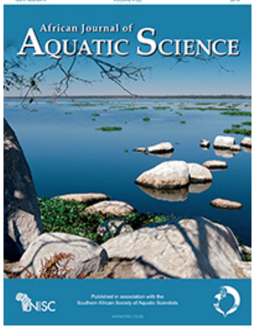

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African Journal of Aquatic Science

ISSN: 1608-5914 (Print) 1727-9364 (Online) Journal homepage: http://www.tandfonline.com/loi/taas20

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African Journal of Aquatic Science 2016, 41(2): 227–234
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AFRICAN JOURNAL OF AQUATIC SCIENCE
ISSN 1608-5914 EISSN 1727-9364
http://dx.doi.org/10.2989/16085914.2016.1151765

Economic evaluation of water loss saving due to the biological control of water hyacinth at New Year's Dam, Eastern Cape province, South Africa

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Water hyacinth *Eichhornia crassipes* is considered the most damaging aquatic weed in the world. However, few studies have quantified the impact of this weed economically and ecologically, and even fewer studies have quantified the benefits of its control. This paper focuses on water loss saving as the benefit derived from biological control of this plant between 1990 and 2013 at New Year's Dam, Alicedale, Eastern Cape, South Africa. Estimates of water loss due to evapotranspiration from water hyacinth vary significantly; therefore, the study used three different rates, high, medium and low. A conservative raw agriculture value of R 0.26 per m^3 was used to calculate the benefits derived by the water saved. The present benefit and cost values were determined using 10% and 5% discount rates. The benefit/cost ratio at the low evapotranspiration rate was less than one, implying that biological control was not economically viable but, at the higher evapotranspiration rates, the return justified the costs of biological control. However, at the marginal value product of water, the inclusion of the costs of damage to infrastructure, or the adverse effects of water hyacinth on biodiversity, would justify the use of biological control, even at the low transpiration rate.

Keywords: benefit/cost ratio, discount rate, evapotranspiration rate

Introduction

Studies have shown that alien invasive plants are a global phenomenon. These species are known to have serious environmental implications as they pose a threat to the world's ecosystems by displacing native plants (van Wilgen et al. 2004; Vilà et al. 2011) and have been recognised globally as the second largest threat to biodiversity (Richardson and van Wilgen 2004). To add to the environmental threats, they also bring about negative economic impacts. They are a source of immense cost to the global economy, with global annual losses estimated at around US$1.4 trillion (Pimentel et al. 2001).

In South Africa alone, up to ten million hectares of land are invaded by 180 different alien species (van Wilgen et al. 2001). These plants not only have adverse environmental impacts, but also threaten the economic productivity of the country (Richardson and van Wilgen 2004). More importantly, South Africa is a water-scarce country and these plants affect both the quality and quantity of available water (McConnachie et al. 2012). Undoubtedly, there is substantial concern, since a reduction in water quantity and quality will not only have major negative environmental and social impacts, but also economic implications in view of the fact that water is regarded as an important 'economic good' (Rogers et al. 2002). While water loss due to terrestrial invasive alien species has been well-studied (Versfeld et al. 1998), the impact of aquatic weeds has largely been ignored. Water hyacinth *Eichhornia crassipes* is South Africa's worst aquatic weed (Coetzee et al. 2011). While its impacts on water resource utilisation (Hill 2003) and biodiversity (Midgley et al. 2006; Coetzee et al. 2014) have been quantified, its impact on water loss through extensive transpiration created by its dense mats has not been studied in South Africa, although, elsewhere in the world, estimates of its transpiration vary between 1.02 and 12 times greater than evaporation from open water surfaces (Timmer and Weldon 1967; Singh and Gill 1996; see Table 1). Consequently, the management of water hyacinth in South Africa is vital given its impact on water loss.

The argument for the recent studies around the economic impacts of alien invasive plants in South Africa is in order to validate the continued funding for clearing, controlling and researching these plants (Turpie 2004). Turpie (2004) has reported that only a few studies have reported on aquatic alien plants such as water hyacinth, and that most studies have focused on terrestrial or riparian invaders. This is a cause for concern since aquatic alien plants are equally damaging to the environment and economy as terrestrial and riparian alien invaders.

Biological control is one of the tools available for controlling and reducing the impacts of water hyacinth (van Wyk and van Wilgen 2002). Crucially, the economic evaluation of biological control programmes allow for the efficient allocation of scarce resources between competing control and management programmes (McConnachie et al. 2003).

The most widely used economic approach to determine the feasibility of biological control programmes is the benefit-cost analysis (van Wilgen et al. 2004). Benefit-cost studies involve quantifying the effects of biological control measures by comparing the benefits with the costs of the programmes (De Groot et al. 2003). The purpose of assessing the costs and benefits of the programme during a certain period is to illustrate the feasibility of the proposed project (Wander et al. 2004). Such analyses include the full financial costs accumulated to control the alien invasive species. It takes into account costs associated with research and technologies of the programme, such as the salaries of researchers according to their time dedicated to the research, costs associated with the use of vehicles, administrative expenses, and complementary services costs, such as libraries and technological transfers. These costs are borne upfront and vary among projects (Turpie 2004).

Once the costs have been calculated, the benefits of the programme need to be determined. These involve the quantification of the benefits associated with preventing invasion – which involve economic losses that would be incurred should an area be invaded (van Wilgen et al. 2004). Historically, studies have focused on the benefits obtained from preventing water quality and quantity reduction in South Africa (Turpie 2004). Research has shown that as much as 70 percent of benefits obtained relate to water, thereby emphasising how biological control programmes of invasive species greatly contribute towards water conservation (van Wilgen et al. 2004).

This economic approach involves calculating the benefit/cost ratio. The benefit/cost ratio compares the present value of benefits versus that of costs (Wander et al. 2004). Biological control programmes of alien invasive plants often show high benefit/cost ratios, and therefore significant returns on investments (van Wilgen et al. 2004). De Groot et al. (2003) illustrated this by obtaining a high benefit/cost ratio of 124:1 for the control of water hyacinth in Benin. McConnachie et al. (2003) emphasised such economic benefits when they highlighted that the biological control of red water fern *Azolla filiculoides* in South Africa yielded a high return on investment of 25:1. The aim of the present study was to quantify the benefit/cost ratio of water saving due to the biological control of water hyacinth on New Year's Dam, Alicedale, South Africa.

Table 1: Ratios of water hyacinth evapotranspiration to open water evaporation (ET/E) from available literature

Ratio (ET/E)	Source
3.1	Otis (1914)
3.2	Penfound and Earl (1948)
3.7	Timmer and Weldon (1967)
5.3	Rogers and Davis (1972)
2.6	Dunigan (1973)
1.4–1.8	van der Weert and Kamerling (1974)
1.7	DeBusk et al. (1983)
1.8	Snyder and Boyd (1987)
0.9–12	Anderson and Idso (1987)
1.4	Rao (1988)

Materials and methods

New Year's Dam is an 80.8 ha impoundment near Alicedale in the Eastern Cape province, South Africa. This dam predominantly supplies water to the local population for domestic use, and water for irrigation of a golf course (Doudenski 2004). Water hyacinth was first recorded on the dam in 1988, and by 1990 the dam was 80% covered (Hill 2003). The weevil *Neochetina eichhorniae* was introduced onto water hyacinth on the dam in 1990, and by 1994 the weed infestation had reduced to 20% cover (Hill 2003).

Alicedale is a small town with a population size estimated to be approximately 7 000 people (Urban-Econ 2012). In the past, the town served as an important national railway junction that was the main source of economic activity and employment in the area. However, in 1996 the railway station closed (Urban-Econ 2012). Currently, the main source of economic activity in Alicedale is within the retail sector such as a supermarket, liquor store and bakery, as well as the Bushman Sands Country Estate and Golf Club – which is the main user of irrigation water from New Year's Dam. In addition, visual evidence suggests that the dam had previously been used for the irrigation of small-scale crop farming, which was located 100 m from the dam's edge. However, such farmland has since been abandoned.

The benefit-cost economic approach was utilised in this study, which involved determining the benefits and costs of biological control efforts in order to calculate the benefit/cost ratio. Data highlighting the costs of the 23-year biological control programme were collected (Appendix 1). The start-up costs of the programme, as well as the costs associated with monitoring of the programme from 1990 to 2001, were obtained from the van Wyk and van Wilgen (2002) study. The monitoring costs associated with the programme from 2002 to 2012 were collected from a long-term dataset housed at Rhodes University's Department of Zoology and Entomology.

The producer price index (PPI), with 2012 as its benchmark year, was used to adjust all cost values for inflation. The 2012 PPI time-series was obtained from Statistics South Africa. All cost and benefit monetary values were expressed in 2012 South African rands (ZAR), so as to make the values comparable over the study period.

The quantification of the benefits associated with preventing invasion required data collection on the open surface evaporation rate of New Year's Dam (Schulze 1997). This figure is important in determining the per hectare (ha) evaporation and evapotranspiration rates. It also involved data on the quantity of water hyacinth since an increase in the surface area of the plant increases the water loss from increased transpiration.

The mean annual pan evaporation rate at New Year's Dam, as well as the monthly variation of this rate, was obtained from the a Water Research Commission Report (Midgley et al. 1994). Data on the monthly percentage distribution of this annual value was collected. The water loss per hectare of water hyacinth on New Year's Dam was calculated by multiplying the annual mean pan evaporation rate per hectare by the evapotranspiration factor of the plant. Whilst there is no consensus of the evapotranspiration rate for water hyacinth relative to an open pan of water, Allen et al. (1997) have been critical of the magnitude of the estimates of evapotranspiration rates, which they considered too large (Table 1). They apportion this to the fact that the measurements were conducted in relatively small tanks, and thus that extrapolation to field conditions was unrealistic. Therefore, for the purposes of this study, low (1.5), medium (3.5) and high (7.5) evapotranspiration rates were chosen. The water loss per hectare of water hyacinth was used to determine the amount of water loss, given the percentage of the dam covered by this plant. Furthermore, data were collected on the percentage cover of the dam by water hyacinth and the percentage of open surface for each year from 1990 to 2012. These values were obtained from the van Wyk and van Wilgen (2002) study of water hyacinth on New Year's Dam, and from monitoring of the coverage by the Department of Zoology and Entomology at Rhodes University. The evapotranspiration and evaporation rate were calculated for each year, these values were then added together to determine the total annual evaporation rate of the dam.

The net benefit was then calculated, which underlined the improvement in the total evaporation rate in terms of the amount of water saved due to the biological control of water hyacinth. The net benefit is thus determined as the difference of the total evaporation rate between one year and the next. The net benefit value was calculated by multiplying each annual net benefit by the price per m^3 of water for irrigation, where a conservative raw agriculture value of R 0.26 m^{-3} was used (Nieuwoudt et al. 2004). The price of the water was converted into 2012 rands.

Lastly, the net present benefit and cost values were determined by discounting each project year by using a 10% and 5% discount rate back to the year 2012. Once these values were determined, the benefit/cost ratio for each discount rate was calculated by dividing the net present benefit value by the net present cost value (Wander et al. 2004). Discounting is a method of reducing a stream of benefits and cost to their present worth to derive a meaningful benefit/cost ratio. The determination of discount rates is a difficult task, as the time horizon differs depending on the type of project. Private projects have a shorter time horizon and therefore have higher discount rates, whereas public projects have longer horizons and therefore can accept lower discount rates (Gittinger 1982). The choice of discount rate for private and public projects is linked to the risk profiles of the two entities. To accommodate both scenarios, two discount rates were chosen, viz. 5% and 10%.

Results

The start-up costs for the biological control programme were relatively high at R 48 088 in 1990 in 2012 rands (Appendix 1). However, the subsequent costs decreased significantly over time. Once the biological control agents were established, the only costs of the programme were those associated with monitoring, which took into account labour as well as travel costs, and occurred roughly once per year. Thus, the total cost of the control programme over the 23-year period was an estimated R 402 385.

The mean annual evaporation rate for New Year's Dam is 1 550 mm (Doudenski 2004). However, the evaporation rate of the dam varied monthly from 0.81 to 0.87 of that value, with the percent distribution of the mean annual value varying from 3.3% to 14.21% monthly (Appendix 2) (Midgley et al. 1994). Although the evapotranspiration factor is expected to vary during the year (Schulze 1997), the factors used in the study were an average over a calendar year. Consequently, the annual water loss from New Year's Dam per hectare covered by water hyacinth at the different evapotranspiration rates is shown in Table 2.

Table 2: Annual water loss (m^3) per hectare by *Eichhornia crassipes* on New Year's Dam at low, medium and high evapotranspiration rates

Evapotranspiration rate	Water loss (m^3) per hectare
Low	19 579.41
Medium	45 728.52
High	97 989.68

In 1990, it was reported that water hyacinth covered 80% of the dam (64.64 ha) (Appendix 3) (Hill 2003). During this year, over 200 adult *Neochetina eichhorniae* were released (van Wyk and van Wilgen 2002). The bio-control agents successfully reduced the weed mat cover to an estimated 20% of the dam's surface by 1995 and 1996 (Hill 2003). In 1996 *Neochetina bruchi*, *Orthogalumna terebrantis*, *Niphograpta albiguttallis* and *Eccritotarsus catarinensis* were released and, except for *Neochetina bruchi*, failed to establish at the study site (van Wyk and van Wilgen 2002). The water hyacinth spread rapidly during 1997 and 1998, covering 80% of the dam's water surface by 1998 (Appendix 3). Van Wyk and van Wilgen (2002) attributed this recovery to higher than normal rainfall, which raised the nutrient level of the dam. Fortunately, *Neochetina eichhorniae* (without further releases) multiplied in number and managed to reduce the plant cover and to maintain it at a low 5% of the dam's water surface from 2002 to 2012, which has been recognised as an acceptable level where the ecological integrity of the area can be maintained (Hill and Olckers 2001). It is estimated that, without bio-control, and thus 80% plant cover of the dam's surface, the total annual evaporation rate of the dam would vary between 1 477 946 m^3 and 6 545 188 m^3, depending on the evapotranspiration factor (Appendix 3). However, this rate significantly decreased with biological control with 5% plant cover of the dam's surface, with the total evaporation rate estimated to be between 1 082 067 m^3 and 1 398 770 m^3 for the low and high evapotranspiration rates, respectively.

The total value of the net benefits over the study period, with the price of water being a low R0.26 m^{-3} (converted to 2012 rands), was estimated to be between R282 458 and R3 671 954. The net present benefit values and net present costs using 10% and 5% discount rates are shown in Table 3.

The benefit/cost ratios at the two discount factors are shown in Table 4.

Discussion

The results indicate that the biological control programme substantially reduced the total annual evaporation rate

Table 3: Present values (PV) of benefits and costs, by evapotranspiration rates and discount factors (rands), on New Year's Dam

Discount factor	Low evapotranspiration rate	Medium evapotranspiration rate	High evapotranspiration rate
10%			
PV costs	121 314.90	121 314.90	121 314.90
PV benefits	63 115.01	315 574.84	820 494.50
5%			
PV costs	208 797.38	208 797.38	208 797.38
PV benefits	128 138.07	640 689.97	1 665 793.76

Table 4: Benefit/cost ratios for the biological control of water hyacinth on New Year's Dam by discount rates

Discount factor	Low evapotranspiration rate	Medium evapotranspiration rate	High evapotranspiration rate
10%	0.52	2.60	6.76
5%	0.61	3.07	7.98

of the dam, depending on the inferred evapotranspiration rate of water hyacinth. The benefit/cost ratios at 10% and 5% discount rates, varied from <1 to almost 8 for the low and high evapotranspiration rates, respectively. This suggests that, for every R 1 spent on this programme, and assuming an evapotranspiration rate of 1.5 times that of an open pan of water, the present value of the benefits would not cover the present value of the costs. At evapotranspiration rates of 3.5 and 7.5 times that of an open pan of water, respectively, the benefit/cost ratios show that the biological control of water hyacinth is economically viable at both the 10% and 5% discount factors. However, this study used a conservative raw agriculture water value of R 0.26 m^{-3} and not the marginal value product of water, which would have been higher, thus resulting in the benefit/cost ratio being larger than that calculated. At the low evapotranspiration rate, the benefit/cost ratio is sensitive to changes in the price of water. An increase of R 0.24 m^{-3} and R 0.145 m^{-3} at the 10% and 5% discount rates, respectively, would make the implementation of biological control economically viable at the low evapotranspiration rate. Furthermore, only a small proportion of the water supply from the dam is used for irrigation, whereas a substantial amount of the water supplied from the dam is for domestic use. Therefore, if the domestic price of treated water were used to determine the value of water saved over the study period, the benefit/cost ratio would be significantly larger.

More importantly, this study only assessed the benefits of a biological control programme in terms of the amount of water saved by preventing water loss from excessive evapotranspiration caused by water hyacinth on New Year's Dam. It did not take into account the prevention of the costs associated with the damage to infrastructure – such as water pipes and pumps – nor did it take into account the adverse effect of water hyacinth on biodiversity. Midgley et al. (2006) found greater diversity of invertebrate communities in open water (zones free of water hyacinth) than under water hyacinth on New Year's Dam. The study emphasised both the negative ecological and economic impacts associated with loss of biodiversity. Therefore, taking into account the prevention of biodiversity loss and the prevention of the costs associated with the damage inflicted on important infrastructure, as well as the hindrance of water utilisation caused by this species, the benefit/cost ratio would increase significantly, further justifying the expenses associated with the control programme.

The benefit/cost ratios that consider the costs of the programme and the loss of water from evapotranspiration due to water hyacinth highlight significant social and economic benefits for the local community of Alicedale. Despite these ratios being high, they remain the smallest return on investment obtained from the project, as this study did not include other benefits from the scheme such as those previously discussed. The inclusion of factors such as biodiversity loss and potential damage to economic infrastructure would increase the benefit/cost ratio and highlight even greater social and economic benefits received by the local community. An additional factor that would influence the benefit/cost ratio is the monitoring costs. They are necessary for assessing the effectiveness of the programme, but do not play an active role in determining the impact of the biological control on the reduction of water hyacinth. Therefore, if the only cost of the programme was the establishment of the weevils on the plants, the benefit/cost ratio would be significantly larger.

Although the biological control programme is evidently cost-effective and successful, the main drawback is that biological control is often slow (especially at first), and generally does not completely eradicate the plant, as has been the case at New Year's Dam. Therefore, low levels of infestation and occasional outbreaks of the species will be present under biological control (van Wyk and van Wilgen 2002).

Conclusion

South Africa is facing a serious water supply crisis, attributed to unreliable, inadequate rainfall, and an increasing demand by certain sectors of the economy, including agriculture, industry and households. This study highlights and supports emerging empirical evidence on the threat that alien invasive species, specifically water hyacinth, pose on water security for many communities. One such example is the local community of Alicedale, which is dependent on the water supply from New Year's Dam for domestic use and sanitation.

This study illustrates that the biological control of water hyacinth at New Year's Dam is cost-effective as it has a low-cost impact, since it does not require high and long-term maintenance. Moreover, the cost effectiveness of the programme is highlighted by the benefit/cost ratios that were obtained by just taking into account the benefits associated with the prevention of water loss through the eradication of water hyacinth because of the biological control programme. In addition, such ratios are expected to be even greater if other benefits, such as the prevention of biodiversity loss, were taken into consideration, as well as if the marginal value product of water for irrigation and the domestic value of water were used. Thus, the biological control programme at New Year's Dam is economically viable.

The economic evaluation of the biological control of water hyacinth is undoubtedly an invaluable task. Ideally, it will enable the necessary leveraging of funds and optimal allocation of financial resources to similar biological control programmes, which may otherwise have struggled to obtain funding.

Acknowledgements — Some funding for this work was provided by the South African Research Chairs Initiative of the Department of Science and Technology and the National Research Foundation of South Africa. Any opinion, finding, conclusion or recommendation expressed in this material is that of the authors and the NRF does not accept any liability in this regard. Additional funding was provided by the Department of Environmental Affairs: Natural Resources Management Programme: Working for Water Programme.

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Manuscript received 16 September 2015, revised 15 December 2015, accepted 12 January 2016
Associate Editor: C Howard-Williams

Appendix 1: Annual costs in 2012 rands of biological control of water hyacinth at New Year's Dam

Year	Total cost (rands)	Action
1990	48 087.86	Weevils released
1991	23 634.53	Monitoring
1992	33 638.95	Monitoring
1993	0.00	None
1994	18 320.97	Monitoring
1995	69 022.81	Monitoring
1996	9 286.10	Monitoring
1997	14 798.19	Monitoring
1998	18 483.53	Monitoring
1999	26 580.85	Monitoring
2000	25 241.09	Monitoring
2001	(Not available)	Monitoring
2002	21 152.10	Monitoring
2003	6 566.94	Monitoring
2004	23 071.66	Monitoring
2005	12 722.40	Monitoring
2006	12 147.59	Monitoring
2007	11 344.59	Monitoring
2008	10 171.50	Monitoring
2009	9 534.28	Monitoring
2010	2 255.10	Monitoring
2011	4 290.50	Monitoring
2012	2 033.74	Monitoring
Total	402 385.27	

Appendix 2: Annual and monthly evaporation at New Year's Dam without water hyacinth

Month	Pan factors – open water evaporation rate	% distribution of annual value	Evaporation (m^3)
October	0.81	0.0931	94 444.7
November	0.82	0.1156	118 717.5
December	0.83	0.1389	144 385.4
January	0.84	0.1421	149 491.5
February	0.88	0.1162	128 065.4
March	0.88	0.1018	112 195.0
April	0.88	0.0677	74 613.0
May	0.87	0.0451	49 140.4
June	0.85	0.0330	35 129.8
July	0.83	0.0350	36 382.2
August	0.81	0.0468	47 476.0
September	0.81	0.0647	65 634.5
Total		1.0000	1 055 675.5
Per ha			13 065.3

Appendix 3: Area covered by water hyacinth per year on New Year's Dam (80.8 ha), and annual total evaporation by evapotranspiration rate

Year	% plant cover	Plant cover area (ha)	Open water surface area (ha)	Low total evaporation rate (m^3)	Medium total evaporation rate (m^3)	High total evaporation rate (m^3)
1990	80	64.64	16.16	1 477 946	3 167 027	6 545 188
1991	70	56.56	24.24	1 425 162	2 903 108	5 858 999
1992	70	56.56	24.24	1 425 162	2 903 108	5 858 999
1993	50	40.40	40.40	1 319 594	2 375 270	4 486 621
1994	35	28.28	52.52	1 240 419	1 979 392	3 457 337
1995	20	16.16	64.64	1 161 243	1 583 513	2 428 054
1996	20	16.16	64.64	1 161 243	1 583 513	2 428 054
1997	70	56.56	24.24	1 425 162	2 903 108	5 858 999
1998	80	64.64	16.16	1 477 945	3 167 027	6 545 188
1999	40	32.32	48.48	1 266 811	2 111 351	3 800 432
2000	20	16.16	64.64	1 161 243	1 583 513	2 428 054
2001	10	8.08	72.72	1 108 459	1 319 594	1 741 865
2002	5	4.04	76.76	1 082 067	1 187 635	1 398 770
2003	5	4.04	76.76	1 082 067	1 187 635	1 398 770
2004	5	4.04	76.76	1 082 067	1 187 635	1 398 770
2005	5	4.04	76.76	1 082 067	1 187 635	1 398 770
2006	5	4.04	76.76	1 082 067	1 187 635	1 398 770
2007	5	4.04	76.76	1 082 067	1 187 635	1 398 770
2008	5	4.04	76.76	1 082 067	1 187 635	1 398 770
2009	5	4.04	76.76	1 082 067	1 187 635	1 398 770
2010	5	4.04	76.76	1 082 067	1 187 635	1 398 770
2011	5	4.04	76.76	1 082 067	1 187 635	1 398 770
2012	5	4.04	76.76	1 082 067	1 187 635	1 398 770