

Short communication

The decline of water hyacinth on Lake Victoria was due to biological control by *Neochetina* spp.

John R.U. Wilson^a, Obinna Ajuonu^b, Ted D. Center^c, Martin P. Hill^{d,*},
Mic H. Julien^e, Francisca F. Katagira^f, Peter Neuenschwander^b,
Stephen W. Njoka^g, James Ogwang^h, Rob H. Reederⁱ, Thai Van^c

^a Centre for Invasion Biology, Department of Botany & Zoology, University of Stellenbosch, Private Bag XI, Matieland 7602, South Africa

^b International Institute of Tropical Agriculture, 08 B.P. 0932 Cotonou, Benin

^c USDA-ARS, Invasive Plant Research Laboratory, 3225 College Avenue, Fort Lauderdale, FL 33314, USA

^d Department of Zoology and Entomology, Rhodes University, Grahamstown 6140, South Africa

^e CSIRO Entomology, 120 Meiers Rd., Indooroopilly, Queensland 4068, Australia

^f Plant Health Services, Ministry of Agriculture & Food Security, P.O. Box 9071, Dar es Salaam, Tanzania

^g Lake Victoria Environmental Management Project, Kenya Agricultural Research Institute, P.O. Box 680, Kisumu, Kenya

^h National Agricultural Research Organization/Coffee Research Institute, P.O. Box 185, Mukono, Uganda

ⁱ CABI Bioscience, Egham, Basingstoke Lane, Surrey TW20 9TY, UK

Received 20 September 2005; received in revised form 1 June 2006; accepted 16 June 2006

Abstract

There has been some debate recently about the cause of the decline of water hyacinth on Lake Victoria. While much of this evidence points to classical biological control as the major factor, the El Niño associated weather pattern of the last quarter of 1997 and the first half of 1998 has confused the issue. We argue first that the reductions in water hyacinth on Lake Victoria were ultimately caused by the widespread and significant damage to plants by *Neochetina* spp., although this process was increased by the stormy weather associated with the El Niño event; second that increased waves and current on Lake Victoria caused by El Niño redistributed water hyacinth plants around the lake; and third that a major lake-wide resurgence of water hyacinth plants on Lake Victoria has not occurred and will not occur unless the weevil populations are disrupted. We conclude that the population crash of water hyacinth on Lake Victoria would not have occurred in the absence of the weevils, but that it may have been hastened by stormy weather associated with the El Niño event.

© 2006 Elsevier B.V. All rights reserved.

Keywords: *Eichhornia crassipes*; *Neochetina bruchi*; *Neochetina eichhorniae*

1. Introduction

Water hyacinth was first reported on Lake Victoria in 1989 (Twongo, 1991), and quickly spread around the lake margins. At the peak of the infestation in the late 1990s, data from Albright et al. (2004) suggest that tens of thousands of hectares of the water surface were covered in plants. This infestation

hampered transport links, reduced levels of fishing, and posed a threat to the biodiversity of the lake, including its unique fauna of cichlids (Seehausen et al., 1997). To control the weed, classical biological control agents (*Neochetina bruchi* (Hustache) and *Neochetina eichhorniae* (Warner) (Coleoptera: Curculionidae) were imported to the Great Lakes Region, and from 1995 onwards they were released onto different parts of the lake. During 1997/1998, there was also an El Niño weather pattern that caused stormy and wet weather in the region. Around the same time, water hyacinth populations started declining on the lake. This decline has continued and there are no reputable reports of any major resurgence of the weed.

In this paper we want to address a recent article in Aquatic Botany by Williams et al. (2005) which states that “Weevils alone were . . . probably not responsible for the rapid reduction

* Corresponding author. Tel.: +27 46 603 8712; fax: +27 46 622 8959.

E-mail addresses: jrwilson@sun.ac.za (J.R.U. Wilson), o.ajuonu@cgiar.org (O. Ajuonu), tcenter@saa.ars.usda.gov (T.D. Center), m.p.hill@ru.ac.za (M.P. Hill), mic.julien@csiro.au (M.H. Julien), fktagira@hotmail.com (F.F. Katagira), P.Neuenschwander@cgiar.org (P. Neuenschwander), swnjoka@yahoo.com (S.W. Njoka), cori@africaonline.co.ug (J. Ogwang), r.reeder@cabi.org (R.H. Reeder), thaivan@saa.ars.usda.gov (T. Van).

in weed biomass”, but that “the wet and cloudy weather of 1997/1998 almost certainly played a major part by accelerating their decline due to extremely low light availability”. They also warn that in the absence of El Niño effects, weevil populations will be unstable and that “the return of water hyacinth proliferation within Lake Victoria may therefore be just a matter of time”. We reanalyse the data of Williams et al. (2005) and, to see whether light had indeed been critically low, we establish a time series of the dynamics of water hyacinth on Lake Victoria and present observations on water hyacinth population dynamics from around the world. We arrive at different conclusions, namely that water hyacinth was controlled by weevils and that the probability of water hyacinth resurgence has been overplayed. In so doing, we reiterate arguments made by Ogwang and Molo (2004), but in the light of new supporting evidence.

2. Methods

A recent study used satellite images of Lake Victoria to estimate the coverage of water hyacinth on the Tanzanian, Ugandan and Kenyan (Winam Gulf) sides of the lake (Figs. 4, 6, and 7 in Albright et al., 2004). In our study, each data-set was linearly interpolated between sample dates, and the resulting trends were summed to give a picture of how lake-wide water hyacinth populations changed over time (Fig. 1). The pattern produced corresponded well with the lake-wide data presented (Fig. 1 in Albright et al., 2004), but included more data as our approach was not restricted to dates where the whole of the lake was clear from cloud cover.

In Fig. 1, water hyacinth populations declined just after the El Niño event (although the sustained reduction in plant populations started about a year later). To test whether low light levels *per se* could have restricted water hyacinth growth, Williams et al. (2005) measured how CO₂ uptake changed with light levels (Fig. 2 in Williams et al., 2005), and separately how plant growth varies with CO₂ uptake rate when photosynthetic active radiation (PAR) was >2000 μE m⁻² s⁻¹ (Fig. 3 in

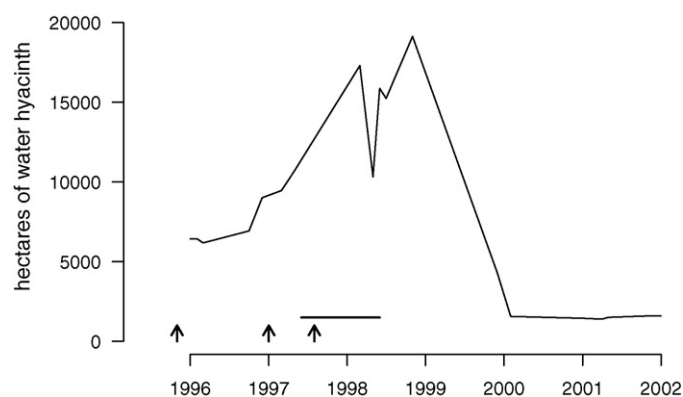


Fig. 1. Coverage of water hyacinth on Lake Victoria based on remote sensing data (adapted from Albright et al., 2004). The arrows show the date of first release of weevil species onto different parts of the lake (Uganda, Kenya, and Tanzania, respectively, in order of date). The line shows the occurrence of an El Niño weather pattern. Biological control of water hyacinth by *Neochetina* spp. normally takes 3–5 years to be effective (Julien et al., 1999).

Williams et al., 2005). In extrapolating from light levels to plant growth, Williams et al. (2005) imply a relationship between water hyacinth growth (in terms of biomass accumulation) and instantaneous light levels. Given the parameter estimates of Table 1 in Williams et al. (2005), we established this relationship and evaluated its consequences.

3. Results and discussion

Albright et al. (2004) provided the first clear data on lake-wide water hyacinth abundance, and it was clear from our redrawing that the lake-wide level of water hyacinth cover increased rapidly from 1995 to 1998 (Fig. 1). There appeared to be a decline during the first half of 1998 co-inciding with an El Niño event, but in the latter half of 1998 the water hyacinth population appeared to be again climbing rapidly. The major turning point appears to have come in early 1999, and by the start of 2000 the population had declined and has maintained a more stable level of under 1000 ha. Given that weevils were first introduced late in 1995, it took at most 4 years for control to be effective. This time-frame is consistent with observations from other countries (Center, 1994; Julien et al., 1999; Center et al., 2002). There were some manual control measures and a few mechanical harvesters, but there were no large-scale herbicide spraying programs on Lake Victoria. Therefore, classical biological control represents the only control method that was implemented across the whole of the lake and the most likely hypothesis to explain the dramatic reduction in water hyacinth populations. While biological control of water hyacinth by *Neochetina* spp. has been less effective in some sub-tropical regions (Hill and Olckers, 2000), the weevils have led to clear reductions in plant density in West Africa (Ajuonu et al., 2003); Papua New Guinea (Julien and Orapa, 1999); and in warmer areas of South Africa (Hill and Olckers, 2000). In each case, biological control agents were the only control measure in place.

Neochetina larvae tunnel the petioles and the root-stock, thereby allowing bacteria and secondary fungi to enter the plant and cause severe damage. Direct destruction of aerenchymous tissue and the flooding of old larval tunnels will reduce plant buoyancy. Consequently, one of the characteristics of control by *Neochetina* weevils is that water hyacinth mats become water-logged and sit lower in the water. As plant destruction increases the mats sink to the bottom of the water-body.

By increasing wind and wave action, the El Niño event may have been a major stress to plants. If plants are already badly damaged due to insect feeding and secondary damage, it is clear that wave action has a much greater impact by breaking up mats and submerging damaged plants.

It is expected that increased surface currents and wave action reinforced by El Niño, would also move mats around the lake leading to some contradictory conclusions and explaining local reports of resurgences. Indeed, Albright et al. (2004) suggest this may explain the reduction in water hyacinth on the Tanzanian side in 1998 and the increase in the relatively sheltered Winam Gulf, which would have received plants blown in by the prevailing winds.

Reports of a “resurgence [that] may be re-starting” date back to 2000, and they understandably generated concerns. However, studies showed that the young healthy rapidly growing plants that had appeared were the result of the germination of seeds which had been deposited in the sediment. Their germination had been stimulated by the collapse of large mats, allowing easier light penetration of the water. Seedling growth may have been enhanced by high levels of nitrates and phosphates in the water due to runoff from agriculture and urban deposition that was no longer taken up by the large water hyacinth mats, and also to the release of nutrients from those mats decaying on the bottom of the lake. In contrast, the weevil populations in the area were very low, presumably because eggs, larvae, and pupae sank with the mats and drowned, while adults would have dispersed as the plant quality of the old mat declined. Therefore, the new growth was able to proliferate in the absence of weevils. The weevils, in due course, dispersed naturally back onto these fringes of plants in the western arm of the lake. A survey conducted in October 2000, recorded an average of three adult weevils per plant at one site, indicating that the weevils were already invading the new growth (Ogwang, 2001).

Williams et al. (2005) state that “weevil populations although present are likely unstable” and suggest that this may lead to a resurgence in water hyacinth populations within Lake Victoria. This statement is unsubstantiated. One of the basic tenets of classical biological control of weeds is that it is sustainable through population regulation (DeBach, 1964). Whilst insect populations change in response to variations in the densities of the host plant and environmental conditions, this does not mean that control fails to be exerted. Given the reduction in buoyancy caused by weevil feeding and the strong wave action of the lake, a large mat cannot develop in future unless the herbivore pressure is removed.

The dynamic nature of water hyacinth on large water-bodies means that plants may temporarily escape this herbivore pressure. Variations in nutrient quality around the lake will lead to variation in dynamics, and these effects have been seen in other systems. However, as agents become established throughout the head-waters, both the quantity of material coming into the lake should be reduced (this was estimated at around 0.75 ha day⁻¹ during 1999 (Moorhouse et al., 2000)); and any material coming into the lake is likely to be infested by weevils. Only thanks to a lake wide standardised survey of the type presented in Albright et al. (2004), has the pattern become apparent, and it is clear from continuing observations that the massive infestations of the 1990s have not returned.

Lake Victoria is the largest single water body for water hyacinth biological control. There is no *a priori* reason to suppose that Lake Victoria will be an inherently unstable system, as substantial sustained control within 3–5 years has been a feature of water hyacinth control in the tropics even on large water-bodies (Julien et al., 1999) (e.g. 3 years after releasing weevils an infestation of 500 ha on the 2500 ha Sanalona Dam in Mexico was reduced to 150 ha (Aguilar et al., 2003)). However, where plant and insect dynamics are disrupted by frost or foliar herbicides, weevil populations

are slow to respond (Wilson et al., 2006), partly because the development of weevils takes at least 70 days. More work is required to establish whether nutrient inputs to the lake could result in a scenario where control in eutrophied bays is no longer satisfactory (either in terms of stability or average level). Continued monitoring of water hyacinth and water hyacinth weevil populations is therefore recommended.

It seems highly unlikely that cloudy weather associated with the El Niño event of 1997–1998 can explain the massive reduction in water hyacinth of 1999–2000. As with many tropical locations, the cloud cover in West Africa and Papua New Guinea is often thick and persistent, but this did not prevent either water hyacinth from becoming a problem or the water hyacinth weevils from causing extensive damage to plants (Julien and Orapa, 1999; Ajuonu et al., 2003). The data presented by Williams et al. (2005) do not provide a substantive link between low light levels on Lake Victoria and plant mortality. The weekly midday PAR on Lake Victoria varied 1800–4400 $\mu\text{E m}^{-2} \text{s}^{-1}$ between 1996 and 2001 (Fig. 4 in Williams et al., 2005), light levels that would allow significant plant growth (depending largely on plant size and less on light levels, growth rates based on the proposed relationship would range 0.03–0.10 g g⁻¹ day⁻¹). However, the effect of changes in field light levels on water hyacinth population dynamics remains an active research question. Plants certainly survive and prosper in very shady back-waters that never receive direct sun-light, but clearly plants will also die if light is low enough for long enough (Brochier et al., 1985). We suggest that measurements of photosynthetic efficiencies should be made *in situ*, e.g. by using various shade treatments on water hyacinth mats. Plants grown in small containers (e.g. Fig. 1 in Williams et al., 2005) suffer from an “island” or “clothes-line” effect, where transpiration is much higher than normal (Allen et al., 1997). Plant size and nutrient status must also be considered as there is a strong robust linear correlation between growth rate and biomass density and between growth rate and nutrient conditions (Wilson et al., 2005).

The effect of El Niño has confused the issue of water hyacinth control in Lake Victoria. Because of the mobility of mats and changing currents caused by El Niño, the quantity of water hyacinth at any one location was quite variable. However, the lake-wide picture is much clearer. While we agree wholeheartedly with Williams et al. (2005) in stressing the need to reduce nutrient inputs to tropical lakes there is little doubt that the devastating problems caused by water hyacinth would not have been alleviated without biological control agents. Given the rate at which the benefits from successful biological control programs scale with the size of the problem (DeGroot et al., 2003; McConnachie et al., 2003), the continuing economic value of the classical biological control intervention on Lake Victoria is considerable.

References

- Aguilar, J.A., Camarena, O.M., Center, T.D., Bojorquez, G., 2003. Biological control of waterhyacinth in Sinaloa, Mexico with the weevils *Neochetina eichhorniae* and *N. bruchi*. *Biocontrol* 48, 595–608.

- Ajuonu, O., Schade, V., Veltman, B., Sedjro, K., Neuenschwander, P., 2003. Impact of the weevils *Neochetina eichhorniae* and *N. bruchi* (Coleoptera: Curculionidae) on water hyacinth, *Eichhornia crassipes* (Pontederiaceae) in Benin, West Africa. *Afr. Entomol.* 11, 153–162.
- Albright, T.P., Moorhouse, T.G., McNabb, J., 2004. The rise and fall of water hyacinth in Lake Victoria and the Kagera River Basin, 1989–2001. *J. Aquat. Plant Manag.* 42, 73–84.
- Allen, L.H., Sinclair, T.R., Bennett, J.M., 1997. Evapotranspiration of vegetation of Florida: perpetuated misconceptions versus mechanistic processes. In: *Proceedings of the Soil and Crop Science Society of Florida*, vol. 56. pp. 1–10.
- Brochier, J., Landon, B., Noyer, J.L., 1985. Culture de plantes aquatiques en milieu contrôlé pour la production de protéines—évaluation de la productivité de la jacinthe d'eau (*Eichhornia crassipes*). *C. R. Acad. Agric. Fr.* 71, 467–479.
- Center, T.D., 1994. Biological control of weeds: waterhyacinth and water-lettuce. In: Rosen, D., Bennett, F.D., Capinera, J.L. (Eds.), *Pest Management in the Subtropics: Biological Control—a Florida Perspective*. Intercept Publishing Company, Andover, UK, (Chapter 23), pp. 481–521.
- Center, T.D., Hill, M.P., Cordo, H., Julien, M.H., 2002. Waterhyacinth. In: Van Driesche, R.G., Blossey, B., Hoddle, M. (Eds.), *Biological Control of Invasive Plants in the Eastern United States. FHTET-2002–04*. US Forest Service, Morgantown, WV, pp. 41–64.
- DeBach, P., 1964. *Biological Control of Insect Pests and Weeds*. Reinhold, New York.
- DeGroot, H., Ajuonu, O., Attignon, S., Djessou, R., Neuenschwander, P., 2003. Economic impact of biological control of water hyacinth in Southern Benin. *Ecol. Econ.* 45, 105–117.
- Hill, M.P., Olckers, T., 2000. Biological control initiatives against water hyacinth in South Africa: constraining factors, success and new courses of action. In: Julien, M.H., Center, T.D., Hill, M.P. (Eds.), *Second IOBC Global Working Group on the Biological and Integrated Control of Water Hyacinth*, ACIAR, Beijing, China, pp. 33–38.
- Julien, M.H., Griffiths, M.W., Wright, A.D., 1999. Biological control of water hyacinth. In: *The Weevils Neochetina bruchi and N. eichhorniae: Biologies, Host Ranges, and Rearing Releasing and Monitoring Techniques for Biological Control of Eichhornia crassipes*, Australian Centre for International Agricultural Research (ACIAR), Canberra.
- Julien, M.H., Orapa, W., 1999. Successful biological control of water hyacinth (*Eichhornia crassipes*) in Papua New Guinea by the weevils *Neochetina bruchi* and *Neochetina eichhorniae* (Coleoptera: Curculionidae). In: Spencer, N.R. (Ed.), *Proceedings of the X International Symposium on Biological Control of Weeds*, Montana State University, Bozeman, MT, USA, p. 1027.
- McConnachie, A.J., de Wit, M.P., Hill, M.P., Byrne, M.J., 2003. Economic evaluation of the successful biological control of *Azolla filiculoides* in South Africa. *Biol. Control* 28, 25–32.
- Moorhouse, T.G., Agaba, P., McNabb, J., 2000. Recent efforts in biological control of water hyacinth in the Kagera River headwaters of Rwanda. In: Julien, M.H., Center, T.D., Hill, M.P. (Eds.), *Second IOBC Global Working Group on the Biological and Integrated Control of Water Hyacinth*, ACIAR, Beijing, China, p. 152.
- Ogwang, J., 2001. Is there resurgence on Lake Victoria? *Water Hyacinth News* 4, 1–2.
- Ogwang, J.A., Molo, R., 2004. Threat of water hyacinth resurgence after a successful biological control program. *Biocontrol Sci. Technol.* 14, 623–626.
- Seehausen, O., Witte, F., Katunzi, E.F., Smits, J., Bouton, N., 1997. Patterns of the remnant cichlid fauna in southern Lake Victoria. *Conserv. Biol.* 11, 890–904.
- Twongo, T., 1991. Status of the water hyacinth in Uganda. In: Greathead, A., deGroot, P.J. (Eds.), *Control of Africa's Floating Water Weeds*. CAB International, Zimbabwe, pp. 55–57.
- Williams, A.E., Duthie, H.C., Hecky, R.E., 2005. Water hyacinth in Lake Victoria: why did it vanish so quickly and will it return? *Aquat. Bot.* 81, 300–314.
- Wilson, J.R., Holst, N., Rees, M., 2005. Determinants and patterns of population growth in water hyacinth. *Aquat. Bot.* 81, 51–67.
- Wilson, J.R.U., Rees, M., Ajuonu, O., 2006. Population regulation of a classical biological control agent in its introduced range Larval density dependence in *Neochetina eichhorniae*, a biological control agent of water hyacinth *Eichhornia crassipes*. *Bull. Entomol. Res.* 96, 145–152.