A Cost-Effectiveness Evaluation of Water Hyacinth Control Methods

The Case of Lakes Kyoga and Victoria Ecosystems in Uganda

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LIST OF ACRONYMS

APC	Agricultural Policy Committee
GDP	Gross Domestic Product
GTZ	German Technical Cooperation
FAO	Food and Agriculture Organisation of the United Nations
FGDs	Focus Group Discussions
MAAIF	Ministry of Agriculture, Animal Industry and Fisheries
MFEP	Ministry of Finance and Economic Planning
MNR	Ministry of Natural Resources
NAARI	Namulonge Agriculture and Animal Research Institute
NARO	National Agricultural Research Organisation
NTCWH	National Technical Committee on the Control of the Water Hyacinth
NWSC	National Water and Sewerage Cooperation
URC	Uganda Railways Cooperation
UEB	Uganda Electricity Board
WHO	World Health Organisation

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A COST-EFFECTIVENESS EVALUATION OF WATER HYACINTH CONTROL METHODS: THE CASE OF LAKES KYOGA AND VICTORIA ECOSYSTEMS IN UGANDA

Abstract: The water hyacinth was first reported on Lake Kyoga in 1988. Given its high proliferation rate it has spread to cover about 70,000 and 20,000 hectares on Lakes Victoria and Kyoga, respectively. It has inflicted enormous negative effects that include: increased evapotranspiration that has reduced the water table; physical obstruction of water transport means loss in quality of fish and other products leading to reduced incomes; increased operational costs attached to fishing activities resulting from loss of nets and boat engine breakdowns; reduced fish reproduction; and being a breeding ground for many disease-causing organisms. These effects have in turn affected the national economy; the environment and the health status of lakeshore residents and have resulted in its condemnation.

Four control methods, namely, biological, chemical, manual and mechanical have been tried in Uganda at different sites. Comprehensive economic data on costs and effectiveness of the four methods are lacking. Given the limited resources at our disposal it is unjustifiable to undertake control of the weed without evaluation of the most cost-effective strategy.

This study was undertaken: to conduct environmental economic analyses and make comparisons among the four control methods, to make simulations of potential combination of the four methods and undertake sensitivity analysis and to develop an analytical procedure that can guide policy makers on deciding the best control strategy.

Findings indicate that mechanical control method is the most cost-effective with a cost-effectiveness (C:E) ratio of 0.016. This is followed by the manual, biological and chemical control methods with cost-effectiveness ratios of 0.116, 0.208, and 0.299, respectively. These ratios suggest the amount of money (in US dollars) required to clear a square metre area per hour.

The mechanical method is, therefore, recommended for use in combination with manual method in a ratio as close to 4: 1 as possible. This is in the interest of effective control and creation of some employment opportunities. This scenario would require about US $32 millions to undertake full-blown achievement. This is equivalent to US $108,000 per month.

Finally, more pragmatic policy intervention and further research are necessary to evaluate use of the weed in animal feed formulations, biogas digesters, mulching and paper industries. More research in

chemical and biological control methods and increasing public awareness and cooperation between the East African countries are also necessary to deal with the problem satisfactorily.

1. INTRODUCTION

1.1 Background

Water hyacinth (*Eichhornia crassipes*), also known as the water weed, arguably the most noxious aquatic weed in the world, is native to South America where it occurs basically harmlessly in streams and seasonally flooded environments. The plant is, however, one of the most widely distributed aquatic weeds, having been translocated almost all over the tropical and sub-tropical world mainly by collectors of ornamental plants.

The weed was first reported in Uganda on Lake Kyoga in May 1988 and on Lake Victoria in December 1989, having entered the latter lake from Kagera River. It is estimated that Kagera River empties into Lake Victoria 1 to 3.5 ha of the weed weekly. This is equivalent to between 350 and 1,225 tonnes.

The weed spread rapidly over the years to fringe over 50% of the shores of Lake Kyoga, about 80% of the banks of Nile River and most of the northern tip of Lake Albert. According to estimates made in July 1995, Lake Victoria had about 2000 ha while Lake Kyoga had 600 ha of the weed. Rough estimates based on the fact that the weed population doubles twice a month showed that by the end of 1996, Lakes Victoria and Kyoga, whose surface areas are 28,655 km^2 and 2,047 km^2 according to the Ministry of Natural Resources (1994), were covered up to 70,000 and 20,000 hectares, respectively.

The water hyacinth is widely distributed in Uganda's aquatic environment. As far as lakes are concerned, Victoria, Kyoga and Albert are all infested. The rivers Victoria Nile and Albert Nile, along with numerous wetlands surrounding many smaller lakes and rivers, are also infested.

Uganda was not the first country to be infested with *E. crassipes*. In 1952, for example, it was introduced into Congo River at Kisanghani and has since then been a problem in development of water transport. It was introduced into Egypt in the early part of this century and it has since remained a problem in irrigation systems. It appeared in central Sudan's upper Nile swamps in 1958 and it remains a problem at the Jebel Aulia Dam.

In Nigeria and Benin, infestation dates back to 1985 and currently it is seriously affecting fish catches. Ghana's water bodies were infested in 1980 and Malawi's in 1968. Available information indicates that about 15 African countries have experienced this problem. Elsewhere in the world, water bodies, such as those in Australia, Indonesia, India, Sri-Lanka and the USA, have been infested.

1.2 Statement of the Problem

The water hyacinth has inflicted enormous negative effects not only on the country's environment but also on the health status and well-being of many people who seek livelihood from the infested waters and the country's economy in general. Therefore, eradication of the weed is highly advocated the world over. However, its fast growth rate, the large water bodies in Uganda that facilitate its growth, and seeds that remain viable for over 30 years are manifestations of the difficulty associated with its complete eradication.

Experiences of other countries indicate that all the control methods tried are very costly and not as effective as they seem to be. For instance, in Sudan manual control takes 500 men to clear a hectare a day. Only 20 sq. metres can be cleared a day (equivalent to 350 kg on a wet basis) to maintain access to a fish landing site. Further, the costs of labour to attract workers are quite high.

The mechanical control methods are not perfect either. A hybaler machine used in Sudan, apart from its high procurement and maintenance costs, lasts from 3.5 to 4 years. A mechanical harvester recently procured by URC from Britain at US $250,000 never worked satisfactorily. On top of this, the chopped weed has to be removed from the water immediately; otherwise, it rots and removes the oxygen or grows into new plants very quickly by vegetative means. This necessitates employing manual labour to supplement the mechanical methods, with further financial implications. Therefore, manual or mechanical control alone is not adequate. From Nigeria's experience in the 1980s, an annual total of US $750,000 was required for mechanical control.

The chemical control method using either glyphosate, diquat or 2,4-D herbicide is being contemplated in Uganda and has been used in Zimbabwe. The grave limitation of this method remains its negative impact on the environment.

As for biological control, the weed has no effective predators in Uganda or Africa because it is not indigenous to Africa and as such has no natural biological enemies. The weevils *Neochetina bruchi* and *Neochetina eichhornia* have been identified as absolutely specific to the hyacinth and they have been tried in Sudan and on Lake Kyoga. Research on these weevils is being carried out at Namulonge Agriculture and Animal Research Institute (NARA) of Uganda's National Agricultural Research Organization (NARO).

There is lack of satisfactory empirical research results to guide policy makers on an economical control method. It is, therefore, imperative that the costs and defectiveness of individual control methods be analysed to identify the least costly and most effective method before full-blown investment in what could turn out to be an inefficient and /or environmentally catastrophic control measure.

1.3 Purpose of the Study

This study aims at comparing and evaluating the water hyacinth control methods in terms of costs, effectiveness and environmental sustainability at sites where the methods have been tried. Further, sensitivity analysis of potential combinations of these methods will be theoretically simulated and evaluated. Results of both approaches are expected to yield an economical and environmentally sustainable scenario worth adopting.

1.4 Objectives

1. To conduct environmental and economic analyses and make comparisons among the weed control methods at sites where each method has been tried.
2. To make theoretical simulations of the potential combinations of four control methods, namely, mechanical, chemical, manual, and biological and evaluate their costs and effectiveness.
3. To develop analytical procedures that will guide policy makers and technocrats on the best control strategies to adopt.

1.5 Significance of the Problem

If the weed is not checked, it will choke out all water life, bring to a halt any economic activity on Uganda's water bodies and drastically affect the environment and its contribution to development. It is because of this that the weed is condemned the world over, and should be eradicated at any cost.

Considering Uganda's many economic constraints that include, *inter-alia*, balance of payment and deficit problems, funds must be spent rationally. Policy makers need to be advised to adopt the most cost-effective strategies to attain the desired results.

The theoretical simulations of the potential combinations of the control methods are expected to give an insight into the possible policy strategies to be considered in weed control. If the weed is brought under control, the water resources will resume their significant contribution to the economy, and people's health status and livelihoods will improve. The research findings will also contribute to existing knowledge and stimulate further research on the weed and use of the analytical technique used herein.

1.6 Hypotheses

1. The mechanical control method is the most costly of the four contemplated methods, viz., biological, chemical or manual method.

2. The chemical controls method, though the most effective of the contemplated control methods, is not environmentally friendly.

2. REVIEW OF LITERATURE

2.1 The Weed: What It Is, Its Effects and Implications

The water hyacinth is a member of the plant family *Pontederiaceae*. Although several species of the genus *Eichhornia* exist, only *E. crassippes* has become a problem. It is believed to have been introduced into Uganda's aquatic environment at Lake Mubanzi, in Rakai District where the Kagera River joins Lake Victoria, intentionally because of its beautiful purple flowers. This may be the reason why it was named the "noxious beauty".

There are basically three ways in which the weed may be dispersed from one location to another: (i) water-borne dispersal which demands connection between water bodies; (ii) diving eater-birds could swallow the weed's seeds as they sift mud for food, and then pass them through the gut, but no concrete evidence for bird-mediated dispersal exists; (iii) people - the reason being its exceedingly attractive purple flower with great demand for aquarium and ornamental ponds. This is how it was introduced into the Congo River, Egypt and Uganda.

Many researchers have contemplated positive utilization of the weed. Whereas it has great potential in theory, in practice, it is poor in terms of nutrient make up. It is 95% water, and after burning off the carbon, you end up with 50% silica and 30% potassium and less than 0.5% of the plant is nitrogen. This makes it unpalatable to livestock. Its fibre length is very short and so cannot make good quality paper and its C: N ratio is too high to make good fertilizer since the decomposing bacteria would use all the available nitrogen without leaving any for the crops. It is usable in water treatment, but the papyrus is environmentally compatible and has better potential according to research

2.1.1 Ecological Niche

The weed grows readily on any open or sheltered water surface due to its high buoyancy. This has far-reaching implications for Uganda. Uganda's wetlands cover an estimated area of 29, 580 km^2, about 18% of the country's surface area (Ministry of Natural Resources 1994). This indicates the weed's high potential.

2.1.2 Growth Rate

Water hyacinth proliferation shows variable rates. It is extremely rapid in nutrient enriched environments such as Murchison Bay and in the deltas of major rivers such as the Kagera and Katonga. However, the proliferation appears to be poor in bays such as Buka and McDonald, which have no major inflow.

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According to Mitchell (1978), the weed grows very rapidly. For instance, one plant can produce up to 140 million vegetative daughter plants a year, covering about 140 hectares. This weighs about 28, 000 tonnes. The weed also produces numerous seeds and its population can double every 5 to 15 days.

2.1.3 Propagation

The weed has vegetative and seed reproduction. In the former case, horizontal stolons or runners are produced and new plants develop at their tips. Soon, inter-woven floating mats of vegetation are formed, which completely carpet water bodies. Under wind or wave action, proportions of the mat break off and shift to new locations.

The weed sheds seeds at flowering which sink into the mud under water. If the water level falls, they will germinate to start a new colony. Such seeds survive up to 30 years and they are an important source of re-infestation after implementation of eradication programs, making it a perpetual problem.

2.1.4 Effect on Evapotranspiration Rate

The weed loses water rapidly through its broad leaves, which is about 3.5 times that from a free water surface (Timmer and Weldon 1967; Gopal and Sharma 1981). Lower of the water table through massive evapotranspiration threatens aquatic life.

2.1.5 Physical Obstruction

The most obvious implication of hyacinth infestation to the fishermen is physical obstruction of access channels to fish landings. Masses of the weed that are blown or swept by storms block water channels. The fishermen have to push the boats through tangled mats of weed. They spend up to 30 minutes pushing a nine-metre fibreglass canoe through a distance of 100m.

Fishermen operating basket traps to catch *tilapiines*, lungfish in the marginal swamps, and those who set gill nets have been affected by large mats of the water hyacinth. Such obstruction leads to loss of the set fishing gear. Economic cost in terms of lost time and energy and destroyed fishing gear has increased since 1989 when the physical obstruction was first observed on Lake Kyoga at Iyingo landing site.

Some landing sites are no longer functional. Katosi landing site in Mukono District has closed down due to lack of serious business. Fishermen and porters have opted for less affected landing sites such as Casey in Mpigi District and others in Jinja District.

Many categories of people have been affected. Porters used to get between Shs. 3000 and 4000 a day loading and off loading; now they barely get Shs.500. Fishermen with powerful boat engines stop half a mile away from the shore. Porters then carry the fish on their heads to the shores. Besides the difficulties involved in wading through the chest-deep waters with cargo, the weed has an itching effect on human skin.

2.1.6 Effects on Fish Reproduction, Feeding and Productivity

Spawning and brooding activities of *tilapiines* and Nile *tilapia* take place largely in shallow in-shore and often-sheltered waters. However, the water hyacinth mats cover such spawning and nursery grounds. The shallow in-shore waters offer both shelter and abundant food for the young fish. So, nursery processes and early growth of both the Nile perch and *tilapia* are confined there. Yet, extensive mats of the weed reduce oxygen level and thus render these environments unsuitable for the high oxygen demanding fish species.

The high shading and oxygen depletion by the hyacinth mats lead to lower primary productivity and reduced biodiversity. possibly throughout the entire food chain. This reduces fish stocks by interfering with the rejuvenation process. The weed also competes for nutrients with other plants on which some fish feed.

2.1.7 Effect on Health

The weed provides a natural habitat for organisms that spread diseases such as bilharzias and malaria. It also harbours snakes and it has an itching effect on human skin.

2.2 Use of Glyphosate to Control Water Hyacinth

Glyphosate, N- (phosphonomethyl) glycine, is a broad-spectrum herbicide widely used to kill unwanted plants both in agricultural and non-agricultural landscapes. Most glyphosate-containing products are either made or used with surfactant, chemicals that help glyphosate to penetrate plant cells.

It is a post-emergent, systemic and non-selective herbicide used to kill broad-leafed grass and sedge species (WHO 1994). The herbicide is marketed under a variety of trade names, the commonest being Round-up and Rodco.

Herbicidal action arises from the inhibition of the biosynthesis of aromatic amino acids, which are used in the synthesis of proteins and are essential for growth and survival of most plants.

Residues of the commonly used herbicide glyphosate have been found in a variety of fruits and vegetables. Residues can be detected long after glyphosate treatments have been made. Some crops planted a year after glyphosate treatment contained residues at harvest.

Glyphosate can drift away to a distance of 400 to 800 metres from the site of its application. Exposure to glyphosate damages or reduces the ovulation of many animals, including beneficial insects, fish, birds and earthworms.

Glyphosate can be taken up by plants and moved to the edible parts. For example, glyphosate has been found in strawberries, wild blue berries, raspberries, lettuce, carrots, barley and fish.

Glyphosate drift is a particularly significant problem. Studies carried out in Canada and America indicated that between 41 and 82 per cent of glyphosate applied from helicopter moves off the target site (Riley, Wesiner, and Sexamith 1991). Long drift distances occur following applications of glyphosate made from fixed-wing airplanes. Three studies conducted on forested sites in Canada showed that glyphosate was consistently found at a farther distance from the target area (200, 300 and 400 metres) (Payne and Thompson 1992; Payne 1992; 1993). A study conducted in California found glyphosate 800 meters downwind of an airplane application.

Glyphosate's persistence is shorter in water than in soils. Two Canadian studies found glyphosate persisted 12 to 60 days in pond water following direct application (Goldsborough and Beck 1989; Goldsborough and Brown 1993).

Glyphosate can affect many organisms not intended as targets for the herbicide. These include beetles, wasps, ladybugs, spiders, fish, earthworms and birds.

2.3 Cost-effectiveness Analysis (CEA)

Cost-effectiveness analysis (CEA) is a technique to assist in decision-making. It involves assessing the gains (effectiveness) and resource input requirements (costs) of alternative ways of achieving a given objective (Creese and Parker 1991).

Broadly, cost-effectiveness analysis is any analytic tool designed to assist a decision-maker in identifying a preferred choice among possible alternatives (Dixon et al. 1994; Mishan 1988; Quade 1967; Winpenny 1993). It had its origin in the economic evaluation of complex defence and space systems (Kazanowski 1974).

Much of the philosophy and methodology of the cost-effectiveness approach are derived from cost-benefit analysis (Fabrycky and Tuesen 1974; Mishan 1988). Whenever cost-benefit analysis becomes impossible, since the benefits cannot be valued, it is useful to compare the costs of providing the beneficial outcome in different ways. The basic concepts inherent in cost-effectiveness analysis are now being applied to a broad range of problems in defence, public health and the environment (Dixon et al. 1994; Lanyard and Glaister 1994).

Specifically, cost-effectiveness analysis involves comparison of alternative courses of action in terms of their costs and their effectiveness in attaining a specific objective. Usually it consists of an attempt to minimize cost subject to some goal; or conversely, to maximize some physical measures of output subject to a budget constraint (Dixon et al. 1994; Mishan 1988; Quade 1967).

In applying CEA, three requirements must be satisfied. Firstly, the systems being evaluated must have common goals. Secondly, alternate means for meeting the goals must exist. Finally, the capability of bounding the problem must exist (Fabrycky and Tuesen 1974).

There are certain steps that constitute a standardized approach to cost-effectiveness evaluations. These steps are useful since they define a systematic methodology for the evaluation of complex systems in economic terms. They are:

(a) Definition of the objective(s). Since the method is undertaken primarily to choose a course of action, it is important to know the objective(s) the decision-maker is trying to attain (Dixon et al 1994; Kazanowski 1974; Layard and Glaister 1994).

(b) Alternative concepts and strategies must be developed (Dennis and Williams, 1993; Kazanowski 1974; Mishan 1988). The alternatives are the means to attain the objective(s). If alternatives do not exist, CEA cannot be used as a basis for selection (Fabrycky and Tuesen 1974; Winpenny 1993).

(c) Establishment of evaluation criteria for both the cost and the effectiveness aspects of the strategies/methods under study. This refers to a rule or standard to rank the alternatives in order of desirability and choose the most promising. It provides means for weighing cost against effectiveness (Dennis and Williams 1993; Layard and Glaister 1994; Mishan 1988; Quade 1967).

(d) Selection of the approach. Two approaches are available: fixed-cost and fixed-effectiveness. In the former, selection for the best method depends on the effectiveness obtained at a given cost; while in the latter, it depends on the cost incurred to obtain a given level of effectiveness (Kazanowski 1974).

(e) Candidate strategies are analysed based on their merits. This may be accomplished by ranking the systems in order of their capability to satisfy the most important criterion. Often this procedure may eliminate the least promising candidates (Dixon et al. 1994). The remaining ones can then be subjected to a detailed CEA. If the cost and the effectiveness of the top contenders are both superior to those of other candidates, the choice is obvious.

(f) Finally, a cost-effectiveness study involves documentation of the purpose, methodology and conclusions.

2.3.1 What Costs Should Be Measured?

According to Walters (1962), economic theory defines costs as payments made to induce factors of production to continue in their employment. Derbetin (1980) and Koutsoyiannis (1979) categorize costs as fixed and variable. In support, Hornby, Cownie, and Gimson (1987) state that though in the long run all costs are variable, in the short run some are fixed and others variable.

2.3.2 Capital Versus Recurrent Costs

To estimate the costs of an option, it is first necessary to classify its components. The most basic classification is by resource inputs, for example, personnel, supplies, and equipment. Inputs are normally divided into capital and recurrent costs. Capital costs are those that provide service for more than one year. These include vehicles, buildings and equipment. Recurrent are those purchased, used or replaced within a year. These include salaries and wages, fuel and lubricants.

2.3.3 Fixed Versus Variable Costs

Fixed costs do not vary with the size of the programme, whereas variable costs do. The purchase of a vehicle, for instance, may represent a fixed cost if it can cover the target population whether the programme covers the whole district or smaller sections within the district. An example of a variable cost would be fuel for the vehicle, since the larger the programme, the greater the distances travelled and the greater the amount of fuel used.

2.3.4 Effectiveness and Its Indicators

Effectiveness refers to how fast the result is achieved (Hornby, Cownie, and Gimson 1987). The indicators of outcome of an intervention will be changes in activity, behaviour or health of the population. Ultimately through these outputs and effects, an intervention may have an impact on disease, health, production and well-being.

Ordinarily, it is easier to establish criteria for cost than for effectiveness. Costs may include research and development, engineering, test, prediction, operation and maintenance. Effectiveness, on the other hand, may be measured by utility, merit, worth, benefit and gain or mobility, availability, maintainability and reliability, which are all difficult to determine (Guyatt and Tanner 1993).

In sum, CEA is a powerful tool that has to be applied carefully. Sensibly applied, CEA can be very helpful in providing environmental protection at a moderate cost while allowing development activities to continue (Dixon et al. 1994).

3. METHODOLOGY

3.1 Descriptive Survey Research Design

3.1.1 Data and Information Sources

The study employed primary and secondary data. Primary data were obtained from fishermen and those residing on lake shores. Also from officials of the Department of Fisheries, Ministry of Agriculture, Animal Industry and Fisheries (MAAIF), Food and agriculture Organization of the United Nations (FAO), NAARI, and URC who have played instrumental roles in the planning, development and maintenance of the control methods on specific lake sites located on Lakes Victoria and Kyoga.

A number of publications, newsletters and working papers from MAAIF, NAARI, MFEP, URC, FAO and GTZ were used as secondary data sources. These sources provided background information that included the nature of the weed and possible origin, social and economic implications, and anticipated/planned strategies for control and government policy.

3.1.2 Sampling Procedures and Data Collection

Primary data were collected through a survey at individual sites by means of direct inquiry to obtain reliable information.

The data collection tools included a pre-tested, structured questionnaire and FGD schedule.

A sampling frame of fishermen in each location was developed from lists provided by local leaders out of which 15 were randomly selected. Ten key informants were also selected and interviewed, who were involved in development, procurement and maintenance of the control methods. All the interviews were preceded by six focus group discussions (FGDs), which were aimed at getting the general perceptions of the efficacy of the control measures and related issues.

3.2 Conceptual Framework

Environmental protection involves financial costs. Though required costs may be high in an absolute sense, they are modest in relation to their contribution to the economic growth.

Given that all the anticipated control methods require expending capital resources to realize benefits, careful preparation in advance of expenditures can reduce inefficient or even wasteful expenditure of money.

In general, many approaches can be used to appraise projects/ alternatives. The major ones are Cost-Benefit Analysis (CBA), Economic and Financial Internal Rate of Return (IRR) and Net Present Value (NPV). All involve weighing discounted benefits against discounted costs. The alternative chosen is that which ranks highest in terms of net benefits. However, for some projects/ alternatives, benefits are difficult to measure in monetary terms (i.e., they are intangible) whereas costs can be measured (Dixon et al. 1994). Therefore, no attempt is made to express benefits in terms of money (Layard and Glaister 1994; Winpenny 1993). The focus is on meeting a predetermined goal (Dixon et al. 1994). In such cases, a least costly alternative can be recommended. Cost-Effectiveness Analysis (CEA) can be used to determine the cheapest and most effective alternative. Therefore, there must be more than one alternative of achieving the required change (Mishan 1988). CEA is appropriate for social programmes dealing with health and population as well as for the analysis of environmental effects (Dixon et al. 1994; Winpenny 1993).

The standardised approach to cost-effectiveness evaluation involves many steps, the most important being establishing evaluation criteria for costs and effectiveness. Both fixed and variable costs will be included (Koutsiyiannis 1979; Debertin 1989). Costs such as procurement, maintenance, operation, research and development, labour and entrepreneurial skills will be enumerated, quantified and valued. The effectiveness evaluation criteria are more difficult to establish (Kazanowski 1974); but in this case, focus will be on efficiency. How quickly a specific/ target area (say 1 hectare or 1 square kilometre) is cleared of the weed using the various control methods will be the efficiency measure. Environmental sustainability will also be accorded priority.

Selection of the approach is the other important consideration (Kazanowski 1974). Fixed cost and fixed effectiveness are the alternate approaches to be addressed. The latter approach will be used since the budget for this work is not known , which is a pre-condition for the former approach. The best method will be selected based on the cost incurred to rid a specific water area thoroughly of the weed in the shortest period. In other words, the method with the least cost incurred will be recommended (Dixon et al 1994; Layard and Glaister 1994; Mishan 1988; Winpenny 1993).

3.2.1 Cost Analysis

The total cost of each of the methods, C_i is calculated as:

$$C_i = F_i + V_i \quad \text{(i)}$$

Where F_i, refers to the fixed costs in period i which includes purchase of vehicles, working tools, and hire of a plane in the case of chemical control, and V_i, variable costs in period i which includes consumables such as fuel and lubricants, spares and allowances. The total costs are presented in US dollars.

3.2.2 Effectiveness Measure

The effectiveness of a method in this study is defined by the following parameters: efficacy, coverage and environmental effects. Efficacy is defined as the quality of work done as judged from the residual debris; coverage is the proportion of the weed destroyed at a point in time; and environmental effects refer to the quantity of untargeted micro fauna and flora destroyed through use of the method. In this study, all the three parameters were assumed independent of the stage of growth of the weed.

However, because it would be hard to determine the parameter criteria for efficacy and environmental effects , only coverage was used. It is based on the time taken to rid a lake area equivalent to a hectare (10,000m^2) of the effects of the weed. The actual indicator for effectiveness, **E**, is then computed by dividing the area by the time.

E= (10,000m^2/time (hours))..(ii)

Table 1. Effectiveness in indicators of the weed control methods

	Biological	Chemical	Manual	Mechanical
Time taken (in hours)	8,760.0	5,544.33	10.0	6.0
Effectiveness (m^2/hour) (E)	1.142	1.804	1,000	1,666.7

The total method costs per period are then divided by the effectiveness to yield a cost-effectiveness ratio (C: E), which gives the cost per area of the weed cleared in a minute (US dollars required to clear an area in a minute). The lower the ratio, the better the method in terms of costs vis-à-vis effectiveness.

C.E = US dollars per unit area per unit time

= (US $/ (m^2/min.)..(iii)

The cost and effectiveness of the control methods and the theoretically simulated potential combination were recorded, summarised and analysed with the help of statistical computer packages. Results were then evaluated and ranked in accordance with cost effectiveness or environmental sustainability and presented in tables. The least costly but most effective and environmentally friendly option was recommended to policy makers.

The hypotheses stated above were tested using analysis of variance (ANOVA) at 5 per cent level of significance. This was based on the assumption that representative samples of trials for the various control methods will be obtained. However, this was not possible as reliable data from only one trial of each control method was obtained. Decisions were made based on the percentage difference between costs and effectiveness of the methods.

4. RESULTS AND DISCUSSIONS

4.1 Results of Focus Group Discussions (FGDs)

Responses on when the weed was first sighted were divergent ranging from late 1980s to early 1990s. This, however, does not deviate much from what is documented.

At first people saw the weed as ornamental. This further supports observations that people spread the weed because of the noxious beauty of its flower. The masses were not sensitised to the dangers of the weed in time to trigger off serious action.

On the question of when the weed became problematic, residents at Ggaba landing site talked of 1992 while those at Nakiwogo and Masese landing sites talked of 1994. This was when the weed hindered mobility and landing of the boats, and led to temporary abandonment of landing sites such as Ggaba.

The detrimental effects of the weed as narrated by the various groups are numerous, with many social and economic implications. They include difficulty in navigation, which is a result of the mesh formed by the roots. This has grave implications such as failure to transport essential commodities from one landing site to another. Residents of some islands such as Kasanje and Busi lack hospitals and therefore depend on water transport to take the sick to hospitals located in the mainland, for example, in Entebbe. When the weed blocks the way, deaths are common. This is exacerbated by the people's fear and uncertainty to rescue those who are trapped in the lake.

Fishing has become difficult and expensive. Nets are torn and some are simply carried away as the weed drifts, engines are destroyed and fish reproduction is reduced. Low reproduction implies reduction in future catch with reduced overall economic benefits for the country. Failure to manoeuvre the boats through the thick mat of the weed increases the time required to deliver the fish to the landing site. The quality of fish therefore deteriorates, reducing the selling price.

There is general contamination from dead bodies trapped by the weed. Other health hazards include deaths from snakebites and bilharzias. During the recent civil strife in neighbouring Rwanda, many corpses that were thrown into Kagera River ended up in Lake Victoria. Such contamination will affect the health of the people who use the lake.

On realising the detrimental effects of the weed, some communities organised themselves and passed some resolutions to control it through manual removal. At Ggaba landing site all pedestrian visitors were being charged Ushs.50 per head and Ushs.100 for those with vehicles. Labour was hired on permanent basis to manually remove the weed. There was significant progress and the people realised that the sun through desiccation easily destroys the plant. Their efforts were frustrated, however, by complaints that the weed problem was a national problem being handled by the government and that they should not be charged for its removal.

Officials in other localities passed by-laws that all fishermen should remove the weed on their way back to the landing site. Failure to comply would imply being sent back to the lake. Entebbe Municipal Council later on facilitated Nakiwogo site with forks, boots, wheelbarrows, rakes, spades, and lorries to continue manual harvesting; but these were not enough given that some residents used to be redundant at times. The people were overwhelmed by the rate at which the weed was multiplying and being blown in from other parts of the lake. Therefore, they lost morale and the weed continued to increase.

Locally, virtually no meetings have been organised to discuss eradication of the weed. This further points out lack of full commitment by those concerned probably stemming from inadequate facilitation and motivation. It was at Ggaba that some meetings were organised in the beginning. The only resolution made was to collect money from visitors who came to the site and to employ some workers. This was done but was later disbanded. Only the manual method has been tried in all sites. This puts other methods at stake since people are not conversant with them.

The participants rejected the use of chemicals for many reasons. Firstly, they are not environmentally friendly and likely to destroy aquatic life. Secondly, effects on people's health are unknown but could be long term. Thirdly, they will not destroy the weed. Fourthly, the chemicals could even be expired and/or contaminated. Fifthly, Ugandan fish will lose market at both domestic and international levels once the lakes are sprayed, and this will negatively affect the economy. Finally, the research results on chemical control are not yet convincing, as far as effectiveness and environmental friendliness are concerned.

The locals unanimously pointed out that chemical control should be a last resort after all the environmentally friendly means have completely failed. Chemical use could be for those areas that are inaccessible by machines and people. For these reasons it would be impromptu to use them.

As for biological means, participants were of the opinion that the weevils may resort to other crops after destroying the weed. On that note, the participants advocated only manual and mechanical control since they are environmentally the safest. Some pointed out that of the two, mechanical means is more effective if the machines are of the right specifications, since they can work continuously without breaking down.

On the question of costs, most participants still wanted chemical and biological methods to be left out. However, some pointed out that chemical control sounds to be the cheapest. Of mechanical and manual, participants felt that the former is cheaper if the right machines are procured. All participants expressed dissatisfaction on the way government has handled the weed problem. They asserted that some officials are simply interested in financial benefits from the weed rather than working towards its eradication. They further said whatever little the government is doing is a result of pressure. The income it realised from the lakes should be ploughed back into the lakes to ensure sustainable future income.

Despite the problems the people are facing, the government has not reduced the Ushs.60,000 paid as income tax. The participants wondered what happens to all the money they pay to the government. They also pointed out that the policy makers do not seem to know the weed and its effects since they have ignored local participation.

4.2 Respondents' Perceptions of the Role of the Government in Controlling the Weed

The participants suggested the following on what the government should have done: proper machines should have been bought, the masses should have been sensitised more about the weed, the funds received from lakes should have been ploughed back and local participation should have been emphasised. Many unemployed people could have been utilised and paid say Ushs.5-20 per kg. Operational funds should have been handled by representatives from the fishermen and other affected people instead of by absentee officials who may misuse the money. Government officials should have visited the landing sites more frequently to know more about the problems. The government should reduce tax paid by the fishermen in affected sites.

Lastly, most participants thought that if the government released enough funds and the unemployed people were hired, the weed could be removed manually. This, however, necessitates regional cooperation among the East African countries, so that manual removal is done concurrently at all landing sites.

4.3 Results of Fisherman Interviews

4.3.1 Background Information

Forty-five fishermen were interviewed, 15 from each of the districts of Kampala, Mpigi and Jinja (Table 2). Forty-two of the interviewed were male despite deliberate efforts made to interview more female respondents (Table 3).

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Table 2. Distribution of survey respondents by district/site

District/Landing Site	No. of respondents	Per cent distribution
Kampala (Ggaba)	15	33.33
Mpigi (Nakiwogo)	15	33.33
Jinja (Masese)	15	33.33
Total	45	99.99

Although in most developing countries full time specialisation in one field may be of great economic risk, 95 per cent of those interviewed are full time fishermen. This, therefore, implies that the weed has adversely affected their livelihood with no alternative.

Table 3. Summary of fishermen responses

Variable/Response	Number of respondents	Per cent
A. Background Information		
Sex		
- Male	42	93.3
- Female	3	6.7
Marital Status		
- Married	19	42.2
- Single	26	57.8
Education		
- O - A level	12	26.6
- P. 7 and below	19	42.2
- None	14	31.2
Fishing Status		
- Full time	45	100.0
- Part time	0	0.0
B. Public Knowledge of the Weed		
How did the weed get into the lakes?		
- Ornamental by people	6	14.3
- Thrown into Kagera River by strangers	13	28.6
- Don't know	26	57.1
When was it first seen?		
- Late 1980s	7	15.6
- Early 1990s	19	42.2
- Don't know	19	42.2
When did the weed become a problem?		
- Late 1980s	0	0.0
- Early 1990s	32	71.4
- Can't remember	13	28.6

Cont.		
What individuals have done		
- Involved in sensitisation of the masses	6	13.0
- Participated in Manual removal	32	71.4
- Nothing	13	15.6
Whether one has attended meetings		
- Yes	7	15.5
- No	39	84.5
Ranking of the methods in terms of costs (cheapest first)		
- Chem., Mechan., Biolog., Manual	5	11.1
- Biolog., Manual and Mechan.	8	17.8
- Manual only	13	28.9
- Chemical only	6	13.3
Ranking in terms of effectiveness (most effective first)		
- Mechan., Biolog., Manual	6	13.3
- Chem., Mechan., Manual, Biolog.	12	26.7
- Mechan., Manual, Chem., Biolog.	6	13.3
- Manual only	13	28.9
Effect of the weed on price of fish		
- Increased	8	17.8
- Decreased	32	71.1
- No effect	5	11.1
C. Opinions on Government Policy		
Whether government has done its best to control the weed		
- Yes	6	13.3
- No	39	86.7
Recommendation	12	26.7
- Mechanical	15	33.3
- Manual	7	15.6
- Mechanical and Chemical	6	13.3
- Chemical	5	11.2
- Govt. Should decide	15	33.3

4.3.2 Knowledge of the Weed

About the origin of the weed, the views were similar to those from the FGDS. Some think that malicious individuals dropped it from an airplane into Kagera River, from where it has spread to the lakes. Others think it was brought in as an ornamental plant because of the noxious beauty of its flower. Some assert that it was directly dropped into each of the lakes.

Most of the respondents claimed to have first seen the weed on Lakes Victoria and Kyoga around late 1980s and very early 1990s. This seems to concur with documented evidence that the weed was first reported in

Uganda on Lake Kyoga in May 1988 and then on Lake Victoria in December 1989.

The responses on how the weed has affected fishing and other activities were much in line with earlier findings. These include: failure of boats to sail through waters covered by the weed given the thick mats created by the meshed roots, which lock up the boats and fishermen sometimes for days. This leads to economic losses due to increase in catch delivery time. These delays have at times resulted in deterioration of the quality thus a reduction in the prices, and at most complete spoilage of the fish rendering it unsafe for human consumption. Fishermen have had to carry ice to maintain the quality.

Higher costs to operators have also resulted from use of more fuel. Maintenance costs of engines have also increased due to knocks from the weed sucked into the engines.

Six of the respondents (13%) had been involved in sensitising the masses about the weed; 32 of them (71.4%) participated in manual harvesting of the weed, but lack of facilitation undermined their contribution. The rest contributed nothing towards its eradication. Meetings to discuss weed control have not been well attended. Only seven (15.5%) had participated in such meetings.

Ranking with respect to costs indicated that 13 (28.6%) advocated only manual control and believed that this would be the cheapest. Eight respondents (17.8%) ranked the methods in this order: biological, manual and mechanical. They did not commit themselves to chemical control. Five respondents (11.1%) ranked them: chemical, mechanical, biological and manual.

In terms of effectiveness, 13 (28.9%) believe in only manual harvesting. This is probably due to the high unemployment rate and the fact that some of the respondents have been involved in it. The other response (26.7%) was for the following order: chemical, mechanical, manual and biological. Mechanical, biological and manual together with mechanical, manual, chemical and biological in that order of effectiveness shared an equal number of responses (13.3% each).

The weed has led the fishermen to economic losses in terms of decreased price resulting from reduction in quality as evidenced by 32 (71.1%) of the responses. The weed traps them in the water where they spend a longer period than expected. The few who argued there had been an increased fish price (17.8%) based their argument on decreased numbers of fishermen who get access to the fishing sites. Another view is that there has been a reduction in reproduction because of the weed. The overall effect of the two is reduced supply of the fish vis-à-vis increased domestic and export demands.

4.3.3 Opinions on Government Policy

The majority of the respondents (86.7%) thought that the government has not done its best to eradicate the weed. They asserted some officials gain from the problem and thus did not act fast and vigorously enough. About 33.3% of the respondents recommended manual harvesting; 26.7% preferred mechanical; 15.6% preferred mechanical and chemical; and 13.3% preferred chemical control alone. Biological control has not been well understood. People wondered how the weevils could destroy the weed. This calls for emphasis on dissemination of research findings on biological control.

4.4 Key Informants

Five key informants were identified and interviewed. Their views are discussed in the next sections.

4.4.1 Biological Control

Through the recommendation of the National Task Force on Water Hyacinth (NTFH), 600 adult weevils from each of the two weevils (*N. bruchi and N. eichhornia*) were imported in July 1993 from IITA. The weevils have since been mass reared and released in over 20 sites on Lake Kyoga. They were taken in batches of about 1,000 - 1,500 monthly to the following landing sites: Kyankole and Bukungu (Kamuli District), Kawongo (Mukono District), Kasambya (Luweero District); Kambate, Kimbuye, Kalenge, Bweyale, Kayago-Namasale, Lenko-Namasale and Dagala.

The weevil adults are nocturnal and feed on the upper surface of the leaf lamina and upper one third of the petioles, which causes desiccation of the leaves. Oviposition is in petioles and legules. Larvae tunnel towards the base of the petioles and into the crown. Pupation occurs under water in a cocoon. The generation time for *N. bruchi* is 96 days while that for *N. eichhornia* is 120 days. Heavy attack causes the plants to float lower in water and can lead to water logging, rotting and plant deaths, The plant populations are slow to develop, while destruction of the weed takes 3-5 years.

(i) Costs

The picture on costs would be more complete if all the costs incurred on research and development of the essential inputs were considered; however, it is difficult to obtain data on research and development of chemicals, machines and so on. Therefore, only procurement and operating costs, which include both capital and recurrent costs, are considered (Table 4). Capital costs are apportioned since they last for more than one year. The procedure of annualisation, i.e., the costs of capital items in terms equivalent to recurrent costs, is therefore required. Annualisation requires information on the current price of the item and its useful life. For biological control, only a vehicle is taken as a capital cost. Its daily depreciation is taken as the daily cost attached to the method:

- Price of a vehicle (4WD) in 1994 = US $20,000
- Useful life (years) = 8
- Annualisation coefficient = 0.15478
- Annual costs = US $20,000 X 0.1547 =US $3,094
- One day's cost = US $3,094 / 365 = US $8.5

(ii) Effectiveness

3,750 weevils take 3 – 5 years to achieve recognisable coverage per hectare. This period needs to be converted to hours in order to match it with those of other methods whose effectiveness are in hours.

(a) Conversion to days: 3 years x 365 days = 1,095 days

(b) Conversion to hours: 1,095 days x 8 hours = 8,760 hours

The biological control day is equivalent to 8 hours since the adult weevils are nocturnal and therefore active at night.

Total cost per hectare per hour = US $911.4/8,760 = 0.104

(c) Effectiveness indicator (Area (m2)/time (hours))

$= 10{,}000\ m^2/8{,}760$ hours

= 1.142 m2/hour

Table 4. Costs for effecting biological control based on 1994

Category	Item	Units	Amount (US $)
Personnel	In charge's allowance	per month	200.0
	Junior staff allowance	per month	200.0
	Driver's allowance	per month	150.0
	Labourer	per month	100.0
Vehicle	A Day's depreciation		8.5
	Fuel	litres	170.0
Sub-total			828.5
Miscellaneous others	(10% of 828.5)		82.9
Total			911.4

NB: Total costs per hectare = US $911.4

(iii) Cost- effectiveness ratio

Costs in dollars divided by effectiveness in hours = **US $0.104/1.142 = 0.091**

4.4.2 Manual Control

This involves manual removal of whole plants from the water and throwing them on the banks, wheelbarrows and / or tipper lorries that ferry them to destinations where they dry up. It has been tried on many landing sites like Ggaba, Katosi, Nakiwogo, Murchison Bay (Luzira) and Owen Falls Dam (UEB power generation unit). Given the health problems related to this exercise, the workers need to be well protected and well paid (Table 5).

(i) Costs

The concept of annualisation is considered here. For those capital items with useful life of less than 2 years, a straight-line method of depreciation, which assumes uniform depreciation throughout the life of the item, is subjected on the cost item.

Capital costs include:

Manure forks (500 each at a price of US $10)

- Price of the forks = US $5.000
- Useful life = 2 years
- Annualisation coefficient = 0.5378
- Annual cost = US $5,000 x 0.5378 =US $2,689
- One day's cost = US $2,689 / 365 = US $7.4

Long sleeve gloves (500 pairs each at a price of US $15)

- Price of the gloves = US $7,500
- Useful life = 1 year
- Annualisation coefficient (not applicable)
- Annual cost = US $7,500
- One day's cost = US $7,500 / 365 = US $20.5

Long boots (500 pairs each at a price of US $15)

- Price of the gloves = US $7,500
- Useful life = 1 year
- Annualisation coefficient (not applicable)
- Annual cost = US $7,500
- One day's cost = US $7,500 / 365 = US $20.5

Wheel barrows (20 each at a price of US $50)

- Price of the forks = US $1,000
- Useful life = 2 years
- Annualisation coefficient = 0.5378
- Annual cost = US $1,000 x 0.5378 =US $537.8

- One day's cost = US $537.8 / 365 = US $1.5

Rakes (500 each at a price of US $6)

- Price of the rakes = US $3,000
- Useful life = 1 year
- Annualisation coefficient (not applicable)
- Annual cost = US $3,000
- One day's cost = US $3,000 / 365 = US $8.2

Table 5. Summary of costs for manual control per hectare

Category	Item	Units	Amount (US $)
Fixed costs			
Implements	Manure forks	500 x10	7.4
	Long gloves	500x15	20.5
	Long boots	500 x15	20.5
	Wheel barrows	20 x 50	1.5
	Rakes	500 x 6	8.2
Sub-total			58.1
Recurrent costs			
Remuneration	Allowance	500 x 2	1,000.0
Miscellaneous (10% of 1, 058.1)			105.8
Total			1,164.0

NB: In manual control method a working day is equivalent to 10 hours.

Total cost per day = US $1164.0

Total cost per hectare per hour = 1,164.0/10 hours = US $116.4

(ii) Effectiveness

It takes about 10 hours for 500 men to clear one hectare. The effectiveness indicator therefore is:

Effectiveness indicator (Area (m^2)/time (hours))

=10,000 m^2/10 hours = 1,000m^2/hour

(iii) Cost-effectiveness ratio

Costs in dollars divided by effectiveness

= US $116.4/1,000 = 0.116

4.4.3 Mechanical Control

Mechanical control was among the first methods to be tried. It was however, abandoned after failure to achieve the desired results, yet the price of the harvester used at first was exorbitant (US $250, 000). It also requires manual labour to get good results. All the costs are therefore considered.

It involves use of machines called "harvesters", which suck in the plants and chop them into smaller pieces before throwing them to the bank. Other types of machines (as those being used at Owen Falls Dam by UEB) suck in and throw the plants on the bank, or the plants are manually fed with the weed. The latter is cheaper and it is considered here.

(i) Costs

The concept of annualisation for capital costs is considered here.

Capital costs include:

Harvesters (2)

- Price of the harvests = US $15,000
- Useful life = 10 years
- Annualisation coefficient = 0.129Annual cost = US $15,000 x 0 .1295 = US $1,942.5
- One day's cost = US $1,942.5 / 365 =US$5.3

Lorry (Tipper)

- Price of the lorry = US $60,000
- Useful life = 10 years
- Annualisation coefficient = 0.1295
- Annual cost = US $60,000 x 0.1295 = US $7,700
- One day's cost = US $7.700 / 365 = US $21.3

Table 6. Summary of costs for mechanical control per hectare

Category	Item	Units	Amount (US $)
Fixed costs			
Implements	Harvesters	2 x 15,000	5.3
	Lorry	1 x 60,00	21.3
Sub-total			26.6
Recurrent costs			
Remuneration	Driver's allowance	3 x 3	9.0
	Labourer's allowance	3 x 2	6.0
	Fuel and lubricants	100 x 1.07	107.0
Sub-total			122.0
Miscellaneous (10% of 148.6)			14.9
Total			163.5

NB: In mechanical control method a working day is equivalent to 10 hours.

Total cost per hectare (for 6 hours) = US $163.5

(ii) Effectiveness

It takes about 6 hours for the harvesters and three people to clear one hectare. The effectiveness indicator therefore is:

Effectiveness indicator (Area (m^2)/time (hours))

= 10,000 m^2/6 hours = <u>1,666.7 m^2/hour</u>

Total cost per hour = 163.5 / 6 hours = US $27.3

(iii) Cost-Effectiveness Ratio

Costs in dollars divided by effectiveness in minutes

= US $27.3/1,666.7 = 0.016

4.4.4 Chemical Control

Suggestions to initiate the chemical control have aroused health and environmental concerns regarding effects of the chemical on untargeted micro flora and micro fauna. This is because lakes and rivers in Uganda are the direct source of water taken largely untreated and of fish, which is a major source of animal protein and export income for most lakeside communities and the country. It was, therefore, essential that verification of the effectiveness, safety and environmental friendliness of candidate chemicals for the control of water hyacinth be undertaken before they were integrated into the other control approaches.

The Chemical Verification Sub-Committee of the National Technical Committee on the Control and Management of Water Hyacinth (NUCWH) was commissioned to carry out a comparative study of three herbicides, namely, 2,4-D, glyphosate and diquat. The studies were undertaken in a laboratory and in ponds with semi-natural environments.

The laboratory experiments were to detertmine the most suitable rate of application for each of the trial herbicides whereas the pond experiments were to assess efficacy and environmental friendliness of the chemicals.

Results indicated that Reglone (diquat) showed the fastest activity within hours of application, killing the above water biomass of the weed at the application rate of 10 and 15 litres/hectare within 8 weeks. This was followed by 2,4 – D amine (2,4-D) whose activity showed after a few days. It completely killed the weed at a lowest rate of 2.8 litres/hectare and at highest rates of 5.6 to 8.3 litres/ha. Roundup (glyphosate) was the slowest of the three, major activity taking 4 weeks after application. At a rate of 8.3 to 11.1 litres/hectare, a complete kill of the above water biomass of the weed was achieved in 4 weeks while at 5.6 litres/hectare it was achieved in 8 weeks.

Extensive re-growth by sprouting occurred on all experimental units sprayed with 2,4 -D and Reglone. Very little renewing application rates were recommended for the experiments in the ponds: Reglone (diquat) 10 litres/hectare, 2.4-D Amine (2,4-D) 2.8 litres/hectare and Roundup (glyphosate) 8 litres/hectare.

4.4.5 Chemical Efficacy Based on Pond Experiment Results

Diquat was the fastest acting in laboratory experiments where a total kill of the above water biomass was achieved in eight weeks at the recommended application rate of 10 litres/hectare. However, complete wetting during application was essential as demonstrated by some patchy recovery in the pond experiments during week 12. Diquat was also accompanied by considerable re-growth during week 14 even from part of what had appeared to be dead biomass.

2,4-D amine was slower acting than Diquat. The recommended rate of 2.8 litres/hectare achieved a maximum kill 9 weeks after application. However, re-growth in parts treated with this was extensive.

Glyphosate exhibited the slowest activity on weed control. However, it exhibited the highest efficacy attaining a complete kill at all application rates used in the laboratory accompanied by no re-growth up to 9 weeks when observations stopped. In pond experiments, the degree of efficacy was poor due to poor coverage caused by drift. However, glyphosate caused total mortality of the above water biomass 14 weeks after application. Re-growth set in after 12 weeks, thus stressing the need for optimum wetting while using the herbicides. The concept of re-growth is crucial when considering fresh water lakes, which are sources of potable water and fisheries. Re-growth occurs mainly when the chemical fails to overpower all the vegetative buds of the weed and/or when insufficient herbicide is applied or when no chemical reaches the target. This will lead to extensive sprouting necessitating repeated spraying to sustain control. This has crucial implications both to the costs and to the environment.

Results further indicate no adverse effects on algae and zooplanktons. The number of macro invertebrates recorded in the experimental ponds before herbicides were applied was generally lower than that recovered after. Tests on three species of Tilapia: *Oreochromis niloticus* (40), *Oreochromis leucostictus* (50) and *Tilapia ziili* (40) indicated no fish mortality after herbicide use, and no herbicide residues were detected in fish from sprayed ponds. Residues were very low in the water and in the weed. In general, the levels of herbicide residues recovered in the water, fish and sediments for all the herbicides tested were minute and very low compared to tolerance levels in the literature.

From the results of the trials in the laboratory scale and pond experiments, glyphosate was recommended as the most suitable herbicide for large-scale evaluation/use in the control of water hyacinth. However, other researchers may give a different version on the effects of this chemical.

The chemical trials have been terminated prematurely. The trials at Kajjansi were never completed since the government failed to get the required funds. The trials in Wazimenya Bay in Lake Victoria, where 2,4-Damine (under the trade name Weeder 64) and glyphosate (under the trade name Rodeo) are being tested, are not comprehensive. The trials are not looking at the effect of the decomposing debris on the quality of the water and on aquatic life. The rotting matter releases nutrients such as phosphorous and nitrates that will deplete dissolved oxygen causing fish deaths.

All this implies that results on chemical trials are not yet conclusive. Though a number of candidate chemicals have been tried at Wazimenya Bay, Kituuza Research Centre and Kajjansi, only glyphosate (Round-up), so far with the highest efficacy according to experimental findings, is considered here. Two approaches are used: the first is to consider chemical control without debris removal while the second involves debris removal.

Approach 1: Without debris removal

(i) Costs

Table 7. Costs for chemical control using aerial spray approach per hectare

Category	Item	Units	Amount (US $)
Aerial spray	Hire of plane (2 items)	1 hectare	1,500.0
	Glyphosate	8 litres/ha	160.0
Sub-total			1,660.0
Miscellaneous (10%)			166.0
Total			1,826.0

NB: In chemical control method a working day is equivalent to 10 hours.

Total cost per hectare = US $1,826.0

(ii) Effectiveness

According to the findings of the Chemical Verification Committee of the NTCWH, glyphosate takes 14 weeks after spraying to achieve complete destruction of the weed. After 12 weeks, re-growths appear hence necessitating the second spraying exercise. The whole of this period has to be considered in calculating the effectiveness of the chemicals. The effectiveness indicator therefore is:

Time from first application of the chemical to weed destruction

-14 weeks x 7 days x 24 hours = 2,352 hours (chemical action takes place day and night)

Time taken for the re-growth to appear

-12weeks x 7 days x 24 hours = 2,016 hours

Time from second chemical application to weed destruction (assumed to be half of the time taken in the first case, as the re-growth is weaker due to the effect of the chemical)

- 7 weeks x 7 x 24 hours = 1,176 hours

Time for the two applications (aerial spray) = 20 minutes

Total number of hours it takes to achieve complete destruction

- 2,352 + 2,016 +1,176 + 0.333 = 5,544.333 hours

Effectiveness indicator (Area (m^2)/time (hours))

= 10,000 m2/5,544.333 hours = 1.804m^2/hour

Total cost per hour = US $1,826.0 / 5,544.333 hours = US $0.329

(iii) Cost-Effectiveness Ratio

Costs in dollars divided by effectiveness in hours

= US $0.329 / 1.804 = 0.182

Approach 2: Manual labour for debris removal is considered for both chemical and biological control methods.

Chemical control method:

(i) Costs

Costs for undertaking the first aerial spray and spraying the re-growth as well as engaging manual labour to remove the debris are taken into consideration. The costs for manual removal are added to the costs for chemical control as shown below.

NB: Cost per hectare (chemical) = US $1,826.0

Cost per hectare (manual) = US $1,164.0

Total cost (for both) = US $2,990.0

(ii) Effectiveness

Chemical control requires 5,544.333 hours; manual removal of the debris involving 500 people takes 10 hours (a day).

Total time = 5,554.333 hours.

The effectiveness indicator therefore is:

Total cost per hectare per hour = US $2,990.0/5,554.333

= US $0.538

Effectiveness indicator (Area (m^2)/time (hours))

= 10,000 m^2/5,554.333 hours =1.800 m^2/hour

(iii) Cost-effectiveness ratio

Costs in dollars per hour divided by effectiveness in m^2 per hour

= US $0.538/1.800 =0.150

Biological control method (with manual removal of debris considered)

(i) Costs

Costs for undertaking the biological control and for engaging manual labour to remove the debris are taken into consideration. The cost for manual removal are added to the costs for biological control as shown below:

NB: Cost per hectare (biological) = US $911.4

Cost per hectare (manual) = US $1,164.0

Total cost (for both) = US $2,075.4

(ii) Effectiveness

Biological control takes 8,760 hours. Manual removal of the debris involving 500 people takes 10 hours (a day). The effectiveness indicator therefore is:

Effectiveness indicator (Area (m^2)/time (hours))

= 10,000 m2/8,770 hours = 1.140m^2/hour

Total cost per hour = US $2,075.4/8,770 hours = US $0.237

(iii) Cost-effectiveness ratio

Costs in dollars per hour divided by effectiveness in m^2 per hour

= US $0.237/1.140 = 0.208

In the next section, the following four scenarios are considered:

Scenario I: Environmental effects are ignored and the control methods are used independently.

Scenario II: Environmental effects are considered and the various methods are used independently.

Scenario III: Environmental effects are ignored, but the debris must be removed; various methods are used in combinations.

Scenario IV: Environmental effects are considered; potential combinations of the various methods are considered.

SCENARIO I

Assumptions:

(i) Environmental effects of chemicals are not known with certainty and are therefore ignored. Removal of the resulting debris is not considered.

(ii) Each method is used independently and only one method is to be recommended on purely economic grounds.

Table 8. Summary of the costs, effectiveness and C:E ratio of the four control methods used independently without considering removal of the resulting debris

Method	Costs (C) ($/ha/hour)	Effectiveness (m^2/hour) (E)	Cost: Effectiveness ratio (C:E)
Biological	0.104	1.142	0.091
Chemical	0.329	1.804	0.182
Manual	116.4	1,000.0	0.116
Mechanical	27.3	1,666.7	0.916

The costs per hour are seemingly high because of the low scale of operation considered. As the scale of operation increases, economies of scale are utilised thus reducing the costs of clearing additional units. A 10% value on expenses was allowed as miscellaneous to cater for incidentals.

It is obvious from the table that used independently and irrespective of the environmental effects (for which we are not sure about), the mechanical method is the most cost-effective since it has the smallest C: E ratio of 0.016. Therefore, less is spent to achieve a similar level of effectiveness compared with the other methods. This is contrary to earlier research work that stated that despite public fear and mistrust of chemicals, they are still the most cost-effective method of controlling the water hyacinth. This conclusion may have been based on the low cost (US $0.329 per hour) attached to this method. Chemical control is seemingly the most effective because spraying takes a very short time. However, effectiveness in this study is based on the time it takes to rid the aquatic life and other water beneficiaries of the effects of the weed. The effectiveness indicator is therefore 1.804 m^2/hour.

Further analysis indicates that the biological method ranks second with C:E ratio of 0.091 though with the lowest cost of US $0.104 per hour. This is why some people assume that it is the most cost-effective option. The method ranks second in terms of effectiveness, as it takes long for the weevil populations to build up and destroy the weed. Ogwang, Molo, and Ebuu (1995) observed that biological control remains the most viable and sustainable long-term option for controlling the weed. However, the time it takes and the perpetual fear that any introduced insects may turn to feed on non target plants create scepticism among policy makers and the local populace.

Manual control method ranks third with a C: E ratio of 0.116 and it incurs an additional US $89.1 an hour with effectiveness 40% lower than that of the mechanical method. Still, it is the method most advocated by the populace.

Chemical control method ranks last in terms of cost-effectiveness (C:E ratio = 0.183). The high costs associated with this method are due to the need for spraying the re-growth.

Further, it is evident that the differences between some control methods in terms of costs are big. For instance, the difference in cost between the manual and the biological methods is US $116.3. These pronounced differences undermine the sensitivity analysis of potential combinations, as one chooses the less costly option.

Therefore, the mechanical method is the most cost-effective, followed by the biological, manual and chemical methods. The situation, however, is different if the effects of the debris resulting from sprays (for chemical) and weevil activity (for biological) are considered. Scenario I is not environmentally sound given that the debris sinks into the water and depletes it of oxygen required for aquatic life.

SCENARIO II

Assumptions:

i) Each method is used independently and only one method is to be recommended on economic grounds.

ii) The mode of action of chemicals and weevils results in debris, which sinks and depletes the water of oxygen. This requires manual labour to remove the debris.

iii) Environmental effects of oil products used in harvesters and other machines are not pronounced and are therefore ignored.

Manual labour for removing the resulting debris is almost the same as that required removing the weeds right away. This scenario affects the costs and effectiveness of only biological and chemical methods. The rank in terms of C: E ratio now changes. Mechanical control method remains the most cost-effective followed by manual, biological and chemical methods. This is a more environmentally sustainable scenario.

Table 9. Summary of the costs, effectiveness and C:E ratio of the four control methods used independently considering environmental effects (debris removal is taken into account)

Method	Costs (C) ($/ha/hour)	Effectiveness (m^2/hour) (E)	Cost: Effectiveness ratio (C:E)
Biological	0.237	1.140	0.208
Chemical	0.538	1,800	0.299
Manual	116.4	1,000.0	0.116
Mechanical	27.3	1,666.7	0.016

Biological control costs increased from US $0.104 to 0.237 while effectiveness dropped from 1.142 to 1.140. The C:E ratio increased from 0.091 to 0.208.Chemical control costs increased from 0.329 to 0.528 and effectiveness dropped from 1.804 to 1.800. In terms of both environmental sustainability and economics, the mechanical and manual methods are superior to the other two.

SCENARIO III

Assumptions:

i) Environmental effects of chemicals are not known with certainty and can therefore be ignored; but the debris must be removed.

ii) The methods are compatible and therefore can be used concurrently. This is the basis for potential simulations. (Theoretical simulations are made.)

iii) Use of oil products in harvesters and other machines is not pronounced; therefore, its effects are ignored.

Simulation 1: The four methods are used in equal proportions (one quarter of each).

Table 10. Summary of the costs, effectiveness and the combined C: E ratio of the four control methods used in proportions

Method	Proportions by area (m2)	Costs (C) ($ per area)	Time (hours)
Biological	2,500.0	227.9	8,770.0
Chemical	2,500.0	456.5	5,554.3
Manual	2,500.0	291.0	2.5
Mechanical	2,500.0	40.9	1.5
Total	10,000.0	1,016.3	14,328.3

NB: Combined effectiveness = 10,000/14,328.3 = 0.698

Effectiveness of all the methods remains the same. Time taken to cover a particular area is proportional to the area to be covered for manual and mechanical methods only. Time for the biological and chemical control methods remains the same. Costs vary in proportions to the area for all methods.

Costs per hour = 1,016,3/14,328,3 =US $0.071

Combined C:E ratio = 0.071 / 0.698 = 0.102

Such a combination has reduced the effectiveness of the mechanical and manual method though it has improved that of the biological and chemical methods. The combined cost is higher than that of mechanical and biological control methods used alone, but it is significantly lower for the chemical method used alone. The combination has reduced the C:E ratios of the biological and chemical control methods from 0.208 and 0.299 to 0.102

Therefore, combinations may reduce costs, improve effectiveness and spread risks. Further, given the great differences between some methods, arbitrary combinations may not yield very good results unless one knows the exact areas on both lakes where specific methods are desired. For instance, for inaccessible areas such as some bays, chemical method is the best approach. However, the total area of the weed in such areas should be known to assign chemical method a proportion.

Simulation 2: Mechanical method is used in half of the total area ($5,000m^2$), since it is the cheapest and most effective. Manual method is used in one half of the remaining area ($2,500m^2$), chemical and biological are used in the same proportion ($1,250m^2$) to cover the remaining area.

This combination has reduced the C:E ratio from 0.102 to 0,071 and the overall cost from US $1,016.3 to 715.0. In fact, the combined effectiveness has in essence not changed but the improvement is a result of the reduced overall costs. The combination will be more effective when it has a higher proportion of the mechanical method (Table 11).

Table 11. Summary of the costs, effectiveness and the combined C: E ratio of the three control methods used in proportions

Method	Proportions by area (m2)	Costs (C) ($ per area)	Time (minutes)
Biological	1,250.0	113.9	8,770.0
Chemical	1,250.0	228.3	5,554.3
Manual	2,500.0	291.0	2.5
Mechanical	5,000.0	81.0	3.0
Total	10,000.0	715.0	14,329.8

NB: Combined effectiveness = 10,000/14,329.8 = 0.698

Cost per hour = 715.0/14,329.8 = 0.050

Combined C: E ratio = 0.050 / 0.698 = 0.071

SCENARIO IV

Assumptions:

i) The effect of the chemicals on the micro fauna and flora is not considered.

ii) The effect of oil products used in the machines is not considered.

iii) Biological control is left out because it is too slow to be compared to manual and mechanical methods.

Given the above assumptions, only manual and mechanical methods are considered.

Simulation 1: Each of the manual and mechanical methods covers half the area (5,000m^2) - (Table 12).

Table 12. Summary of the costs, effectiveness and the combined C: E ratio of two control methods used in proportions

Method	Proportions	Costs (C) ($ per area)	Time (hours)
Manual	5,000.0	582.1	5.0
Mechanical	5,000.0	81.8	3.0
Total	10,000.0	663.9	8.0

NB: Combined effectiveness = 10.000/8.0 =1,250.0

Costs per hour = 633.9/8.0 = 79.2

Combined C: E ratio = 79.2 / 1,250 = 0.063

The C:E ratio and costs have improved significantly. It is, therefore, cheaper to engage such a combination than those in earlier scenarios. Results will improve tremendously if the proportion of the mechanical method is increased.

Simulation 2: The area for manual method reduced to a fifth, while that for mechanical method for the remaining area (8,000m^2) - (Table 13).

Increment in the area for mechanical method improves the C:E ratio from 0.063 to 0.036 and lowers the cost from 663.9 to 363.6. Results from scenario IV are recommended in the interest of environmental protection. This scenario suggests eliminating the weed from both lakes requires about US $108,000 (US $0.036 x 10,000 x 90,000 ha), and this may be accomplished within a month (300 hours).

Table 13. Summary of the costs, effectiveness and the combined C: E ratio of manual and mechanical control methods used in proportions

Method	Proportions by area (m^2)	Costs (c) ($ per area)	Time (hours)
Manual	2,000.0	232.8	2.0
Mechanical	8,000.0	130.8	4.8
Total	10,000.0	363.6	6.8

NB: Combined effectiveness = 10,000/6.8 = 1,470.6

Costs per hour = 363.6/6.8 = 53.5

Combined C: E ratio= 53.5 / 1,470.6 =0.036

It should be noted that the line items in the budget do not take account of some expenses such administrative costs (such as allowances for those who handle the money) and interest rates (in the event that the capital is borrowed). The miscellaneous costs allowed may partly cater for such expenses. Therefore, the figures may look rather lower than are anticipated by some researchers.

Hypothesis testing

Hypothesis 1: The mechanical control method is the most expensive.

Mechanical control method is the cheapest with US $163.5 per hectare per hour. Biological control method, which is the second cheapest, is 5.6 times more expensive than mechanical. Manual and chemical control methods are 7.1 and 11.2 times more expensive, respectively, than mechanical.

Hypothesis 2: The chemical control method though the most effective is not environmentally friendly.

Mechanical control method is the most effective. It is 1, 462.0 more effective than the biological method, which is the least effective. It is 925,9 and 1.67 more effective than the chemical and manual methods respectively. This is a result of the need for manual removal of the debris when chemical and biological control methods are used. Otherwise, the actual spraying exercise is much quicker than the operations that follow.

Glyphosate is not environmentally safe. It kills untargeted micro flora and fauna. The debris resulting from the chemical application depletes the oxygen in the lake to the detriment of aquatic life. Still, its environmental degradation is not easy to ascertain, as most of its effects have not been quantified.

5. POLICY IMPLICATIONS, CONCLUSIONS AND RECOMMENDATIONS

5.1 Policy Implications

Agricultural sector policy objectives target at self-sufficiency in food production and export diversification, industrial development enhanced by agricultural growth, and enhancement of rural development aimed at equal share of the national income between rural and urban sectors. However, government policies have not been implemented consistently with stated policy objectives. For instance, fish is a major food to many people but the weed has undermined the self-sufficiency target in terms of nutrition and food availability.

Export diversification is currently an important issue. Revenue from the fisheries sub-sector has increased from a low figure in the 1980s to over US $70,000, implying that the dependency on coffee income had been reduced. There is greater demand for fish because of population growth, rapid urbanization and improved infrastructure. Its contribution to the GDP is significant and it generates substantial incomes for many Ugandans engaged in fish harvesting, processing and marketing. However, recent developments indicate that if the weed problem is not addressed, whatever little had been achieved will be lost. Firstly, fish exports to Spain were recently banned due to high bacterial content. Fish exports to the European market will dwindle and even the domestic demand will fall. This will result in the closing down of the fish processing industries. It can be argued that the government is not fully committed to exploring all the possibilities regarding the weed control methods. It is imperative that more research on the problem be supported. Scientists working on these control methods must be facilitated to undertake the research to the end rather than only to provide partial assistance as was observed for the chemical control tests at Kajjansi and Wazimenya Bays.

Many Ugandans feel that the weed problem would not have reached such a level had the government acted more pragmatically. Since its appearance, the government, through MAAIF, has done a lot to control its spread. The following are notable: surveillance to establish distribution and abundance of the weed on our waters; sensitisation of the public on dangers of the weed; community mobilization for manual removal, though with limited facilitation; seminars and workshops to assist in drawing up control programmes; enlistment of financial and material support for the control programmes; limited provision of tools and equipments for manual removal; breeding of biological control agents through facilitation of NAARI; and making contacts with Kenya, Tanzania, Rwanda, Burundi, Sudan, Zaire, and Egypt for regional collaboration. The problem remains effective communication to the people on what has been achieved so far.

5.2 Conclusions and Recommendations

Although there is scientific data demonstrating that herbicide (chemical) application has been found to be the most cost-effective method for controlling water hyacinth, there are growing fears and mistrust on its use due to environmental implications. It is true that the use of chemicals has negative effects on the environment and may cause some bio-diversity loss. Still, after convincing and well-disseminated research results, chemicals may be sparingly used in specific sites that are completely inaccessible to other methods. In scenario IV, simulation 2 gives a combination of manual and mechanical methods in a ratio of 1:4. It is worth being adopted given its small C: E ratio of 0.036. It may be improved by increasing the area to be covered with the mechanical method. The manual control method is strongly recommended because it creates employment for the local communities and ensures local participation. Fishermen and local communities residing near affected lakeshores should be mobilised and facilitated to undertake weed control. This is likely to bring the situation under control since such groups are the immediate beneficiaries. The government should spearhead the process of soliciting funds, which should be handled by officials duly appointed by the groups concerned. The mechanical method is strongly supported because it has a superior C: E ratio and it reduces the drudgery associated with manual labour. The only snag remains with identification of the right machines. Those being used at Owen Falls Dam are appropriate though ones that are more efficient could do a better job. A combination of the two methods (manual and mechanical) could of course be more reliable as the risks and uncertainties that may arise are reduced.

Biological method is not the most cost-effective option, but it is the cheapest in terms of cost per hectare per hour. This method could be employed on a limited scale as more research is being carried out to investigate its potential in other pest, disease and weed control regimes for the future.

The task of eradicating the waterweed is an enormous one. It calls for a more responsible approach by the government and the affected communities. The government should look for financiers who can give long-term loans to undertake the exercise since the required investment is huge. In the analysis, only a hectare was considered for simplicity. If the total area of the weed on both lakes is considered (about 90,000 ha) about US $32 million is required to implement the recommended scenario. Mechanical control with the least C:E ratio (0.016) requires about US $14,4 million to eliminate the weed. Manual, biological and chemical control methods require about US $105, 187 and 269 million, respectively.

These figures would tremendously reduce if implementation were done over a longer period. If a period of one month (300 working hours) were considered, the recommended scenario would require about US $106,000.

Manual, biological and chemical controls used alone would require US $350,000, 623,000 and 890,000, respectively. Such amounts of money may seem to be high but considering the anticipated revenue from the sale of fish, they are not so high. If the government cannot raise the money immediately, the short-term solution would be to borrow. The incomes resulting from the weed-free lakes will be sufficient to pay back any loan with interest within a short period.

The most certain strategy is to undertake a full-blown use of the mechanical and manual methods to fight the weed, protect the environment and create jobs for the local communities. Researches on chemical and biological use need to continue to get convincing results. It is imperative that the three East African countries which share Lake Victoria come together to draw up a long-term and sustainable solution to the weed problem. This will indeed be facilitated and strongly supported given the recent revitalisation of the East African Cooperation.

Lastly, public awareness in all aspects of the weed is of paramount importance. According to the survey, the view people have for the government has been undermined because many people do not know that the government is fighting very hard to eradicate the weed.

5.3 Implications for Further Research

Research on utilisation of the weed should be urgently undertaken by multidisciplinary teams. It has been reported that it can be useful in biogas digesters, as animal feed, in paper industries and as mulch. Such positive attributes of the weed could lead to income generation.

Since chemical control may require manual or mechanical removal of the debris to be effective, why not remove the weed outright without first spending money on chemical trials, as one scientist put it?

Chemical control trials carried out do not consider the long-run effects of the chemicals through accumulation of the residues via the food chain. Their findings were not conclusive considering the time element within which they had to carry out the experiment. Further research should be conducted to come up with data that are more concrete on costs, effectiveness and overall benefits.

The concept of re-growth is of paramount importance as it suggests repeated use of the chemicals. It is imperative that we determine the number of times that the re-growth has to be re-sprayed to ensure complete weed destruction vis-à-vis the availability of resources and the protection of the environment.

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