Biological Control 194 (2024) 105544

Contents lists available at ScienceDirect

Biological Control

journal homepage: www.elsevier.com/locate/ybcon

Bridging boundaries: Six years of community engagement with biological control implementation and monitoring of water hyacinth on Hartbeespoort Dam, South Africa

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HIGHLIGHTS

- Bridging the research-implementation gap requires engagement with affected communities.
- Implementing biological control in a system with a history of chemical and mechanical control can be challenging.
- Augmentative biological control was implemented on a nutrient-enriched impoundment by fostering a community of practice.
- Nearly half a million biological control agents were released between 2018 and 2023 through the collective efforts of professional and private stakeholders.
- Bridging the boundaries between the research and public sector has strengthened biological control efforts, enabling successful and sustainable management of water hyacinth on Hartbeespoort Dam.

ARTICLE INFO

Keywords:
Augmentative biological control
Post-release monitoring
Mass-rearing
Community of practice
Pontederiaceae

ABSTRACT

Water hyacinth has been present on Hartbeespoort Dam since the 1960s. Historical weed management consisted of herbicide and mechanical/manual removal. However, due to funding constraints, biological control was implemented as a cost-effective and environmentally friendly alternative. The impoundment receives excessive phosphorus and nitrogen due to its location downstream from densely populated cities, which includes one of the capital cities of South Africa, Pretoria. Considering that Hartbeespoort Dam is in a temperate region, with cool winters, we embarked on an augmentative biological control approach. To increase our biological control efforts, we had to bridge the research-implementation gap. We fostered a community of practice, by creating a space for the affected community to actively participate in the programme. This would give us the opportunity to share scientific knowledge to affected stakeholders, gauge the public perception, and align potential goals. Social media, in-person meetings and training sessions were used to engage with the public. To increase the availability of the water hyacinth biological control agent, *Megamelus scutellaris*, community members (i.e. private stakeholders) were offered the opportunity to manage satellite rearing stations. Between 2018 and 2023, nearly half a million *Megamelus scutellaris* individuals, sourced from both the Centre for Biological Control's mass-rearing facility and satellite rearing stations around Hartbeespoort Dam, have been released into the dam. Water hyacinth cover on the dam drastically declined every year following a build-up of *Megamelus scutellaris*. Over the course of the programme, private stakeholders that were actively involved grew from two (2018) to 16 (2023). Analysing the participation of private stakeholders using a framework that looks at the level of value gained from our interactions, two partners reached a value chain phase that led to an expansion of biological control implementation. Longer-term private stakeholders generated increased interest for biological control implementation in their community, which resulted in recruitment of new private stakeholders. We also evaluated the knowledge of the affected community in 2023 through an online questionnaire. Out of 132 respondents, 51 % had knowledge of what biological control entails, with 56 % acknowledging that biological control has had a positive impact on the management of water hyacinth. Bridging the research-implementation boundary has

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https://doi.org/10.1016/j.biocontrol.2024.105544
Received 28 February 2024; Received in revised form 25 April 2024; Accepted 29 May 2024
Available online 31 May 2024

strengthened biological control efforts, enabling a more sustainable approach to the management of water hyacinth on Hartbeespoort Dam. However, continued community engagement is necessary to increase the public's knowledge about the practice of biological control.

1. Introduction

Public engagement and communication have become increasingly important in the sustainable implementation and monitoring of biological control programmes (Briese and McLaren, 1997; Morelli et al., 2021, Weaver et al., 2021). This is important because the management of natural resources involves more than science, and its success depends on public perception, knowledge transfer, bureaucracy, resources availability and competing goals (Ntshotsho et al., 2015, Foxcroft et al., 2020). Bridging these boundaries can assist in obtaining the same goal of invasive species management, cost-effectively at a potentially faster rate (Morelli et al., 2021, Shaw, 2023). The value of incorporating biological control implementation, long-term monitoring and public engagement is illustrated in the successful biological control of water hyacinth (*Pontederia* (=*Eichhornia*) *crassipes* (Mart.) Solms (Pontederiaceae)) in the Dique Los Sauces Reservoir (surface ~ 110–150 ha), Argentina. Water hyacinth has been present on the dam since the 1960 s, covering almost the entire water surface by reaching a maximum cover of 90 % (Faltlhauser et al., 2022). The biological control agent *Neochetina bruchi* Hustache (Coleoptera: Curculionidae) was released in 1974, and long-term monitoring from 1964 to 2023 showed that herbivory by *N. bruchi* was linked to a reduction in water hyacinth coverage to 0 %. Despite this success, only a small group of people knew that a management plan was in place, and even fewer people were aware that the management strategy was biological control (Faltlhauser et al., 2022). Clearly, engaging with local communities at the outset of the control programme would have highlighted the positive impact of biological control, and perhaps resulted in their buy-in for future biological control endeavours.

Traditional top-down teaching can be useful in educating the public on the invasion and management of an invasive species. However, learning can be enhanced by intentionally cultivating a community of practice through interactions with community partners (Wenger-Trayner and Wenger- Trayner, 2020). A community of practice is defined as a group of people with a shared concern that work and learn together to change the situation (Wenger, 1998). This learning partnership has various forms of interactions (e.g. social media, face-to-face meetings, training sessions) over the shared goal or objective (Wenger et al., 2011). The value created for the partners can be evaluated using the Value Creation Framework (Wenger et al., 2011, Hanley et al., 2018), which is used to assess whether value is created through communities and networks, and this indicates learning (Wenger et al., 2011).

The Value Creation Framework breaks down forms of value into five cycles (Fig. 1). The cycles do not represent a hierarchy of levels, meaning that one cycle leads to the other. This is because learning is dynamic, and values obtained during engagement will be different among stakeholders. Cycle one is reached when participants find immediate value from the engagement process e.g. useful information. Cycle two is reached when participants find value that has potential for change, and they choose to continue to participate. Cycle three is reached when participants recognize the value when applied, leading to adapted actions. Cycle four is reached when participants experience payoff for their efforts and dedication. This is the realised value of the engagement process. Cycle five is reached when transformative value is achieved. Here, participants generate interest among other stakeholders, thereby recruiting new individuals.

Biological control of water hyacinth in South Africa has largely remained outside of the public domain, with various research organisations responsible for research and implementation of this programme. It has been particularly challenging to implement biological control in highly degraded systems where the history of invasive alien plant management has been chemical or mechanical removal for many years. Hartbeespoort Dam is a case in point. This impoundment is located on the border of the Northwest and Gauteng provinces in South Africa, at the foot of the Magaliesberg mountain range and forms part of the upper Crocodile catchment (Matlala, 2023). Construction of the 1822 ha dam started nearly 100 years ago (1925) to provide irrigation and domestic water. In addition to many housing estates that have been built along its 54 km shoreline, its natural setting makes it one of South Africa's most visited tourism destinations.

The dam is located downstream from densely populated cities and receives excessive loads of phosphorus and nitrogen from improperly treated wastewater treatment effluent and agricultural runoff. A multivariate analysis of factors affecting the dam's water quality showed that nutrient loading in the dam has increased over the last 20 years (Matlala, 2023). Between 2010 and 2017, the average phosphorus (TP) and nitrogen (TN) influx into the dam was 528 tonnes per annum and 4 687 tonnes per annum, respectively. Approximately half of this nutrient load is retained in the dam (Carol and Curtis 2021), which contributes to the excessive growth of invasive macrophytes and blue-green algae such as *Microcystis aeruginosa*. Two invasive macrophytes, native to the Americas, are present on the dam. Water hyacinth has been present on Hartbeespoort Dam since the 1960 s, with cover reaching 40 % (~729 ha) in August 2017 (Coetzee et al., 2022), while Salvinia *minima* Baker (Salviniaceae) or common salvinia, was first recorded on the dam in 2011 (Coetzee et al., 2022a,b). It was only 10 years later that common

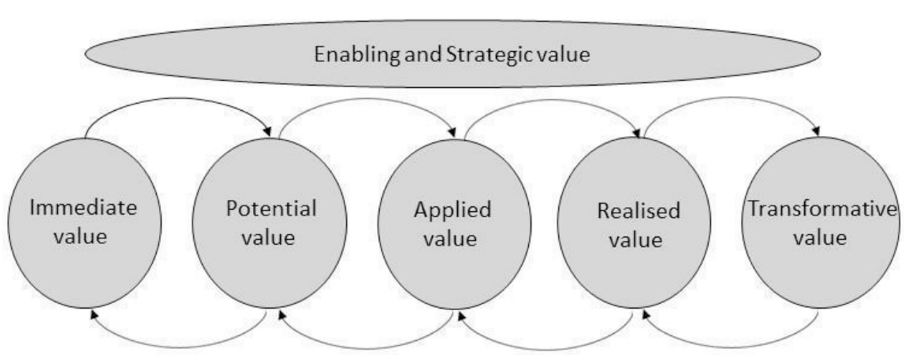

Fig. 1. The value creation cycles that describes the level of participation and signifies the learning of participants through the engagement process (Modified from Wenger-Trayner and Wenger-Trayner, 2020).

salvinia grew to conspicuous nuisance levels, covering 38 % (~692 ha) of Hartbeespoort Dam in July 2021 (Coetzee et al., 2022a,b).

1.1. Historical weed management

Between the 1990 s and 2016, a combination of management options was used to control the excessive growth of water hyacinth on the dam. Herbicide application was the main control method used between 1977 and 2001 and was successful in reducing water hyacinth. Herbicide application during this time totalled ~$226 000 (exchange rate: 18.56 ZAR) (van Wyk and van Wilgen, 2002). Classical biological control was implemented concurrently in the 1990 s with the introduction of five biological control agent species. However, insect population build-up was limited due to herbicide application which reduced habitat and food availability for the control agents. Between 2006 and 2016, the Hartbeespoort Dam Integrated Biological Remediation Programme or "Harties Metsi a Me" was implemented to improve water quality and manage water hyacinth (Mitchell and Crafford, 2016; Carroll and Curtis, 2021). The programme aimed to rehabilitate the dam by restructuring its food web through invasive fish removal, macrophyte and algal removal, sediment dredging and construction of floating wetlands. During this time, approximately 213 296 m^3 of water hyacinth and 67 947 m^3 of algae was removed. Despite these efforts, the reduction in upstream nutrient loading was insufficient, so the trophic status of the dam continued to decline due to nutrients locked within the sediment of the dam (Matlala, 2023).

At the end of the remediation programme's term in 2016, herbicide application to water hyacinth was halted due to funding constraints. Until 2017, an exclusive biological control programme had never been implemented on Hartbeespoort Dam. Chemical and manual removal produce immediate visual results, while biological control produces results over time. Thus, implementing biological control as the main water hyacinth control strategy on Hartbeespoort Dam poses some challenges, not only due to the highly enriched water and cool winter temperatures that may affect the success of the programme (Hill and Olckers, 2001), but also in gaining the trust of the community.

Biological control of water hyacinth is the longest running water weed programme in South Africa, with the first biological control agent, *Neochetina eichhorniae* Warner (Coleoptera: Curculionidae), released in 1974. To date, eight arthropod biological control agents have been released, with the most recent agent, *Megamelus scutellaris* Berg (Hemiptera: Delphacidae), released in 2015 (Coetzee et al., 2021), but despite this, water hyacinth biological control in South Africa has been variable (Winston et al., 2024). Limiting factors include the antagonistic use of herbicides, cool winters that affect biological control agent populations, enriched water that enables water hyacinth to compensate for herbivory, and the inability of agent-infested water hyacinth mats to break up and sink (Hill and Olckers, 2001). In a *meta*-analysis of the effect of water nutrient status on the herbivory of several water hyacinth biological control agents, Coetzee and Hill (2012) found that the effect of herbivory on water hyacinth was not significant in the presence of high water nutrient levels (P and N). Miller et al. (2020) proposed that augmentative releases of water hyacinth biological control agents are necessary in temperate regions to reinforce biological control agent populations after winter, thereby shortening the lag-period between the host plant and biological control agent population build-up. Augmentative releases should also be accompanied by long-term post-release evaluations to not only record successes, but to fine-tune the biological control programme accordingly (Miller et al., 2020).

To tackle the large-scale water hyacinth infestation on Hartbeespoort Dam, we embarked on an augmentative biological control programme, using *M. scutellaris*. To achieve this, we had to educate the Hartbeespoort Dam community on the practise of biological control, and we also needed their participation to assist in rearing the biological control agent. We could achieve this by creating a community of practice through various social networks, in-person interactions and training events. We offered participants the opportunity to manage their own satellite rearing station, which gave them direct access to biological control agents and increased the availability of *M. scutellaris*.

2. Material and Method

2.1. *Megamelus scutellaris*

The water hyacinth planthopper is multivoltine and native to Peru, Brazil, Uruguay, and Argentina. Adults are small, about 3 mm long and colouration varies from pale cream to dark brown. Adults can live for up to 80 days. Females oviposit eggs in pairs at the base of a water hyacinth leaf. The planthopper can have egg densities of 4.1 eggs per cm^2 of water hyacinth petioles (Sosa et al., 2015). Nymphs emerge after just 7 days (25 °C) and develop through five instars. Total development time from egg to adult takes 36 days (May and Coetzee, 2013; Sosa et al., 2015).

Both adults and nymphs feed on the sap of its host plant. Piercing of water hyacinth plants during feeding damages plant cells which results in water logging. Plants lose buoyancy and plant tissues start to rot. Plant damage becomes evident once leaves start to brown and curl. A sooty mould may also develop on the leaves. High population densities and low plant quality (i.e. intra-specific competition) can activate wing dimorphism in nymphs, thus allowing them to distribute to sites with higher plant quality (Fitzgerald and Tipping, 2013).

2.2. Augmentative releases of *Megamelus scutellaris*

Inundative releases of the planthopper into Hartbeespoort Dam began in May 2018. *Megamelus scutellaris* was mass reared at the Centre for Biological Control's (CBC) Waainek Mass Rearing Facility, at Rhodes University, Makhanda, South Africa. Planthoppers (mostly adults) were collected using vacuum pooters, and then emptied into ventilated, transparent tubs containing healthy water hyacinth leaves. Tubs were sealed inside polystyrene boxes containing two ice packs to maintain cool temperatures during transit. Overnight courier services were used to transport *M. scutellaris* 1 000 km to professional or private stakeholders for release at Hartbeespoort Dam. Professional stakeholders are stakeholders that are trained in conservation or ecology and are paid to work on the management of invasive species. Private stakeholders refer to community members that volunteer to participate in the programme. Delivery generally occurred within 1–2 days. The receiver was requested to send release data back to the CBC, including GPS coordinates of the release location, the specific site name, and the requestor's contact information.

2.3. Community rearing of *M. scutellaris*

One of the forms of community engagement was through community rearing of *M. scutellaris* in satellite rearing stations around Hartbeespoort Dam (Fig. 2). Bell and Paton (Pty) Ltd greenhouse tunnels (6 m x 3 m x 2.5 m) were constructed to house pools or tubs for rearing *M. scutellaris* on water hyacinth. Sources of funding for setting up the stations were either provided by the CBC or by private estate entities. Depending on capacity, each satellite station had one to four polytunnels. In some cases, private stakeholders added water heaters to the tubs to increase the temperature within the polytunnel, thus allowing them to rear biological control agents during winter. The 'champion' of each satellite rearing station received a mass rearing document with details on station maintenance and troubleshooting. Satellite rearing stations were also visited by professionals from the CBC as often as needed to ensure optimal rearing conditions. Inundative releases were made from the satellite rearing stations when sufficient numbers of planthoppers were available.

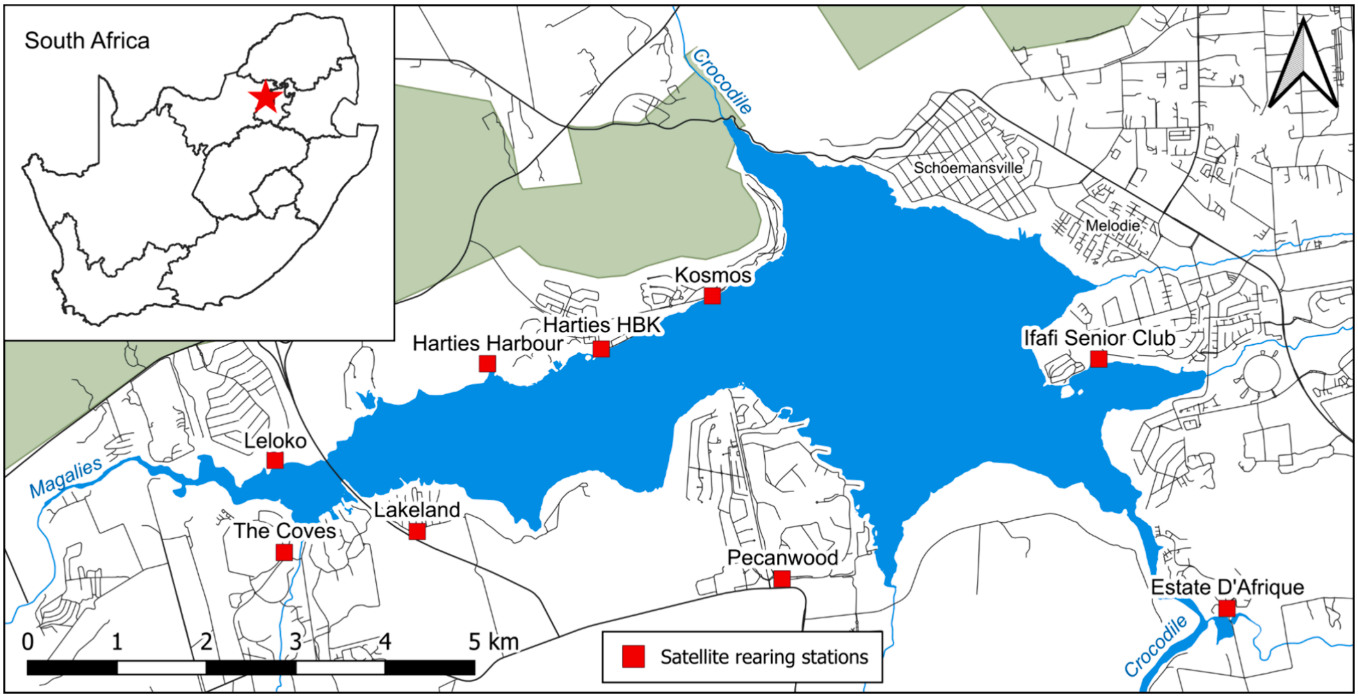

Fig. 2. Locations of the nine satellite rearing stations at Hartbeespoort Dam.

2.4. Post-release evaluation

We measured *M. scutellaris* densities monthly from October 2019 to January 2024 at several sites around the dam (Fig. 2). *Megamelus scutellaris* densities were measured using a modified 70 L black plastic bin. The base of the bin was removed and a cross of wires was added to the bottom, allowing the bin to be submerged over water hyacinth plants at wading depth, thus allowing *M. scutellaris*, whose lightly coloured cuticles contrast with the dark bin, to be counted. Bin counts were repeated ten times per site and were converted to *M. scutellaris* density/m^2 with no differentiation made between nymphs and adults, as in Miller et al. (2020).

2.5. Water hyacinth cover measurements

The water hyacinth coverage from January 2019 to January 2024 was mapped with Sentinel-2 MSI satellite imagery from the European Space Agency. The floating vegetation was identified through a decision tree, based on spectral indices, to produce open water, cyanobacteria, and water hyacinth classes as outputs. A K-means classifier determined the thresholds within the decision tree. Finer resolution PlanetScope satellite imagery was used as reference data for the accuracy assessment, which found a mean difference of 0.84 % and a standard deviation of 2.84 % between the PlanetScope and Sentinel-2 cover percentages (Coetzee et al., 2022a,b). Using Google Earth Engine, a cloud computing platform for remote sensing analysis, a detailed time series of the study period was produced with a temporal frequency of five days, weather permitting. The time series was smoothed with a centred rolling mean of 15 days to account for the aeolian-induced variability in the floating mats between observations.

2.6. Participant involvement and public perception questionnaire

Through the CBC's engagement activities with community members, participation was enabled in social learning spaces by cultivating a community of practice. Learning in these spaces creates value for participants as they learn how to better make a difference that they care to make (achieve a shared objective of clearing water hyacinth from Hartbeespoort Dam). The Value Creation Framework was used to measure the value catalyzed from the engagement with partners, this is a measure of impact that typically goes unnoticed (Wenger et al., 2011). Semi-structured interviews (Sup. Table S1) were conducted in early 2022 with the nine partners involved in the mass-rearing of *M. scutellaris* around Hartbeespoort Dam, some of whom were very new to insect rearing. Fourteen questions guided the interview.

To gauge the general public's understanding and perception of weed biological control and the CBC's involvement, an anonymous online questionnaire was disturbed via email, WhatsApp, Twitter, Facebook, and Instagram, and open for a month. The semi-structured questionnaire had three sections with 17 questions in total and Google Forms was used to administer it. Introductory paragraphs explained the purpose of the research and introduced each section, with the objective of each question. Section one had six questions, to obtain baseline information regarding the respondents' use of Hartbeespoort Dam, and whether they knew of the Centre for Biological Control. Section two consisted of five questions designed to assess the knowledge of invasive species and the identification of species on Hartbeespoort Dam. Section three had six questions which were mostly open ended to gauge knowledge about biological control. Thematic analysis was used to group respondent's open-ended responses according to themes that emerged, especially with the impact of water hyacinth and in gauging knowledge of biological control.

3. Results

3.1. Quantification of release events and sizes

Approximately 480 500 *M. scutellaris* individuals, reared at the CBC's mass-rearing facility, were sent to Hartbeespoort Dam between May 2018 and December 2023 with 95 consignments (Fig. 3). Between May and December 2018, 64 000 water hyacinth planthoppers were released into Hartbeespoort Dam (Fig. 3). In 2020, 77 000 *M. scutellaris* were sent to Hartbeespoort Dam, and in 2023, a total of 167 000 planthoppers were sent either to satellite rearing facilities or for direct release into the dam.

Biological control agents reared in satellite rearing stations were

Table 1
Survey questions asked in the online questionnaire.

Section 1	
1	Do you: A) live close to the dam? B) Go to the dam at least once a month? C) Go to the dam less frequently than once a month?
2	What do you do at the dam?
3	Have you heard of the Centre for Biological Control (CBC)?
4	If Yes, how did you hear about the CBC?
5	What interactions did you have with the CBC?
6	What did you get out of your interactions with the CBC?
Section 2	
	Invasive species (in South Africa) are controlled by the National Environmental Management Biodiversity Act (NEMBA) – Alien and Invasive Species (AIS) regulations. Invasive species are divided into four categories. This assists with invasive species prioritisation and management. * Category 1a: Invasive species which must be combatted and eradicated. Any form of trade or planting is strictly prohibited. * Category 1b: Invasive species which must be controlled and wherever possible, removed and destroyed. Any form or trade or planting is strictly prohibited. * Category 2: Invasive species, or species deemed to be potentially invasive, in which a permit is required to carry out a restricted activity. Category 2 species include commercially important species. * Category 3: Invasive species which may remain in prescribed areas or provinces, such as jacaranda trees in urban centres. Further planting, propagation or trade, is however prohibited.
7.	Did you know about the invasive species categorisation?
8	What species of invasive water weed is shown in the photo?
9	Has water hyacinth impacted your life? (scale of 0 to 5, with 0 representing no impact, and 5 representing a high impact).
10	Has this impact been positive or negative?
11	Explain how it has impacted your life?
Section 3	
12	What is your understanding of biological control?
13	Do you think implementing biological control on water hyacinth has had an impact on Hartbeespoort Dam?
14	As a long-term solution, do you think biological control is effective in controlling water hyacinth?
15	The pictures below show different levels of water hyacinth growth. Please tick which level of growth you consider to be a nuisance, if any. You can select multiple pictures.
16	What control measures would you like to see on the dam?
17	How effective are these suggested control methods?

released onto the dam from 2020. However, it took time for volunteer partners to learn to count and record releases from their satellite rearing stations. In 2021, the recorded releases from satellite rearing stations totalled 2 600 planthoppers (Fig. 4), although unrecorded releases were also made. In 2023, following training exercises, approximately 684 000 planthoppers reared in satellite rearing stations were released onto Hartbeespoort Dam. These releases were made during late Winter and early Spring (August – October).

Between 2018 and 2021, the earliest augmentative release after winter started in September, with most releases occurring from November. However, during the programme we learned that the onset of water hyacinth growth (either from seeds or remaining plants from the previous season) occurred before September. Thus, in 2022 and 2023 we started augmentative releases in August to close the gap between water hyacinth growth and biological control agent population build-up.

Over the span of six years (2018 to 2023), the number of volunteer partners that participated in the programme gradually increased (Fig. 5). Biological control agent releases were initially made by CBC researchers between 2018 and 2019. Thereafter volunteer partners released *M. scutellaris* which was sourced from the CBC Waainek mass-rearing facility or from satellite rearing stations around the dam. In 2020, four volunteer partners were involved in this programme, and by the end of 2023, a total of 19 volunteer partners had either received, released or mass-reared *M. scutellaris*.

Fig. 6 illustrates the water hyacinth percentage cover and *M. scutellaris* density per m^2 from January 2019 to January 2024. The first post-release survey, and thus planthopper counts, was conducted in October 2019. Generally, water hyacinth cover was highest at the peak of summer (January), followed by a gradual decrease in cover, nearing 0 % cover. The decrease in water hyacinth was followed by a build-up in the water hyacinth planthopper population. In January 2020, water hyacinth covered 20 % of the dam, while planthopper densities were 2 000/m^2. In January 2021, water hyacinth covered 20 % of the dam, and planthopper densities doubled from the previous year to 4 000/m^2. Water hyacinth covered 28 % of the dam in January 2022, while planthopper densities were 3 800/m^2. In 2023, a combination of invasion by common salvinia and late rains resulted in slower than usual water hyacinth growth and biological control population build-up.

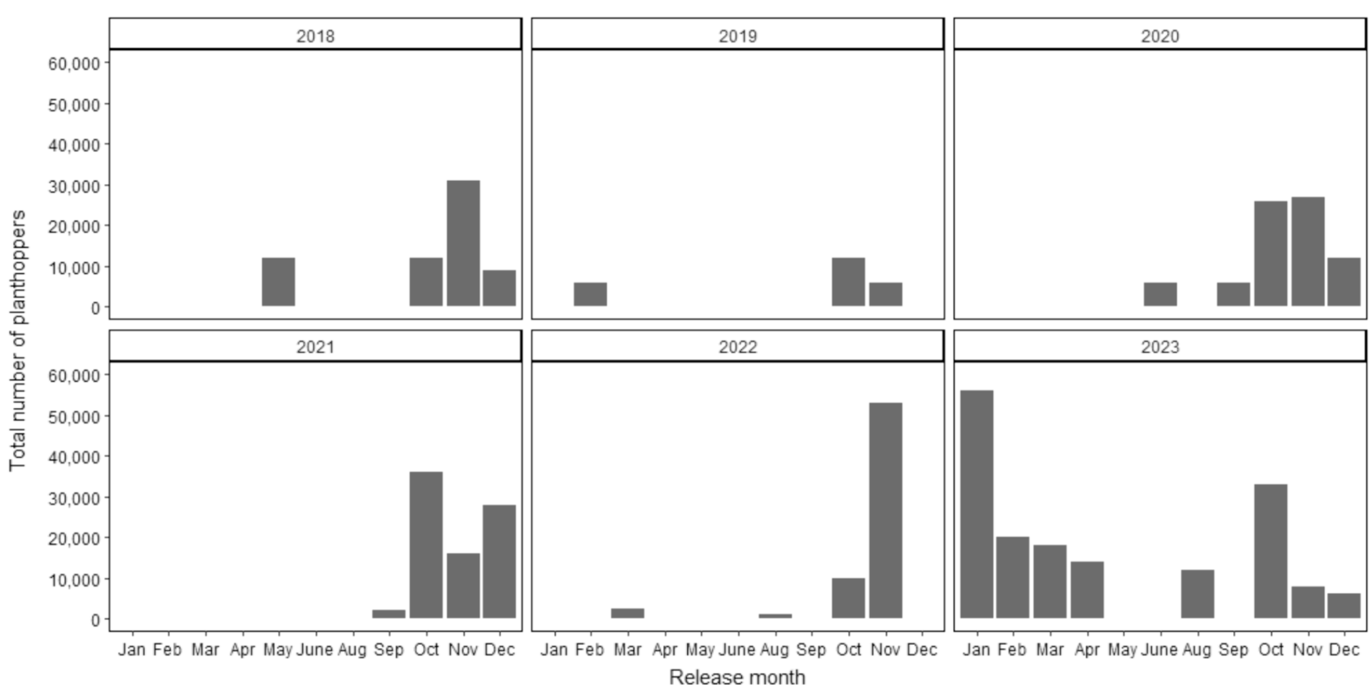

Fig. 3. Number of *Megamelus scutellaris*, sourced from the CBC's mass-rearing facility released at Hartbeespoort Dam, between May 2018 to December 2023.

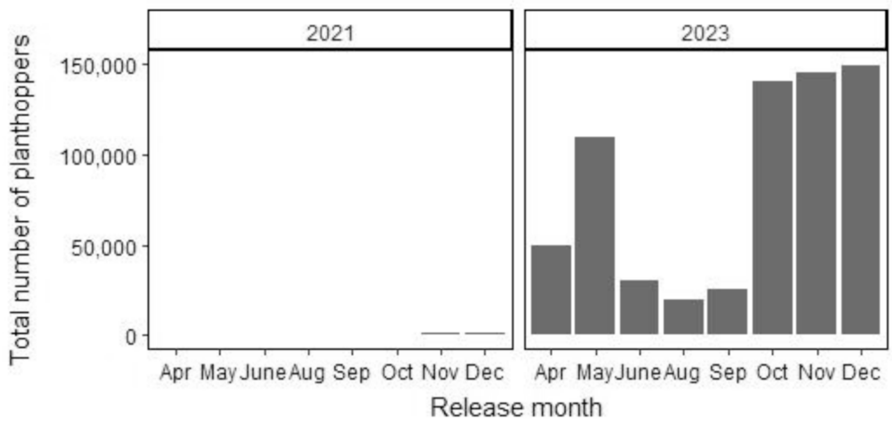

Fig. 4. Number of *Megamelus scutellaris*, sourced from satellite rearing stations that are managed by private stakeholders, released at Hartbeespoort Dam between April 2021 and December 2023.

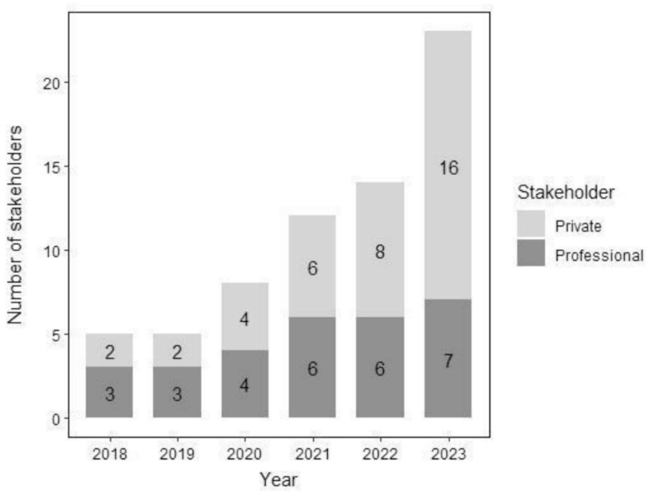

Fig. 5. Number of stakeholders that were involved in the water hyacinth biological control programme between 2018 and 2023.

While this large-scale decrease in water hyacinth cover on Hartbeespoort Dam was observed from satellite imagery (Fig. 6), monthly field-based post-release surveys confirmed this. Large counts of *M. scutellaris* were always accompanied by brown, unhealthy water hyacinth plants. In addition, large stands of brown, unhealthy water hyacinth contained green patches of other aquatic plants, confirming that water hyacinth die-off was a result of specialized natural enemies.

3.2. Interview and questionnaire results

Bridging boundaries through community engagement increased the numbers of *M. scutellaris* reared and released into the dam i.e. through satellite rearing stations managed by volunteer partners. Each biological control agent released into the dam contributed to the shared goal of the community of practice in reducing water hyacinth through an augmentative biological control management approach. The partners' interviews revealed that those partners who managed rearing facilities reached cycle four or five of the value chain, while the newer partners reached somewhere between cycles three and four. Thus, partners gained value from the programme, regardless of their level of involvement.

The programme was also successful in creating awareness and educating the Hartbeespoort Dam community on the science and practice of biological control. During the interviews, all our partners

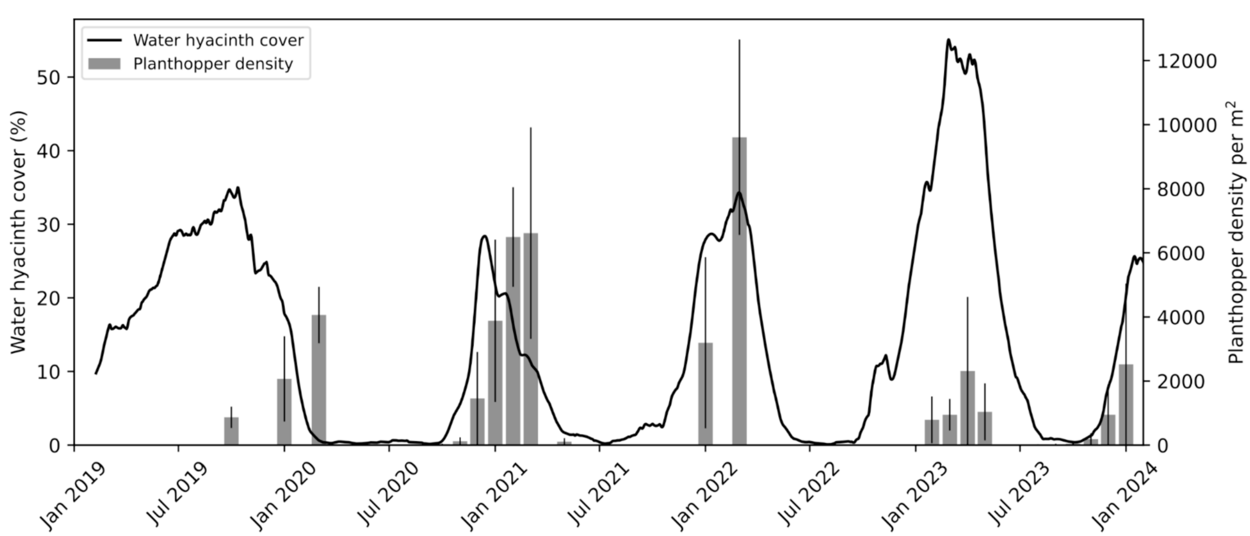

Fig. 6. Time series chart depicting satellite-derived water hyacinth coverage and the sampled *Megamelus scutellaris* density in Hartbeespoort Dam from January 2019 to January 2024. The time series is smoothed with a centred 15 day rolling mean and the bar chart lines indicate standard error

expressed that they gained a greater understanding of biological control. It was also evident that participants appreciated the process of biological control based on hands-on involvement. At this point, the participants had reached the third cycle of the value framework, because they recognized the applied value of rearing the biological control agent in their satellite rearing stations. They acknowledged the potential of biological control to bring about positive change. During our interviews, two partners expressed their enjoyment in actively contributing to the solution rather than relying on the government or other private entities for control measures.

In the fourth cycle, realised value becomes evident, and partners felt the payoff for their efforts and dedication to the programme, particularly with a noticeable change in water hyacinth health following the release of biological control agents. One of the partners, who had managed a rearing station for more than three years, shared their realisation that the augmentative release programme has had positive effects, because of the water surface clearing up in front of their property. Two partners progressed to the fifth cycle of the value chain, achieving transformative value. This is evident in the last year or so where the partners involved grew from 8 to 16 (Fig. 5). The reinforcement of overall enabling and strategic value was not solely driven by the CBC, but also emanated from partners with longer-term involvement.

Biological control is not widely recognized as a method of pest management in South Africa, due to preference in using chemicals and limited exposure to biological control. Consequently, the public harbours numerous concerns about this practice. To get support and demonstrate the programme's value, it is crucial for partners to comprehend and voice their apprehensions. The CBC has found it beneficial to establish platforms where partners can pose queries and interact with the scientific aspects. Meaningful learning often takes place when partners are actively involved in rearing, releasing, and monitoring activities, whether through one-on-one sessions with the CBC team during site visits or in more formal training sessions.

Additional aspects of value noted by the research team include partners taking pride in their involvement and expressing satisfaction in being part of the programme. The community of practice has expanded, fostering relationships based on shared activities and approaches. The quantity of insects released by community partners serves as evidence of the knowledge gained and the ongoing value they derive from participating in such a programme.

The online questionnaire was completed by 132 respondents. Of these, 75 % of the respondents lived close to the dam, while 9 % visited the dam at least once a month, and 15 % visited the dam less than once a month. Respondents mostly visited the dam for recreational purposes, which included relaxation, boating, fishing, and cycling. Respondents generally perceived water hyacinth as having a negative impact, with only 5 % indicating a positive influence. Those who viewed it positively provided diverse reasons, including research and job opportunities, as well as claims that it contributes to water purification and reduces unpleasant odours. Conversely, respondents who perceived a negative impact listed various reasons, with the following themes emerging in descending order of frequency: reduced recreational opportunities, aesthetic concerns, biodiversity loss, impacts on tourism, and property devaluation. Additionally, 5 % of responses emphasised the opinion that the government should take action to address this issue.

Respondents were queried about their understanding of biological control, and 51 % provided an accurate explanation of the concept. Unfortunately, baseline information prior to the CBC's community engagement is unavailable, making it challenging to assess any changes over time. Nevertheless, this finding suggests the potential for increased awareness regarding biological control. Regarding the impact of biological control in the dam, 56 % of respondents believed it made a difference. Similarly, 52 % considered biological control a long-term solution, while 8 % perceived it as a potential solution. Notably, 61 % expressed a preference for integrated control measures, including manual removal or chemical control. Intriguingly, 26 % of respondents independently highlighted the importance of reducing water pollution, recognizing it as crucial in addressing the ecological state of the dam — a perspective not prompted by the questionnaire. Additionally, three respondents emphasised the need for increased awareness and education as an integral component of successfully managing water hyacinth.

In summary, the questionnaire showed the need for enhanced and continued awareness and education regarding biological control. Respondents with an understanding noted a significant positive change compared to previous summers with lower public involvement and limited biological control. Those endorsing an integrated approach for controlling the invasive species on Hartbeespoort Dam emphasised the impact of manual removal during winter and early spring.

4. Discussion

This is the first time that biological control as a sole management strategy has been employed on Hartbeespoort Dam. Our results indicate that the augmentative biological control programme was successful in managing the large-scale water hyacinth invasion on this hypertrophic system. Nearly half a million biological control agents have been released onto the dam between 2018 and 2023, which assisted in the large-scale die-off of water hyacinth for four consecutive years. Our objective was not only to implement and monitor the biological control of water hyacinth on the dam, but also to bridge communication gaps with the local community. Engaging the local community would be particularly important considering the historical weed management approaches on the dam.

In South Africa, research has shown that people are more aware of invasive alien species when it directly affects them (Byrne et al., 2020). This was also true in our study, as respondents to our online questionnaire listed that water hyacinth directly impacts the recreational, aesthetic, tourism (business, economy) and property value of Hartbeespoort Dam. Because of the common goal of managing water hyacinth on the dam, community members actively participated in this programme, by rearing and releasing biological control agents into the dam. As seen from the value chain cycles, community members gained value from this programme. Most research on management of invasive species and engagement seek to improve knowledge as opposed to finding ways to implement it i.e. research-implementation gap (Shackleton et al., 2020). Here we bridge this gap by creating a community of practice.

With buy-in from affected communities, initiatives to manage invasive species may become less difficult to coordinate (Byrne et al., 2020). Water hyacinth has the ability to produce large numbers of seeds in its introduced range (Pérez et al., 2011). An inflorescence with 20 flowers can produce ~ 3 000 seeds that remain viable for more than 5 years. A survey of rivers and dams in the Eastern and Western Cape Provinces of South Africa in 2009, found that water hyacinth seed densities in the sediment ranged between 0 and 2 534 seeds m^2 with maximum germination at around three days (Pérez et al., 2011). Water hyacinth has been present on Hartbeespoort Dam for decades, suggesting that the seed bank will be large. Thus, water hyacinth management on the dam is a long-term programme. Long-term monitoring will be important to highlight milestones, and communication of these successes to the public and affected stakeholders is important to ensure the longevity of the programme.

Uptake of augmentative biological control for invasive species has generally been slow due to ignorance and negative attitudes from chemical companies, government entities and land managers (van Lenteren, 2012). Often a shift in management strategies is considered when target organisms become resistant, regulations in chemical application change or products become unavailable. In the case of Hartbeespoort Dam, augmentative biological control has proven to be successful as a sole management option. However, it is evident that a holistic approach that addresses eutrophication would be necessary to shift the ecosystem into a healthier regime. Although water hyacinth management has been successful, common salvinia or blue-green algae blooms replace water hyacinth once it has been cleared. Fortunately, through active community engagement, the affected community has knowledge of this, as seen from the online questionnaires.

Community engagement (e.g. communication, knowledge sharing) cannot be a once-off effort. Researchers should aim to find ways to be in constant communication with stakeholders affected by alien plant invasions. In addition, in-person presence is invaluable, as seen from our programme. After six years of community engagement and creating a community of practice, 51 % of respondents to our online questionnaire knew accurately what biological control entails, and 56 % believed that biological control was having a positive effect on the large-scale water hyacinth invasion. This is significant, considering the history of water hyacinth management on the system. It is possible that these numbers may increase through continued efforts, and more community partners reaching the fifth cycle in the value chain (Wenger-Trayner and Wenger-Trayner, 2020).

CRediT authorship contribution statement

Rosali Moffat: Writing – original draft, Visualization, Investigation, Formal analysis, Conceptualization. **Kim Weaver:** Writing – original draft, Visualization, Project administration, Investigation, Formal analysis, Data curation, Conceptualization. **Samella Ngxande-Koza:** Writing – original draft, Resources, Project administration, Investigation, Data curation. **Keneilwe Sebola:** Writing – original draft, Investigation, Data curation. **Kelby English:** Methodology, Investigation, Data curation. **David Kinsler:** Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis. **Julie Coetzee:** Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work is based on the research supported in part by the National Research Foundation of South Africa (Grant Numbers: 84643). Other funding came from the South African Department of Forestry, Fisheries and the Environment, and the South African Water Research Commission (K5/2951), MadMacs (Mass development of aquatic macrophytes—causes and consequences of macrophyte removal for ecosystem structure, function and services) in the frame of the collaborative international consortium of the 2017 call of the Water Challenges for a Changing World Joint Programme Initiative (Water JPI). Any opinion, finding, conclusion or recommendation expressed in this material is that of the authors. We acknowledge contributions to this paper by students and colleagues of the authors. We also extend thanks to the editors and anonymous reviewers for their valuable comments, which has improved the quality of this manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocontrol.2024.105544.

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