia in Sri Lanka (and in Australia) would have been lost.

J.R. McWilliam
Director
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Abstract

In the mid 1980s the Australian Centre for International Agricultural Research (ACIAR) committed itself to a program of biological control of the aquatic weed *Salvinia molesta* in Sri Lanka. Salvinia in Sri Lanka interferes with irrigation and drainage of rice paddies, it reduces the fish catch in water reservoirs and it also poses a health risk in providing additional breeding opportunities for mosquitos. The agent of biological control is a Brazilian weevil called *Cyrtobagous salviniae.* Spectacular results with this beetle have already been achieved in Australia, Papua New Guinea and other countries following entomological work during the 1970s in which the Commonwealth Scientific and Industrial Research Organization (CSIRO) played a pioneering role.

This study estimates the economic benefits from the Sri Lankan program. A feasible range of net present values were determined over a forward-looking 25-year time horizon. At the mid-point of the likely feasible range, the present value of salvinia control is A$16 million (433 million rupees) at 1987 prices. Considering both the Australian and Sri Lankan contribution to the program, the estimate represents a return of A$53 (or rupees) per dollar (or rupee) invested. When the same calculation is cast in terms of the value of Sri Lankan labour the ratio is boosted from 53 to a dramatic 1673.

The research demonstrates: (a) an effective case of foreign aid; (b) the value of biological control methods; and (c) the role of publicly funded research in biological control.

I. Introduction

This study has been undertaken to estimate the value of the program of biological control of the water weed *Salvinia molesta* currently under way in Sri Lanka. The Sri Lankan program is being sponsored from Australia. During the 1970s, Australia developed the required biological control expertise to deal with salvinia. The findings of this paper suggest a range of values for the Sri Lankan program, all of which indicate high rates of return.

The paper begins with an account of the discovery of the agent of biological control of salvinia (Section II). It then proceeds to the Sri Lankan setting and provides background information on the program which is the subject of this evaluation (Section III). Section IV contains details of the costs brought about by the salvinia weed, and provides estimates of the benefits of biological control. These benefits are principally derived from a reduction in the costs associated with salvinia prior to its control. Finally, in Section V, benefits of salvinia control are valued over 25 years and matched against the implementation costs of the biological control program.

II. Biological Control of Salvinia

Salvinia molesta, outside its native South America, is an aquatic fern described as one of the world's worst aquatic weeds. The damage it causes rivals water hyacinth. Its spread has posed major problems in a number of tropical and subtropical countries (e.g. Australia, Botswana, Kenya, Papua New Guinea, India, Indonesia, Malaysia, Namibia, the Philippines, Sri Lanka, Zambia and Zimbabwe). Salvinia propagates by division and is capable of colonising large areas of stagnant fresh water in very short periods. Under ideal conditions, the plant grows at a doubling rate as low as 2 days. Given this multiplication potential, the accidental release of just one salvinia plant can cause havoc. If for instance an aquarium with one cubic centimetre of salvinia were emptied in a receptive aquatic environment, within 93 days, or a single season, the result would be a mat of salvinia 1m thick covering $100km^2$.

Thomas and Room (1986a) report that the search for an agent of biological control of this virulent weed began in earnest in 1959. At the time serious infestations on Lake Kariba, on the border between Zambia and Zimbabwe, prompted the commissioning of the Commonwealth Institute of Biological Control (CIBC) to look for salvinia's natural enemies in South America. Modest headway was made at first. It took until 1970 before it was realised that the salvinia on Lake Kariba and elsewhere was not *Salvinia auriculata* but a separate strain. This strain was subsequently named *Salvinia molesta* by D.S. Mitchell, currently with the Commonwealth Scientific and Industrial Research Organization in Australia (CSIRO). *Salvinia molesta* is also similar to *Salvinia cucullatta,* which is native to Southeast Asia and not as virulent (Ferrar 1988).

Eight years later, Forno and Harley (1979), also of CSIRO, succeeded in locating the native range of *Salvinia molesta* in Brazil (see Forno 1983; Mitchell 1981; Room et al. 1984). At the same time they isolated a weevil which kept the salvinia in check. The weevil proved to be an unknown species now called *Cyrtobagous salviniae. Cyrtobagous salviniae* is distinct from *Cyrtobagous singularis,* one of three insects used in earlier control experiments. Unlike *Cyrtobagous singularis,* the new weevil turned out to be most effective.

Cyrtobagous salviniae has an exclusive taste for salvinia. It kills the weed by feeding on new growth while its larvae tunnel through buds and rhizomes. Weevils multiply rapidly to the detriment of salvinia. As the stock of salvinia declines, the *Cyrtobagous* population does likewise. The decline will eventually come to a low-level equilibrium between weed and beetle, with only scattered remnants of salvinia surviving. This low-level equilibrium generally appears robust enough to prevent new outbreaks of salvinia. However, *Salvinia molesta* survives low temperatures better than *Cyrtobagous salviniae.* Hence a control problem could persist at the temperate fringe of salvinia's geographic range. This is perhaps the case in New South Wales, Australia.

Cyrtobagous salviniae has become the agent of choice in the control of salvinia. Not only is the weevil effective, it works fast, and laboratory and field tests have confirmed it to be strongly host-specific. The first success with *Cyrtobagous* has been recorded in Australia at Lake Moondarra in Queensland. Salvinia, which covered approximately half of the lake, had previously been treated with chemical sprays administered by means of hovercraft and helicopter. This treatment would only yield brief respite before remnant salvinia would begin to multiply again. In June 1980, *Cyrtobagous* beetles were released by CSIRO. The beetles achieved spectacular and lasting control within 12 months. In subsequent years, a large number of other salvinia sites in Queensland responded similarly (Julien et al. 1984).

The Australian solution to the problem of salvinia has produced a large number of international inquiries, including requests for assistance from Papua New Guinea, India, Namibia and Botswana. Especially in the case of Papua New Guinea, CSIRO has been able to help overcome a dramatic salvinia problem. The problem affected the Sepik River delta in that country. Half of 500 km^2 of lakes in the lower floodplain of the Sepik River was covered by impenetrable mats of salvinia after the weed first appeared in the early 1970s. This threatened the economic viability of some 80 000 people dependent on open water for sago palm transport, fishing and access to community facilities.

When *Cyrtobagous salviniae* was released in Papua New Guinea in September 1982, the early results were disappointing. A shortage of nitrogen, it was discovered, hindered the beetle's establishment. Nitrogen applications, however, completely restored the effectiveness of the beetle. As a result, salvinia has virtually disappeared. Between mid 1984 and late 1985 the spread of salvinia comprised a total area of a mere 2 km^2. By then the beetles had consumed 2 million t of salvinia (Thomas and Room 1986b). The team responsible for this remarkable achievement was awarded the 1985 UNESCO Science Prize. The results were achieved through effective collaboration between CSIRO, the government of Papua New Guinea, the United Nations Development Programme (UNDP) and the United Nations Food and Agricultural Organization (FAO).

III. The Sri Lankan Program of Salvinia Control

Sri Lanka is an agricultural country with a population of 16.5 million people. Farmers and farming communities rely on a multitude of reservoirs for water because the country knows prolonged dry periods. Salvinia, observed in Sri Lanka since the early 1940s, has spread to a number of these reservoirs and the associated distribution and drainage systems. The water buffalo may have acted as an important carrier in the spread of the weed.

Salvinia constitutes a hazard to the production of rice which forms part of the staple diet. Rice production is affected because salvinia enters the paddies and because it interferes with irrigation. This problem has the potential to get worse in future. The reason is that Sri Lanka is rapidly expanding the area of farmland under irrigation by virtue of the very large hydroelectric Mahaweli Scheme, which is currently approaching completion. (Australia is amongst a number of western contributors to the Mahaweli project.) The irrigation value of this scheme is judged to be greater than the value of its 500-megawatt electricity generating capacity. The Mahaweli Scheme is doubling Sri Lanka's power supply.

In the mid 1980s the Australian Centre for International Agricultural Research (ACIAR) decided to act as a sponsor of a verification experiment on salvinia control in Sri Lanka on the strength of the expertise then developed by CSIRO. Officers of CSIRO have assumed responsibility for this program in collaboration with the National Resources, Energy and Science Authority of Sri Lanka (NARESA), together with other official Sri Lankan government bodies and researchers from the University of Kelaniya in Colombo. Project leader Dr Peter Room (CSIRO) released the first beetles late in 1986. To date progress is promising. On the other hand, results in the Sri Lankan situation are expected to take some time because of the great number of localities with independent infestations.

It is estimated that approximately 25% of Sri Lanka's 50 000 reservoirs (often referred to as tanks) are affected by salvinia. Reservoirs or tanks vary in size between 2 and 25 ha. Since 1986 to the beginning of 1989, *Cyrtobagous salviniae* has been released in 96 places. Successful control has resulted in 16 cases. Another 23 cases show a vigorous beetle population likely to succeed in the near future, while in 37 more cases the continuing presence of beetles has been recorded. Experimentation is proceeding to establish whether nitrogen and/or other factors may assist the establishment of the beetle. Establishment may also be assisted by introducing beetles to new target areas from areas where *Cyrtobagous* is proving effective instead of introducing laboratory-raised insects. This can be done by taking salvinia invaded by beetles to new locations on the back of a truck.

Although the program to control salvinia is in an unfinished state, the outlook for its successful completion is good. The current study of the value of the program is therefore based on the assumption that the beetle will work as expected. By the same token, it follows that the findings have to be seen as provisional. They are based on estimates of the annual costs of salvinia for Sri Lanka which belie the absence of field work and statistics dealing with this problem.

Findings revolve around the estimation of the annual benefits of a successful salvinia control program. The detail of this estimation will be addressed in the next section, which examines the various categories of costs associated with salvinia prior to biological control. The annual benefits of control result from a reduction in these costs. Annual benefits are projected forward over a period of 25 years in order to gain an impression of the total value of the program. Total value is obtained by calculating the present value of this quarter-century stream of benefits.

The choice of a time horizon of 25 years is, of course, arbitrary. Benefits may flow from the biological control of salvinia on an indefinite basis and well beyond 25 years. However, for (most) high discount rates, the lack of consideration of benefits beyond 25 years will not significantly alter the present value of the program.

The findings on the value of the biological control of salvinia in Sri Lanka are very encouraging. Full recovery of the control program costs is expected to take less than 1 year and ongoing costs are expected to be negligible. Therefore, rates of return over the projected term of 25 years are high and well in excess of commercial investment returns.

IV. Costs of Salvinia and Benefits of Control in Sri Lanka

Agricultural and other output in Sri Lanka has been adversely affected by salvinia. In addition, public health and the aquatic ecology have suffered. In the current section, these costs will be identified and quantified in money terms on a per annum basis.

Costs are categorised as follows: (1) losses in rice production; (2) fishing losses; (3) other commercial losses; (4) human health costs; and (5) environmental costs. In addition to these costs, a further category (6) will consider abatement expenditure. Abatement measures are undertaken to gain favourable reductions in the actual costs of salvinia considered under (1)–(5). Finally, any commercial benefits (7) from salvinia must be deducted from the costs (1)–(6). The result provides the net measure of the costs of salvinia prior to the introduction of biological control.

The net total costs of salvinia prior to control also measures the benefits of the biological control program if successful. However, two modifications need to be entertained before adopting this measure of the benefits of salvinia control. The first modification is that any future ongoing costs (8) needed to maintain the salvinia control program must be charged against benefits. Secondly, if the resolution of the control of salvinia invites substitute weeds (9), then a discount to the value of the benefits of control may have to be taken into account.

The categories (1) to (9) which make up the calculation of the annual benefits of salvinia control will each be discussed below. Preceding these discussions, a summary of estimates for each of the headings (1)–(9) is set out in Table 1. The estimates relate to the base year of 1987 and are expressed in millions of Sri Lankan rupees (1 rupee ≈ 4 cents Australian). Estimates for the subsequent 24 years will be obtained by the simple application of a growth rate of 3%. The rationale for this formula is that would-be future costs due to salvinia are assumed to maintain a measure of proportionality with population size and the level of economic output. The choice of 3% is viewed as a conservative estimate of long-run demographic and economic growth in Sri Lanka.

(1) Paddy Losses

Amongst agricultural crops only rice production appears to have suffered from salvinia. The problem arises in the paddies and is commonly introduced by infested irrigation water. Rainfed paddies may also be affected by salvinia but only in wet periods. Relative to Sri Lanka's total rice output, production losses due to salvinia are small. Wooden booms can be used to restrict access of salvinia to the paddy. Moreover, paddies should ideally be drained on a regular basis to reduce the incidence of vector disease. Drainage will also curtail salvinia.

Salvinia rarely leads to abandonment of paddies although recently some square kilometres of paddy were abandoned. When salvinia gets into the paddy it generally acts as a hindrance to production by its competition with rice for space and nutrients and by

Table 1. Base-year benefits of the Sri Lankan program of biological control of salvinia (in 1987 Rp — millions).

	Costs and benefits prior to biological control		
	Low	Medium	High
(1) Paddy losses	9.2	16.1	23.0
(2) Fishing losses	4.1	6.1	8.2
(3) Other	0.2	0.35	0.5
(4) Health costs	5.8	8.7	11.6
(5) Environmental costs	?	?	?
(6) Abatement costs	5.4	9.5	13.5
(7) Economic benefits	—	—	—
Total costs of *salvinia*	24.7	40.7	56.7
(8) Ongoing costs		negligible	
(9) Substitute weeds	1.8	3.2	4.5
Control benefits/annum	22.9	37.6	52.2

its interference with drainage. In terms of the costs of the control program, losses in rice production are significant. These losses constitute the foremost component of the costs of salvinia. Note that the loss in production is dealt with separately from the salvinia-associated labour costs of the farmer. The latter are incurred in the prevention or repression of salvinia problems in order to keep production losses minimal. They will be considered later under abatement costs.

The value of paddy rice production in 1987 was 5423 million rupees or 4.8% of GNP. Due to severe drought and unsettled political conditions in the Northern and Eastern Provinces, 1987 was a disappointing year. By contrast, the year 1985 produced a record rice crop which stood at 6.4% of GNP. On the other hand, 1986 was described by the Central Bank as 'a temporary setback' at 5.9%. Perhaps therefore an average of 5.7% of GNP could be taken as a representative figure for 1987 rice production. Taking 5.7% of 1987 GNP at 113 billion Rp, rice output is estimated at 6400 million Rp. Such a crop would consist of Maha (harvest January–July) which is cultivated on approximately 530 000 ha and Yala (harvest August–December) from approximately 307 000 ha. The average area under rice cultivation is thus around 418 000 ha.

Only a fraction of the cultivated area is affected by salvinia. No reliable estimates are available but the authorities quote a range from 9000 to 25 000 ha. However, these are historic estimates which do not take into account a likely increase in the problem should salvinia spread to the new irrigation systems of the Mahaweli Scheme. The Mahaweli Scheme has already added 130 000 ha of irrigated lands with a further 50 000 ha to come. Rice is the predominant crop on these lands as Sri Lanka still imports up to one-fifth of its rice requirements. In view of these considerations, a new range for the potential area of rice production affected by salvinia must be adopted. And this range should be typical for the period of the next 25 years. The range proposed is an area of 30 000–50 000 ha.

The Department of Agriculture suggests that crop losses in salvinia-affected areas are 2–3%. On this basis, the low cost estimate of rice production lost is 30 000/418 000 × .02 × 6400 million Rp =9.19 million Rp. The corresponding high cost estimate is 50 000/418 000 × .03 × 6400 million Rp = 22.97 million Rp. These estimates ignore any effect salvinia might have on the price of rice. However in view of the relative insignificance of our estimates compared to a total rice production of 6400 million Rp, any such price effect is expected to be minimal.

(2) Fishing Losses

Salvinia inhibits aquatic life by cutting out light and oxygen which result in anaerobic conditions characterised by high concentrations of carbon dioxide and hydrogen sulfide. The oxygen balance is worsened because plankton dies. Fish cannot survive. On the other hand, fish like tilapia and various types of carp can be used to control aquatic weeds at an early stage. Especially, the grass carp (*Ctenopharygodon idella*) has a voracious appetite. However, grass carp will only eat salvinia if left with no choice, and will not eat *Eichhornia, Nymhoides* and *Nymphae* (Jayasekare 1986).

In practice it has been found that salvinia contributes to fishing losses in affected reservoirs in two ways. Firstly, fish breeding is hampered thus reducing the stock of fish. Secondly, the preferred method of gill netting is rendered ineffective by the weed. Fortunately, salvinia has not caused the dislocation of fishermen and their families. Reservoir fishing is mixed with a variety of farming tasks and is not a full-time pursuit.

To arrive at an estimate of fishing losses, consider that fishing accounts for 1.9% of a GNP of 113 billion Rp and that 19% of Sri Lanka's 1987 fish supply was made up of inland catch (79% coastal, 2% offshore and deep sea). River fisheries are not affected by salvinia but a quarter of reservoirs are affected in various degrees and these effects cannot be ignored. Against this background, it is assumed that 5% of the inland catch may have suffered losses due to salvinia and that on average the catch may have been reduced in a range from 20 to 40%. Accordingly, a low estimate of fishing losses would be $.019 \times .19 \times .05 \times .2 \times 113\ 000$ million Rp $= 4.1$ million Rp. The high estimate yields a figure twice the low result, or 8.2 million Rp.

(3) Other Losses

Salvinia does impinge on activities other than rice production and fishing. These activities include power generation, transport, and washing and bathing. However in none of these cases does there appear to be losses of consequence. In respect of power generation, the Mahaweli Authority claims that turbines depend on big reservoirs which are not subject to infestation because of wind and water movement. Any potential difficulties are resolved by using booms on tributaries. Also the spillway can be used to flush out salvinia.

Regarding transport, river shipping is not impeded by drifting clumps of salvinia. On the other hand, although boating on salvinia-infested reservoirs would be impeded, this is not considered an important problem. Likewise, the hindrance caused by salvinia in reservoirs to washing or bathing is of minor significance. The latter problem can be managed by the use of bamboo enclosures which are kept free of the weed. Nonetheless, the quality of the water will be adversely affected.

It would be difficult to account with any precision for the nuisance factors outlined in this category of costs. We have settled for a low estimate of 200 000 Rp and a high estimate at 500 000 Rp for 1987.

(4) Health Costs

Sri Lanka, as with many other tropical countries, is suffering from a resurgence of vector diseases. Of particular concern here are the mosquito-borne diseases malaria, filariasis, dengue fever and encephalitis. Chemical controls, widely and successfully used in the 1950s, now seem to have resulted in resistant strains of mosquitos. Moreover drugs such as chloroquine, taken to inhibit the pathogens, are losing some of their effectiveness.

Salvinia is increasing the breeding opportunities of the mosquito. Whereas open water bodies are subject to wave action and therefore avoided by the mosquito, a mat of salvinia settles the water and renders the shallow conditions the mosquito prefers for its breeding. Such conditions also prevail in the rice paddies but these are supposed to be drained on a daily basis. Naturally, reservoirs cannot be drained. Also low-lying paddies may fail to drain adequately, in particular if salvinia were to clog drainage channels.

The extent of salvinia's contribution to mosquito-borne diseases is not known. However, it is known that salvinia plays a major role in filariasis. Filariasis is transmitted by the *Mansonia* genus of mosquitos which favours salvinia. *Mansonia* will also breed on water lily (not on hydrilla or water hyacinth). *Mansonia* mosquitos are different from the species transmitting malaria. The latter are more likely to breed in small rain puddles such as may be contained by buffalo footprints. In these cases mosquito eggs may lay dormant on land for long periods, making control very difficult.

The control of salvinia, however, is within reach. Moreover, there is the promise that especially the smaller water bodies, when freed from salvinia, need not continue to be a source of mosquitos. Following encouraging results in Madras in India, Sri Lanka is turning to the possibilities of stocking larvivorous fish such as minnows (*Gambusia*) and guppies (*Lebistes*) to eat the mosquito larvae. The guppy particularly has the ability to survive in adverse and shallow conditions.

There are no field studies to provide guidance to the costs of salvinia in terms of filariasis and other diseases. This necessitates some assumptions. We assume that salvinia, in providing a breeding ground for mosquitos, will add between 1 and 2% to the incidence of vector disease. The cost of this increase in disease incidence is crudely measured as the percentage increase in the health budget spent on this type of disease (around 30% of a total budget of 1935 million Rp in 1987). For the base year, a low estimate of the health costs of salvinia then works out at .01 × .3 × 1935 million Rp = 5.8 million Rp. The high estimate doubles these costs to 11.6 million Rp.

(5) Environmental Costs

No allowances have been made for environmental costs. Unlike the salvinia problems which developed in the Sepik River delta in New Guinea, there are no records of salvinia threatening the dislocation of communities in Sri Lanka. In that respect, the weed has not impacted on the social environment.

The same cannot be said with respect to the natural environment. Clearly salvinia is capable of rapidly reducing a complex ecology to a monoculture. Thus as salvinia has spread in Sri Lanka, aquatic plants and animals as well as birds must have suffered. However there are no records in this regard. A recent and substantive environmental plan produced for the Mahaweli Authority in 1981 devotes two pages to aquatic weeds and makes no mention of salvinia. Therefore, and because of a lack of methodology on the monetary evaluation of natural but non-commercial biological assets, we have left the valuation of environmental costs unspecified.

(6) Abatement Costs

In addition to the costs of actual production lost due to the incidence of salvinia, a measure is required of costs currently incurred in attempting to limit such losses from the presence of salvinia. In other words, in addition to actual or unavoided damage of salvinia, the costs of current control measures must be taken into account. These costs are here called 'abatement costs.' The profit from abatement is defined as the difference between the value of damage abated and abatement costs. In theory, abatement would be pursued until it ceases to be profitable, i.e. to the point where abatement cost is equal to abated damage.

Unfortunately, this equality at the margin provides no clue to the total of abatement costs in relation to the total of unabated costs or actual production losses. As shown in Figure 1, for the case of rice production, there need not be any relation in respect of the totals.

In the diagram, the vertical axis measures the price of rice (OP). The horizontal axis sets out three levels of rice production. OA is the production level should salvinia be allowed to go entirely unchecked. On the other hand, OC is the production level that would have prevailed in the absence of any salvinia. The actual production level is expected to be an intermediate level OB. OB is the economically rational result which minimises the damage from salvinia to BCC'B'. Rationality demands that the marginal cost of abatement, as traced by the MM curve, equals marginal revenue or the price of rice (OP).

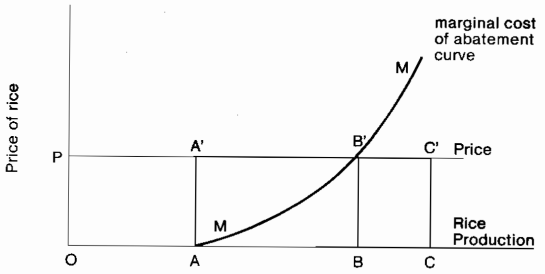

Figure 1. Abatement cost (ABB'), abatement benefit (ABB'A') and unabated cost (BCC'B').

If marginal abatement costs exceeded the price of rice, too much abatement would have been applied. And if marginal abatement costs fell short of the price of rice, too little abatement would have been undertaken. It can be seen therefore that the determination of point B depends on the marginal relationship between abatement costs and production losses and not on their respective totals. Quite the contrary, the total of abatement cost (ABB') and the total loss of rice production (BCC'B') depend on the location of point B.

Abatement costs can be substantial. Indeed, the cost of chemical control of salvinia has proved to be prohibitive in Sri Lanka. Chemical control of salvinia, using paraquat, was attempted in Sri Lanka during the 1950s but has since been abandoned. The preparation of chemicals has not been of prime concern but rather the costs of application and the need for repeated applications. Chemicals also present dangers of toxicity. Reservoirs are a source of drinking water for people and cattle. More recent developments in chemical control of salvinia do not appear to overcome the inherent problems with this approach given the virulence of salvinia and the likelihood that new outbreaks might occur (Diatloff et al. 1979).

In recent years, salvinia abatement measures in Sri Lanka have been mechanical in nature. Early physical removal on a regular basis may be sufficient to stop the weed taking over in critical areas and booms can be used to restrict the weed to less critical areas. Occasionally, a major clean-up exercise is organised at community level or by relevant authorities. Records of one such exercise by the Mahaweli Authority shows a budget of 75 000 Rp to clear 4 ha of salvinia, using 80 persons for one month approximately. The follow-up maintenance involved two people.

Major clean-ups are not a regular event. As a rule salvinia problems are contained with modest effort. Tanks or reservoirs are often seasonal and this means that the dry season takes on much of the work of eliminating salvinia. The Department of Agriculture estimates that 2–3 hours of labour on average per month per hectare is all the affected farmer needs to keep irrigation and drainage channels free and pumps protected. This estimate can be combined with our earlier estimate that 30 000–50 000 ha of paddies might be affected by salvinia in the absence of biological control. Allowing a 1987 agricultural wage per hour of 7.5 Rp, we arrive at a low abatement cost estimate of 30 000 × 2 × 12 × 7.5 Rp = 5.4 million Rp and a high estimate of 50 000 × 3 × 12 × 7.5 Rp = 13.5 million Rp. These estimates pale in comparison with a recent report that farmers in Kuttanad (Kerala, India) saved 68 million Rp for not having to remove *Salvinia molesta* after the introduction of *Cyrtobagous salviniae*. The report was included in News from Commonwealth International Institute of Biological Control 1988. The sum of 68 million Indian rupees works out at roughly A$4.9 million and 131 million Sri Lankan rupees. No details on how the figure has been derived are available at this point.

(7) Economic Benefits

Salvinia can be exploited and benefits extracted. New profit-making opportunities in this respect may yet be developed. To date, however, gainful exploitation of salvinia has proved to be inconsequential even though Sri Lanka has had to contend with this weed for over four decades. Nonetheless there are reports that salvinia has been used to supplement fodder as well as for mulching of coconut palms but not on a systematic basis. The difficulty lies in harvesting the bulky salvinia, which is largely made up of water. In practice, therefore, salvinia removed in abatement efforts is generally dumped and left.

Salvinia has been cited as useful in sewage treatment, in biogas production and as a raw material for papermaking. However, no enterprise along these lines has come to fruition. Accordingly, no benefits of salvinia have been entered into our calculations.

(8) Ongoing Costs

Once the initiating biological control program is completed and assuming full control of salvinia is realised, the question arises whether ongoing costs should be charged against the benefits of control. Ongoing costs include the costs of reestablishing *Cyrtobagous* colonies should they fail at certain times and locations in the future. Experience within CSIRO, however, suggests that such failure is unlikely and that costs in this respect can be expected to prove negligible. The impact of *Cyrtobagous* on salvinia is proving a durable one. Besides, the weevil is capable of dispersing of its own accord and thus recolonising a new salvinia outbreak. Also, supplies of beetles for back-up purposes can easily be maintained.

(9) Substitute Weeds

A feature of the success of salvinia control is that other aquatic weeds may take its place. One could be philosophical as to whether this should be weighed against the value of the biological control of salvinia. Other weeds are another problem. Yet, if the prospect of removal of salvinia was its rapid replacement by an equally undesirable weed, then an investment in the control of salvinia, however effective, would have little to recommend itself. We have therefore allowed a discount in the benefits of control. The chosen rate is one third of abatement expenditure as derived earlier. The reduction is mainly to account for substitution by water hyacinth (*Eichhornia crassipes*). Progress is being reported in the use of *Neochetina eichhorniae* and *N. bruchi* as biological control agents of water hyacinth in many countries. Dr Room took a colony of *N. eichlorina* to Sri Lanka in February 1988. They will be released into the field following host-specificity testing. Water lily, hydrilla and kankun (Singhalese) are other replacement weeds that pose lesser problems. Note that *Cyrtobagous* is not expected to attack plants other than salvinia.

V. Valuation of the Sri Lankan Program

The benefits of the biological control of salvinia must be measured against the cost of the ACIAR/CSIRO/NARESA program which aims to achieve its elimination. These program costs are set out in Table 2. The compilation of Table 2 is relatively straightforward. The first column lists the total ACIAR contribution (1984-85, $123 000; 1985-86, $95 100; 1986-87, $99 300; 1987-88, $76 223; 1988-89, $58 838). The 1987 present value of the total of ACIAR money is $493 632 (at 10%). Of this sum, approximately 40% ($197 453) has been diverted to

Table 2: Costs of the Sri Lankan program of biological control of salvinia.

			Rupees (millions)	Average labour (hours)	1987 Average hourly wage
Australian costs		$298 179	8.1	22 403	$13.31
Sri Lankan costs		$3 821	0.1	14 953	6.9 Rp
	Total	$302 001	8.2	37 356	

basic research on salvinia. The remaining 60% has been directly invested into the Sri Lankan program of salvinia control. To this remainder must be added a small item of $2000 as the imputed costs of CSIRO's supply of stock of *Crytobagous salviniae.* The total of $298 179 thus obtained represents Australia's investment in the program. This investment equals 8.1 million Rp (at 27Rp/$A).

Sri Lanka's contribution to the program amounts to a budgeted 4127 hours of input by NARESA staff. In the main, these have been hours worked by senior staff and scientists. Their professional time has been valued at 25 Rp/hour, yielding $3281 or .1 million Rp. The comparison of the two contributions highlights the difficulty of translating currency values between countries which enjoy a different standard of living. To arrive at an alternative comparison, the table also shows the value of the respective contributions of Australia and Sri Lanka in terms of time. The time measure is expressed in 'average labour hours' and derived as follows. The Australian dollar contribution has been divided by the average hourly wage in Australia of $13.31 in 1987. Likewise, the Sri Lankan contribution in rupees has been divided by the country's average hourly wage of 6.9 Rp in the same year.

Given the total program costs in terms of dollars, rupees and labour time, a set of corresponding measures is required on the program's benefit side. The per annum net benefits set out in Table 1 provide the foundation for this. Table 1 supplies estimates of benefits on the 'as if' basis that the first year of successful control was 1987. Benefits for the subsequent 24 years have been assumed to grow at the rate of 3%. To compare these projected benefits with costs of the program requires the calculation of the 1987 present value of a 25-year annuity of which the annual instalments are subject to exponential growth. Given the present value of benefits, the ratio of the present value over program cost defines the return ratio. A set of results for present values and return ratios are combined in Table 3.

Table 3 sets out the 1987 present value of successful salvinia control against: (a) the low, medium and high annual benefit estimates of Table 1, and (b) a low, medium and high rate of discount, viz. 5%, 10% and 15%. It does so first in terms of Sri Lankan rupees, then in Australian dollars and finally in Sri Lankan work hours (dividing the Rp value by the average Sri Lankan wage per hour). For each result the corresponding return ratio has been added in parentheses. Note that this ratio is not a per annum ratio but the program's lifetime return ratio.

Clearly, the findings are encouraging. Depending on the rate of discount, medium estimates for the return ratio range from 36 to 88. Thus for every dollar (or rupee) invested, 36 to 88 dollars (or rupees) are gained. These results are not surprising considering that the program's outlay of 8.1 million Rp is fully recovered in one quarter of one year of successful control (valued at medium benefits for the base year). What is perhaps surprising are the corresponding time return ratios which range from an impressive 1133 to 2771 hours for every hour invested. This major shift in return ratio outcomes reflects that the Australian input of time, although indispensable, has been expensive by Sri Lankan standards. In turn, it underlines the comparative utility of a short-term injection of developed country labour with the bulk of the work being done collaboratively by Sri Lankans.

Return ratios are somewhat flattered by virtue of the fact that the research costs which have been incurred in Australia in order to produce the necessary biological know-how do not appear in this Sri Lankan account. On the other hand, there is nothing unusual about a third country benefiting from scientific research elsewhere. Inevitably, to a large extent scientific progress has a public good character which readily transgresses national boundaries. Indeed ACIAR has been specifically set

Table 3: Present values (25 years) and return ratios of the Sri Lankan program of biological control of salvinia for different rates of discount.*

Value and return	Low	Medium	High
Present value of biological control (Rp millions)			
PV (25 years) (5%) return ratio	436 (54)	717 (88)	997 (122)
PV (25 years) (10%) return ratio	264 (32)	433 (53)	602 (74)
PV (25 years) (15%) return ratio	178 (22)	293 (36)	408 (50)
Present value of control ($A millions)			
PV (25 years) (5%) return ratio	16 (54)	27 (88)	37 (122)
PV (25 years) (10%) return ratio	10 (32)	16 (53)	22 (74)
PV (25 years) (10%) return ratio	7 (22)	11 (36)	15 (50)
Present value (Sri Lankan labour hours, millions)			
PV (25 years) (5%) return ratio	63 (1687)	103 (2771)	144 (3854)
PV (25 years) (10%) return ratio	38 (1019)	62 (1673)	87 (2327)
PV (25 years) (15%) return ratio	26 (690)	42 (1133)	59 (1576)

* The costs of the research program prior to 1987 are not parameterised at three different discount rates (5, 10, and 20%) applied to the benefit and cost stream after 1987. Instead they are brought to account using the 10% rate only, reflecting the greater degree of certainty inherent in the recent past.

up to capture those benefits which can be achieved by facilitating the flow of expertise and the products of that expertise beyond Australia for the solution of developing country problems.

Given that the range of results presented in Table 3 is of a realistic order, a number of conclusions can be drawn. Firstly, Sri Lanka can be expected to benefit some hundreds of millions of rupees from the salvinia control program. Secondly, the program offers Australia good value for its foreign aid dollar. Thirdly, biological control methods appear to open new prospects in cases where chemical control methods are proving problematic. Fourthly, the value of biological control is largely public in nature and cannot readily be commercialised. It is important that this value be recognised at a time when so much political emphasis is placed on the marketability of research output. Without this recognition, investment in publicly-valuable, but non-commercial research (such as biological control), is likely to fall behind desirable levels. (See Tisdell (1988) on the point of the international undersupply of public research. For evidence of the value and return of research in biological control in Australia, see Marsden et al. 1980.)

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