Ecological Indicators 7 (2007) 362–370

ECOLOGICAL INDICATORS

This article is also available online at:
www.elsevier.com/locate/ecolind

Indicators for an invasive species: Water hyacinths in Lake Victoria

Eseza Kateregga [a], Thomas Sterner [b,*]

[a] Makerere University, Kampala, Uganda
[b] Department of Economics, Gothenburg University, Sweden

Received 27 October 2005; received in revised form 23 February 2006; accepted 27 February 2006

Abstract

The purpose of this paper is to create and discuss a measure of water hyacinth abundance in Lake Victoria. Water hyacinths have dramatic effects on other activities such as fisheries. However, understanding their spread and effects is hampered by the lack of reliable information. Available data on mat coverage was collected from a number of scattered reports and used to fit hyacinth growth curves for the three sections of Lake Victoria. Estimates of the annual rates of infestation are derived from this analysis and were found to be significantly correlated with effect estimates based on hyacinth-attributed generation outages in hydroelectric production. Hyacinths started to grow massively in 1992–1993, reached their maximum in 1997–1998 and were basically gone after 2001. Outages follow a similar pattern but decline faster.

JEL classification: O13; Q22; Q56

Keywords: Water hyacinths; Lake Victoria; Ecological indicators

1. Introduction

The water hyacinth (*Eichhornia crassipes*), is an invasive aquatic macrophyte with a potential for particularly rapid growth and dispersal (Cook, 1990) and can cause considerable damage to local environments. Lately the hyacinth has invaded many tropical lakes (Mironga, 2004). To work out successful strategies of mitigation or adaptation, we must understand something of their spread although data are often inadequate—particularly in poor countries and for the early phases of an invasion.

Lake Victoria is the second largest freshwater lake in the world, with a surface of 68,800 km^2 and catchment of 258,700 km^2. With a mean depth of

* Corresponding author. Tel.: +46 31 7731377; fax: +46 31 7731326.
E-mail address: Thomas.sterner@economics.gu.se (T. Sterner).

1470-160X/$ – see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ecolind.2006.02.008

40 m^2 it is rather shallow[1] and sensitive to nutrient loading (Kaufman and Ochumba, 1993; Hecky et al., 1994; Goldschmidt et al., 1993). It is shared between Kenya (6%), Tanzania (51%) and Uganda (43%) and is very important for the riparian states in providing food, water, transport, recreation, tourism and in Uganda it is the main source of hydroelectric energy. Current estimates show that annual fish catch from Lake Victoria is between 400,000 and 500,000 metric tons. The fishery directly employs about 100,000 people, but more than 2 million are involved in ancillary activities. Catches from the lake constitute more than 60% of total catch in Kenya and Uganda, and fish provides over 60% of household protein in Uganda (LVEMP, 1997).

Several studies have shown that the capability of the lake to provide sustainable services is threatened by various forces: (1) the decline in fish stocks and biodiversity due to over-fishing (Gitonga, 2001); (2) increasing levels of municipal, industrial and agricultural pollution causing eutrophication and algal blooms (Hecky et al., 1994); and (3) the effect of invasive species. One of these is the Nile perch, (*Lates niloticus*) cited as causing loss in lake bio-diversity (Goldschmidt et al., 1993; Pitcher and Bundy, 1992). The other invasive species is the topic of this paper: the water hyacinth.

The water hyacinth first appeared in Lake Victoria in late 1988 and its rapid spread was partly due to abundant nutrient availability. Consequences of infestation are often dramatic and there is quite a literature on its management (see Mitchell, 1985; Gopal, 1987; Harley et al., 1997). The amount of weed was enough even to stop modern ships and close commercial harbors—the effect on small fishing communities that rely on canoes was all the worse. Several reports have described the deleterious local effects (see Masifwa et al., 2001; Twongo, 1996; Mailu, 2001). According to the Lake Victoria Environmental Management Project (LVEMP, 1999) the following major problems were caused: (i) reduction in fish through de-oxygenation of the water in the sheltered bays that are their nursery grounds (the hyacinths may however also provide refuge for smaller fish which might actually promote biodiversity); (ii) physical interference with fishing and transportation; (iii) impediment to urban and rural water supply and to the Owen falls hydro power station; and (iv) provision of habitat for dangerous organisms like snails that cause bilharzia, and for mosquitoes and snakes. The welfare losses caused were so great that considerable efforts and large costs were undertaken to eliminate or control the weed (Mailu, 2001).

Facing these problems, managers had insufficient overview of weed extension, which hampered control efforts and analysis. The causal links are likely to be complex, for instance in fisheries, the hyacinth mats may have direct ecological effects on the fish stocks and at the same time indirect effects since they hinder fishing which benefits stocks. To analyse such issues we need appropriate indicators and this paper seeks to create such an indicator of the extent of the water hyacinth infestation in the lake. Section 2 discusses measurement issues, Section 3 presents the available data. Section 4 contains the estimation of the water hyacinth mats, Section 5 looks at the induced power outages and their correlation with the estimated hyacinth indices and Section 6 concludes.

2. Measurement issues and indices

Studies of environmental issues must face the fact that there are multiple and complex links between the original cause and the effects of interest to society. An activity (such as an emission) may have immediate effects on the environment but the ecosystem and society will react triggering further rounds of social and eco-system responses. There are several analytical frameworks using causal relationships as a scientific basis for Integrated Environmental Assessment (IEA) and for the construction of different kinds of environmental indices. One of the more prominent is the "DPSIR" (Driving Force–Pressure–State–Impact–Response–framework) used by the European Environmental Agency (EEA, 1999) (see for instance Wieringa (1999) or Jin and High (2004) for a similar approach). The main idea is that along the line of causality from the driving forces through the states of the environment to

[1] While the authors quoted call the lake "shallow" this is a relative concept. Scheffer (2001) for instance uses the word in a more narrow sense to mean lakes without stratification which usually means less than about 4 m. According to Scheffer, Lake Victoria is not itself "a shallow lake" but large parts of it, the multitude of bays where infestation by hyacinths was worst, are definitely shallow (personal communication, January 2006).

the impacts, there may be responses, which, in turn, have effects that must be taken into account.

Available statistics tend to cover phenomena that are easily measured but may fail to describe the variables of greatest interest. We may be interested in the impact of an infestation but the data available may just cover physical extension. The concepts that interest us may be immeasurable and we need to find relevant indicators that cast light on a particular phenomenon, or act as a reasonable proxy for it. There are similar problems in the social sciences, where indicators are considered useful to identify broad trends in phenomena for which relevant statistics are unavailable. For example, in his comparative analysis of economic success among societies, Sen (1998) discarded "income" as an insufficient indicator. Money is according to Sen, an instrument to other ends: It is valued for what it can achieve, but it is the attainment or deprivation of the desirable living standard that captures economic success. He therefore opts to use mortality as a more reliable indicator of economic differences across countries.

A number of desirable properties of ecological indicators are stressed in the literature (see for example, Bennet (2000) or Dale and Beyeler (2001)). Typically a good ecological indicator should (1) have a sound conceptual basis, (2) be easily measurable, (3) respond to the ecological stress at issue in a predictable manner, (4) have manageable data requirements and finally (5) correspond well to the issue we are interested in. Mironga (2004) shows how GIS and remote sensing could be used for assessing the spread of weeds and specifically mentions hyacinths in Lake Victoria as a possible application although recognizing that this requires very significant amounts of data.[2] The challenge here is to derive simple and affordable indicators that meet the criteria above sufficiently well using only data readily available. There is also the fact that this was a new problem in this area and thus there were no data in the initial phase. Once the weed had been identified as a serious problem, data collection did start but in an uncoordinated and ad hoc manner with no firm methodological basis in spite of the fact that there is a scientific literature on weed management (e.g. Harley et al., 1997).

[2] "Using this same approach, it is possible, for instance, to create an integrated database to address the issue of rapid spread of water hyacinth in Lake Victoria, Kenya. To achieve this, it is imperative that various data sets are structured. These should include information on bathymetry of the lakes, data on water quality, depth, aspect, suspended sediments, water temperature, wave action and a base map. Maps of vegetation representing changes over years, derived from aerial photographs or satellite imagery, are also part of this database." Op cit. p. 89.

3. Data on water hyacinth abundance on Lake Victoria

There are numerous estimates of hyacinth cover but they were made with varying survey methods and their reliability is open to question. Though the weed was reported as early as 1989, there are few estimates before 1993. The reported estimates of area covered are also very unsystematic, some reports cover the whole lake, while others cover one national or subnational part or even just a certain bay. The aim of this paper is to use as much as possible of the available estimates from these reports to estimate growth curves for hyacinth mats for the period 1992–2001.

Measurements were not carried out systematically but concentrated in areas of commercial importance. Use of estimates of water hyacinth abundance in these strategic areas to extrapolate over sectional or lakewide water hyacinth abundance may yield biased results. On the other hand, one could argue that a measure that gives more weight to areas of commercial importance might be preferable.

We also have information on a potential effect of the water hyacinth invasion: induced hydroelectric generation outages. Records of generation outages attributed to water hyacinths have been collected and we may expect these to increase with hyacinth biomass; thus these outages are a possible candidate of the Impact as opposed to the Driving forces or Pressure (the abundance of hyacinths) in the DPSIR scheme. However, as we will see, the Impact type indicator suffers from the problem that with time, people adapt and thus data also reflect learning.

4. Developing an area-based indicator

Although there are no perfect or systematic surveys, we have managed to find a multitude of reports, observations and studies with incomplete estimates. From this we have screened for consistency

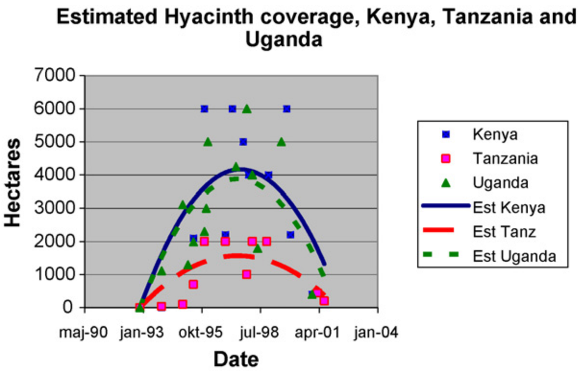

Fig. 1. Observed hyacinth coverage and fitted curves for hyacinth population in the Ugandan, Kenyan and Tanzanian parts of Lake Victoria.

in spatial coverage and only included those that meet certain minimum requirements: they must have definite data and they must cover either the whole lake or at least the entirety of one national part thereof. An entire list of the estimates used is given in the table in Appendix A.[3] There is a big variation in hyacinth coverage reported in theses studies even in similar periods, and for the same area. We believe that the large variations in the reported acreage of mats are most likely due to differences in methodology and perhaps to error. Without the resources to buy and analyze satellite images, we opt to use the available data to fit regressions to give us our overall measures of weed abundance. This also allows us to impose the constraints that the weed starts from zero, grows and declines smoothly to very low levels.

In Fig. 1, we plot the estimates of weed coverage, for each section in scatter diagrams. The plots show that maximum weed area seems to have been in 1997. In the early 1990s the hyacinth biomass was at lower levels but then accelerated. After 1997 it seems control programs became more effective including mechanical harvesting and biological methods such as the introduction of two species of weevils, *Neochetina eichhorniae* and *N. bruchi* that predate on hyacinths. The scatter plots show an inverted U-shape for hyacinth extension. This shape is explained by the circumstances that influenced water hyacinth growth in Lake Victoria explained above. We estimate a quadratic trend regression for each section assuming that there were zero weeds in 1992. The fitted quadratic regression equations of hyacinth coverage (WH) as a function of months (t starting in December 1992) and the respective R^2 were:

$$\mathrm{WH_K} = 147t - 1.3t^2, \quad R^2 = 0.47 \text{ for Kenya}$$
$$\mathrm{WH_U} = 142t - 1.3t^2, \quad R^2 = 0.52 \text{ for Uganda}$$
$$\mathrm{WH_T} = 57t - 0.52t^2, \quad R^2 = 0.61 \text{ for Tanzania}$$

The fit of the regressions is intermediate (suggesting there may be quite a lot of error in at least some of them) but they all portray a consistent timing of the infestation. Although multiplication rates of the water hyacinth have been reported to be alarmingly high in several aquatic systems, the rate of water hyacinth infestation in lake Victoria was not quite so high (particularly not in the Tanzanian part). Perhaps this is explained by weed control procedures in place over the period as well as the translocation and eventual destruction of the weed mats by the wind/wave action on the lake. Based on the fitted curves for hyacinth population we can provide the following approximate estimates of the water hyacinth infestation in lake Victoria (Table 1).

The estimates are far from perfect but given the contradictory nature of the different reports, this is as much as we can say today.

5. Electricity outage based indicator of water hyacinth abundance

As a form of check—or alternative measure of the hyacinth invasion we can study measures of the effects

Table 1
Mid-year estimates of Hyacinth coverage

Year	Kenya	Tanzania	Uganda
1992	0	0	0
1993	840	320	800
1994	2230	860	2130
1995	3250	1250	3080
1996	3890	1480	3670
1997	4160	1570	3880
1998	4040	1500	3720
1999	3550	1290	3190
2000	2690	930	2280
2001	1440	420	1010

Area in hectares, estimated for June of each year.

[3] More information including a longer list of estimates for local bays, etc. is available in Kateregga (2004).

Table 2
Hyacinth induced outages and estimated mat area, Uganda

Year	Outages (h)
1990	54.25
1991	67.56
1992	75.53
1993	63.01
1994	226.07
1995	293.23
1996	367.18
1997	335.59
1998	563.08
1999	147.53
2000	2.52
Correlation coefficient[a]	0.76**
Correlation coefficient[a] up till 1998	0.92**

Source for outage duration: Uganda Electricity Generation Company Ltd.

[a] Correlation coefficients between this indicator and mat area for Uganda according to Table 1.

** Significant at 5% level.

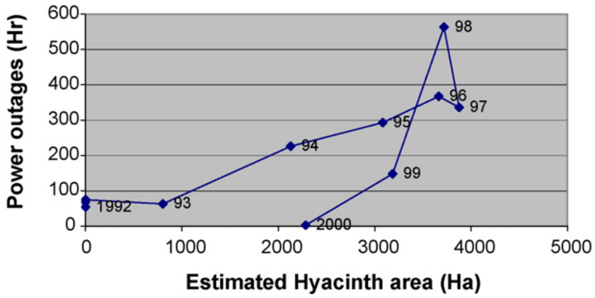

Fig. 2. Power outages vs. estimated extent of water hyacinth, Owen Falls, Uganda, 1992–2000. Sources: Tables 1 and 2.

caused. Hyacinth induced generation outages are one such possible variable and were obtained from the Uganda Electricity Generation Company. These are reported numbers of hours the turbines had to be turned off due to water hyacinth interruptions (mainly the cleaning of debris from screens). Table 2 shows the same general picture of increase and then decline. However the decline in outages is already very strong in 1999.

This allows us to explore the relationship between the two indices that represent different positions in the chain of events behind the DPSIR approach: the area measures of infestation reflect the State of the environment while the outage duration is a measure of Impact—an impact that is moderated by the Response of the power company: The correlation coefficient for hyacinth mats and outage duration was 0.76 and significant, however if the last 2 years are removed the correlation coefficient goes up to 0.92. In the beginning, outages clearly increase with the abundance of water hyacinth mats. However in the last 2 years, outages fall drastically even though there are still large masses of weed. This shows the impact of abatement measures and presumably of learning effects. The power station appears to have found an effective response, a means of dealing with the infestation, whether by locally harvesting or by more effective screen cleaning or some combination thereof (see Fig. 2). It is for this reason that we prefer direct measures of the weed to output-based measures, which are not good towards the end of the period. Clearly the higher the precision of our state-based measures the more information such comparisons can give.

The fact that there is learning and adaptation makes impact indicators inadequate as measures of the changes in weed biomass since the magnitude of effects are determined by both weed biomass and abatement efforts. Another example would have been inconveniences to shipping but according to the shipping company in Uganda, inconveniences occurred only in the first half of 1995 [personal communication from officials at the Uganda Railways Corporation]. Manual and mechanical harvesting effort employed during the period were able to free ports by the middle of 1995. Since then, routine harvests were maintained to crop out any new weed mat inflows. This ensured smooth shipping operations even in the period of maximum water hyacinth abundance on the lake. Clearly shipping inconveniences in Uganda cannot pass for an appropriate indicator of weed biomass changes. Water hyacinth induced outages continued throughout the water hyacinth infestation era because by location the electricity-generating firm is on the major outflow out of the lake. The Nile current brought down masses of the weed to the dam. While weed-harvesting efforts in this case freed the dam from water hyacinth biomass, the debris that it brought down with it continued to flow down into the screens protecting the turbines and the cooling system. This was the major cause of generation outages, and it persisted much longer than for the shipping but eventually the power company appears to have found methods to deal with the hyacinths.

6. Conclusion

Although the conduit through which the water hyacinth infested Lake Victoria remains a mystery, the eutrophication and conducive climate facilitated its rapid spread. Initially there were no measurements but with increasing attention there came an increasing number of reports but they were not standardized, or harmonised. In this paper we have used the myriad of reported estimates of the average of water hyacinth mats to construct a single smooth, annual and we believe reasonably reliable estimate of the extent of water hyacinth coverage for the period 1990–2001. Our estimations of the extent hyacinth infestation show that the most massive coverage of Lake Victoria by the water hyacinth occurred after 1995. The estimates of hyacinth mats show reductions in the extent of hyacinth coverage after 1997. The correlation coefficient between the estimated water hyacinth mats in Uganda's section of Lake Victoria, and the incidence of water hyacinth induced outages is high and significant—except for the last 2 years when the impact of learning and successful abatement measures appears to interfere with this relationship. This makes outages a poor indicator of the water hyacinth in later years and shows a limitation of such impact indicators. Finally, the hyacinth remains a recognisable resident of the lake (FIRRI, 2002) and new outbreaks are not unlikely. Stringent control measures will be necessary to check further explosions of the weed and it would seem wise to collect more systematically, data on the causes, extent and effects of the hyacinth. This would be a natural task for the organisations created to coordinate development in the Lake Victoria basin.

Acknowledgements

The authors would like to thank Gardner Brown, Per Fredrikson, Håkan Eggert, Renato Aguilar and two anonymous referees for useful comments. Financial support from the Swedish International Development Cooperation Agency to the Environmental Economics Unit, EEU at the University of Gothenburg is gratefully acknowledged.

Appendix A

Reports on water hyacinth abundance is given in Table A.1.

Table A.1
Reports on water hyacinth abundance

Year	Hectares	Source for lakewide estimates
1988	Present	World Bank/Global Environmental Facility (1996)
1996	2500	National Environment Management Authority, Uganda (1996)
1995	14000	Julien and Nokham (2000)
1995	12000	Economic Commission for Africa (1999)
1997	69900	UN Department of Humanitarian Affairs (1997)
1998	70000	Lindsey and Hirt (1999)
1998	12000	Collins (2001)
1998	40000	Amuyunzu and Navarro (1998)
1998	70000	ICRAF (1998–1999)
1998	15000	Chamuya (2000)
1998	12000	Twongo and Odongkara (1998)
1999	14000	Lake Victoria Bulletin, issue no. 1 (1999), LVEMP (Kenya)
1999	12000	East African Cooperation Initiative (1999)
1999	20000	Technical Team Report, March (1999)
1999	40000	Economic Commission for Africa (1999)
2001	12000	Collins (2001)

Table A.1 (*Continued*)

Year	Hectares	Source for lakewide estimates
Year	Hectares	Source for Kenyan estimates
1995	2000	Julien and Nokham (2000)
1995	6000	Economic Commission for Africa (1999)
1998	5000	Mailu et al. (1998)
1998	2100	Ochiel et al. (1998)
1998	6000	Technical Team Report, March (1999)
1998	4000	Economic Commission for Africa (1999)
1999	4000	Lake Victoria Bulletin, issue no. 1 (1999), LVEMP (Kenya)
Year	Hectares	Source for Tanzanian estimates
1995	2000	Economic Commission for Africa (1999)
1995	2000	Julien and Nokham (2000)
1997	1000	Nyirabu (2001)
1998	2000	Mallya (1998)
1998	2000	Technical Team Report, March (1999)
1999	1200	Economic Commission for Africa (1999)
2001	440	Nduguru (2001)
Year	Hectares	Source for Ugandan estimates
1995	1300	Baarveld et al. (1995)
1995	2300	NTFCMWH (1996). Final draft
1995	2000	Uganda Agriculture Policy Committee (1995)
1995	10000	Julien and Nokham (2000)
1995	4000	National Environment Management Authority (1996)
1996	3000	USAID IEE (1998)
1996	5000	Norwegian Institute of Water Research (1996)
1996/1997	3873	Twongo and Ochieng (1997)
1997	1800	Economic Commission for Africa (1999)
1997	4250	Aquatics Unlimited (AU) (1997)
1998	4000	Technical Team Report, March (1999)
1999	5000	Orata (1999)

This is a selection of the most useful, consistent and reliable reports. A full list is available on request.

References

Amuyunzu, C.L., Navarro, L., 1998. Exchange of information for action on water hyacinth network (EIAWHN). In: Proceedings of the 1st IOBC Working Group Meeting for the Biological and Integrated Control of Water Hyacinth.

Aquatics Unlimited, 1997. Water Hyacinth Estimates on Uganda Section of Lake Victoria.

Baarveld, W.G., Nkedi-Kizza, P., Odongkara, O.K., 1995. Emergency Control of Water Hyacinth in Lake Victoria, Uganda. FAO Mission Report. Technical Cooperation Programme, TCP/RAP/2371.

Bennet, J.P., 2000. Ecological Indicators for the Nation Committee to Evaluate Indicators for Monitoring Aquatic and Terrestrial Environments. National Research Council, National Academy Press, Washington DC, ISBN: 0309-06845-2.

Chamuya, N., 2000. Move to combat illegal fishing. Tanzania Wildlife Quart. Mag. (19).

Collins, B., 2001. Weevils in Lake Rescue. In: Msafiri, Kenya Airways In Flight Magazine, issue 34, February.

Cook, C.D., 1990. Origin, autoecology and spread of some of the world's most troublesome aquatic weeds. In: Pieterse, A., Murphy, K. (Eds.), Aquatic Weeds: The Ecology and Management of Nuisance Aquatic Vegetation. Oxford University Press, Oxford, UK.

Dale, V.H., Beyeler, S.C., 2001. Challenges in the development and use of ecological indicators. Ecol. Indic. 1, 3–10.

East African Cooperation Initiative, 1999. Regional Strategy for the Control of water Hyacinth and Other Invasive Aquatic Weeds in East Africa. Technical Team Report, in the 2nd East African Cooperation Ministerial Meeting on Water Hyacinth. AICC, Arusha, Tanzania. Report Ref. No: EAC/SR/12/99.

Economic Commission for Africa, 1999. Studies of the Control and Management of Water Hyacinth in the Lake Victoria Basin: The Need for Coordinated Strategies, Policies and Programmes. ECA/EA/SRDC/R/1 Mailu Report.

EEA, European Environment Agency, 1999. Environmental Indicators: Typology and Overview, Technical Report No. 25, Copenhagen.

Fisheries Resources Research Institute (FIRRI), 2002. Experiences with Water Hyacinth Infestation in Uganda. National Agricultural Research Organisation.

Gitonga, M., 2001. Report on Fish Stock Status in Lake Victoria, Ministry of Agriculture and Rural Development, Fisheries Department, Kenya.

Goldschmidt, T., Witte, F., Wanink, J., 1993. Cascading effects of the introduced Nile perch on the detritivorous/phytoplanktivorous species in the sublittoral areas of Lake Victoria. Conserv. Biol. 7, 3686.

Gopal, B., 1987. Water Hyacinth. Elsevier, Amsterdam, 471 pp.

Harley, K.L.S., Julien, M.H., Wright, A.D., 1997. Water hyacinth: a tropical worldwide problem and methods for its control. Appendix 7. In: Proceedings of the International Water Hyacinth Consortium, World Bank, Washington, DC, March.

Hecky, R.E., Bugenyi, F.W.B., Ochumba, P., Talling, J.F., Mugidde, R., Gophen, M., Kaufman, L., 1994. Deoxygenation of the deep water of Lake Victoria, East Africa. Limnology and Oceanography 39 (6), 1476–1481.

ICRAF et al., 1999. Improved Land Management in the Lake Victoria Basin. Final Technical Report financed by Swedish International Development Agency.

Jin, X., High, K.A., 2004. A new conceptual hierarchy for identifying environmental sustainability metrics. Environ. Prog. 23 (4).

Julien, M.H., Nokham, S., 2000. Biological Control of Water Hyacinth on Lake Victoria. Division of Entomology, Commonwealth Scientific and Industrial Research Organisation, Australia, unpublished.

Kateregga, E., 2004. Essays on the investation of Lake Victoria by the water hyacinth, PhD Thesis in Economics, Economics Studies, 140, University of Gothenburg, Sweden.

Kaufman, L., Ochumba, P., 1993. Evolutionary and conservation biology of cichlid fishes as revealed by faunal remnants in northern Lake Victoria (in Special Section: The Great Lakes of Africa). Conserv. Biol. 7 (3), 719–730.

Lake Victoria Environmental Management Program (Uganda) 1997. Project Report.

Lake Victoria Environmental Management Programme (Kenya), 1999. Lake Victoria Bulletin, 1, February.

Lindsey, K., Hirt, H.M., 1999. Use Water Hyacinth!: A Practical Handbook of Uses for the Water Hyacinth from Across the World Anamed, Winnenden, Germany.

LVEMP, Lake Victoria Environmental Management Project, 1999. Report of the Second East African Cooperation Ministerial Meeting on Water Hyacinth, August 19th, 1999. AICC Arusha, Tanzania. Report Ref. No: EAC/SR/12/99.

Mailu, A.M., 2001. Preliminary assessment of the social, economic and environmental impacts of water hyacinth in the Lake Victoria basin and the status of control. In: Biological and Integrated Control of Water Hyacinth, *Eichhornia crassipes*. ACIAR Proceedings No. 102.

Mailu, A.M., Ochiel, G.R.S., Gitonga, W., Njoka, S.W., 1998. Water hyacinth: an environmental disaster in the Winam Gulf of Lake Victoria and its control. In: Proceedings of the 1st IOBC Global Working Group Meeting for the Biological Control and Integrated Control of the Water Hyacinth.

Mallya, G.A., 1998. Water hyacinth control in Tanzania. In: Proceedings of the first IOBC Global Working Group Meeting for the Biological Control and Integrated Control of Water Hyacinth.

Masifwa, W.F., Twongo, T., Denny, P., 2001. The impact of water hyacinth, *Eichhornia crassipes* (Mart) Solms on the abundance and diversity of aquatic macroinvertebrates along the shores of northern Lake Victoria, Uganda. Hydrobiologia 452, 79–88.

Mironga, J.M., 2004. Geographic information systems (GIS) and Remote sensing in the management of shallow tropical lakes. Appl. Ecol. Environ. Res. 2 (1), 83–103.

Mitchell, D.S., 1985. African aquatic weeds and their management. In: Denny, P. (Ed.), The Ecology and Management of African Wetland Vegetation. Dr W. Junk Publishers, Dordrecht.

National Environment Management Authority, Uganda, 1996. State of the Environment Report. Uganda Government Printers.

National Task For the Control and Management of the Water Hyacinth (Uganda), 1996. Report on Verification Study on Chemical Control of Water Hyacinth, March.

Nduguru, J., 2001. A Recent Survey on Water Hyacinth Estimates. Plant Protection Division. Ministry of Agriculture, Mwanza, May.

Norwegian Institute of Water Research, 1996. Limnological Study of Murchison Bay and Napoleon Gulf, Uganda with reference to Water Supply and Waste Water Disposal at Kampala and Jinja. A case study.

Nyirabu, C., 2001. Estimate of Water hyacinth in Lake Victoria. In: The African (News Paper) as reprinted and distributed by the Integrated Regional Information Network (IRIN) of the UN office for the coordination of Humanitarian Affairs (OCHA), October.

Ochiel, G., Mailu, A., Gitonga, W., Njoka, S., 1998. Biological control of water hyacinth on Lake Victoria. In: Proceedings of the 1st IOBC Global Working Group for the Biological Control and Integrated Control of Water Hyacinth, Kenya.

Orata, D., 1999. The removal of Water Hyacinth in Lake Victoria. In: The Daily Nation (Kenya's Newspaper), 23rd July.

Pitcher, T.J., Bundy, A., 1992. Assessment of the Nile perch fishery in Lake Victoria. In: Pitcher, Hart, (Eds.), The Impact of Species Changes in African lakes. Chapman and Hall, London, Fish and Fisheries Series, 18.

Scheffer, M., 2001. Ecology of Shallow Lakes. Kluwer Academic Publishers, Dordrecht, Boston & London, The Netherlands.

Sen, A., 1998. Mortality as an indicator of economic success and failure. Econ. J. 108, 1–25.

Technical Team Report, 1999. Water Hyacinth Estimates on Lake Victoria, March.

Twongo, T., 1996. Growing impact of water hyacinth on near shore environments of Lakes Victoria and Kyoga (East Africa). In: Johnson, T.C., Odada, E. (Eds.), Proceedings of Symposium: The Limnology, Climatology and Paleoclimatology of East African Lakes, 18–22 February 1993, Jinja Uganda.

Twongo, T., Ochieng, H.M., 1997. Water Hyacinth in Uganda: Distribution and Coverage. Fisheries Research Institute, Jinja, unpublished.

Twongo, T., Odongkara, C.O., 1998. Update on the Water Hyacinth Problem in Uganda. Fisheries Research Institute, Jinja, unpublished.

Uganda Agriculture Policy Committee, 1995. Emergency Action Plan for Control of Water Hyacinth, unpublished.

UN Department of Humanitarian Affairs, Integrated Regional Information Network for Central and Eastern Africa, 1997. Briefing on Water Hyacinth. Based on Surveillance Satellites.

USAID IEE, 1998. Water Hyacinth Control Program 1998. In: Final Environmental Impact Statement. Aquatics Unlimited and The Uganda Ministry of Agriculture, Animal Industry and Fisheries.

Wieringa, K., 1999. Towards integrated environmental assessment support for the European Community's environmental action programme process. Int. J. Environ. Pollut. 11 (4), 525–541.

World Bank/Global Environmental Facility, 1996. World Bank/Global Environmental Facility. Project Report No: 15541-AFR. Kenya, Tanzania, Uganda—Lake Victoria Environmental Management.