Development of case studies on the economic impacts of invasive species in Africa

Salvinia molesta

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EXECUTIVE SUMMARY

This report details the results of an extensive desktop study to quantify the economic impacts of an invasive weed species in Africa.

Salvinia molesta (Salvinia) is a floating water weed found in the lower Senegal River delta in Senegal. Salvinia reproduces vegetatively, is easily spread by flowing water as well as by stock, vehicles and water craft. The plant forms a thick mat on the water's surface, making transport by water difficult, interfering with fishing activities as well as limiting biodiversity by blocking sunlight and impeding oxygen exchange. Salvinia infestation of the Djoudj National Park and other areas may lead to a reduction in tourist numbers.

This report examines the economic impact of this invasive weed species, including impacts on fishing yields, agricultural production and tourism. The impacts were valued using market prices (where available) and published data on yields and productivity.

Table E1: Annual economic cost of Salvinia invasion per hectare by land use in the Lower Senegal Delta, Senegal ($US 2005)

Land use	Annual cost
Rice cultivation	$19
National park (tourism)	$268
Fishing	$12

A risk assessment was carried out for the species, on the basis of both natural and structural (political) risks. This identified a number of countries at significant risk of invasion by the species considered, including invasion of Salvinia into Mali and Nigeria. Further spread within the Senegal was also noted to be a significant risk.

A number of potential management methods are investigated, including chemical, mechanical and biological control. Cost-benefit analyses of management methods are presented. The effectiveness of management measures is expected to increase if a variety of methods are used in conjunction as part of an integrated weed management plan. Management costs per hectare varied from approximately US$11 to US$4000. Low management costs may be partly due to the assumption that labour has a very low opportunity cost in regions where unemployment is high. However, this disguises the fact that labour availability for other domestic chores is reduced when labour is required for weed management activities.

Prevention measures to avoid weed infestation are examined, including legislative measures, quarantine controls, education and community participation, monitoring and early detection and contingency planning. Although little evidence of the cost and effectiveness of these measures was available in the literature, it was generally acknowledged that prevention of invasion was more cost effective than management of established weed populations. Annual prevention costs of less than US$2 per hectare are estimated for capital-intensive methods of monitoring and early detection to avoid establishment of weed infestations.

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1 INTRODUCTION

Invasive species are widespread in Africa and place a huge economic burden on African countries. Many different invasive species have become established in Africa, emanating both from other regions in Africa and from many locations around the world.

These invasive species have impacts on natural habitats, agricultural systems, social and cultural practices, human health, and economies.

This project focuses on *Salvinia molesta* an aquatic floating weed (hereafter referred to as Salvinia). The aim of the study is to estimate the economic impact of both current and potential infestations of Salvinia in Senegal. In addition, the study looks at the costs and benefits of management actions, prevention strategies and identifies countries in Africa that face similar threats.

The first two chapters present the methodology that will be used for assessment of the economic impacts and the cost benefit analysis of management actions.

The following chapter deals with Salvinia – first reviewing its biology to set the context, then assessing its economic impacts in the Lower Senegal Delta, Senegal, and conducting a cost benefit analysis on potential management actions. A discussion of risk of invasion of neighbouring countries and regions is included, as well as an assessment of potential prevention measures.

2 METHODOLOGY FOR ASSESSMENT OF ECONOMIC IMPACTS

2.1 Introduction

The aim of assessing economic impacts is to determine the cost per hectare of an invasion by Salvinia in the Lower Senegal Delta in Senegal.

The impact of the species on economic variables must be determined, and valued in the context of the Lower Senegal Delta in Senegal. The change in economic welfare resulting from these impacts must then be estimated.

2.2 Determining the impacts of Salvinia

2.2.1 Use of existing examples

There are very few studies that estimate quantitatively the impact of invasive species on production, consumption, health, transport and water access. Even fewer are based in Africa. Many studies note that much of the evidence that does exist is anecdotal (eg Mack *et al* 2000; Joffe and Cooke 1997). In addition, the studies that do exist have taken a 'top down' approach, by trying to value the costs of one or more invasive species in reference to countries, regions or globally.

This study is limited to using available data and studies. Given the dearth of African based case studies, examples from other continents have been used.

Similarly, given the lack of studies which focus on *Salvinia molesta*, the search for data was widened to include species which would be likely to have a similar effect. These species are set out in Table 2-1, and were selected for their comparable growth forms and habits (i.e. floating, mat-forming aquatic weed) in relation to the target species. However, aside from papers relating to the water hyacinth, no useful literature was found that related to the species in Table 2-1.

Table 2-1: Species which may have a comparable effect to the target species

Target species	Comparable species
Salvinia molesta	*Azolla pinnata, Eichhornia crassipe* (water hyacinth*), Pistia stratiotes*

The following steps have been taken to use the information uncovered in the literature search:

- Calculation of average values from the range of values that can be used; and
- Conversion of the impact data to a Senegalese context using, where possible, local data on prices, average yields etc, where available. Where local data is not available, this is highlighted as an area where further research is needed.

There are some limitations to this approach:

- Assumptions on the business as usual case - many of the studies assess the impact on productivity by looking at the yield before and after an infestation (eg De Groot *et al* 2003). Using these figures to extrapolate to other areas means we are implicitly assuming that the business as usual rate of growth of yield would be zero, that is, that all of the change in yield found over the period of infestation can be attributed to the invasive weed. In practice, other factors are likely to be important;
- Difference in the interactions of species with ecosystems. For example, the effect of *Salvinia molesta* on evapotranspiration is thought to be less than that of water hyacinth (in

fact, Salvinia may not have any impact on evapotranspiration at all) (Howard and Harley 1998); and

- Different baseline levels of productive efficiency in different countries means that the impact of the invasive weeds will be different. For example, traditional low yield crops lose less to pests in absolute terms, but more in percentage terms. Even with these losses the high yield variety of crop may be more productive (Yudelman et al 1998).

Where each of these limitations are present in a valuation, they will be highlighted. The resulting values will be indicative, but can be used to gain a sense of the magnitude of the problem.

These impacts are particularly acute when offsite impacts are involved. For example, an infestation of *Salvinia molesta* upstream might reduce the amount of fish available downstream, but the impact will vary greatly depending on natural and social conditions in the area.

In order to best use the case studies, comparisons of the areas where the studies were carried out to the areas where the information will be used are included, wherever the information is available.

2.3 Methodology for estimating the change in economic welfare

2.3.1 Focus on use values

Invasive species impact on both use and non-use values of natural resources:

- Use values include the values of the productivity of the natural resource. For example, rivers have a use value through the fish that can be caught in them and common land has a use value through the fuel that can be collected from it; and
- Non-use values include existence values (the value of knowing that something exists) and option values (the value of having the option to use a resource in the future). For example, biodiversity has an existence value (eg, somebody who will never see a black rhino may still take pleasure in the fact that it is not yet extinct) and option value (eg, there may be medicinal value in some plants that we do not yet know about).

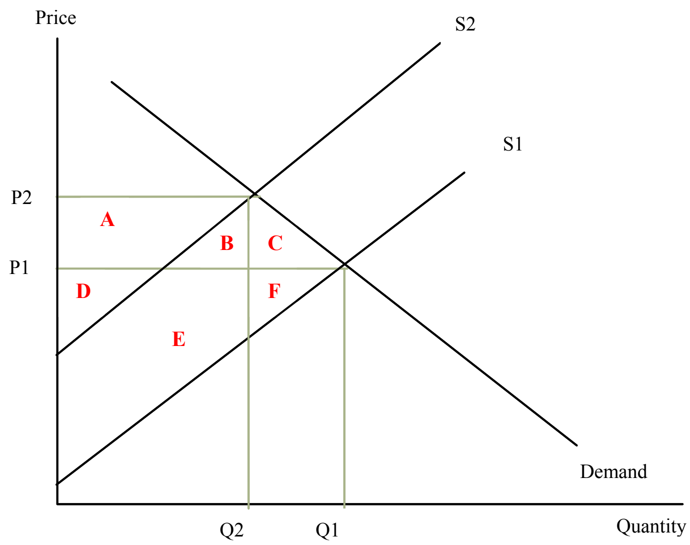
This study will focus on the impact invasive species have on the *use values* of ecosystems. Non-use values are notoriously hard to estimate. It is also argued that they are much smaller than use values in this context (De Groot *et al* 2003). An exception might be where large areas of forest are being cleared due to existing agricultural land being invaded - Wilson and McFayden (2000) noted a tendency for invaded land to be abandoned and primary forest to be cleared as a substitute.

Nevertheless, it should be borne in mind that the results of this study do not include the impact of Salvinia on non-use values and are therefore likely to be an underestimate of the total economic impact of the invasive species in question.

2.3.2 Estimation of the change in economic welfare

In order to estimate the economic impact of an infestation in a given area, the change in economic welfare should be estimated. This is valued by summing the change in producer surplus and the change in consumer surplus. To illustrate this concept, the impacts of an infestation on production and yields are illustrated in Figure 2-1.

Figure 2-1: Change in economic welfare



Before a given area is infested producers sell quantity Q1 at price P1. The amount that they are willing to supply at each price is illustrated by S1, the supply curve;

- Both the decrease in yield per hectare and the increase in the costs of production per hectare have the effect of decreasing the quantity of the product supplied at any given price, shifting the supply curve to the left (from S1 to S2);
- The new equilibrium price and quantity demanded are P2 and Q2;

- The change in consumer surplus is measured by the areas A + B + C; and
- The change in producer surplus is measured by the area E+ F –A.

In order to calculate these figures, knowledge of elasticities is required. Elasticities measure the response in demand or supply to a change in price and are the slopes of the demand and supply curves. They will vary for different commodities, for different populations, for different price levels and across time. It is therefore very difficult to obtain accurate data on elasticities of supply and demand, and for this reason no attempt is made in this study to quantify the change in producer and consumer surplus using this method. The alternative methodology adopted is described below.

2.3.3 Alternative valuation methodologies

Estimation of the changes in consumer and producer surpluses requires a substantial amount of data. Some of these data, such as estimates of demand and supply elasticity are very rare.

In practice, there is a trade off between methodological soundness and accuracy of data employed. Using the 'first best' method that is consistent with economic theory may require many assumptions to be made to cover data gaps. It will sometimes be better to use a 'second best' method which can be based on more reliable data, and to note whether this method is likely to over or underestimate the true value.

Due to the sparse nature of data available for this study, 'second best' methods have been adopted to ensure that the results are based on reliable data. Insufficient data is available to achieve a reliable result using the 'first best' method.

Table 2-2 sets out a number of methodologies and discusses their advantages and disadvantages, and when they are used in this study.

Table 2-2: Potential valuation methodologies

Methodology	Example	Comments	Should be used	Used
A. Estimate the change in producer surplus plus the change in consumer surplus	An infestation may increase the production costs and lower the yield of fish in a water body. This pushes up the price of fish increasing the cost to consumers and lowering the quantity of fish they can consume. Thus both consumers and producers are affected	'First best' valuation methodology Requires knowledge of demand and supply elasticities Accuracy will be lost if too many assumption have to be made to cover data gaps	Where enough data exists for a reasonably accurate assessment	Not used. Data regarding supply and demand elasticities required for accurate conclusion.
B. Estimate the direct cost increases incurred by producers or industries, along with the loss in revenue from reductions in the quantities produced	An infestation may increase the production costs and lower the yield of fish in a water body. This lowers the profit of producers but may not impact too heavily on consumers in an open economy, where the price is determined by exports or where the majority of the goods being produced is for export	Implicitly assumes that producers do not reduce the amount of effort they put into the activity in response to the increase in costs – that is supply falls due to a decrease in yield, but for no other reason This may not be accurate as producers may substitute effort into a different activity. Hence this method may overestimate the costs	Where exports and imports are important, and where there is not enough information for Methodology A	Used for the impacts on agriculture
C Estimate the change in production or economic activity resulting from an infestation	An infestation may lower the yield of fish in a water body. There may be few other opportunities for fishermen to use their capital and labour, hence the opportunity cost of these inputs are low, so any change in the effort they put into fishing does not have a large economic cost	May overestimate the impact on producers as it does not take into account any change in input costs. May underestimate the impact on consumers as the consumer surplus is not valued.	Where there is not enough information available to use methodology A or B, or it is likely that the opportunity costs of inputs to production are low	Used for the impacts on fishing and tourism

Methodology	Example	Comments	Should be used	Used
D. Estimate the cost of replacing the ecosystem service from another source	An infestation may result in a reduction in households' access to water from common sources such as rivers. The amount of money spent on purchasing water from an alternative source is an indication of how much the free water was worth to the affected households	Ignores the fact that as well as paying more, consumers will use less of the resource that was previously free Thus this method may underestimate the costs	Where the species is impacting on a good that was previously collected from common resources such as water or fuel	Not used. Additional data required to quantify the impacts on water supply. Salvinia is unlikely to have an impact on fuel.
E. Damage control costs	The amount of money it is decided to spend on clearing up an infestation is an indication of the value of the negative impacts it has on communities.	Public control expenditures are frequently politically influenced. In addition, they can be underestimated in the long run when fixed cost elements such as permanent salaries, training, research, etc are ignored (Joffe and Cooke 1997) The amount of time spent by individuals in clearing up infestation may be a better indication of the impact	Where data constraints do not allow use of the other methodologies. (Could be used to estimate the impact of low density infestations where these infestations increase inputs to production but do not reduce output)	Not used in this report.

2.4 Other methodological issues

2.4.1 Marginal versus average effects

This study seeks to value the impact of a hectare of infestation. However it is important to note that the marginal impact of a hectare of infestation is not constant. In fact, the marginal impact will depend on how many hectares are already infested. For example if one hectare of a water a body is affected by Salvinia this will have an impact on the production and profits of those producers directly affected (i.e. fishermen), but would probably not have an effect on the price of related products (i.e. fish) in the market. However, if there is substantial infestation across a whole region, the market price of the products is likely to be affected, and consumers as well as producers will thus be impacted.

Where a per hectare impact is referred to in this study, it refers to the average impact rather than the marginal impact.

2.4.2 Level of infestation

No data has been found on how economic impacts change with the varying degrees of infestation of Salvinia. Hence, throughout this study, levels of infestation are compared with a situation of no infestation. This is not too serious a limitation for the case of Salvinia which spreads so rapidly that a given area is either infested or is not.

2.4.3 Shadow price of labour

Senegal has a very high unemployment rate of 48% (CIA, 2006). Because of the lack of opportunities for labour in Senegal, it is assumed that the shadow price of unskilled labour is close to zero. That is, the opportunity cost of unskilled labour to society is close to zero as there is a large surplus of labour.

This follows Turpie (2004) who argues that the shadow price of labour in the Working for Weeds programme in South Africa should be close to zero, due to the high unemployment rates in that country and the fact that the programme targets unskilled, unemployed labour.

This implies that any impact that the weeds have on labour requirements does not have an economic cost to society. However, it is clear that there is a financial cost to hiring labour – management agencies still have to find room in their budget to pay wages of unskilled workers. This cost is identified in the management section.

2.4.4 Discounting

Where it is necessary to take into that account costs and benefits are occurring over time, a discount rate of 10% will be used.

3 METHODOLOGY FOR COST BENEFIT ANALYSIS OF MANAGEMENT AND PREVENTION ACTIONS

3.1.1 Introduction

The aim of the cost benefit analysis of management and prevention actions is to determine which actions can be employed most beneficially to clear water bodies of Salvinia or to avoid invasion by this species.

In order to assess the costs and benefits, examples of cases where each management technique has been used in the past are examined. The costs of implementing these management techniques in the Lower Senegal Delta for Salvinia are then estimated by using a schedule of costs developed for this region and applying these to the amount of inputs needed to manage the species as described in the case studies. Note that management techniques (i.e. clearing established infestation) and prevention measures (i.e. avoiding infestation) are considered separately in this report. It is likely that an effective land management plan will combine both of these approaches.

3.1.2 Costs and benefits to whom?

Costs to society

The aim of a cost-benefit analysis is usually to assess the costs and benefits to society (in practice usually the inhabitants of one country). There are several implications for this including:

- Costs should be presented net of taxes, as taxes are simply a transfer from one agent in the economy to another, rather than a real cost; and
- Shadow prices, representing the opportunity cost of the resource in that society, should be used. For example, as unemployment is extremely high in Senegal (particularly in rural areas), the shadow price of unskilled labour for weed control could be considered to be close to zero as it can be assumed that many of those employed in the weed management effort would otherwise not be engaged in any productive economic activity. However, it should be noted that labour spent on weed management efforts reduces the availability of labour to be spent on other tasks such as caring for children, collecting fuel, tending subsistence agricultural plots, fishing etc. Although these activities may not all be recognised for their economic value they are important tasks in the context of these communities.

In order to assess the societal costs and benefits, the costs and benefits to Senegal of managing a hectare of each weed will be examined using tax free prices and shadow prices.

Costs to agencies involved in management

The financial cost of management techniques to those who will be implementing them is also of interest. For example, even though the shadow price of labour might be close to zero, government agencies and NGOs still have to meet the actual cost of this labour out of their budgets.

Therefore, as well as a standard cost-benefit analysis, an analysis comparing the financial costs to the benefits will be presented.

3.1.3 Costs

Estimates of the costs of management and prevention actions are taken from other studies and converted to the context of the regions being examined in this paper through the use of data on costs specific to those regions.

The following are key methodological issues:

- Only studies relating to the specific weeds were used. For example, although Salvinia has similar economic impacts to the water hyacinth, the management regime is very different.

Studies relating to the management of water hyacinth are thus not relevant for costing purposes;

- Subsequent infestation by another weed. Management of one weed species can sometimes result in a later infestation by another weed. This was the case in Lake Naivasha in Kenya. After successful control of Salvinia through the introduction of Salvinia-specific weevils, the lake was subject to a water hyacinth infestation with even more severe consequences (ECZ 2004). While the risk of reinfestation (by the target weed species) needs to be recognised when a management decision is being made, the costs of subsequent infestation by another weed will not be incorporated into the cost-benefit analysis. This would require estimating the economic impacts of infestation by other weeds, which is beyond the scope of this study; and
- Environmental non-use costs of management actions have not been quantified, however they will be discussed qualitatively.

3.1.4 Benefits

The benefits of management and prevention are assumed to be equivalent to the avoided economic impacts of the weed, as identified in Sections 5. Note that where there are benefits gained from the weed species, such as for compost, fire wood or charcoal production, this is not considered here.

The qualifications applied in Sections 5 are relevant here also. In particular, it should be recalled that this assessment is only concerned with use values. Environmental non-use values have not been assessed. However, where these non-use values are likely to be important their presence will be noted.

Where a management action has only been temporarily effective, the benefits will be assumed to be zero. Some benefits may have been realised during the short period over which the infestation was cut back before reinfestation occurs. However, these benefits are likely to have been minimal.

Note that there is anecdotal evidence of weed removal contractors or employees deliberately carrying out their work ineffectively, to enhance the possibility of ongoing work. That is, weed control efforts are poorly executed by the contractor to ensure re-infestation occurs and further work becomes available. This analysis assumes that weed clearing efforts are carried out properly, and levels of effectiveness arising from private weed clearing efforts (where no such perverse incentives exist) are used.

3.1.5 Consideration of institutional capability

While integrated weed management is widely considered to be the first best method of weed control, some commentators say that biological control of weeds is the only method that is affordable and sustainable in resource poor developing countries (eg Wilson and MacFadyen 2000).This is due to the need for a particular degree of institutional capacity required to support the introduction and maintenance of any weed management measures (as well as capital resources and technology).

Institutional capability will be discussed qualitatively during the assessment, but will not be explicitly costed.

3.1.6 Crowding out of private sector activity

It has been noted that government provision of weed control can create a dependency among farmers and discourage them from managing the problems themselves (eg FAO 2001).

However, set against this problem is the fact that pest control is a public good – one individual's refusal to invest in weed control will have consequences on neighbouring areas. In addition, weed infestations commonly occur on common land (such as in nature reserves and national parks, on government controlled land (such as water catchment areas) or on land under the control of a local community leader rather than private individuals), requiring government efforts to control them.

While it is recognised that in some circumstances, government intervention will crowd out actions that individuals would have taken anyway, this effect only affects the incidence of the costs (i.e. who bears them), rather than their magnitude. Thus it will affect the financial cost to policy makers but not the overall cost to society.

In the financial assessment presented below it is implicitly assumed that complete crowding out occurs, so 100% of the management has to be undertaken by policy makers.

4 BIOLOGY OF SALVINIA MOLESTA

4.1 Introduction

Salvinia is a prolific weed species in many countries in Africa, as well as in Australia, Fiji, Hawaii, India, New Zealand, Papua New Guinea, the Philippines, South-East Asia, Sri Lanka, and mainland United States. The species is considered one of world's worst weeds due to its invasiveness and potential for spread, as well as its economic and environmental impacts.

Salvinia floats on the surface of lakes and waterways, often creating a thick and complete mat, cutting out light and impeding oxygen exchange. These mats can prevent boating, fishing, swimming, irrigation and use for drinking water. They can also create ideal habitats for mosquitoes which often carry significant diseases.

4.2 Taxonomy

Salvinia is an aquatic fern, and like other ferns in this order, do not look particularly fern-like. They are very variable as a group. The ferns of the families Azollaceae and Salviniaceae are floating, while those of the family Marsileaceae are rooted. However, the floating species may temporarily grow on wet mud and the rooted species may grow as emergent species during times of low water.

Table 4-1: Taxonomy of *Salvinia molesta*

Class:	*Pteridopsida*
Order:	*Marsileales* (water ferns)
Family:	*Salviniaceae*
Genus:	*Salvinia*
Species:	*Salvinia molesta*
Common Name:	Salvinia
Other Common Name:	Giant Salvinia, water fern, Kariba weed, African payal

4.3 Description

Salvinia is a floating plant, with round to oblong fronds with a distinctive fold in the centre. There are two types of fronds: buoyant and submerged fronds – submerged fronds function as roots as it lacks true roots. The fronds have hairs on the surface which trap air and enhance their buoyancy. The fronds are light to medium green in colour but often with brownish margins in mature plants. They have a submerged rhizome from which fronds grow.

Figure 4-1: Salvinia molesta – primary and tertiary forms

(photo credits: left = © Barry A. Rice/The Nature Conservancy; right = © Paul Latham)

4.4 Natural distribution and habitat

Salvinia is a native of South America and was originally thought to be restricted to a small area of south-eastern Brazil. It occurs between latitudes 24°05' S and 32°05' S and up to 500 metres elevation. Subsequent surveys for biological control agents also identified the species in other South America countries; Argentina, Colombia, Cuba, Guyana, Mexico, Paraguay, Trinidad and Tobago, Uruguay and Venezuela (Forno & Harley 1979, Julien *et al*. 2002, ISSG Database 2006).

These areas all have tropical, sub-tropical or warm temperate climates and the plants grow best in slow flowing water bodies, such as wetlands, lakes, lagoons, lowland and slow-flowing rivers and irrigation channels.

4.5 Introduced range

Salvinia is widespread in the world and has been distributed to over 30 countries. The species has been distributed from the 1940's by humans for ornamental, nursery and aquarium trade purposes.

Table 4-2: Introduced range

Africa	Asia Pacific	Americas
Botswana	Australia	USA
Burkina Faso	Fiji	
Ivory Coast	French Polynesia	
Ghana	India	
Kenya	Indonesia	
Madagascar	Malaysia	
Mauritius	New Caledonia	
Namibia	New Zealand	
Senegal	Papua New Guinea	
South Africa	Philippines	
Swaziland	Singapore	
Tanzania	Sri Lanka	
Uganda	Thailand	
Zambia	Vanuatu	
Zimbabwe		

4.6 Ecology

Salvinia only reproduces vegetatively as the spores produced are not viable. The species is a pentaploid, that is, it has five sets of chromosomes. This means it cannot complete viable spore production and can therefore only reproduce asexually. However, the plant is prolific via vegetative growth and propagules fragment from the main plant to establish new populations.

In tropical locations, the species tends to be perennial, growing all year. In non-tropical areas it tends to function as an annual species with its major growth period during the summer period which, under the right temperature and nutrient conditions, can double its biomass in two days.

There are three growth phases of the plant. Primary growth stage is when single plants are produced. Following this stage the plant can grow as a linear chain of plants which is described as secondary growth stage. The tertiary stage is a compact cluster of plants (see Figure 4-1). Primary stages tend to be the invading propagules. The second stages are formed when the plant has been growing in open water for sometime and the tertiary stages result when the species is growing in crowded situations.

4.7 Invasion pathways

Salvinia is distributed by humans initially and then uses its reproductive and dispersal abilities to expand its occupation.

Salvinia has been used for ornamental purposes in commercial horticulture sites or botanic gardens. It is often cultivated in private gardens and therefore is distributed by the nursery trade. The plant is also a popular aquarium species for tanks or ponds. It is sold in aquarium and pet shops, and is informally traded amongst home and pet owners.

Once established in the wild, Salvinia can be spread within or between water bodies via boats, fishing gear, boat trailers, equipment and ballast water. The size and nature of the plant means that small but viable pieces of the plant can easily attach to boats and associated equipment and then be transported to other locations.

Other mechanisms for spread include off-road vehicles which often pass through infested waters, picking up propagules of the Salvinia which can be transported large distances to other water bodies. Animals such as hippos and water birds are known to transport Salvinia attached to their bodies as they move from one location to another. Wind and water currents can also transport Salvinia along rivers and across catchments.

4.8 Environmental tolerances

Salvinia is a hardy species adapted to respond to a wide range of environmental conditions such as temperature, nutrient levels and other water quality conditions. The species grows optimally at water temperatures of between 20°C and 30°C. Plants are killed when exposed to temperatures below -3°C or above 43°C (for periods over 2 hours) and may be killed by frost. Only exposed plants, or parts of plants, are killed by frost and cold conditions, leaving part of the plant still alive and able to respond when conditions are favourable.

Salvinia will respond quickly to high nutrient levels, growing quickly and producing propagules for colonisation. Growth is very rapid in those areas where the flow regime has been altered and nutrient levels have been increased (for example, in those irrigation or intensive agriculture zones where fertiliser use or run-off is increased). Under low nutrient levels, growth slows but the plant is efficient in taking up any available nutrients to sustain itself until more favourable conditions return.

Salvinia is also able to tolerate relatively high salinity levels, despite mostly growing in waters only 100 to 1,400 EC (seawater is no less than 35,000 EC). It can withstand up to 4,800 EC with little effect (25% reduction growth), growth is severely restricted at 9,600 EC and it is killed when salinities reach 14,400 EC. This would restrict the species expansion into estuaries.

4.9 Current status in Africa

Salvinia is widespread in Africa, though biological controls have been effective in many locations to reduce its populations. At present, it has spread through most of the sub-Saharan countries. It is specifically recorded in Botswana, Burkina Faso, Ivory Coast, Ghana, Kenya, Madagascar, Mauritius, Namibia, Senegal, South Africa, Swaziland, Tanzania, Uganda, Zambia and Zimbabwe.

5 ECONOMIC IMPACTS OF SALVINIA IN THE LOWER SENEGAL DELTA, SENEGAL

5.1 Economic impacts of Salvinia

5.1.1 Likely impacts

Salvinia could potentially have the following economic impacts:

- Reduce the quality of cultivatable land, thereby increasing the costs of producing agricultural goods, and impacting on yield per hectare;
- Reduces the ability to access waterways, thereby increasing the cost of transport and impeding other water access;
- Reduces the attractiveness of national parks thereby reducing income from tourism;
- Increases the amount of disease harbouring mosquitoes, snails and other vectors; impacting directly on human health;
- Reduces the amount of oxygen exchange causing death or stress to fish thereby increasing the costs of fishing and reducing the yield per hectare; and
- Increases the rate of evapotranspiration which reduces the amount of water available for household use and increases costs of irrigation and watering livestock.

5.1.2 Evidence of economic impacts

Table 5-1 sets out evidence from existing studies on the impacts of Salvinia and water hyacinth on various economic activities. No studies examining the impacts of the other similar species (listed in Table 2-1, page 10) were found. Note that most of the studies recorded here considered the impact of water hyacinth, with two specific to Salvinia. The nature of impacts caused by both types of weed infestation are expected to be similar due to their similar habit and form (both floating, mat-forming aquatic weeds), although they may vary in degree.

Table 5-1: Evidence of impacts of Salvinia

Study	Economic impact	Estimated degree of negative impact	Country	Notes
Agriculture				
Doeleman (1990)	Impact on rice yield	3%	Sri Lanka	Department of Agriculture estimate of the impacts of Salvinia infestation
Transport				
Chikwenhere *et al* (undated B)	Impact on transport time	50% (increase)	Zimbabwe	Water hyacinth infestation
De Groote *et al* (2003)	Impact on household income from trading food crops	39%	Benin	Water hyacinth infestation
Chikwenhere *et al* (undated B)	Impact on the amount of agricultural production sold	50%	Zimbabwe	Water hyacinth infestation
Fuel				
De Groote *et al* (2003)	Impact on household income from trading wood	73%	Benin	Water hyacinth infestation
Overall impact on income				
De Groote *et al* (2003)	Impact on household income overall	66%		Water hyacinth infestation
Fishing				
Joffe and Cooke (1997)	Impact on fishing yields	40-50%	Niger and Malawi	Interference of water hyacinth with nets
De Groote *et al* (2003)	Impact on household income from fishing [1]	69%	Benin	Water hyacinth infestation
De Groote *et al* (2003)	Impact on household income from trading fish	74%	Benin	Water hyacinth infestation
Doeleman (1990)	Impact on fishing yield	20-40%	Sri Lanka	Salvinia
Chikwenhere *et al* (undated A)	Impact on fishing yields	30%	Zimbabwe	Water hyacinth infestation

[1] Assuming 1.45 women per household (De Groot 2003)

5.2 The Lower Senegal Delta in Senegal

5.2.1 The Lower Senegal Delta

The Senegal River Valley stretches across the states of Senegal, Mauritania, Mali and Guinea covering an area of 289,000 km^2 (Black and Sessay, 1998). The Lower Senegal Delta is located in the North of Senegal and extends west from Dagana until it reaches the sea at St Louis (Figure 5-1).

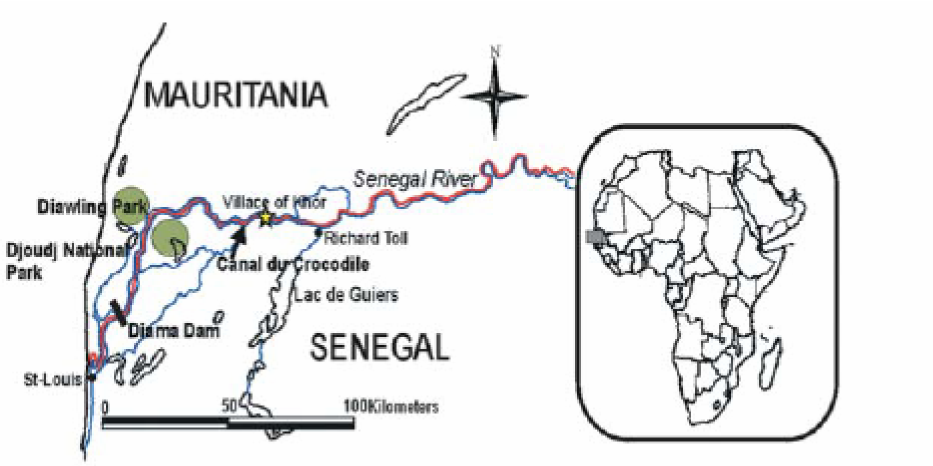
The region experiences the majority of its rain fall during June and October (Black and Sessay, 1998). However during the seventies and eighties the entire region experienced successive droughts. These environmental extremes contributed to the growing poverty in the region.

At present the delta supports approximately 330,000 people (Niang-Diop *et al*. 2002). This number has doubled in the last 25 years (Varis 2002). The combined impact of increased population and lower rainfall has lead to the region experiencing an increase in poverty.

The main economic activities that have developed in the delta are irrigated farming, rain fed agriculture, recession agriculture, herding, and fishing. (Horowitz and Salem-Murdock, 1993)

The Diama and Manantali dams which have been developed along the river have had a major impact on both the environment and the local inhabitants. At present the artificial flow regime that has been set up does not seem to be able to generate a suitable flow pattern for the native vegetation.

Figure 5-1: Map of Lower Senegal Delta



Source: Pieterse *et al* (2003)

5.2.2 History of introduction of Salvinia

In the Senegal River, the Salvinia invasion is thought to have started from a plantation near the village, Khor, 50 km upstream from the Djoudj National Park. Salvinia was to be used as an ingredient in chicken feed (Pieterse *et al* 2003). It was accidentally introduced when a centre growing feed for chickens was flooded (Triplet *et al* 2000).

Shortly after its introduction, thick mats of Salvinia formed over a 70-km long stretch of the river. These mats had several important effects (Pieterse *et al* 2003):

- Blocked the inlets to national parks;
- Blocked the narrow corridors through native vegetation kept open by the local population;
- Blocked the inlets of irrigation channels;
- Threatened Lac de Guiers which is used for fishing as well as water supply to Dakar.

The poor condition of the river and local ecosystems were important factors in creating favourable conditions for weed dispersal. Places where the natural balance of the ecosystem has been disrupted are more vulnerable to weed invasions than those which are balanced (Pieterse *et al* 2003). The flow of Senegal River has been altered by the construction of two high dams, the erection of dykes, development of hydraulic works and development of irrigation schemes. On top of this, there has been decreased water level fluctuation and less salt water intrusion. This has meant that many of the wetlands of the floodplain have disappeared. Another impact has been that much of the floodplains have been converted to agriculture, mostly for rice production (Pieterse *et al* 2003).

A major impact of dams is that they prevent salt water travelling upstream, resulting in an increase of fresh water which has been responsible for the rapid growth of plants such as *Salvinia molesta*, *Typha australis* and *Pistia stratoites* (Triplet *et al* 2000). As a result of these environmental changes, permanent shallow freshwater pools formed along the river. The water in these pools is relatively stagnant and provides breeding grounds for mosquitos and snails with consequences for human health. These pools became filled with a native plant, *Typha australis* which caused problems of access for the local fishing industry. These problems were made worse by the Salvinia invasion.

5.2.3 Socio-economic context

The main activities in the Lower Senegal Delta are (Niang-Diop *et al* 2002):

- Industrial sugar production around Richard Toll (about 7,520 ha in 1980);
- Rice growing in the lows - present north of Ross Béthio (7,730 ha in big fields and 1,174 ha as smaller fields);
- Industrial tomato production (production of 82,000 tonnes in 1990/91);
- Market gardening in the Gandiolais;
- Fishing, mainly in the Lac de Guiers and the Taoué as well as between Saint-Louis and the mouth; and
- Tourism in the city of Saint-Louis and in the Djoudj Bird National Park.

5.3 Salvinia and agriculture

5.3.1 Introduction

Paddy rice is thought to be the only agricultural crop directly impacted by Salvinia (Doeleman 1990). However, other crops may be indirectly affected through reductions in availability of water in irrigation channels. The impact of Salvinia on rice production will first be estimated. A qualitative discussion of the impact on the other main crops in the Senegal Delta (tomatoes, sugar and market gardening) will then follow.

5.3.2 Salvinia and rice

Salvinia can invade rice paddies through irrigation. It impedes production by competing with rice for space and nutrients, and interfering with drainage (Lubulwa and McMeniman 1997). Salvinia usually does not lead to abandonment of the infested paddy; however it does reduce productivity and increase costs. Doeleman (1990) estimates that farmers spend 2-3 hours each month clearing each hectare of Salvinia-infested rice paddy.

Lubulwa and McMeniman (1997) draw on a number of studies (including Doeleman 1990) to estimate the impact Salvinia had on rice yields and costs of production in Sri Lanka and the Philippines. The cost and yield estimates are not the results of field studies, rather they are an estimate by the Sri Lankan Department of Agriculture and the International Rice Research Institute. The estimated impacts are presented in Table 5-2. It is noted that they are average figures for Sri Lanka and the Philippines, rather than relating to a specific region. They relate to yields and costs in the late 1980s.

Table 5-2: Impact of *Salvinia* on rice production and costs (Lubulwa and McMeniman 1997)

	Sri Lanka	Philippines
Percentage reduction in yield caused by infestation	3%	3%
Percentage increase in costs	2%	5%

5.3.3 Rice production in Senegal

Table 5-3 shows the price, yield and production costs of rice in Senegal. There are several qualifications relating to the data in this table:

- These figures are national averages rather than being specific to the region. However, this might not be such a problem for rice, given that much of the crop is found in the Senegal Delta (no regional data could be found);
- It should be noted that there are concerns about the estimated price of rice. Most rice produced in Senegal is consumed locally so export prices may not necessarily be a good indictor of the average prices received by consumers. However no data on producer prices were available; and
- Some of the literature report higher yields than are shown in Table 5-3. For example, Jepsen (2003) assumes that rice yields are set at a default value of 4tonne/ha in Senegal. However, no source is given as the basis of this estimate, and it may be founded on the higher yields commonly seen in Asian countries.

Table 5-3: Rice production in Senegal

	Senegal	Senegal-Source	Senegal –Notes
Yield (tonne/ha)	2.56	FAOSTAT (2006) Average 2003-04	
Price (US$ 2005)	$217	FAOSTAT (2006) Average export price 2003-05	Export prices are not necessary a good indicator of the average prices received by producers
Production cost, Senegal River (US$ 2005)	$188-$226	FAOSTAT (2001) Based on production costs in 1994	The bottom of the range represents the production costs for large properties. The top of the range represents production costs for small properties This cost predates Salvinia infestation, which occurred from 1999 in the Senegal river

Table 5-4 presents paddy rice yield estimates for Sri Lanka and the Philippines in 1990- roughly the time to which the estimates in Table 5-2 relate. It can be seen that paddy rice was more productive in Sri Lanka and Philippines in 1990 than in Senegal more recently.

Table 5-4: Rice production in Sri Lanka and the Philippines

	Sri Lanka	Philippines
Yield (tonne/ha) 1990	3.06	2.98

5.3.4 Estimating the impacts of Salvinia on rice in Senegal

As noted above, the best way to estimate the economic impact of an infestation of rice would be to estimate the change in the consumer surplus plus the change in the producer surplus. However, the situation described by Figure 2-1 (page 12) is not likely to describe the rice market in Senegal well. Senegal is a net importer of rice, importing around five times the volume of rice that is produced domestically. An import tax of US$38 (2005 prices) is levied on each tonne of rice imported. However local producers still find it difficult to compete with the less costly production in Asia (Oryza 2003).

With reference to Figure 2-1, an increase in infestation shifts the supply curve inwards, reducing the amount sold by producers and raising the price for consumers. However, given the relative magnitude of domestic production of rice to imports, it is likely that a shift in the supply curve for domestic producers in Senegal would not affect the market price. Instead, unless quotas or tariffs are increased on Asian imports, the competitiveness of the local producers with importers would not be affected.

It is therefore assumed that, following a Salvinia infestation, local rice producers would spend more time to produce a crop but would receive the same price for their crop as before the infestation (a higher price could not be charged due to the availability of cheaper imported rice). Local rice producers will therefore produce less, and at a higher cost, after the infestation, but will receive the same price as before the infestation.

The change in economic welfare would thus be estimated as;

$$\Delta W = \Delta \text{ producer profit}$$

$$\Delta W = (P\text{-}C1)^*Q1\text{- }(P\text{-}C2)^*Q2$$

Where P is the price of rice, which is not affected by the Salvinia infestation (rather it is equal to the price of imported rice), C1 is the cost of production before the infestation and C2 is the cost after the infestation. Q1 is the quantity produced before the infestation and Q2 is the quantity produced after the infestation.

Estimates for P, C2, and Q1 are set out in Table 5-3. Estimates of C1 and Q2 can be found by using the results of case studies from Sri Lanka and the Philippines.

5.3.5 Results and qualifications

Using the estimates set out in Table 5-3 and Table 5-2, the resulting calculation of the change in welfare is set out in Table 5-5.

Table 5-5: Cost per ha of Salvinia infestation to rice production

	$US 2005
Cost per hectare of Salvinia infestation of rice paddy	$19

Though it gives an indication of the degree of magnitude of the cost per hectare, the absence of accurate and consistent data on price, costs and yields mean that this estimate should be treated with a degree of caution.

In particular:

- It is implicitly assumed that producers do not shift their effort into other activities in response to a fall in their profits due to an infestation, thus this estimate may over estimate the costs;
- The % changes in yield are from countries where rice is produced more efficiently than in Senegal. It is difficult to know whether this would result in an over or underestimate of the cost per hectare; and
- It is implicitly assumed that no other factors than Salvinia impacted on changes of yield over time found by Lubulwa and McMeniman (1997). This paper found that yield increased once Salvinia had been biologically controlled. However, increases in technology may have also been improving the yield over time. Thus extrapolating from this study may mean the impact of Salvinia has been overestimated.

5.3.6 Salvinia and other forms of agriculture in the Lower Senegal Delta

As noted above, the key agricultural activities other than rice in the Senegal Delta are:

- Tomato production;
- Sugar production; and
- Market gardening.

There is no discussion in the literature of the impact of Salvinia on these agricultural activities. However, thick mats of Salvinia can reduce flow in irrigation channels. The impacts of this include the following:

- Reduction in cultivated areas as it becomes harder to irrigate outlying regions;
- Less timely watering of crops (and lower yields and/or quality of produce as a potential consequence) because sufficient flow rates cannot be achieved; and

- More expensive pumping as pipelines blocked by Salvinia reduce pumping efficiency.

While there is some quantitative evidence in the literature that water hyacinth impacts on irrigation channels, no quantitative evidence is available on the impact of Salvinia. Because Salvinia causes evapotranspiration at a different rate to water hyacinth, it is not appropriate to extrapolate from the water hyacinth results, as the magnitude of the impacts will be different. (Howard and Harley 1998).

Given the lack of evidence, it has not been possible to quantify the impacts on Salvinia on agricultural crops other than rice. This is an area where further field work may be needed.

5.4 Salvinia and tourism

5.4.1 Introduction

Salvinia impacts on tourism by degrading biodiversity, impeding access to waterways for recreational purposes and degrading waterside aesthetics.

5.4.2 Tourism in the Lower Senegal Delta

Tourism is a very important industry in Senegal. It is estimated to have generated at least 12,000 jobs directly and 18,000 indirectly (Compton and Christie 2003).

The key tourist attraction in the Lower Senegal Delta threatened by Salvinia is the *Parc National des Oiseaux du Djoudj* (Djoudj National Park) one of the most important wetland bird sanctuaries in the world.

The Djoudj National Park is located about 60 km northwest of Saint-Louis. It covers an area of 160 km^2 between the Senegal River and the Djeuss. It is composed of three lakes (Lamantin Lake, 1000 ha, Grand Lake, 5500 ha and Khar Lake, 1500 ha) that are linked with the Senegal River through a number of small rivers (Niang-Diop *et al* 2002). Its importance for birds derives from the fact that it is one of the first places south of the Sahara with permanent water. Djoudj is most famous for its flocks of pelicans and flamingos, and attracts around 3 million birds of about 400 different species that pass through each year (Crompton and Christie 2003).

The volume of demand for niche markets such as bird watching in the Djoudj National Park is much less than the demand for beach tourism in Senegal. However, these niche markets are growing quickly and many bird watchers are people with above average incomes (Crompton and Christie 2003).

Between 1990 and 2000, the number of tourists that visited the park annually grew from 2,226 to 9,812 with a peak of 12,931 in 1998 (Niang-Diop *et al* 2002).

5.4.3 Estimating the impacts on tourism

If the ecological status of Djoudj is degraded enough to inhibit migratory birds from using the wetlands, tourism in the Lower Senegal Delta would decline rapidly (Jepsen 2003). Salvinia infestation may prevent birds from inhabiting the wetland by limiting biodiversity (by blocking sunlight and impeding oxygen exchange) and thus reducing the abundance and/or variety of suitable food resources. Salvinia infestation may also prevent waterbirds landing on the surface (Triplet et al, 2000).

Table 5-6 presents figures available from the literature on tourism in the Djoudj National Park.

Table 5-6: Tourism in the Djoudj national park

	Estimate	Cited in	Notes
Annual number of tourists	8000	Jepsen *et al* 2003	Has been constant for the period 1995-1997
Annual number of visitors to Djoudj National Park	12,913 in 1998 9,812 in 2000	Niang-Diop *et al* 2002	
Annual turnover of park	210m FCFA (US$381k)	Jepsen *et al* 2003	
Average expenditure per day of a tourist in Senegal	FCFA 69,044 (US$106, 2005)	Compton and Christie 2003	Sourced from a visitor survey undertaken in 1995/1996
Average number of days spent in Senegal per visitor in 2000	5.6	Compton and Christie 2003	For resort tourists.
Average amount of expenditure of tourists that is spent on exports	35%	Compton and Christie 2003	
Potential area of infestation	8,000ha	Niang-Diop *et al* 2002	Assuming only the lakes in the park will be infested; this means a potential area of infestation of 8000 ha

A number of assumptions are required in order to use the above figures to calculate the cost of a Salvinia infestation on tourism. These are set out in Table 5-7 below.

Table 5-7: Further assumptions necessary to estimate the impact of Salvinia on tourism in the Djoudj nation park

	Assumption	Notes
Number of days expenditure attributed to visit to Djoudj	2	The days of expenditure attributed to the Djoudj could be higher than this if it is the main factor motivating those who visit Senegal. However there are other bird parks in Senegal and neighbouring countries
Current average amount of expenditure per tourist per day ($US 2005)	$136	This is based on the Crompton and Christie (2003) figure in Table 5-6, but raised in line with the assumption that the income growth of the countries of origin of the tourists (mainly Europe) has been around 2.5% a year, and that expenditure in Senegal would rise accordingly Birdwatchers tend to earn above average incomes and thus are more likely to spend more than other tourists (Crompton and Christie 2003), however it is not clear how much more they may spend
Annual number of tourists	10,000	Figures from Niang-Diop *et al* (2002) and Jepsen (2003) diverge slightly, but suggest that annual visitor numbers are in the region of 10,000
Area of water bodies in the park	8,000ha	

The total cost of infestation was calculated as follows (using Methodology C from Table 2-2, page 14). The following calculation was undertaken:

Annual turnover of park + (1-% tourist expenditure on exports)* (annual tourist numbers x 2 days expenditure)

The cost of infestation per hectare was then calculated by dividing this total figure by the area of the water bodies in the park.

5.4.4 Results and qualifications

Using the estimates set out in Table 5-6 and Table 5-7, the resulting calculation of the change in welfare is set out in Table 5-8 below.

Table 5-8: Annual cost per hectare of Salvinia infestation to tourism

	$US 2005
Annual cost per hectare of Salvinia infestation of Djoudj national park	$268

Though it gives an indication of the degree of magnitude of the cost per hectare, this estimate should be treated with a degree of caution. In particular it should be noted that:

- This is an average cost rather than a marginal cost. That is, it is based on infestation occurring across the whole 8000ha of lakes in the park to reach a level that would stop birds, and thus tourists, coming to the park. Infestation of an additional hectare once tourists have stopped coming would not have an impact. The cost per hectare is very sensitive to this assumption, for example if we assume that an infestation of 4,000 ha would be enough to drive tourists out of the park, the cost per hectare doubles;
- It is implicitly assumed that the opportunity cost of all of the inputs to tourism (aside from the 35% purchased from abroad) are close to zero. This may not be accurate as goods that tourists spent their money on such as food and transport would have an opportunity cost. Hence the figure presented in Table 5-8 may be an overestimate;
- If visitors to Djoudj National Park are increasing in number over time, the annual cost of the infestation will also increase over time;
- The available figures are not recent (dating from the 1990s). There are some divergences in figures quoted in the literature.

  This estimate is not readily transferable to different regions and national parks. The number of visitors to the park is a critical element to the calculation and this will vary from park to park; and
- If an infestation in one park encourages tourists to go to another, the actual cost may only be a local one, as the economic activity is displaced to another park rather than stopped completely.

5.5 Salvinia and fishing

5.5.1 Salvinia and fishing

An infestation of Salvinia may impact on fishing revenues in a number of ways:

- Fish breeding may be hampered, reducing the stock of fish; and
- Access to water for fishing and for transport of fish to the market is impeded; and
- Some fishing methods such as gillnetting are not possible (Doeleman 1990).

5.5.2 Fishing in the Lower Senegal Delta

There is very little published information or data on fishing in the Lower Senegal Delta.

In the absence of information that would allow us to look at the Lower Delta as a whole, this section will focus on the area around Djoudj National Park, for which there is some information.

Fishing in this area is primarily subsistence, but since the recent introduction of a grant system, production has increased and the area has become the main supplier to the major cities in the lower Senegal valley such as Saint-Louis and Richard-Toll. (Fall *et al* 2003). Fishing occurs both outside of the park, and illegally inside the park. Fish is the primary source of protein in the diet of the population of the Senegal Delta (Varis and Fraboulet-Jussila 2002).

Quantitative estimates from the literature are presented in Table 5-9.

Table 5-9: Fishing around the Djoudj National Park

	Estimate	Source
Value of fishing activities in the park and its periphery	15 million FCFA, representing 48 tonnes of fish landed annually	Pandare and Sanogo (1996), cited in Niang-Diop *et al* (2002)
Proportion of households naming fishing as one of their economic activities	66%	Ba *et al* (2001) cited in Niang-Diop *et al* (2002)
Population living around the periphery of the park	5,000	Ndiaye (2001)

5.5.3 Evidence of impacts

There is plenty of anecdotal evidence of the impact of aquatic weeds on fishing (eg Varis and Lahtela 2002; Doeleman 1990). However, there is very little quantified evidence in the literature.

Table 5-10 presents a summary of the quantified evidence found. All of these relate to difficulties fishermen have with nets, access to water or transport to the market rather than different levels of fish available for catching. Because many factors such as overfishing, introduced fish species and diffuse pollution from agriculture also affect the available stock, it is difficult to isolate the marginal effect of Salvinia.

Table 5-10: Evidence of impacts of weeds similar to Salvinia on fishing

Study	Economic impact	Estimated degree of negative impact	Country	Notes
Fishing				
Pieterse 1996 and Terry 1991 cited in Joffe and Cooke 1997	Impact on fishing yields	40-50%	Niger and Malawi	Interference of water hyacinth with nets of artisanal fishermen. [No response yet from authors of original studies]
De Groote *et al* 2003	Impact on household income from fishing	69%	Benin	Water hyacinth's impact on subsistence fishing in Benin through a perceived reduction in the stock, difficulties throwing the net and difficulties transporting fish to market
Doeleman 1990	Impact on fishing yield	20-40%	Sri Lanka	Salvinia is assumed to have reduced fishing yields by this amount- no actual evidence is cited
Chikwenhere *et al* undated A	Drop in fish catches	30-95%	Zimbabwe	Water hyacinth causing difficulties for commercial fisherman to launch their boats.
Bikangaga *et al* 1998	Proportion of fisherman who do not go out when weed is present	14%	Uganda	Water hyacinth causing difficulties for commercial fisherman to launch their boats.

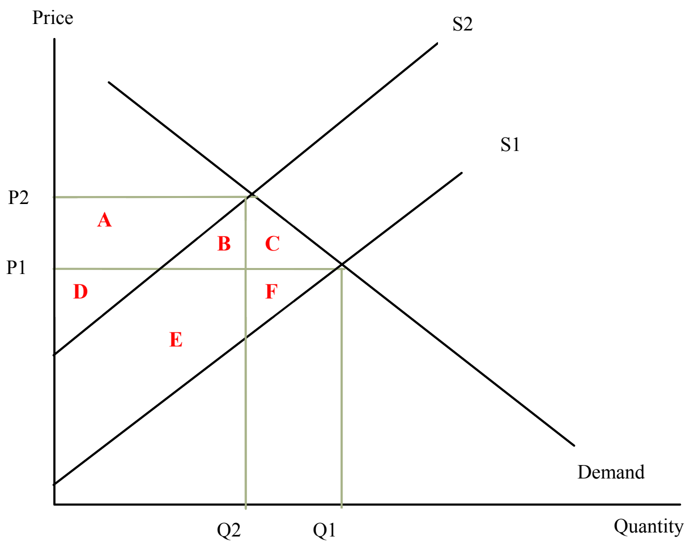
Of these studies, the most relevant are those carried out in Niger, Malawi and Benin as they deal with subsistence and artisanal fishing. They are thus more similar to the fishing types undertaken in Senegal than the commercial fishing undertaken in the areas covered by the Zimbabwean and Ugandan studies. The study in Sri Lanka is based on an expert assumption rather than evidence, and thus is less relevant.

Given the lack of evidence on the impacts of Salvinia on fishing, further research in this area may be warranted.

5.5.4 Estimating the impacts on fishing

As the area around Djoudj National Park is an important supplier of both the local market and the market in nearby cities, the impact of Salvinia may be felt in the price as well as in the quantity of fish supplied. The impact will be similar to that shown in Figure 2-1 (page 12) and repeated below (Figure 5-2). In order to best estimate the change in economic welfare, elasticities of supply and demand must therefore be known. However, we do not know what these elasticities are.

Figure 5-2: Change in economic welfare



The next best methodology to roughly estimate the change in economic welfare is to assume that economic welfare is approximated by the change in the value of production, less the costs of production. This can be estimated as follows.

$$\Delta W = \text{Change in value of production less costs of production}$$

$$\Delta W = (P\text{-}C1)*Q1\text{-}\ (P\text{-}C2)*Q2$$

Where P is the price of fish C1 is the cost of production before the infestation and C2 is the cost after the infestation. Q1 is the quantity before the infestation and Q2 is the quantity after the infestation.

We do not know what the production costs are for fisheries in the area. However, the opportunity cost of these can be assumed to be close to zero, given the high unemployment rate in Senegal, the low capital intensity of the fishing and the lack of alternative uses for this capital in the event of a reduction in fishing opportunities in the area.

It is also assumed that if Salvinia makes it more difficult to access waterways, fishermen will compensate by dedicating more effort to fishing. Due to the lack of alternative economic opportunities in the area, the cost of this additional effort has a shadow price close to zero.

The equation then becomes simply (Methodology C, Table 2-214).

$$\Delta W = P * \Delta Q$$

Estimates needed for the calculation of the change in welfare are shown in Table 5-11.

Table 5-11: Assumptions for estimating the impact on fishing

	Estimate	Notes
Price before infestation (P)	312,500 FCFA/ton Approximately US$480	Pandare and Sanogo 1996, cited in Niang-Diop *et al* 2002
Annual quantity before infestation	48 tonnes	Pandare and Sanogo 1996, cited in Niang-Diop *et al* 2002
% change in quantity	40-50%	Pieterse 1996 and Terry 1991 cited in Joffe and Cooke 1997
Assumed area of infestation	2000ha	Area of water bodies in the park. Arbitrarily assumed that villagers are able to access a quarter of the water resources in the park.
Opportunity cost of labour used in production	Close to zero	Given the high unemployment rate in Senegal, it is assumed that the opportunity cost of the labour used in the production of the fish is close to zero.
Opportunity cost of capital used in production	Close to zero	Subsistence and artisanal fishing is not capital intensive. No data is available on the value of the boats and gillnets used, however it could reasonably be assumed that these values would be close zero were the fishing resource to be destroyed.

5.5.5 Results and qualifications

The results are set out in Table 5-12 below.

Table 5-12: Cost per hectare of Salvinia infestation in a fishery ($US 2005)

	40% change in quantity	50% change in quantity
Welfare loss through the impact of Salvinia on a ha of fishing resource	$7	$9

While this result gives a general idea of the magnitude of the impact of Salvinia on fishing (eg that it is much lower than the potential impact on tourism), there are a number of important uncertainties. This means that the resulting estimate must be treated with much caution. In particular:

- It is not clear whether the estimates of the impact on fishing in Niger and Malawi are transferable to the situation in the Lower Senegal Delta. The studies were cited in Joffe and Cooke (1997) but attempts to obtain the original studies failed. To illustrate the potential bounds of the values the results of a 1% and a 100% reduction in production are set out in Table 5-13.
- The lack of data on elasticities means that we have not estimated the change in consumer surplus that would follow from a reduction in fish production and the

corresponding rise in price. This means that the change in economic welfare may be slightly underestimated.

- Although the per-hectare cost of Salvinia infestation on tourism is higher than the cost to fishing, it is likely that fishing supports more families and individuals than tourism. Information provided in Table 5-9 above indicates that 66% of households in the Djoudj region include fishing amongst their economic activities. Therefore, although the cost of Salvinia infestation to fishing is less than for tourism, the impact on fishing may affect a broader sector of the community.

Table 5-13: Illustration of boundaries of the costs of Salvinia infestation ($US 2005)

	2% change in quantity	**100% change in quantity**
Welfare reduction through the impact of Salvinia on one hectare of fishing resource	$0	$18

5.6 Other impacts of Salvinia in Senegal

It was not possible to monetise all of the impacts of Salvinia in Senegal. Even when using data from other countries and related to other species, not enough information was available to quantify the impacts on:

- Health;
- Access to water for drinking;
- Hydroelectric generation;
- Transport;
- Beneficial uses.

These are discussed qualitatively below and are areas where further research will be necessary.

5.6.1 Salvinia and health

Salvinia provides habitat for mosquito species involved in the transmission of rural elephantiasis, encephalitis, dengue fever and malaria (Julien *et al* 2002). This is due to water infested with Salvinia producing the ideal conditions for breeding of mosquitoes in shallow, stagnant water. (Doeleman 1990).

The extent of Salvinia's contribution to mosquito borne diseases is not known. There are some studies that quantify the impact of water hyacinth on health (eg Bikangaga *et al* 1998). However, Salvinia is a host to different vectors so results from these studies cannot be used.

There is evidence that the incidence of some vector borne diseases has risen since the construction of the Diama Dam in the Senegal Delta. Aside from the increase in aquatic plants that accompanied the building of the dam, many other factors such as increasing population and the higher levels of sewage in the lakes may be to blame (Varis and Fraboulet-Jussila 2002). Thus it is hard to isolate the effect, if any.

In the absence of any evidence, Doeleman (1990) assumes that Salvinia will add between 1-2% of the incidence of vector disease. However this is an assumption and it is not clear on which evidence it is based. Doeleman (1990) then values this for Sri Lanka by taking 1-2% of the current health budget spent on vector borne diseases.

Given the uncertainties between the link between Salvinia and vector borne diseases, and the cost of those diseases relative to the health budget, an attempt to value the health impacts of Salvinia will not be made here. Instead this is recommended as an area where further study is needed.

5.6.2 Salvinia and livestock

The rearing and breeding of cows, goats and sheep is an important economic activity in the Lower Senegal Delta.

No evidence was found on the extent to which aquatic weeds impact on livestock production. In addition, no estimates of the prices and quantities of production of livestock in the Lower Senegal Delta were found.

For these reasons, no estimation was made. However, as Varis and Fraboulet-Jussila (2002) note, much of the cattle rearing in the Delta are totally dependent on access to surface water. This may be an important factor in determining the impact of Salvinia. This is an area where field work and further study will be required.

5.6.3 Salvinia and water access

No evidence of the impact of Salvinia on water supply was found. There is some evidence of the impact of water hyacinth (eg Bikangaga 1998). However, as noted above, the rate of evapotranspiration of water hyacinth is thought to be much greater than that of Salvinia. Therefore these results cannot be used to estimate the impact of Salvinia of water supply.

Again, this is an area where further field work may be required.

5.6.4 Salvinia and hydroelectricity generation

There is no quantified information available on the impacts that Salvinia has on hydroelectric dams. There is evidence of the impacts of water hyacinth (eg Bikangaga 1998), but much of this impact is due to the high evapotranspiration rate of the water hyacinth, meaning that much water is either lost to the atmosphere or is held up in the plant tissues and inaccessible for hydroelectricity power generation. As noted before, Salvinia does not have the same high rate of evapotranspiration.

Some of the impact on hydroelectricity generation found by Bikangaga is due to the blockage of screens and generators by the water hyacinth – Salvinia could have this effect. However, Doeleman (1990) found that Salvinia did not impact on power generation in Sri Lanka. He explains that this is because turbines depend on big reservoirs which tend not to be subject to infestation by Salvinia because of wind and water movement.

This is an area where further field work may be required.

5.6.5 Salvinia and Transport

Again, while there is evidence of the impact of water hyacinth on transport (e.g. De Groot *et al* 2003), there is very little evidence of the impact of Salvinia.

It is unlikely that large scale water transport is affected by Salvinia. Doeleman (1990) found that Salvinia was not a problem for river shipping in Sri Lanka as mats of Salvinia break up into clumps when in fast flowing rivers.

Quantifying the impact of Salvinia on small scale transport will not be possible without additional field work – evidence of the current value of small scale transport is not available.

5.6.6 Benefits of Salvinia

Due to its nature as an invasive species, it is not suggested that attempts to cultivate Salvinia be carried out. However, there is discussion in the literature of what uses could be made of it once the infestation is already present.

Doeleman (1990) found that there was some non-systematic use of Salvinia to supplement fodder and to mulch coconut palms. However Doeleman points out, because of the difficulty of harvesting Salvinia, which is mainly water, most of the Salvinia that has been harvested in abatement efforts is generally dumped and left.

Beneficial use of Salvinia is likely to be minimal. Therefore these values have not been quantified.

6 MANAGEMENT OF SALVINIA: COSTS AND BENEFITS

6.1 Introduction

This section evaluates the major management and control approaches for Salvinia including:

- Manual or mechanical removal;
- Biological control;
- Chemical control (herbicides);
- Revegetation and habitat improvement; and
- Integrated pest management.

In addition, a search was carried out in order to assess the effectiveness of genetic modification in the management of Salvinia. However, no references to genetic modification, either existing or proposed, were found in the literature for Salvinia.

Fire control was also looked at, but this is not effective for Salvinia due to the high level of water in the leaves. However, it can be used to destroy dried up leaves after physical removal.

6.1.1 Valuing the benefits of management of Salvinia

The benefits of management are assumed to be the avoided damage costs of the weed as identified in Section 5. The benefits of managing a hectare of Salvinia are presented in Table 6-1.

All of the qualifications set out in Section 5 above apply here also.

Table 6-1: Benefits of managing Salvinia per ha by land use in Senegal (US$, 2005)

	Annual	Net present value over 20 years
Rice cultivation	$19	$172
National park	$268	$2,433
Fishing	$12	$109

6.1.2 Costs: Schedule of rates

Table 6-2 sets out the schedule of rates which will be used to calculate the costs of each management technique.

Table 6-2: Management of Salvinia - schedule of rates

Item	Estimate	Shadow price/opportunity cost	Source
Labour			
Unskilled labour (minimum wage)	40,000 FCFA per month. US$76 per month	0 – due to high unemployment among the unskilled, the opportunity cost of labour is probably close to 0	http://www.kassoumay.com/guide-senegal/index.html
Semiskilled labour (machine operators)	3,500 per day US$140 per month	US$140 per month	Daily rate paid for mechanical removal in Senegal in 2000 (Triplet *et al* 2000)
Man hour – scientist/ supervisor	US$2500 per month	US$2500 per month	Assumed
Inputs			
Weevils and materials for establishing colony	$3750	$3750	Pers. comm.- Steve Wingrave, Northern Territory Weeds Management Branch, Department of Natural Resources, Environment and the Arts. This assumes that some infrastructure is already in place as part of existing programs.
Glyphosate	$7/ha	$7/ha	Estimate based on price of Glyphosate in Australia (equivalent to $US3.4/l) http://wahri.agric.uwa.edu.au/News%20&%20Views%20Articles/Autumn06/rlno-till.htm
Diesel per litre	$0.90	$0.57 (International benchmark level for non subsidised transport policy)	Metschies (2005)
Airplane for spraying per hour (including pilot and fuel)	US$200	US$200	Cost from locust spraying in Mali in 2004 http://reliefweb.int/rw/rwb.nsf/0/f9bbe9d709f0d69349256f66000736d8?OpenDocument&Click= Each plane can spray up to 2,500 hectares per day.

6.2 Manual or mechanical control

6.2.1 Effectiveness

Evidence from the literature suggests that manual or mechanical control of Salvinia is difficult and costly. Manual or mechanical control does not eliminate all of the juvenile plants and because of the rapid rate of reproduction of Salvinia, physical control has to be intensive and regular. Thus, ongoing management is needed and costs can accumulate.

However manual or mechanical control is useful in the following situations:

- Very small infestations; and
- Cases where immediate and highly targeted control is needed.

Physical means can halt the spread of the weed in the short term; booms or control nets are often successfully used to control physical spread.

Manual removal has the added advantage of removing nutrients from the water. Treatments which kill the Salvinia mean the nutrients from decaying leaves are released into the water. These nutrients can then be used by Salvinia or other weeds to cause further problems such as reductions in oxygen in the water.

However, while manual management can be an important part of an integrated management strategy, or combined with chemical management (e.g. in Kununurra, Western Australia, see below), there is no evidence of it being effective by itself as a management technique.

6.2.2 Evidence of costs and effectiveness

Evidence of costs and effectiveness is set out in Table 6-6.

Table 6-3: Mechanical and manual management of Salvinia – evidence of costs and effectiveness

Study	Infestation	Description	Estimated effectiveness	Cost	Country (year)
Triplet *et al* 2000	200ha	Salvinia pushed into river. Removal and allowed to degrade onsite. Installation of fencing to halt spread	Removed Salvinia temporarily only	200 people, 6000 hours of work, 5000 litres of diesel fuel No information on machinery that was used.	Senegal (2000)
Chikwenhere and Keswani 1997	16ha "completely covered"		Unsuccessful- Manual removal of the weed temporarily and partially cleared the water body. However reinfestation was apparent within two to three weeks	400man-days of manual labour Z$ 3000	Zimbabwe (1989)
Chikwenhere and Keswani 1997	16ha completely covered	Floating barriers were erected on both dams in order to prevent further spread of the weed to new areas and to allow access for livestock to drink water from the dams as well as the installation of irrigation equipment Dry biomass was burnt using paraffin	Unsuccessful	Barriers – Z$ 3815. Fire - Z$750. Z$4565	Zimbabwe (1990)

Study	Infestation	Description	Estimated effectiveness	Cost	Country (year)
Pieterse *et al* 2003 Invasive Species website: www.invasivespecies.net).		Army called in to manually remove. The biomass was so large, that the equipment was not adequate.	Unsuccessful- cleared waterbodies were reinvaded after 2 months. Efforts were then abandoned.	$1000	Senegal (2000)
Doeleman 1990	4ha	Mahawelli	No information	75,000 Rp 80 people for one month and follow up maintenance with two people	Sri Lanka (1980s)
Doeleman 1990	1ha	Farmer keeping irrigation and drainage channels free and pumps protected –Sri Lankan Department of agriculture estimate.		2-3 hours of labour month	

6.2.3 Cost-benefit analysis of mechanical/manual management

Given that there are no recorded incidences of successful management of Salvinia using mechanical and manual methods in isolation, it is assumed that the benefits of this technique are zero.

However, since mechanical and manual management may be an important part of integrated pest management, it is still useful to estimate the costs. These are estimated in Table 6-4 below. Both the financial costs and the costs to society are estimated, using information from those case studies presented in Table 6-3 for which enough information was available.

The cost estimates are based on an assumption that there are 160 man hours in one month's work.

Table 6-4: Estimating costs of mechanical/manual management per hectare

Case study	Area cleared (ha)	Labour	Diesel (L)	Total financial cost per ha (US$ 2005)	Total cost to society per ha (US$ 2005)	Notes
Mechanical (manual) clearing in Senegal 2000 (Triplet *et al* 2000)	200	6000 hours - Assumed 10% unskilled, 85% semiskilled and 5% scientist/supervisor	5000	$71	$67	This cost does not include the cost of renting/buying equipment (including boats and rakes)
Manual clearing in Zimbabwe 1989 (Chikwenhere and Keswani 1997)	16	3200 hours - assumed 95% unskilled, 5% scientist/supervisor	0	$247	$156	
Manual clearing in Sri Lanka -1989 (Doeleman 1990)	4	12800 hours - assumed 95% unskilled, 5% scientist/supervisor	0	$3944	$2500	Based on what had been budgeted for this work by a Government organisation in Sri Lanka – perhaps not a reliable estimate of actual costs

The results show a wide divergence between the two case studies which examined manual clearing. This may be explained by the following:

- Different labour productivity – there might be large differences between labour productivity, depending on rates of pay, training given before the clearing started and health and motivation levels of workers. None of the studies cited above give any information on this; and
- Inaccurate estimates of the number of man hours.

However, the Sri Lankan estimate is based on the amount which had been budgeted by government for this work and is discussed in the least detail (Doeleman 1990). Hence it is recommended that this example is disregarded.

It is recommended that the results presented in Table 6-5 are used when costing manual and mechanical management.

Table 6-5: Cost of manual/mechanical management of Salvinia per ha

	Total financial cost per ha (US$ 2005)	**Total cost to society per ha (US$ 2005)**
Manual	$247	$156
Mechanical (excluding equipment hire / purchase costs)	$71	$67

Qualifications:

- These costs are presented on a per hectare basis. However, it is noted that economies of scale might apply. That is, high fixed costs (e.g. rental of machinery, management and training of workers) may mean that the cost per hectare falls as the number of hectares cleared increases. This would particularly be the case for the mechanical work; and
- No information is available on the relative effectiveness of the manual method to the mechanical method. The invasions resumed very quickly after both attempts, however it is possible that one method cleared more than the other.

6.3 Biological management

6.3.1 Introduction

Biological control is often an effective way of bringing introduced weeds and pests under control. It usually involves the selection of a predator, parasite or disease from the native range of the invasive species. For biological control to be permitted, the biological control agent must only harm the specific host and not any other species.

Salvinia infestations can be effectively controlled using one biological control agent, the salvinia weevil, *Cyrtobagous salviniae*. Other biological control agents have been used less successfully for Salvinia, including a fish and a grasshopper.

6.3.2 Necessary conditions

Biological control, using the salvinia weevil, is extremely effective. However, particular conditions and follow-up is required. The weevil needs Salvinia to survive - therefore complete eradication of Salvinia can lead to a decline in weevil populations and local extinction, creating a need to repeat introduction of the weevil if further outbreaks occur.

The success of biological control using the weevil depends on the following:

- Temperature - the weevils are more sensitive to cold temperatures than Salvinia itself. Thus certain climates (e.g. southern Australia) allow Salvinia to thrive but do not support the weevil.
- Nitrogen levels - the weevil needs high nitrogen levels to survive;
- Vegetation density - dense Salvinia populations tend to slow the weevils dispersal and excessive rainfall reduces the nutrient levels in the Salvinia leaves, therefore slowing the weevil's reproduction; and
- High rainfall.

6.3.3 Process

Only 100 weevils are required to start a population. The weevil is able to fly but they do not appear to travel long distances so transporting the weevils to new infestations is usually required. This is relatively easily done by translocating some of the weevil infested Salvinia from another area. However there is a risk that this will also translocate other weed species.

6.3.4 Effectiveness

The salvinia weevil is a very effective grazer on Salvinia. The larvae burrow into the stems and adult weevils feed on the growing buds of the plant. Eventually, the weevil destroys more leaves than the Salvinia infestation can replace and the Salvinia infestation is reduced. Full control may take from one to three years. The weevil does not destroy all the Salvinia, otherwise the weevil population itself would die out. In the long term, an equilibrium between the numbers of Salvinia and the weevil becomes established - fortunately this is at a level below which Salvinia causes ecosystem or economic impacts.

In warm climates, full control of Salvinia populations takes 1-3 years. Weevil control of Salvinia may take longer (or may require repeated introductions of weevils) in cooler climates (Australian DEH 2003).

Other biological control agents have been proposed and tested with varying success. These included the use of fish and a grasshopper species which are explained in case studies 3 and 4. The grasshopper, *Paulinia acuminata*, was released in Zimbabwe, Kenya, Zambia, Botswana, Sri Lanka, India, Fiji and either did not establish or was ineffective in other locations (Julien *et al* 2002).

6.3.5 Interaction with other management techniques

Healthy growing populations of Salvinia are required for the weevil to be most effective. Therefore control with other methods is not recommended while attempting biological control. The use of herbicides on Salvinia is counterproductive as the herbicides are known to kill the weevils as well. However, if the Salvinia mats are well established and in tertiary forms of the plant (i.e. multilayered), then some initial thinning should be undertaken with chemical treatments before biological control is started.

6.3.6 Evidence of costs and effectiveness

Costs of biological control relate to the following:

- Acquiring and transporting the weevil;
- Setting up a colony of the weevil; and
- Maintenance of the weevil colony.

Setting up a colony of the weevil requires checking every few days and weekly ongoing tending (fertilising, stirring, changing Salvinia between tubs). In Australia, start up costs are estimated at AUD$5000 (US$3750) for materials. Significant input is needed from a technician to help set up the process and train workers to keep it going. Significant commitment and ongoing time and labour input are also required to tend the weevils (personal communication-Steve Wingrave, Northern Territory Weeds Management Branch, Department of Natural Resources, Environment and the Arts).

Evidence of the costs and effectiveness of biological control of Salvinia is set out in Table 6-6.

Table 6-6: Evidence of the costs and effectiveness of biological management of Salvinia

Study	Infestation	Description	Estimated effectiveness	Cost	Country (year)
Triplet *et al* 2000		Release of 200 specimens of *Cyrtobagous salviniae*	Not yet estimated	Not possible to estimate	Senegal (2000)
Chikwenhere and Keswani 1997	16ha completely covered	Approximately 500 infested plants, holding more than 3500 weevils of all stages, were transported in plastic buckets and distributed equally between two dams. All releases were made on one farm and no pesticides were used thereafter.	Successful 99% of both dams were clear within 2-3 years	Z$ 6385.	Zimbabwe (1992-3)
Pieterse *et al* 2003	70km of river	Release of 1600 specimens of *Cyrtobagous salviniae*	Successful within a year	<US$1000 2000 prices	Senegal and Mauritania (2000)
Mbati and Neuenschwander 2005	Not cited but very large areas inspected of over 900ha	This study reviewed 20 releases of the salvinia weevil in Republic of Congo. Of the three water weeds (Pistia, Water Hyacinth and Salvinia) in the Congo, Salvinia had the greatest and quickest negative impact on human livelihoods but also quickest to be control.	Control had occurred at each location and adult weevils were present at each location. Recorded testimonies were uniform and reported that boat traffic was no longer impeded, abandoned parts of villages reclaimed and fishing resumed.	No costs given	Congo Basin, Republic of Congo (2003)
Mitchell *et al* 1980	1977 – 32km2 1979 – 79km2	Weevil introduced to the Lower Sepik River and then distributed by various means (local movements, canoes, airplanes, etc). Once established the weevil is easily distributed by humans by transporting small amounts of	Excellent control in a short time (exact time-frame not specified – Program ran for 3 years)	Initial costs for involvement of CSIRO scientists, Office and lab set-up	Sepik River, PNG (1982-1985 for control program)

Study	Infestation	Description	Estimated effectiveness	Cost	Country (year)
		weevil infested Salvinia. Most of this was done by local canoe transport but airplane transport was also used to take the weevil to remote areas.		on site, plus cost for distribution of the weevil was low due to community involvement.	
Lake Moondarra, Queensland, Australia Australian Department of Environment and Heritage 2003	800ha	This was part of the early biological control research by CSIRO in Australia, *Cyrtobagous salviniae* was first released into the Lake's Salvinia.	This was successful reducing the infestation of tens of thousands of tonnes to less than 1 tonne in 15 months.	No cost given	Australia (1980)
Lower Colorado River Irrigation Channels, USA McIntosh *et al* 2003	Not given	Tilapia (fish) were used in an experimental control system after field observations of limited expansion of Salvinia in irrigation channels in the lower Colorado River where Tilapia were ubiquitous.	In limited situations, such as experimental trials and small contained areas (irrigation channels), some control was achieved. Off target impacts of the use of Tilapia in areas where the fish is not native are likely to be large. Some species of Tilapia are native to Africa and enhancing native populations of Tilapia may be part of integrated management.	None specified but costs probably similar to other biological control, however transport of fish may be slightly more expensive.	USA (1999)

Study	Infestation	Description	Estimated effectiveness	Cost	Country (year)
Lake Kariba, Zimbabwe Marshall and Junor 1981	1000km^2	This grasshopper (*Paulinia Acuminata*) was trialled in 1970 and 1971 in the Lake Kariba. Two small populations of the grasshopper were released in these years but large numbers were bred latter in 1970 and some 3500 Paulinia were released at two sites in Lake Kariba. In 1973 the population had built up to its greatest level and Salvinia was declining.	The infestation was reduced from the 22% of the lake's surface to cover only 1% of the lake's surface. Mitchell and Rose (1979) claiming this was due to the grasshopper. Marshall and Junor (1981) reviewed this and believe that while the grasshopper did contribute to the decline, other factors also contributed	Not cited	Zimbabwe (1971)

6.3.7 Cost-benefit analysis of biological management

A number of assumptions need to be made in order to undertake a cost-benefit analysis on biological control of Salvinia. These are set out in Table 6-7. The rationale for these is as follows:

- The area infested is assumed to be 200ha. Biological control is subject to economies of scale. The larger the area infested, the better value it will be; and
- It is assumed that two months of employment by scientists will be required to get the biological control up and running and two full time unskilled labourers for one year thereafter.
- It is assumed that the facilities required (scientific establishment or breeding facility) are already established.

Table 6-7: Assumptions underlying cost benefit analysis of biological control

	Assumption
Area infested	200ha
Cost of weevil and related materials	$3750
Cost of labour (2 months scientist/supervisor) plus two years unskilled	$3824 (financial cost) $2000 (shadow price)
Time it takes for biological control to be effective	3 years

The results are set out in Table 6-8. Financial costs are higher than costs to society as the shadow price of unskilled labour has been assumed to be zero (as per Table 6-2).

Table 6-8: Cost benefit analysis of biological control

	Total financial cost (US$ 2005)	Total cost to society per ha (US$ 2005)	Benefit per ha(over 25 years, assuming no impact in first 3 years)	Benefit cost ratio – financial	Benefit cost ratio - society
Rice growing area	$20	$11	$125	6	11
National park	$20	$11	$1,766	88	161
Fishing	$20	$11	$79	4	7

The benefit-cost ratio for biological management is very high, no matter what the land use is, even though many of the benefits (e.g. health, water access, environmental) have not been valued and are therefore not included.

It is noted that biological control could not be easily applied directly to rice paddies; the weevils would be killed at each harvest. However infestation of rice paddies could be prevented by controlling the infestation at its source.

It is also noted that where institutional capability is low, biological control may be the best option. Though some technical expertise and time commitment is necessary initially, over the long run the system should reach an equilibrium and little ongoing management of the weed will be required.

6.4 Chemical management

Herbicide application can be an effective method of short term control of Salvinia. Several herbicides are commonly used for Salvinia control, including 2,4-D, Hexazinone Terbutryn, Diquat and Glyphosate. Herbicides that reduce buoyancy are most effective on light infestations as they cause Salvinia to "drown".

However, problems associated with the use of chemicals are:

- Non-target plant species are affected;
- Some fauna is affected by the chemicals (causing further ecosystem disturbance);
- Water quality can be detrimentally affected if large amounts of Salvinia are killed and decomposes at once; and
- Herbicides need to be re-applied regularly.

Table 6-9: Evidence of the costs and effectiveness of chemical management of Salvinia

Study	Infestation	Description	Estimated effectiveness	Cost	Country (year)
Chikwenhere and Keswani 1997	16ha completely covered	Roundup® (glyphosate) Sprayed from the air.	Unsuccessful-Temporarily controlled by turning the plants into slightly brown mass, but rapid regeneration of the weed reinfested the area within three to four weeks. The effect of pesticide on the water quality was not ascertained.	Helicopter (Z $4000) and herbicide (Z$10,038) Z$14,038	Zimbabwe (1990)

Study	Infestation	Description	Estimated effectiveness	Cost	Country (year)
Kununurra, Western Australia Australian Department of Environment and Heritage 2003	15m^2	The Salvinia was contained by reeds to a small area and was further contained by booms installed to prevent further spread during control. It involved the removal by hand using boats to reach the infestation. 100kg of Salvinia was removed, dried out for a week and then buried away from the waterway. Follow-up monitoring and control with chemicals was needed to eradicate the infestation. An education program was employed to inform the community throughout the project.	"Almost complete" eradication of the infestation has been achieved and the program was regarded as a success. However, constant monitoring is likely to be necessary.	Not specified.	

6.4.1 Cost-benefit analysis of chemical management

Given that there are no recorded incidences of successful management of Salvinia using chemical management in isolation, it is assumed that the benefits of this technique are small.

However, since chemical management may be an important part of integrated pest management, it is still useful to estimate the costs.

The case study looking at chemical control in Zimbabwe presented in Table 6-9 does not provide enough information to estimate what the costs of application would be in Senegal. The costs of application are thus based on the costs set out in Table 6-2 (page 45).

The following additional assumptions underlie the calculation in Table 6-10.

- Airplanes fly at 100km/hr with a spray span of 12m;
- Airplanes will only be spraying for 50% of the time they are in the air; and
- Glyphosate is used.

Table 6-10: Cost of chemical management of Salvinia

	Total financial cost per ha (US$ 2005)	Total cost to society per ha (US$ 2005)
Estimates of chemical control per hectare	$10	$10

It must be noted that economies of scale are very important for this method. The more hectares that are sprayed, the lower the cost would be, up until a certain level. The figures set out in Table 6-10 assume that these economies of scale are fully exploited, that is an area of at least 500ha is being sprayed at a time.

6.4.2 Combination of physical and chemical controls

A combination of physical and chemical controls is thought to be more effective than either applied in isolation. Effectiveness is likely to be greatest for very small infestations.

The costs of a combination of physical and chemical controls could be assumed to roughly equal the sums of their components, but the effectiveness is greater.

The following assumptions underlie the calculation of the cost benefit analysis of clearing a very small infestation of Salvinia using a combination of physical and chemical means:

- The chemical (glyphosate) is applied manually, so the costs of the airplane are not included. Instead, one day's semiskilled labour is included for each application;
- 50% of the work is carried out by semiskilled labour and 50% by unskilled labour; and
- The process needs to be repeated twice a year.

In Table 6-11, costs are presented on a per hectare basis so they can easily be compared to other management costs. However, it is stressed that this technique is likely to only be useful for very small infestations e.g. Kununurra, Western Australia (Australian Department of Environment and Heritage 2003).

Table 6-11:Cost benefit analysis of a combination of manual and chemical removal

	Total financial cost (US$ 2005)	Total cost to society per ha (US$ 2005)	Annual benefit per ha (assuming benefit only lasts for one year)	Benefit cost ratio – financial	Benefit cost ratio – society
Rice growing area	$412	$150	$19	0.046	0.127
National park	$412	$150	$268	0.650	1.787
Fishing	$412	$150	$12	0.029	0.080

These results show that the benefit:cost ratios are below one, except for the case of the national park. However, it is noted that:

- The benefit estimates are likely to be underestimates as many of the economic impacts of Salvinia have not been estimated;
- Benefits are assumed to just relate to the small area cleared. However this may underestimate the benefits of this management action, if one of its effects is to prevent a larger infestation occurring; and
- On the other hand, the costs of the chemical application on other biodiversity have not been included.

6.5 Revegetation and habitat modification and improvement

Water bodies with high nutrient levels are often subject to invasion by aquatic weed species such as Salvinia. Therefore, reducing the amount of nutrients entering a water body through revegetation, habitat and catchment management will help to reduce Salvinia growth. Agricultural run-off, sewage, stormwater and erosion runoff are the main preventable forms of nutrient input that could be targeted for control.

Habitat modification such as drying out a water body can also be effective in controlling Salvinia. However, this management action might be restricted to man-made dams and lakes, irrigation channels, etc, where management controls and environmental values allow this action. Water bodies dried out for Salvinia control need careful refilling and a watching brief to ensure no Salvinia has survived.

No evidence of the costs or effectiveness of this technique has yet been found and it is an area where further field work may be useful.

6.6 Integrated Weed Management

Integrated weed management involves the use of multiple but compatible techniques to control a weed or pest species. This might be necessary in cooler areas where biological control is not possible. A catchment management approach is the usual type of integrated weed management strategy used for Salvinia.

A catchment management approach (nutrient and sediment controls) is perhaps the most environmentally sustainable management action as it considers the whole context in which the weed occurs. This might involve water regime management, decreasing the nutrient level and improving sewage drainage and effluent treatment, and habitat improvement to allow competition for nutrients by increasing native species. Removing or reducing the amounts of nutrients is likely to reduce the biomass of floating plants such as Salvinia (Howard and Harley 1998; Chikwenhere and Keswani 1997; Room and Fernando 1992; McFarland *et al*. 2003). Steps such as reducing nutrient loads to waterways, promoting the growth of indigenous species may also assist.

Community education will play an important part in integrated management of Salvinia, as the community may inadvertently act as a vector for the spread of this species. Joint action between the community, government at all levels and intergovernmental co-operation will be needed to ensure the success of this integrated approach. Research is also necessary to keep abreast of the problems and for adoption of new and effective methods for control of Salvinia.

Although integrated pest management is environmentally sustainable, strong and stable institutions are required for it to be politically sustainable. Thus it might not be suited to some developing countries where many competing demands on government budgets mean that institutions in these areas may have less funding.

No evidence on the costs or effectiveness of this technique for Salvinia was found.

Due to the lack of evidence on this type of management strategy, the catchment management approach has not been costed for the Senegalese case.

7 RISK ASSESSMENT – SALVINIA INVASION

A risk assessment has been carried out to identify likely pathways of spread of Salvinia to neighbouring countries and to other regions of West Africa, as well as further spread within Senegal. This assessment was based on examination of the habitat and ecology of Salvinia, the occurrence of suitable habitats in neighbouring regions and countries, and the likely pathways for invasion.

7.1 Risk Assessment Methodology

The following risk elements formed part of the assessment. Note that the risk assessment is divided into two categories; natural risk, including factors relating to the natural environment, and structural risk, including factors relating to the ability of a country and community to respond to the threat of Salvinia invasion.

Natural Risk:

- Introduction pathway – waterways: assessment of the existence and inter-connection of waterways that may act as dispersal vectors for Salvinia;
- Introduction pathway – potential for mechanical dispersal: given the risk associated with the mechanical dispersal of Salvinia (eg. attached to boats, in mud that can contaminate vehicles), the presence of mechanical vectors was assessed;
- Survival likelihood – flow regimes: although not particularly critical to Salvinia, flow regimes were assessed for two major risk factors: (i) the absence of prolonged dry periods that may impact on the survival of the plants and (ii) the occurrence of floods, dispersing Salvinia and creating isolated smaller water bodies (ponds, swamps) where Salvinia may survive until the next flood event;
- Survival likelihood – climate: the assessment of climate with respect to survival focused on investigating the extreme climatic conditions (dry periods and extreme temperatures) that may eliminate Salvinia;
- Establishment risk – climate match: the assessment of climate with respect to longer term establishment of Salvinia. Average temperatures and precipitations were investigated;
- Establishment risk – habitat match: habitat match was defined as the existence of suitable habitat condition for the establishment on the longer term of Salvinia: low flow river stretches, wetlands, marshes, rice paddies, etc.
- Establishment risk – land use in catchment: the risk assessment focused on a number of factors identified as contributing to the survival and growth of Salvinia. Particular attention was given to the land use in the catchment (level of agricultural development), the type of agriculture (cash-crop/subsistence farming) and the use of fertilizers, which may contribute nutrients to waterways and subsequently promote growth of Salvinia.
- Establishment risk – proximity to existing infestation: finding precise information on the location of Salvinia infestation at a local level proved to be challenging. Efforts were made to try to locate recognised infestation areas and the proximity of new areas to be contaminated was assessed. When this proved to be impractical, a general risk level was assumed for the country/region on basis of comments/references to Salvinia in the literature.

Structural Risk:

- Control possibilities – organisational resources: the assessment focused on determining the existence and activities of governmental and parastatal organisations for each of the country/region that may have interest and/or responsibilities in the management of natural resources and water. International and regional organisations were also recorded;
- Control possibilities – political stability: the assessment of political stability was performed without any judgement of political orientation using the Political Stability Index developed by

Kaufman *et al* in 2002[2]. Investigations focused on event affecting political stability which have occurred since 2002. Information sources accessed were provided by third party bodies meaning that information arising from sources within the country itself was considered as background information but not relied upon when determining the score.

Each risk element is given equal consideration in assessing the total risk of invasion.

While the best efforts were exercised in the risk assessment for Salvinia, the level of information available and the scope of the project make it impossible to guarantee that all existing documents have been reviewed. There may be a number of documents that have not been included, especially documents published in languages other than English or French (which were used in the present study).

It should be noted than in some cases where significant variation in the level of risk existed within a country; the country was considered as a number of regions, to better reflect the risks associated with different parts of the country. For example in Mauritania, the risks observed in the Senegal River valley in the south are much higher that in the rest of the country (north-east) which is arid.

The risk of invasion was assessed for each of the following countries and regions:

- Senegal;
- Mauritania (north-east);
- Mauritania (Senegal River valley);
- Mali (northern region);
- Mali (Senegal River valley);
- Mali (Niger River valley);
- The Gambia;
- Guinea Bissau;
- Guinea;
- Sierra Leone and Liberia;
- Niger (Niger River valley);
- Niger (eastern region);
- Volta River Basin (Burkina Faso, Ghana, Togo and Benin);
- Nigeria; and
- Ivory Coast.

Each of the factors was assessed and scored according to the following scale:

- Negligible risk of infestation – 0;
- Very limited risk - infestation is unlikely under current conditions – 1;
- Limited risk - infestation is possible – 2;
- Medium risk - infestation is likely under current conditions – 3;
- High risk - infestation highly probable if no control/management in place – 4; and
- Extremely high risk - infestation most probable if no control/management in place – 5.

[2] The authors draw 194 different measures from 17 different sources of subjective governance data constructed by 15 different organizations. These sources include international organizations, political and business risk rating agencies, think tanks, and non-governmental organizations. The Political Stability index measures perceptions of the likelihood that the government in power will be destabilized or overthrown by possibly unconstitutional and/or violent means, including terrorism. This index captures the idea that the quality of governance in a country is compromised by the likelihood of wrenching changes in government, which not only has a direct effect on the continuity of policies, but also at a deeper level undermines the ability of all citizens to peacefully select and replace those in power. For more information : (http://humandevelopment.bu.edu/dev_indicators/show_info.cfm?index_id=117&data_type=1)

7.2 Risk Assessment Results

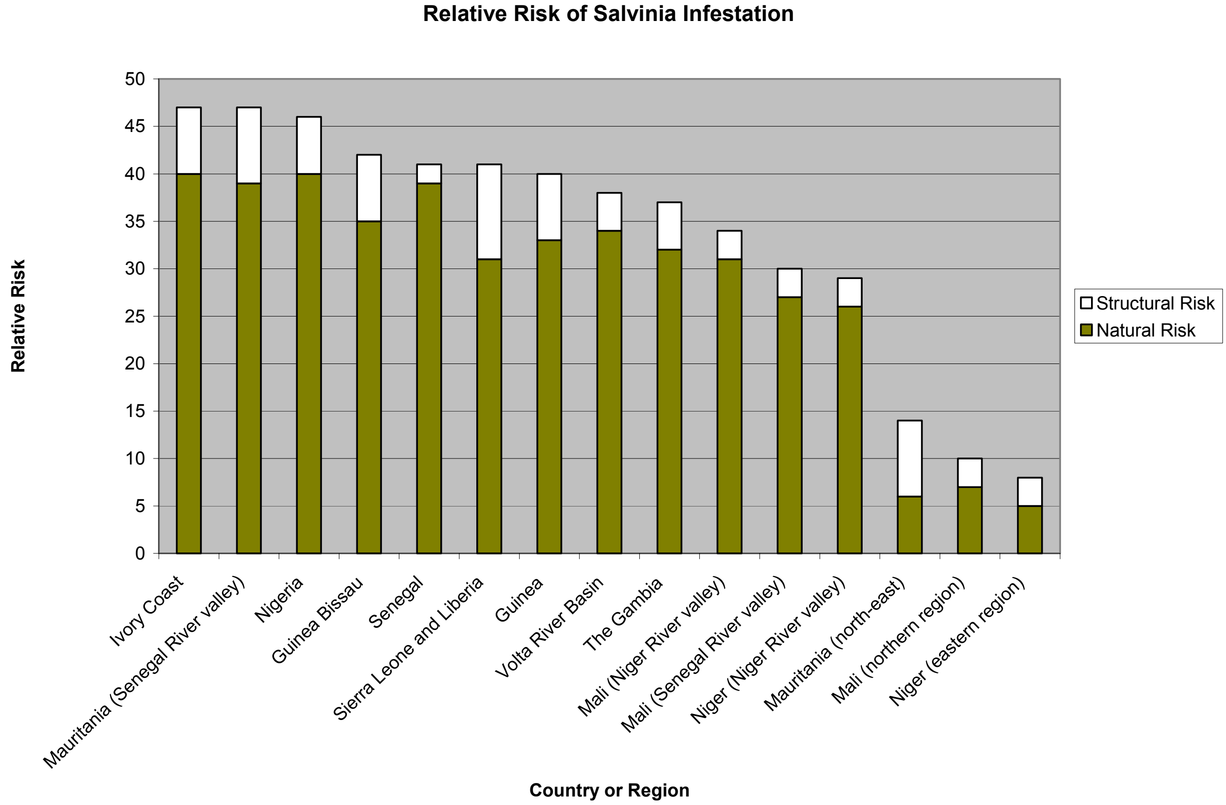
Detailed results of the risk assessment for Salvinia invasion are provided in Appendix A. A summary of results is provided in Table 7-1 below. Note that a high score indicates a high risk of invasion.

Table 7-1: Relative risk of Salvinia invasion.

Country or Region	Natural risk score (max 40)	Structural risk score (max 10)	Total risk score (max. 50)
Senegal	39	2	41
Mauritania (north-east)	6	8	14
Mauritania (Senegal River valley)	39	8	47
Mali (northern region)	7	3	10
Mali (Senegal River valley)	27	3	30
Mali (Niger River valley)	31	3	34
The Gambia	32	5	37
Guinea Bissau	35	7	42
Guinea	33	7	40
Sierra Leone and Liberia	31	10	41
Niger (Niger River valley)	26	3	29
Niger (eastern region)	5	3	8
Volta River Basin (Burkina Faso, Ghana, Togo and Benin)	34	4	38
Nigeria	40	6	46
Ivory Coast	40	7	47

This indicates that, in the absence of any control or prevention measures, Salvinia is most likely to invade and become established in Nigeria, Ivory Coast and the Senegal River valley area of Mauritania, as well as spreading to other regions of Senegal. The risk of Salvinia invasion in the north-east of Mauritania, the northern region of Mali and eastern region of Niger is very low due to the absence of suitable habitat in those areas.

Figure 7-1 Relative risk of Salvinia infestation



The estimated ultimate expected area of invasion, in the absence of any control or prevention measures, has been determined according to

Table 7-2 below, using total susceptible waterway area (area of suitable habitat) adjusted for relative risk. Note that the area indicated is an approximation only, and therefore should not be considered as an absolute value. It indicates the theoretical expected ultimate area of invasion in the very long term if no preventative or control measures are taken.

Suitable habitat for Salvinia was considered to comprise the permanent channel area (estimated to be 25 metres wide) of major river systems, and any wetlands, lakes and deltas which are inundated year-round or for most of the year. Flood plains and seasonal or ephemeral water bodies were not included in the susceptible area calculations due to Salvinia's need for water to survive and prosper. However, due to the ability of Salvinia to reproduce and spread rapidly, ephemeral water bodies may be susceptible to Salvinia invasion.

Note that this assessment does not include small waterways which are not documented in the available literature, and therefore is likely to underestimate the true area of potential invasion. However, the analysis allows for comparison of relative infestation risk between countries and regions.

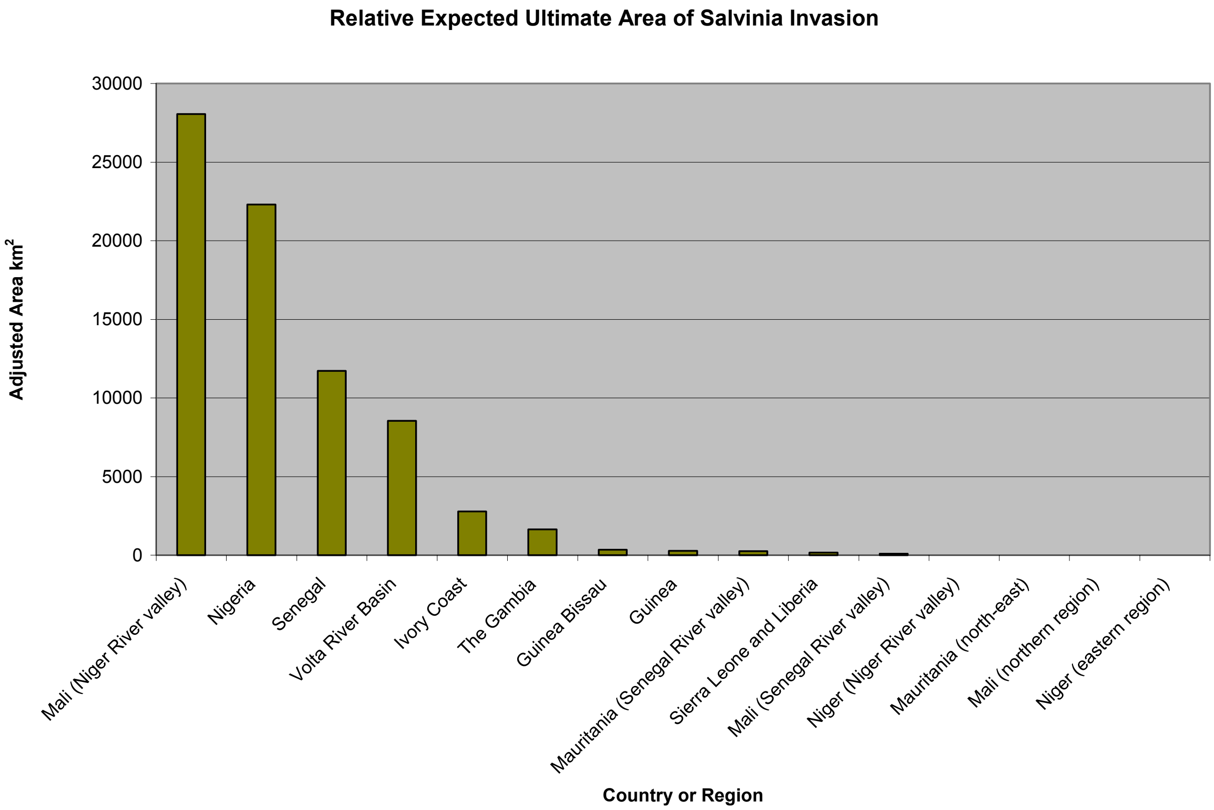
In order to account for the risk presented by small waterways which are not documented in the literature, a nominal area of 200 km^2 has been adopted where the susceptible area described in the literature is less than 200 km^2. This includes Mali (Senegal River Valley), Niger (Niger River Valley) and Sierra Leone and Liberia, for which small areas of susceptible waterways were reported in the literature. It also includes Mauritania (north-east region), Mali (northern region) and Niger (eastern region), for which no evidence of water bodies susceptible to Salvinia invasion was found in the literature.

Table 7-2: Expected size of ultimate invasion, if no preventative or control measures are applied.

Country or Region	Susceptible waterway area (km^2)	Risk score (max. 50)	Adjusted ultimate infestation (km^2)
Senegal	14,304	41	11,729
Mauritania (north-east)	200	14	56
Mauritania (Senegal River valley)	275	47	259
Mali (northern region)	200	10	40
Mali (Senegal River valley)	200	30	120
Mali (Niger River valley)	41,242.5	34	28,045
The Gambia	2,208	37	1,634
Guinea Bissau	412	42	346
Guinea	343	40	274
Sierra Leone and Liberia	200	41	164
Niger (Niger River valley)	200	29	116
Niger (eastern region)	200	8	32
Volta River Basin (Burkina Faso, Ghana, Togo and Benin)	11,245	38	8,547
Nigeria	24,239	46	22,299
Ivory Coast	2,953	47	2,776

The relative expected ultimate area of Salvinia invasion is also indicated in Figure 7-2 below. This indicates that the greatest potential for Salvinia invasion in the region surrounding Senegal in West Africa, based on consideration of susceptible area and risk of invasion, include the Niger River valley region of Mali, as well as Nigeria, Senegal and the Volta River Basin (Burkina Faso, Togo, Benin and Ghana).

Figure 7-2 Relative expected ultimate area of Salvinia invasion, by country or region.



8 PREVENTION OF SALVINIA INVASION

Strategies to prevent the invasion of Salvinia (and similar species) into new countries and regions of Africa are described in this chapter.

This section examines:

- Similar invasive species;
- Invasion pathways; and
- Prevention strategies.

8.1 Similar Invasive Species

The following invasive species have similar characteristics to Salvinia:

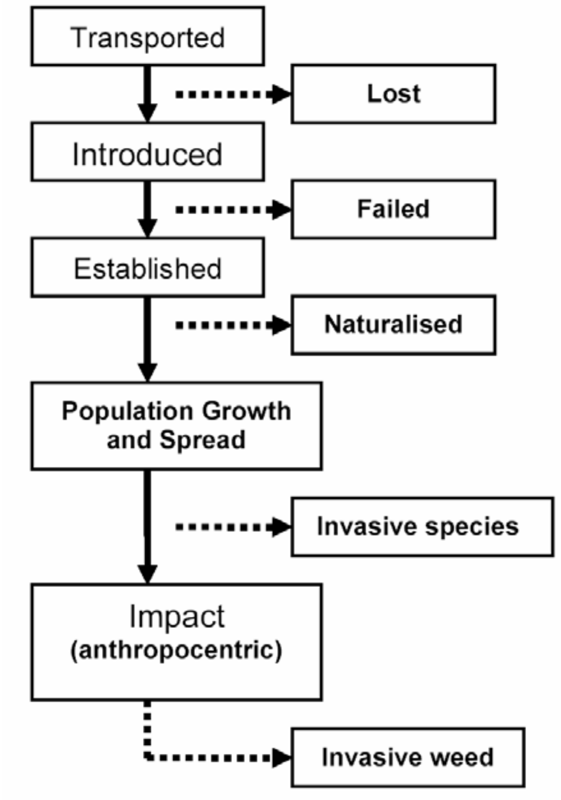
- *Azolla pinnata* (water fern);
- *Eichhornia crassipes* (water hyacinth); and
- *Pistia stratiotes* (water lettuce).

Each of these species are floating plants with a remarkable ability to spread through asexual reproduction. There are other weed threats which inhabit waterways and wetlands but these species are the most studied and perhaps the most invasive.

8.2 Invasion Pathways

Species become invasive following a series of processes after being transported to a new location. A subset of these organisms is actually introduced and some of these become established, before the populations grow and spread. It is usually at this stage they impact significantly upon human and natural values and are then recognised as invasive weeds (see Figure 8-1, Schooler *et al* 2005). Risk assessment procedures (see Champion & Clayton 2000) allow the identification of the species which are likely to become invasive.

Figure 8-1. Steps in the process of invasion leading to anthropocentric impacts (from Schooler et al 2005).



Invasion pathways have been clearly documented in New Zealand which has extremely high level and effective weed control and quarantine procedures (Champion & Clayton 2000). While these controls are unlikely to be replicated in Africa, the pathways of invasion which have been recognised are likely to be similar. These include:

- **Natural spread** consists of wind-blown or water-borne seed or propagules which arrive in a new country or new location and become established;
- **Ship ballast** sometimes contains soil which can harbour weed seeds or propagules. If ballast is then discharged into a suitable receiving environment for the particular weed species carried, invasive species can become established;
- **Forage plants** are introduced to feed grazing animals and can then become established and invasive;
- **Industrial purposes** include species which might be used for wastewater treatment (e.g. reeds) or other purposes such as biofuels;
- **Research purposes** account for specific species which may be legally imported for research or teaching purposes but then escape to become established in the wider environment due to poor internal controls;
- **Culinary and medicinal purposes** is known as an invasion pathway for invasive species. Alligator weed has been used and cultivated in New Zealand and Australia in the mistaken belief that it is another species which is a traditional vegetable. Other species, such as water lettuce (*Pistia stratiodes*), are used for medicinal purposes and escape from cultivation to become invasive;

- **Incorrectly identified imports** occurs when the lack of taxonomic knowledge by border control authorities allow species to enter a country without recognition of its invasive potential. Small samples or young specimens can be very difficult to identify, even for trained staff;
- **Contaminated products** such as imported machinery, crates and packaging can transport invasive species (less likely for aquatic species);
- **Mail order plants** are dispatched world-wide. This is potentially a growing problem in Africa as many African nations become more prosperous, with businesses and private individuals accessing these services; and
- **Pocket plants** are those species which accidentally (or carelessly, or deliberately) find their way into traveller's pockets or luggage and are not detected by quarantine authorities.

Mechanisms of spread for Salvinia are described earlier in the report (refer section 4.7). This includes the rapid reproduction through production of numerous propagules, which may be transported long distances by wind or by water. They are also frequently distributed in mud on vehicles or by the movement of stock or marine craft between waterways. Botanical escapes, particularly from aquariums, also contribute to the establishment of invasive Salvinia populations.

8.3 Potential Invasion Prevention Strategies

A range of prevention strategies are required to prevent invasive plants including Salvinia, from colonising further habitats in Africa.

These include:

- Legislation;
- Education and community involvement;
- Quarantine and controls on movement, spread and use of the species;
- Monitoring & early detection; and
- Contingency planning

It is likely that effective control of invasive species can be more easily achieved using a combination of the above techniques. While the marginal benefits (marginal effectiveness) of each of these strategies may decline when used in combination with others, the total effectiveness will be increased. Over the long term, this may provide a better approach to weed invasion prevention.

There may be synergies in the development of prevention programmes for Salvinia and prevention of invasion by other similar weed species (for example, some measures designed to prevent to spread of Salvinia, such as limiting the access of stock to waterways or mandating wash-down of boats and vehicles before transporting them to other waterways will also effectively prevent the spread of Water Hyacinth). Other measures will have a low marginal cost associated to include further invasive species in their scope (for example, quarantine measures to prevent importation of Salvinia may require significant capital and labour costs but once the facilities are established and staff trained, the same capital and labour may be utilised to effectively prevent importation of other invasive species at very low marginal cost).

Because of these complex synergies and inter-relationships, and the varying level of established programs in each country, it is difficult to estimate the true cost of implementing many of these prevention techniques. The effectiveness of these approaches will vary considerably depending on whether they are executed in isolation or in combination with other approaches, and will depend on the institutional and organisational capability of the government and relevant agencies in each nation.

8.3.1 Legislation

Legislation is required to prevent transport from one country to another and the prevention of in-country spread. The costs of controlling and managing outbreaks of either species are generally much larger than the costs of preventing it entering a country or being distributed within a country. The types of legislation which have served some countries well, in recent times, includes:

- Prohibiting the entry of identified weeds into the country;
- Mandating quarantine procedures of all people, parcels and other imported items;
- Prohibition of the keeping of invasive plants;
- Mandatory risk assessment of applications to import species; and,
- Mandatory risk assessment of applications to translocate species within countries.

The most powerful argument for this type of legislation is the disastrous results from unfettered importation of exotic species into Australia and Africa in past times without such legislation. Obviously legislation is only one of the tools required but is a useful first step and links closely with other prevention strategies, such as education.

Many African countries do not currently have legislation covering weeds. The Organisation for African Unity has established the Pan-African Phytosanitary Council, but this has not been effective in developing lists of prohibited species to date (Martin Hill, pers comm.)

Cost-Benefit analysis for legislation

No data has been found in the literature regarding the cost or quantified effectiveness of invasive species control by legislation. Prevention of invasive species establishment using legislation development would generally be expected to involve an entire country (not individual infestations). Therefore costs must be estimated at the national level and compared with the total area at risk of invasion in each country.

Due to the many variables which influence both the cost and effectiveness of this prevention technique, and the difficulty in estimating the required inputs to legislation development, no attempt can be made to estimate the associated benefit-cost ratio. The associated costs would include the development of legislation, which is expected to be a complex and lengthy process in most countries and may require lengthy revision and approval processes. Stakeholder consultation would also be required to ensure legislation developed is appropriate. A program of monitoring and enforcement will then be required indefinitely to ensure compliance with the law.

Where institutional capability is poor or the required resources for development and enforcement of legal requirements are not present, this method is unlikely to be successful.

Case Study	Prevention Strategy	Description	Estimated effectiveness	Cost	Cost US$ 2005	Country (year)
Jacot Guillarmod (1979)	Legislation	The Republic of South Africa (1964) and other African countries have weed control Acts. These acts make it illegal to keep or distribute weed species (which includes Salvinia and other water weeds). The Act requires land holders to also control these weeds.	Many issues exist with the enforcement of this legislation which include: ▪ Too few weed inspectors ▪ General public ignorant of the laws or the dangers the weeds pose and how to identify these weeds ▪ Some countries don't have proclaimed weeds ▪ Provisions within the Acts are too general ▪ Ownership of water bodies at dispute ▪ Some rivers pass from one Country to another making control even more difficult Without remedy, such legislation is ineffective in controlling weed spread, and alone it is also ineffective. This case study indicates that legislation needs to be backed up by: ▪ Compliance measures and funds expended on weed inspectors ▪ Education programs to inform the general public of the: o laws themselves o impacts of the weeds o weed identification ▪ Risk assessment to identify weed species ▪ Specific provisions and actions within the Acts ▪ Ownership of water bodies to be clarified and responsibilities assigned ▪ Inter-country agreements on weed control			South Africa (1964)

8.3.2 Education and community involvement

Education and community involvement is required to enable stakeholders:

- to understand the potential impacts of Salvinia invasion;
- to identify this species and similar potential invasive species;
- to use alternative species (natives and non-invasive species);
- to learn what actions individuals can undertake to prevent or control infestation; and
- to learn what actions which communities can support governments to undertake in the prevention and control of Salvinia.

The education to assist local communities to identify Salvinia and other invasive plants will allow these communities to understand the extent of the infestations and develop appropriate strategies to control outbreaks.

Most countries in Africa have been ad hoc in their approach to education and community actions to date (Martin Hill, pers. comm.). As a result, no case studies could be found in the literature describing the implementation, cost or effectiveness of education and community involvement in the prevention of weed invasions.

Cost-Benefit analysis for education and community involvement

No data has been found in the literature of the cost or quantified effectiveness of the prevention of invasive species by education and community involvement.

No case studies were found in the literature identifying programs of education and community involvement which had been used successfully to prevent invasion by Salvinia.

8.3.3 Quarantine and controls on movement, spread and use of the species

Controls on the movement, spread and use of invasive species is critically important in terms of managing these species. Quarantine procedures will control these species from local movements and between countries. These controls need to be supported by legislation, regulations and enforcement. Not only would they set out quarantine procedures to prohibit importation into a country, but would prohibit use of the species in aquariums, public gardens or private garden ponds. Prohibition of use is equally as important as limiting importation of these species.

Weed control legislation should ensure landholders are required by law to control Salvinia and other invasive species when it occurs on their property.

Controls on stock movement will also prevent distribution of Salvinia, as the propagules adhere to animals' coats. Therefore, fencing and control of stock movement may be necessary and useful in preventing Salvinia from colonising new waters (fencing stock out of waterways may also improve water quality). The movement of boats, cars and equipment in infested areas is a known pathway for new infestations and washdown facilities at these locations are effective in removing Salvinia and other weed species. In Lake Kariba in Zimbabwe, controls such as mandatory washdown of cars and boats, coupled with education, has been moderately successful in making people aware of the impacts caused by Salvinia (Chikwenhere and Keswani 1997) and preventing some movement of the species.

Quarantine controls are generally not very effective in Africa, as most of the introductions of plants (which subsequently become weeds) are intentional imports for some reason or other (Martin Hill, pers. comm.).

Cost-Benefit analysis for quarantine control

No data was found in the literature regarding the cost or quantified effectiveness of invasive species control by quarantine. Prevention of invasive species establishment using quarantine controls and restrictions on movement of invasive species would generally be expected to involve an entire country (not individual infestations). Therefore costs must be estimated at the national level and compared with the total area at risk of invasion in each country to establish a cost per hectare of prevention measures.

Due to the many variables which influence both the cost and effectiveness of this prevention technique, and the difficulty in estimating the required inputs to developing and maintaining quarantine controls, no attempt can be made to estimate the associated benefit-cost ratio.

The associated costs would include the development of quarantine control processes and protocols (including stakeholder consultation and potentially complex government review and approval processes), as well as significant capital and labour requirements for enforcement. This would include inspection and administrative facilities at all ports, airports and border crossings, as well as prevention of border-crossing away from designated points.

Where institutional capability is poor or the required resources for development and enforcement of quarantine regulations are not present, this method is unlikely to be successful.

Case Study	Prevention Strategy	Description	Estimated effectiveness	Cost	Cost US$ 2005	Country (year)
Wingrave (2006)	Quarantine and Control Measures	Local quarantine measures have been introduced to control the spread of a weed, Cabomba, in Australia. Part of the Darwin River in Northern Territory in Australia has been made off limits to fishing, swimming and boating with fines up to $50,000 AUD.	▪ These have been effective in restricting the local spread of this weed ▪ It would be difficult to implement in many countries as the financial penalties are not viable and subsistence farmers likely need access to all available resources			Australia (2006)

8.3.4 Monitoring & early detection

Monitoring and early detection are beneficial measures to identify and control outbreaks of invasive species (Howard and Harley 1998; Bowcher and Lee 2003; Bloosey 1999).

Small outbreaks are easier and less costly to control than established populations (Howard-Williams and Thompson 1985; Howard and Harley 1998; Bloosey 1999, Bowcher and Lee 2003; Mumba 2005). Early identification and intervention have been found to be key factors in a successful weed management program, particularly in developing countries where resources and expertise are not generally available (Triet *et al.* undated).

Monitoring programs offer the opportunity of involving communities, providing education and building the community's capacity to identify and address outbreaks before infestations become established and difficult to control due to their sheer size.

In practice, monitoring and early detection is poorly done, even in the most stable and advanced countries in Africa. While this approach has great potential to reduce the impact of invasive species, it is generally not realised (Martin Hill, pers. comm.).

Cost-Benefit analysis for monitoring and early detection

No data was found in the literature regarding the cost or quantified effectiveness of Salvinia control by the use of monitoring and early detection measures. Prevention of invasive species establishment using these methods would generally be expected to involve an entire country (not individual infestations). Therefore, costs must be estimated at the national level and compared with the total area at risk of invasion in each country in order to estimate the cost of this measure per hectare.

Due to the many variables which influence both the cost and effectiveness of this prevention technique, and the difficulty in estimating the required inputs to a monitoring and early detection plan, no attempt can be made to estimate the associated benefit-cost ratio.

It is expected that this prevention measure would have low capital requirements, and could be executed primarily using unpaid labour (that is, member of the community would carry out much of the monitoring and early detection work). However, in the case of community monitoring, there would be a need for program administration and co-ordination (including at the local and regional level) which would incur cost. Note also that this method only identifies the need for weed control measures – additional cost would be incurred for the control of the invasive species once it is identified.

The effectiveness of this approach would depend on the willingness of community members to remain vigilant and to co-operate by reporting presence of the weed species and addressing any invasion appropriately.

Case Study	Prevention Strategy	Description	Estimated effectiveness	Cost	Cost US$ 2005	Country (year)
Blossey (1999)	Monitoring and Early Detection	Surveys to determine the abundance and range of invasive species are extremely useful for the management of invading species. Such monitoring should occur before, during and after the species invades and becomes established in a location. Monitoring programs need to be designed such that they are comprehensive and statistically robust by being standardised, well replicated and sophisticated.	▪ Logistical difficulties exist in terms of the need for long-term multi-disciplinary projects, resistance from funding agencies to fund such work (which apply to well-funded western countries let alone African countries) ▪ The program will be costly and will require co-operation across country borders ▪ Likely to be very effective if implemented but operational difficulties may make this unlikely in Africa ▪ Alternative community based monitoring programs may be needed to enable some monitoring to occur			New Zealand (1993)
ECZ (2004)	Monitoring	A biological impact assessment method was designed and implemented. The study employed a systematic sampling which targeted Mimosa areas on the Kafue Flats. This sampling procedure used the Braun-Blanquet approach examining species presence, abundance, plant height, canopy size and aspect of the site.	▪ The comparative tool proved effective and quick to implement on the Kafue Flats ▪ The tool was not able to indicate the rate of Mimosa spread ▪ The program was effective in identifying two other species which were becoming invasive (a grass and a wattle)			Zambia (2004)

8.3.5 Contingency planning

Many invasive species become established following arrival in a new location due to inaction or lack of recognition of the seriousness of the problem. Contingency planning, especially when underpinned by objective risk assessment before any invasions occur, are intended to allow immediate action once an invasion does occur. These contingency plans are best developed following a risk assessment of the possible invasive species and their impacts (economic and ecological). The plans would set out monitoring required and the options for management for different species and different sizes of infestations. This allows decisive and rapid action on discovery of an invasive species.

Cost-Benefit analysis for contingency planning

No data was found in the literature regarding the cost or quantified effectiveness of invasive species control by contingency planning. Prevention of invasive species establishment using contingency planning methods would generally be expected to involve an entire country (not individual infestations). Therefore costs must be estimated at the national level and compared with the total area at risk of invasion in each country.

Due to the many variables which influence both the cost and effectiveness of this prevention technique, and the difficulty in estimating the required inputs to developing, maintaining and actioning contingency plans, no attempt can be made to estimate the associated benefit-cost ratio.

Case Study	Prevention Strategy	Description	Estimated effectiveness	Cost	Cost US$ 2005	Country (year)
Champion and Clayton (2000)	Contingency Planning	A risk assessment model and method was established to identify and classify the species' invasiveness. This risk assessment allows Pest Management Strategies to be developed and contingency planning to be put in place.	▪ This model is considered quite effective in identifying potentially invasive species ▪ The risk assessment work is well supported by legislation ▪ The legislation allows for excellent contingency planning and control measures ▪ This risk assessment model and legislation could be transferred to African countries successfully ▪ Their effectiveness would depend upon the resources which were made available to support these initiatives			New Zealand (1993)
Rouget et al. (2002)	Risk assessment and Contingency planning	A risk assessment framework for invasive tree species was developed and applied to South Africa.	▪ This model is considered quite effective in identifying potentially invasive species ▪ The risk assessment was constrained on the available data ▪ The method was useful in informing policy making and contingency planning			South Africa (1996)
Walden et al (2004)	Risk Assessment	A comprehensive wetland risk assessment procedure was applied to Mimosa in Australia's north.	▪ The risk assessment was useful in identifying which sites were at risk of invasion, the likely consequences of these invasions and what management actions which might be necessary to control these invasions ▪ The program was resource intensive and may not be possible to transfer without modification to the African situation without substantial investment of resources			Australia (2004)

9 SUMMARY OF RESULTS

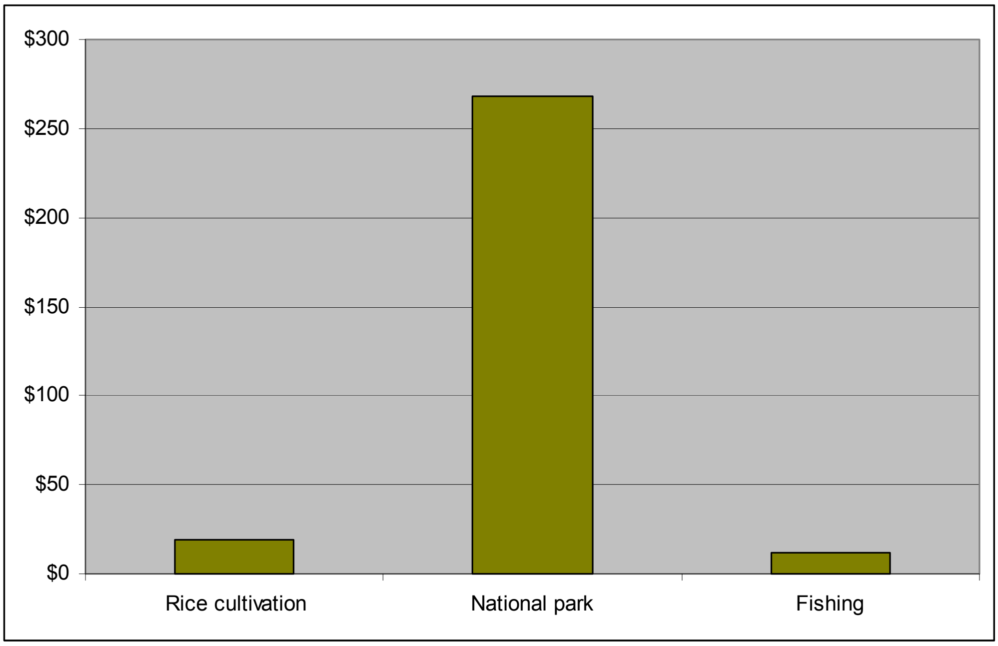
9.1 Economic impact of Salvinia

For Salvinia the impacts of invasion on rice cultivation, fishing and tourism were estimated. These are presented in Table 9-1 and Figure 9-1. A single density (high density) of invasion was assumed.

Table 9-1: Annual economic cost per hectare by land use in the Lower Senegal Delta ($US 2005)

	Annual
Rice cultivation	$19
National park (tourism)	$268
Fishing	$12

Figure 9-1: Annual economic cost per hectare by land use in the Lower Senegal Delta ($US 2005)



While there is substantial uncertainty around these figures, they do indicate the approximate economic impact of Salvinia on different land uses. It is clear that the impact on national parks has the potential to be the most severe in economic terms, even without any value being included for the loss of biodiversity.

Though the impacts on rice cultivation and fishing may be much smaller in dollar terms, there is likely to be a substantial social impact associated with these effects, which has not been valued here. For example, if opportunities for fishing and rice cultivation are no longer available, communities may break up as individuals move to urban areas to seek other employment.

9.2 Management of Salvinia

The case for using biological management of Salvinia in Senegal seems very clear cut, provided that the required legislative arrangements, infrastructure and skilled labour resources exist. While there are reasonably substantial set up costs and technical expertise required to establish biological control measures, the benefit cost ratios are very high for each land use and the management should be self-sustaining once the weevil becomes established.

The benefit cost ratios for this management technique are presented by land use in Table 9-2. Benefit cost ratios are very high, no matter what the land use, suggesting that governments and management agencies should focus on this technique for Salvinia.

Table 9-2: Cost benefit analysis of biological control of Salvinia in Senegal

	Benefit cost ratio - society
Rice growing area	11
National park	161
Fishing	7

9.3 Further field work on Salvinia

It was not possible to determine the monetary value of all of the impacts of Salvinia in Senegal. Even when using data from other countries and related to other species, not enough information was available to quantify the impacts on:

- Health;
- Access to water for drinking;
- Hydroelectric generation;
- Transport; and
- Agriculture other than rice.

While further research may be warranted in these areas, the case for biological control of Salvinia can be made even without estimating the extent of these impacts. No attempt has been made to quantify the social impacts of Salvinia invasion, nor the impact of invasion on non-use values of invaded areas.

9.4 Risk of further Salvinia invasion

A risk assessment carried out using a combination of natural risks and structural risks (relating to the institutional capability of a government and community to manage threatened invasion) for neighbouring countries and other regions of Senegal suggests that invasion of Salvinia is most likely to affect Ivory Coast, Mauritania (Senegal River valley region) and Nigeria. Adjusting for the area of susceptible habitat in each of the countries or regions considered, the greatest risks lie in Mali (Niger River Valley, Nigeria and Senegal).

9.5 Prevention of Salvinia invasion

A number or prevention methods were considered, including legislative measures, development of quarantine processes, eduction and community involvement, monitoring and early detection of invasion, and contingency planning.

No quantifiable evidence was found in the literature regarding the cost and effectiveness of these measures. However, it was noted in the literature that prevention is generally more cost-effective than control of established populations of invasive species.

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11 APPENDIX A. RISK ASSESSMENT – SALVINIA

Psi-Delta Risk Assessment Matrix

Risk Scale

0 Negligible risk of infestation
1 Very Limited risk - infestation is unlikely under current conditions
2 Limited risk - infestation is possible
3 Medium risk - infestation is likely under current conditions
4 High risk - infestation highly probable if no control/management in place
5 Extremely high risk - infestation most probable if no control/management in place

	Senegal	Mauritania (northeastern regions)	Mauritania (Senegal River valley)	Mali (northern regions)	Mali (Senegal River Basin)
Risk element Introduction pathways waterways	5 There is a very strong risk of dispersal along the Senegal River ar especially in the lower valley and the delta (downstream of Bakel) where Salvinia and other floatting weeds have already been observed (Lloyd Environmental, 2006) The Saloum river sub-basin does also form a suitable contamination pathway, with temporary affluents crossing some of the Senegal river affluents (eg Ferlo Valley) UNESCO-WWP 2003 Further south, the Cacheu (Casamance) river would form a likely pathway as well http://fr.wikipedia.org/wiki/Casamance_(fleuve)	1 There is little risk associated with introduction of Salvinia plants via waterways since only a few waterbodies exist in the Sahel region and are temporary only (*oueds*), except for the Aleg Lake. http://www.american.edu/ted/ice/senegal-mauritania.htm	5 There is a very strong risk of dispersal along the Senegal River and especially in the lower valley and the delta (downstream of Bakel) where Salvinia and other floatting weeds have already been observed (Lloyd Environmental, 2006)	1 Northern regions feature arid conditions that do not offer any suitable conditions for contamination or survival of Salvinia (<150mm). http://www.nationsencyclopedia.com/Africa/Mali-CLIMATE.html	4 There is a very strong risk of dispersal along the Senegal River and especially in the lower valley and the delta (downstream of Bakel) where Salvinia and other floatting weeds have already been observed (Lloyd Environmental, 2006)
potential for mechanical dispersal	5 Mechanical dispersal is likely given the fishing and general boating activities in the country. Fishing is the first economic activity of the delta and lower valley of the Senegal River and the second one at Senegal River basin scale. UNESCO-WWAP 2003 As for the Saloum River, Kaolack market is the largest in Senegal and include a large fish market. Transport of market products (fish/arachid) and related equipement could be vectors of propagation. Most commercial transports in Senegal are done via Kaolack. http://www.au-senegal.com/decouvrir/geo_saloum.htm# http://www.planete-senegal.com/visites/kaolack.php Migrating birds are well known throughout the coastal and delta areas of western Africa representing an additional contamination pathway. (IUCN, RAMSAR 2002) Common Hippo populations are also recorded in some areas. http://www.iucnredlist.org/search/details.php/10103/all	0 The arid areas in northeastern regions are largely unexploited. http://www.american.edu/ted/ice/senegal-mauritania.htm	5 Mechanical dispersal is likely given the fishing and general boating activities in the basin. Fishing is the first economic activity of the delta and lower valley and the second one at basin scale. UNESCO-WWAP 2003	0 The arid areas are largely unexploited	2 It is not clear if boats and material is transported from one basin to the other on a regular basis. It is believed to be possible. Common Hippo populations are also recorded in some areas. http://www.iucnredlist.org/search/details.php/10103/all
Survival likelihood flow regimes	4 Flow regimes have been modified by developing dams and hydro-dams in a number of locations along the river (1 in Senegal - Diama dam). Flows are more regular and feature less extreme events. River bed is now stabilised with controlled still occuring to allow for flood agriculture (*walo*) on both sides of the Senegal River. On the Cacheu river, flows are typically slow with a very flat river profile. http://fr.wikipedia.org/wiki/Casamance_(fleuve)	1 Northern regions typically receive low precipitations (<100mm). Rainfall only occurs in periodical events producing temporary water ways only (*oueds*). http://www.photius.com/countries/mauritania/climate/mauritania_climate_climate.html http://www.fao.org/docrep/V8260B/V8260B16.htm	4 Flow regimes have been modified by developing dams and hydro-dams in a number of locations along the river (1 in Mauritania - upstream of Kaedi). Flows are more regular and feature less extreme events. River bed is now stabilised with controlled still occuring to allow for flood agriculture (*walo*) on both sides of the Senegal River	1 Northern regions typically receive low precipitations (<150mm). Rainfall only occurs in periodical events producing temporary water ways only (*oueds*). http://www.nationsencyclopedia.com/Africa/Mali-CLIMATE.html	4 Flow regimes have been modified by developing dams and hydro-dams in a number of locations along the river (Manantali dam and hydro-dams in Felou and Gouina). Flow are more regular and feature less extreme events. River bed is now stabilised with controlled still occuring to allow for flood agriculture (*walo*) on both sides of the Senegal River

	Senegal	Mauritania (northeastern regions)	Mauritania (Senegal River valley)	Mali (northern regions)	Mali (Senegal River Basin)
Establishment risk					
climate match	5 Particularly suitable climatic conditions: warm average temperatures and absence prolonged extreme conditions (frost/ aridity)	0 Climate conditions under current trends are too dry in mos of the country to allow any development of Salvinia	5 Particularly suitable climatic conditions: warm average temperatures and absence prolonged extreme conditions (frost/ aridity)	0 Climate conditions under current trends are too dry to allow any development of Salvinia	4 Even though rainfall may be erratic and vary significantly between seasons and between consecutive years, conditions are expected to be suitable: warm average temperatures and absence prolonged extreme conditions (frost/ aridity). Suitable average rainfall (900mm/year in Kayes). http://www.fao.org/docrep/V8260B/V8260B14.htm#Mali
habitat match	5 The Senegal River basin in Senegal consists in a number of meandering confluents and main stream. In the delta low discharge and Diama dam make it a very suitable habitat for Salvinia. There also is a number of lakes that might be contaminated (Senegal: Guiers Lake) UNESCO-WWP 2003 The Cacheu River also have a large number of meanders particularly suitable to the establishment of Salvinia. http://fr.wikipedia.org/wiki/Casamance_(fleuve)	0 Northern arid environment does not form a suitable habitat	5 The Senegal River basin in Senegal consists in a number of meandering confluents and main stream. In the delta low discharge and Diama dam make it a very suitable habitat for Salvinia. There also is a number of lakes that might be contaminated (Mauritania: Lake Rkiz)	0 Northern arid environment does not form a suitable habitat	4 The Upper Basin of the Senegal River is expected to present a number of habitats suitable for the establishment of Salvinia. A number of dams may be particularly suitable.
land use in the catchment	5 85% of the Senegal River basin population (3.5m) live near the river. Risks associated with increasing levels of nutrients in water are high due to built areas run-off and agricultural activities. UNESCO-WWAP 2003	0 Arid areas are largely unhabited and Sahel and Sahara regions are unused.	5 85% of the Senegal River basin population (3.5m) live near the river. Risks associated with increasing levels of nutrients in water are high due to built areas run-off and agricultural activities. UNESCO-WWAP 2003. Irrigated agriculture is developing quickly since the 1980's and fertilizers and other intrants use has significantly increased. http://www.african-geopolitics.org/show.aspx?ArticleId=3522	0 Arid areas are largely unhabited and Sahel and Sahara regions are unused.	1 Irrigation and agriculture are largely limited in the Upper Senegal Basin (0.4% in 1994) http://www.fao.org/docrep/V8260B/V8260B14.htm#Mali
Proximity of existing infestation	5 Salvinia has already been observed in the lower valley and delta. So have other similar floatting weeds. (Lloyd Environmental, 2006) http://www.ramsar.org/ram/ram_rpt_42e.htm Salvinia is currently also present in the Saloum delta http://www.ramsar.org/cop8/cop8_nepad_thematic.doc	4 Salvinia is expected to be present in the Senegal Valley to the south.	5 Salvinia has already been observed in the lower valley and delta of the Senegal River. So have other similar floatting weeds. (Lloyd Environmental, 2006). Presence of Salvinia has also been recorded in the Diawling National Park in Mauritania. http://www.ramsar.org/cop8/cop8_nepad_thematic.doc	5 Salvinia is likely to be present in the Upper Senegal Basin to the south.	5 Salvinia has been recorded in the Valley and delta of the Senegal river. Salvinia is likely to be present in some areas of the Upper Senegal Basin already.
Control possibilities					
Organisational resources	1 Organisations exist in the area that may be able to develop and implement relevant management approaches (eg. OMVS - Organisation for the Development of the Senegal River) UNESCO-WWAP 2003	3 Mauritania has a Ministry for Hydraulics and Energy in charge of questions related to water. Their focus however is more on delivering water to people and developing national policies and do not seem to have a strong environmental focus on issues such as Salvinia propagation http://www.mauritania.mr/fr/index.php?niveau=6&coderub=4&codsoussous=124&codesousrub=9&codsoussous1=145 and http://www.hydraulique.mr/engine.php?xp=siteNavigator&cid=1	3 Mauritania has a Ministry for Hydraulics and Energy in charge of questions related to water. Their focus however is more on delivering water to peop and developing national policies and do not seem to have a strong environmental focus on issues such as Salvinia propagation http://www.mauritania.mr/fr/index.php?niveau=6&coderub=4&codsoussous=124&codesousrub=9&codsoussous1=145 and http://www.hydraulique.mr/engine.php?xp=siteNavigator&cid=1	2 Mali does provide with a number of organisations and projects that indicate a suitable basis for the development of invasive species control measures and policies. This include the Direction Nationale de l'Hydraulique et de l'Energie and projects such as GHENIS (Projet de Gestion Hydro-écologique du Niger Supérieur) http://aochycos.ird.ne/HTMLF/PARTNAT/DNHE/OHRAOC.HTM	2 Mali does provide with a number of organisations and projects that indicate a suitable basis for the development of invasive species control measures and policies. This include: the Direction Nationale de l'Hydraulique et de l'Energie and projects such as GHENIS (Projet de Gestion Hydro-écologique du Niger Supérieur) http://aochycos.ird.ne/HTMLF/PARTNAT/DNHE/OHRAOC.HTM

			Senegal		Mauritania (northeastern regions)		Mauritania (Senegal River valley)		Mali (northern regions)		Mali (Senegal River Basin)
Political Stability (Kaufmann et al.) This index is one of six indices developed to measure governance. The authors draw 194 different measures from 17 different sources of subjective governance data constructed by 15 different organizations. These sources include international organizations, political and business risk rating agencies, think tanks, and	Political stability (Political Stability Index: 2002 from http://humandevelopment.bu.edu/dev_indicators/show_info.cfm?index_id=117&data_type=1)	1	Senegal is one of the most stable countries in Africa, free of any dramatic political event since its independence in 1960. Socio-politic tensions are nearly nonexistent. http://fr.wikipedia.org/wiki/S%C3%A9n%C3%A9gal (SPI:-0.36)	5	Mauritania stability is currently very fragile and the last military push in 2005 has lead the country to a rather instable situation, not favourable to environmental considerations and measures such as the one required related to invasive species control http://www.crisisgroup.org/home/index.cfm?id=4075&l=2 (PSI:0.43)	5	Mauritania stability is currently very fragile and the last military push in 2005 has lead the country to a rather instable situation, not favourable to environmental considerations and measures such as the one required related to invasive species control http://www.crisisgroup.org/home/index.cfm?id=4075&l=2 (PSI:0.43)	1	Mali is a very stable democracy well established since the 1980's and 1990's. Mali is regularly mentioned as an examp for democracy in Africa. http://www.unctad.org/Templates/webflyer.asp?docid=4825&intItemID=3214&lang=2&mode=highlights (PSI:-0.10)	1	Mali is a very stable democracy well established since the 1980's and 1990's. Mali is regularly mentioned as an example for democracy in Africa. http://www.unctad.org/Templates/webflyer.asp?docid=4825&intItemID=3214&lang=2&mode=highlights (PSI:-0.10)
	Total risk	**34**	**0**	**6**	**0**	**34**	**0**	**7**	**0**	**24**	**0**
	River length		Casamance 300km Saloum 250km Senegal (Senegalese part) approx. 1200km Senegal (total) 1790km Gambia approx. 220km http://guides.tangka.com/senegal/Chapt3Sub2.htm http://www.africa.upenn.edu/CIA_Maps/Guinea_19847.gif		-		Senegal approx 1100km (total:1790km)		-		Senegal River: 700km
	Lakes, wetlands and floodplains Total floodplain area for the whole Sahel: 67,000km2 http://intranet.iucn.org/webfiles/doc/WWRP/Publications/GestionDur/Chp1.pdf		Ramsar wetlands 1,000km2 http://www.ramsar.org/profile/profiles_senegal.htm Lake Guiers 240km2 12,970km2 wetlands http://www.fao.org/docrep/008/n0084f/N0084F02.htm#ch3.26		-		Lake Rkiz (Senegal delta) 12km2 http://www.fao.org/docrep/008/n0084f/N0084F02.htm#ch3.21		-		
	Total Area at Risk		14304.00		0		275		0		175

Mali (Niger River Basin)	Gambia	Guinea-Bissau	Guinea	Sierra Leone and Liberia	Niger (Niger River Valley)	Niger (eastern regions)
4 Senegal and Niger Rivers form two permanent waterways capable of contributing to the dispersal of Salvinia in western Africa. Contamination between the two basins is expected to be possible in the upstream reach of the Senegal river (Bafing) where river flows within 25km of the Tinkisso that flows into the Niger river in Siguiri. The Bani River also forms a possible introduction pathways from/to Ivory Coast and Burkina Faso. http://www.fao.org/docrep/W4347E/w4347e0i.htm	4 The Gambia rivers is an unregulated river with regular flooding events inundating large areas of floodplains.	5 There are a number of waterways in Guinea-Bissau that might represent possible introduction pathways including: Rio Geba and Rio Corubal. UNESCO-WWAP 2003	5 Guinea may be considered as the center of risk in terms of introduction pathways for Salvinia. Most rivers in western Africa have their source located in the Fouta Djallon in Guinea including the Senegal (Bafing), Niger, Gambia, flowing to the North and the Konkoure flowing to the south-west. UNESCO-WWAP 2003	5 Both country featrure a number of small rivers (approx. 200km) with relatively torrential flows in the upper regions (Fouta Djalon) while the lower sections are more suitable with large meandering rivers and extensive floodplains. http://www.africa.upenn.edu/CIA_Maps/Liberia_19852.gif http://www.fao.org/docrep/008/n0084f/N0084F03.htm#ch3.27 http://www.fao.org/docrep/008/n0084f/N0084F02.htm#ch3.17	5 The Niger River flows continually from Mali (North) to Nigeria (South). The Niger River is expected to be a significant dispersal vector of Salvinia throughout west Africa. All other surface water bodies are only temporary and tend to be declining recently (Lake Tchad and in the Azaouagh Valley) http://www.fao.org/ag/agl/aglw/aquastat/countries/niger/indexfra.stm	0 The Tenere and Sahara deserts do not have any suitable contamination pathways. http://www.routard.com/guide/niger/1530/geographie_et_climat.htm
3 It is not clear if boats and material is transported from one basin to the other on a regular basis. It is believed to be possible. Common Hippo populations are also recorded in some areas. http://www.iucnredlist.org/search/details.php/10103/all	4 The Gambia economy is depending on agricultural and fishing activities. Fishing appears to be largely informal and difficult to quantify. Dispersal by contamination of fishing equipment and boats is probable. http://www.fao.org/docrep/008/n0084f/N0084F02.htm Migrating birds are well known throughout the coastal and delta areas of western Africa representing an additional contamination pathway. (IUCN, RAMSAR 2002). Common Hippo populations are also recorded in some areas. http://www.iucnredlist.org/search/details.php/10103/all	4 No specific information was found on activities related to the use of rivers as sources or transport mode. However, it is expected that a in most countries of west Africa, rivers form a highly valued asset for fishing and transport. Risks are supposed to be significantly high. Common Hippo populations are also recorded in some areas. http://www.iucnredlist.org/search/details.php/10103/all	4 The geographic proximity of waterways make it very possible for plants to be transported from one river to the next. It is not clear if equipment is regularly transferred. Precautions undoubtedly would need to be taken. Fishing equipment is definitely present in the area. Fishing activities are for example recorded on the Niger river and on the Konkoure especially upstream of the Garafiri dam. http://www.mpl.ird.fr/suds-en-ligne/fr/eau/barrages/garafir4.htm#suds Common Hippo populations are also recorded in some areas. http://www.iucnredlist.org/search/details.php/10103/all	4 No specific information was found on activities related to the use of rivers as sources or transport mode. However, it is expected that as in most countries of west Africa, rivers form a highly valued asset for fishing and transport. Risks are supposed to be significantly high. Common Hippo populations are also recorded in some areas. http://www.iucnredlist.org/search/details.php/10103/all	3 No specific information was found on activities related to the use of rivers as sources or transport mode. However, it is expected that as in most countries of west Africa, rivers form a highly valued asset for fishing and transport. Risks are supposed to be significant. Common Hippo populations are also recorded in some areas. http://www.iucnredlist.org/search/details.php/10103/all	0 The arid areas are largely unexploited
4 Flow regimes are characterised by two seasons: dry and wet seasons which include flooding event over prolonged time period during the year (July-September). It is believed that survival would be possible in some stretches of the Niger River throughout the year and seasonal dispersal possible during the floods. http://www.apfm.info/pdf/case_studies/cs_mali.pdf	4 Flow regimes are characterised by two seasons: dry and wet seasons which include flooding events over prolonged time period during the year (June-October). It is believed that survival would be possible in some throughout the year and seasonal dispersal possible during the floods. http://www.nationsencyclopedia.com/Africa/The-Gambia-CLIMATE.html	4 Rainfall generally approaches 2000mm/yr. Floods occuyred regularly in the past with significant areas of wetlands being covered for parts of the year. The development of a dam at Anambe tends to limit the low flow regimes and guarantee water availability throughout the year. http://www.fao.org/ag/agl/aglw/aquastat/countries/guineabissau/indexfra.stm http://www.nationsencyclopedia.com/Africa/Guinea-Bissau-CLIMATE.html	4 Waterways in the area are subject to substantial flooding on a regular basis. Salvinia is expected to survive easily in the area. A number of dams exist in the country that has one of teh largest hydro-power generation potential in Africa. http://www.g-eau.net/index.php?option=com_content&task=view&id=114&Itemid=140 http://www.mpl.ird.fr/suds-en-ligne/fr/eau/barrages/garafir4.htm#suds	4 Risk of survival in the lower sections are high with low river profiles, large meandering sections of the river and extensive floodplains. Risks are higher during the wet seasons. http://www.fao.org/docrep/008/n0084f/N0084F03.htm#ch3.27 http://www.fao.org/docrep/008/n0084f/N0084F02.htm#ch3.17	4 The Niger River is characterised by extensive periods of flooding that essentially impact the upper part of the Niger River. In Niger, a number of dams (eg. Kandadji) modify the flow of the river. http://aochycos.ird.ne/HTMLF/PARTNAT/BAR-KAND/OHRAOC.HTM	0 The Tenere and Sahara deserts do not have any suitable contamination pathways. http://www.routard.com/guide/niger/1530/geographie_et_climat.htm

Mali (Niger River Basin)	Gambia	Guinea-Bissau	Guinea	Sierra Leone and Liberia	Niger (Niger River Valley)	Niger (eastern regions)
4 Even though rainfall may be erratic and very significantly between seasons and between consecutive years, conditions are expected to be suitable: warm average temperatures and absence prolonged extreme conditions (frost/ aridity). Suitable average rainfall (200-600mm/year in Niger River Internal delta). http://www.fao.org/docrep/V8260B/V8260B14.htm #Mali	5 Particularly suitable tropical climatic conditions: warm average temperatures and absence prolonged extreme conditions (frost/ aridity). Suitable rainfall reliability (900-1400mm/year). http://www.nationsencyclopedia.com/Africa/The-Gambia-CLIMATE.html	5 Guinea-Bissau has a hot, humid, typically tropical climate, with a rainy season that lasts from mid-May to mid-November and a cooler dry season occupying the rest of the year. Rainfall generally approaches 2000mm/yr. http://www.nationsencyclopedia.com/Africa/Guinea-Bissau-CLIMATE.html	5 Climate in Guinea ranges from soudano-sahelian climate to tropical conditions near the Guinean Gulf coast. All of them are suitable for Salvinia to survive. http://www.fao.org/docrep/008/n0084f/N0084F02.htm #ch3.14 Generous rain is also recorded with 1600-4300mm/yr on the coast and the Fouta Djallon and between 1500 and 2700mm/yr in the Upper Guinea http://www.britannica.com/eb/article-55205/Guinea	5 Climate varies between tropical and equatorial for most the region with high rainfalls and high temperatures throughout the year. This form a very suitable combination for the survival of Salvinia. Precipitation ranges from 2000 to 5100mm/yr. http://www.nationsencyclopedia.com/Africa/Sierra-Leone-CLIMATE.html http://www.nationsencyclopedia.com/Africa/Liberia-CLIMATE.html	2 Climate is very arid with high temperatures and typically low rainfall. There is a very short wet season (June-September). Average rainfall is low in the north (500mm/yr) but reached approximately 900mm/yr in the south (Gaya). Survival might be easier in the southern part of the valley in Niger. http://www.nationsencyclopedia.com/Africa/Niger-CLIMATE.html	0 The aridity of the eastern regions make the environment totally hostile to the establishment of Salvinia.
4 The area located between Bamako and Tonbouctou is generally refered as the Niger River Inland delta clearly indicating the the general valley is regularly flooded and would form suitable habitats for the survival of Salvinia http://www.apfm.info/pdf/case_studies/cs_mali.pdf	5 Flat topography of the country and extensive areas of wetlands (20% of the country) indicate that the region is very suitable for the establishment of Salvinia. Salt water tongue upto 250km inland is not believed to have a significant impact on Salvinia establishment. http://www.fao.org/docrep/V8260B/V8260B0u.htm#The%20Gambia	5 A number of rice fields are developed and may be rapidly contaminated by Salvinia. Additionally, river profiles are relatively flat with a number of slow flowing meanders particularly suitable to Salvinia development. http://www.fao.org/ag/agl/aglw/aquastat/countries/guineabissau/indexfra.stm	5 Waterways in the area are subject to substantial flooding on a regular basis. Salvinia is expected to survive easily in the area which features a number of wetlands. http://www.g-eau.net/index.php?option=com_content&task=view&id=114&Itemid=140 http://www.aswm.org/wetlandsnewslink/archives/March02.htm http://www.mpl.ird.fr/suds-en-ligne/fr/eau/barrages/garafir4.htm#suds	3 Both country featrure a number of small rivers (approx. 200km) with relatively torrential flows in the upper regions (Fouta Djalon) while the lower sections are more suitable with large meandering rivers and extensive floodplains. http://www.africa.upenn.edu/CIA_Maps/Liberia_19852.gif http://www.fao.org/docrep/008/n0084f/N0084F03.htm#ch3.27 http://www.fao.org/docrep/008/n0084f/N0084F02.htm#ch3.17	3 Waterways do not present particularly suitable habitat conditions downstream of Niamey in Niger. However, upstream of Niamey, particularly between Ayorou and Boubon, the Niger River offer meanders and floodplains especially during the wet season. http://www.nigerembassyusa.org/profile.html Google Earth, 2006	0 The aridity of the eastern regions make the environment totally hostile to the establishment of Salvinia.
4 Large irrigation and agricultural development exist in the Niger River Inland delta. 88.1% of developed land for irrigation in 1994 was located between Koulikouro and Tombouctou http://www.fao.org/docrep/V8260B/V8260B14.htm #Mali	3 Agriculture is highly developed on river banks but is essentially rainfed. Irrigation has not been developed extensively (1500ha). The use of fertilizers is not expected to be of consequence while still possible locally. http://www.fao.org/docrep/V8260B/V8260B0u.htm#The%20Gambia A population of a less than1.5 million lives with 25km of the river in the country. Contamination of the river by nutrients is likely but of a limited magnitude.	4 Agriculture is largely dominated by rice production which can be very suitable for Salvinia development . On the other hand, agriculture is still predominantly of subsistance meaning using little inputs such as fertilizers. http://www.fao.org/ag/agl/aglw/aquastat/countries/guineabissau/indexfra.stm	2 Agriculture in Guinea is essentially oriented towards auto-consumption with less than 15% being traded. As a result, very little fertilizers and other inputs are used in agriculture. Population is not particularly concentrated near the waterways but local pollution is still possible particularly in Conakry. http://www.fao.org/ag/agl/aglw/aquastat/countries/guinea/indexfra.stm	2 Irrigation and agriculture are largely limited in both countries with a rainfed agriculture oriented towards subsistence. http://www.fao.org/docrep/008/n0084f/N0084F03.htm#ch3.27 http://www.fao.org/docrep/008/n0084f/N0084F02.htm#ch3.17	2 A large portion of Niger's population is located near the Niger River, the reason being that Niger is the only reliable source of water (90%). Niamey, growing to a population of 900,000 is also located on the River. Subsistence agriculture is essentially located on the fertile areas along the river but the use of fertilizers is believed to be limited while developing. http://en.wikipedia.org/wiki/Niamey	0 The arid areas are largely unexploited
5 Infestation has been reported in the Niger River http://www.fao.org/ag/agp/agpp/IPM/Weeds/SlideShw.htm	2 No record of infestation in the Gambia River basin was found but the Saloum River and delta to the North is infested and the whole region is considered under threat by the RAMSAR Organisation. http://www.ramsar.org/cop8/cop8_doc_25_e.htm	3 No information was found on current status of Salvinia in Guinea-Bissau. However, Salvinia has been identified as a major risk throughout west Africa by the RAMSAR organisation and the ICUN. http://www.ramsar.org/ram/ram_rpt_42e.htm http://193.194.138.128/GMNewsMgmt/news/docs/IUCNwa.pdf	3 No information was found on current status of Salvinia in Guinea. However, Salvinia has been identified as a major risk throughout west Africa by the RAMSAR organisation and the ICUN. http://www.ramsar.org/ram/ram_rpt_42e.htm http://193.194.138.128/GMNewsMgmt/news/docs/IUCNwa.pdf	3 No information was found on current status of Salvinia in Sierra Leone and Liberia. However, Salvinia has been identified as a major risk throughout west Africa by the RAMSAR organisation and the ICUN. http://www.ramsar.org/ram/ram_rpt_42e.htm http://193.194.138.128/GMNewsMgmt/news/docs/IUCNwa.pdf	5 Infestation has been reported in the Niger River http://www.fao.org/ag/agp/agpp/IPM/Weeds/SlideShw.htm	5 Infestation has been reported in the Niger River http://www.fao.org/ag/agp/agpp/IPM/Weeds/SlideShw.htm
2 Mali does provide with a number of organisations and projects that indicate a suitable basis for the development of invasive species control measures and policies. This include: the Direction Nationale de l'Hydraulique et de l'Energie and projects such as GHENIS (Projet de Gestion Hydro-écologique du Niger Supérieur) http://aochycos.ird.ne/HTMLF/PARTNAT/DNHE/OHRAOC.HTM At an international level, the Niger Basin Authority (NBA) may be able to contribute to invasive species management. http://www.fao.org/ag/agl/aglw/aquastat/countries/niger/indexfra.stm	3 The Gambia has a national water policy, a biodiversity policy and an environmental action plan all of which consider wetland issues. http://www.ramsar.org/cop8/cop8_nepad_thematic.doc Unfortunately funds are very limited and impact on the propoer functioning of governmental bodies and relevant organisations such as the OMVG (Organisation de Mise en Valeur de la Gambie).	4 Water management in Guinea-Bissau is essentially managed through the Ministry for Agriculture (Ministère de l'agriculture, des forêts, de la chasse et de l'élevage) via the Rural Enginnering division (Direction de services de génie rural-DSER). The problem is that funds are extremely limited and may affect the capability to develop suitabel management approaches and policies. http://www.fao.org/ag/agl/aglw/aquastat/countries/guineabissau/indexfra.stm	4 Guinea has a number of governmental services and divisions in charge of water and environment. The most relevant one is the Direction Nationale de la Gestion des Ressources en Eau. Guinea is also involved in a number of regional projects such as the GHENIS project (Gestion Hydro-Écologique du Niger Supérieur) which offer adequate basis for the development of control policies and management tools. http://aochycos.ird.ne/HTMLF/PARTNAT/INDEX.HTM Unfortunately the current status of the country which is very poor and seriously lacks financial and physical means. http://www.reliefweb.int/rw/RWB.NSF/db900SID/RMOI-6UXVX3?OpenDocument	5 Given the early stages of democracy and peace in the region, potential structures and organisations in charge of environmental and water related issues are at a development stage and may not be able to contribute to limiting Salvinia dispersal for a number of years.	1 At National level, Niger has a Ministry for Water Resources and is highly involved at regional level. http://aochycos.ird.ne/HTMLF/PARTNAT/DRE/OHRAOC.HTM At an international level, the Niger Basin Authority (NBA) may be able to contribute to invasive species management. http://www.fao.org/ag/agl/aglw/aquastat/countries/niger/indexfra.stm	1 At National level, Niger has a Ministry for Water Resources and is highly involved at regional level. http://aochycos.ird.ne/HTMLF/PARTNAT/DRE/OHRAOC.HTM At an international level, the Niger Basin Authority (NBA) may be able to contribute to invasive species management. http://www.fao.org/ag/agl/aglw/aquastat/countries/niger/indexfra.stm

	Mali (Niger River Basin)		Gambia		Guinea-Bissau		Guinea		Sierra Leone and Liberia		Niger (Niger River Valley)		Niger (eastern regions)
1	Mali is a very stable democracy well established since the 1980's and 1990's. Mali is regularly mentioned as an example for democracy in Africa. http://www.unctad.org/Templates/webflyer.asp?docid=4825&intItemID=3214&lang=2&mode=highlights (PSI:-0.10)	2	Before the coup d'état in July 1994, The Gambia was one of the oldest existing multi-party democracies in Africa. It had conducted freely contested elections every 5 years since independence. http://en.wikipedia.org/wiki/Politics_of_the_Gambia#Administrative_divisions (PSI:0.55)	3	Guinea-Bissau recently moved out of a ten year period heavily marked by violence and instability. In 2005 a government has been elected and works on reinforcing the legitimity and applicability of its decisions. http://www.izf.net/IZF/Actualite/RDP/Guinebissau.htm (PSI:-0.47)	3	Guinea appears to be a fairly stable country but highly subject to corruption. http://www.africatime.com/guinee/nouvelle.asp?no_nouvelle=292050&no_categorie= The stability of the country is however threatened and a number of analysts are concerned about high risks of a military coup. http://www.reliefweb.int/rw/RWB.NSF/db900SID/RMOI-6UXVX3?OpenDocument (PSI:-1.78)	5	Liberia clearly is an instable country with major risks associated with the absence of organisations and resources to develop policies and approaches against the development of any invasive species on its territory. After 14 years of civil war, the election in November 2005 of President Ellen Johnson-Sirleaf, the first woman to obtain this position democratically in Africa, appears to be a decisive political turning point in Liberia's history and is creating much hope for peace. The president's main challenge will be to rebuild a country that has been torn apart by violence and is still placed under international supervision. http://www.diplomatie.gouv.fr/en/france-priorities_1/conflicts-and-crisis_1959/western-africa_1961/liberia_1353.html Since 1996, institutional stability has been re-establishe	2	With a succession of coups since its independence, the last ones being in 1996 and 1999, Niger seems to be stabilising with the successful completion of democratic elections in 2000. http://www.acdi-cida.gc.ca/niger-f http://www.ondd.be/webONDD/Website.nsf/DisplDocuFr/Documentation_Newsletter_Country+Policy+Niger?OpenDocument (PSI:-0.30)	2	With a succession of coups since its independence, the last ones being in 1996 and 1999, Niger seems to be stabilising with the successful completion of democratic elections in 2000. http://www.acdi-cida.gc.ca/niger-f http://www.ondd.be/webONDD/Website.nsf/DisplDocuFr/Documentation_Newsletter_Country+Policy+Niger?OpenDocument (PSI:-0.30)
28	**0**	**27**	**0**	**30**	**0**	**28**	**0**	**26**	**0**	**24**	**0**	**5**	**0**
	Niger: 1700km		Gambia: 330km		Rio Geba approx. 200km Rio Corubal >160km Rio de Canjambari>130km		Niger 320km (4,100km in total) Tinkisso (Niger) >220km Konkoure approx. 250km Gambia approx. 120km http://www.africa.upenn.edu/CIA_Maps/Guinea_19847.gif http://www.fao.org/docrep/W4347E/w4347e0i.htm		Number of rivers in Liberia forming approximately 1200km of waterways. In Sierra Leone: Sewa (approx. 340km) Jong (230km) Small Scarcies (260km) Rokel (260km) Moa (190km) It is assumed that only 60% of the waterways above would present suitable conditions for the development of Salvinia. http://www.fao.org/docrep/008/n0084f/N0084F03.htm#ch3.27 http://www.fao.org/docrep/008/n0084f/N0084F02.htm#ch3.17		Niger > 300km (4,100km in total)		-
	41,200km2 (Niger River Interior Delta) http://www.ramsar.org/wwd/4/wwd2004_rpt_mali_press_f.pdf		wetlands: 2,200km2 http://www.fao.org/docrep/V8260B/V8260B0u.htm		400km2 of Ramsar wetlands		Konkoure delta 320km2 http://www.ingentaconnect.com/content/klu/wetl/2000/00000008/00000001/00237565;jsessionid=1tdmv00833ifu.alice		There is no large inland water body (either natural or artificial) other than a very limited number of small hydroelectric dams including near Monrovia and a few small lakes such as the Lake Piso (180km2)				-
	41242.5		2208.25		412.25		342.75		198		7.5		

Volta River Basin (Burkina Faso, Benin, Togo, Ghana)	Nigeria	Ivory Coast
5 Numerous waterways exist: the various voltas (Black and White Voltas), but a number of significant size rivers such as the Oueme (Benin). All the countries present a number of suitable waterways: eg. Bani River from Ivory Coast/Burkina Faso to Mali. http://www.fao.org/docrep/W4347E/w4347e0i.htm	5 The Niger River flows from the northwest of Nigeria to its delta in the Gulf of Guinea. A number of tributaries could form possible contamination pathways to other regions in equatorial Africa such as the Benue that flows from Chad via Cameroon to reach the Niger in Lokoja. http://www.fao.org/docrep/W4347E/w4347e0i.htm	5 There are a number of possible introduction pathways in Ivory Coast forme by 4 major waterways/basins: In the west: Cavally (700 km) connecting with Guinea and forming the border with Liberia ; Sassandra (650 km) that receives water from Guinea via a number of tributaries including the Bafing river; Bandama basin including the White Bandama, the Red Bandama (or Marahoué) and the N'zi (1,050 km); The Comoé River to the east connecting with Burkina Faso (1,160km). There are also a number of smaller rivers, tributaries of the Niger River including the Baoulé, the Bagoé and the Gbanhala http://www.fao.org/ag/agl/aglw/aquastat/countries/cote_divoire/indexfra.stm
3 No specific information was found on activities related to the use of rivers as sources or transport mode. However, it is expected that as in most countries of west Africa, rivers form a highly valued asset for fishing and transport. Risks are supposed to be significant. Common Hippo populations are also recorded in some areas. http://www.iucnredlist.org/search/details.php/10103/all	5 Fishing sector clearly causes aggravated risks of contamination by Salvinia as FAO estimates that about 11,000t of fishes are caught each year in the inland waters of Nigeria. http://www.fao.org/docrep/008/n0084f/N0084F02.htm#ch3.24	5 Fisheries are developed in the country with approximately 17,000t/yr production. It is expected that both transport and fishing boats may significantly travel along the numerous river systems, forming a significant risk of contamination. Common Hippo populations are also recorded in some areas. http://www.fao.org/docrep/008/n0084f/N0084F02.htm#ch3.15 http://www.iucnredlist.org/search/details.php/10103/all
4 Flow regimes in the region are expected to contribute to the survival of Salvinia with a number of river stretches featuring slow flows and meanders. There also is a number of lakes (either natural or artificial) that could be contaminated by Salvinia (eg. Lake Volta).	5 Flow regimes in the region are expected to allow for the surviv of Salvinia with a number of river sections featuring slow flows and meanders. There also is a number of lakes (either natural or artificial) that could be contaminated by Salvinia (eg. Kainji Lake).	5 There is a large number of meandering section of the rivers in Ivory Coast that provide with suitable conditions for the survival of Salvinia. More, a number of lakes and reservoirs are present in the region that are represent high risks of contamination: Buyo, Kossou, Taabo and Ayame lakes. Rice is also grown in the area representing a large potential of contamination given the Salvinia's high level of survival in rice fields. http://www.africa.upenn.edu/CIA_Maps/Cote_19848.gif

Volta River Basin (Burkina Faso, Benin, Togo, Ghana)	Nigeria	Ivory Coast
4 Tropical/equatorial conditions are particularly suitable conditions for the establishment of Salvinia. Precipitations in the southern part of the region range fro 900 to 2000mm/yr http://www.nationsencyclopedia.com/Africa/Ghana-CLIMATE.html http://www.nationsencyclopedia.com/Africa/Benin-CLIMATE.html http://www.nationsencyclopedia.com/Africa/Togo-CLIMATE.html The northern part of the region (Burkina Faso) receives far less rain with average values of 250mm/yr in some parts. http://www.nationsencyclopedia.com/Africa/Burkina-Faso-CLIMATE.html	5 The northern part of Nigeria might not be particularly suitable f the establishment of Salvinia with rainfalls of 500mm per year. The southern and central regions which present tropical/equatotial conditions are on the other hand very suitab with high temperature throughout the year and significant precipitation (1800 to 4300mm/yr). http://www.nationsencyclopedia.com/Africa/Nigeria-CLIMATE.html	5 The climate in Ivary Coast varies from tropical to equatorial conditions with rainfalls ranging from 900 to >1500mm/yr from North to South. http://www.fao.org/ag/agl/aglw/aquastat/countries/cote_divoire/indexfra.stm
5 Waterways in the region have a number of slow flowing meanders and extensive areas of wetlands that would provide a suitable habitat for Salvinia. The fact that Salvinia is already present in a number of areas is an indication of a larger risk.	5 Habitats along the waterways in Nigeria are suitable for the establishment of Salvinia with a number of meanders and slow-flowing sections of the rivers as well as dams and lakes. The extensive areas of teh Niger delta would also be particular suitable. http://www.africa.upenn.edu/CIA_Maps/Nigeria_19877.gif	5 There is a large number of meandering section of the rivers in Ivory Coast that provide with suitable conditions for the survival of Salvinia. More, a number of lakes and reservoirs are present in the region that are represent high risks of contamination: Buyo, Kossou, Taabo and Ayame lakes. http://www.africa.upenn.edu/CIA_Maps/Cote_19848.gif
3 Agriculture in the area is still under-developed in the sense that mostly oreited toward subsistence. Low impact on waterways is expected except for potential localised point source pollution from specific farms/properties/plantations.	5 Nigeria has a quite developed agriculture sector in the central part of the country where it can be expected that nutrient pollution may occur favorising the development of Salvinia. Pollution due to contamination from human wastes can also be expected in the most populous country of Africa (Pop. >130m) http://en.wikipedia.org/wiki/Nigeria#Economy http://worldfacts.us/Nigeria.htm http://www.fao.org/docrep/008/n0084f/N0084F02.htm#ch3.24	5 Ivory Coast presents industrial agriculture with cash-crops being developed throughout the country. Risks associated with nutrients loading of water bodies are assumed high. http://www.fao.org/docrep/008/n0084f/N0084F02.htm#ch3.15
5 Presence of Salvinia has been reported in Ghana and Ivory Coast and is expected be present in the upper tributaries of the Lake Volta in Togo and Burkina Faso. Status of Benin is unclear but similar aquatic weeds are present (Water Hyacinth). http://www.invasive.org/eastern/biocontrol/2FloatingFern.html http://spore.cta.int/spore112/spore112_feature.asp	5 Salvinia has been reported in Nigeria especially in Lake Kainji. http://www.fao.org/docrep/005/T3660E/T3660E03.htm	5 Salvinia has been reported in Ivory Coast and particularly in the Grand Bassam area (east) in the Komoe River. http://www.ramsar.org/profile/profiles_cotedivoire.htm http://www.ramsar.org/wn/w.n.cotedivoire_5_e.htm http://www.invasive.org/eastern/biocontrol/2FloatingFern.html
2 The Volta River is shared by six countries: Ghana, Côte d'Ivoire, Togo, Burkina Faso, Benin and Mali. There is no mechanism to develop the Volta River together, but a permanent joint commission has been set up to discuss ways of sharing benefits and increasing cooperation for better management of the Volta river basin Developments in the White Volta Basin by Burkina Faso affect Ghana since it is downstream. This is creating insecurity and conflict, as it is perceived to be the cause of the drop in water level in Lake Volta below the minimum operating level of the Akosombo hydropower plant. Ghana shares hydropower created at Akosombo and Kpong hydropower plants with all the riparian countries except Burkina Faso and Mali.	2 In Nigeria, the Federal Ministry of Water Resources has put up an enduring institutional framework through the creation of seven (7) Departments, twelve (12) River Basin and Rural Development Authorities (RBDAs) and the national Water Resources Institute (NWRI). At the regional level, Nigeria participates in the regional bodies such as the Niger Basin Authority (NBA) and the Lake Chad Basin Commission (LCBC). http://aochycos.ird.ne/HTMLF/PARTNAT/FEDWATER/INDEX.HTM	2 There is a number of government structures and bodies in place that look after water management and environmental issues in Ivory Coast. These include the Ministry for Forests and Environment which has a dedicated Division for Environment that would be in charge of Salvinia related issues More, an Ivory Coast Water Code was passed by the Parliament on 23 December 1998, with the following objectives: better resource identification, interministerial coordination, better consensus-seeking between elected officials and users, the implementation of a water law enforcement system project leadership and better management of cross-border waterways. http://www.fao.org/ag/agl/aglw/aquastat/countries/cote_divoire/indexfra.stm http://www.eau-international-france.fr/article.php3?id_article=180&idRubSel=216&id_parent=&id_rubrique=219&id_pere=

Volta River Basin (Burkina Faso, Benin, Togo, Ghana)		Nigeria		Ivory Coast	
2	Benin is politically a very stable country (PSI: 0.63) Ghana appears to be fairly stable with a democratic system surviving the 2004 elections but with serious issues raising with increasing unemployment (PSI:-0.11) Togo seems to be politically stable a the moment but with a number of areas of concern among the population (PSI: 0.01) Burkina Faso is evolving progressively towards a fully democratic system without much trouble and is stable (PSI: -0.10) http://www.gouv.bj/benin/economie/investir_benin/index.php http://www.fao.org/docrep/005/Y4172M/rep2/benin.htm http://www.ufctogo.com/article.php3?id_article=1422 http://www.oecd.org/dataoecd/20/55/34883758.pdf http://ec.europa.eu/comm/development/body/country/country_home_fr.cfm?cid=bf&lng=fr&status=new	4	Nigeria is working hard towards a fully democratic society with the country being freed from pure military regimes for nearly a decade now. However, the country remains burdened by ethnic cleavages and a high militarisation of the society, as the events around the 1999 elections showed. Risks associated with political instability are present. http://www.twnside.org.sg/title/1944-cn.htm (PSI: -1.49)	5	Ivory Coast has been in a severe politico-military crisis since the coup attempt in September 2002 launched by armed rebels, who remain in control of the northern part of the country. The situation has somehow improved over the recent period but remains very fragile. http://www.diplomatie.gouv.fr/en/france-priorities_1/conflicts-and-crisis_1959/western-africa_1961/cote-ivoire_1352.html (PSI:-2.04)
29	**0**	**35**	**0**	**35**	**0**
	Benin: Niger 120km Pendjary (Volta) 400km Oueme 700km Couffo 240km Mono 360km Togo: Oti 210km Mono 360km Ghana: 3 Voltas: >600km Oti 150km Afram and Pru <300km + number of coastal waterways Burkina Faso: Black Volta <500km (1350km in total) White Volta approx. >450km (720km in total) Red Volta approx. 200km http://www.africa.upenn.edu/CIA_Maps/Ghana_19845.gif		Niger 1,300km Benouye 1,440km http://www.fao.org/docrep/008/n0084f/N0084F02.htm#ch3.24		Cavally (700 km) Sassandra (650 km) Bandama basin including the White Bandama (1,050km), the Red Bandama (or Marahoué) (600km) and the N'zi (800 km); The Comoé River (1,160km). There are also a number of smaller rivers, tributaries of the Niger River including the Baoulé (>100km), the Bagoé (>100km) and the Gbanhala http://www.fao.org/ag/agl/aglw/aquastat/countries/cote_divoire/indexfra.stm
	Benin 2291 km2 (+260km2 of delta) Togo 0 km2 (+ 80km2 of delta) Ghana 8500 km2 (lake Volta) Burkina Faso		Kainji Reservoir (dam) 1,270km2 Niger floodplain 4,800km2 Benoue floodplain 3,100km2 http://www.fao.org/docrep/008/n0084f/N0084F02.htm#ch3.24 Niger delta: approx. 15,000km2 of floodplains and marshes http://www.fao.org/docrep/005/T3660E/T3660E03.htm		Largest lakes: Lake Kossou (Bandama) 1,700km² Lake Ayame (Bia) 84 to 197km² flood depending Delta areas and lagoons: Ebrie (532 km2) complex of Abi-Tendo-Eki (410 km2). And a number of smaller water bodies
	11245.75		24238.5		2953

Salvinia Molesta Risk Assessment Summary

Country / Region	Natural Risk	Structural Risk	Area	Nominal Area		Relative area corrected for risk
Senegal	39	2	14304	14304		11729
Mauritania (north-east)	6	8	0	200		56
Mauritania (Senegal River valley)	39	8	275	275		259
Mali (northern region)	7	3	0	200		40
Mali (Senegal River valley)	27	3	175	200		120
Mali (Niger River valley)	31	3	41242.5	41242.5		28045
The Gambia	32	5	2208.25	2208.25		1634
Guinea Bissau	35	7	412.25	412.25		346
Guinea	33	7	342.75	342.75		274
Sierra Leone and Liberia	31	10	198	200		164
Niger (Niger River valley)	26	3	7.5	200		116
Niger (eastern region)	5	3	0	200		32
Volta River Basin	34	4	11245.8	11245.75		8547
Nigeria	40	6	24238.5	24238.5		22299
Ivory Coast	40	7	2953	2953		2776