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ORIGINAL PAPER

# The impact of the invasive alien plant *Vernonanthura polyanthes* on conservation and livelihoods in the Chimanimani uplands of Zimbabwe

**Lameck Kachena · Ross T. Shackleton**

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**Abstract** Biological invasions can have major social-ecological consequences for rural communities across the world. However, the dimensions (characteristics, infestation and socio-ecological impacts) of emerging invasive alien plants are often less known and urgent information is needed to guide policy and management. In light of this, this paper assesses the social-ecological impacts of *Vernonanthura polyanthes,* an emerging invasive alien plant found in a Zimbabwean upland landscape which supports conservation and livelihoods. The paper employs qualitative methods—community mapping, time series analysis, and key informant interviews—involving individuals from diverse socio-economic backgrounds, to examine the socio-ecological and economic implications of *V. polyanthes* and its management in Chimanimani, Zimbabwe. We found that there are nuanced perspectives regarding this invasive alien plant among different socio-economic groups in the region who have different experiences of living with *V. polyanthes*. Some are embracing it for apiculture, firewood, and ethnomedicine while, on the other hand, some see the tree as negatively affecting key livelihoods (crop farming, pastoralism, and tourism) that are common in the region. Local people also identified that *V. polyanthes* is associated with ecological impacts that include loss of biodiversity, promoting pests, and negatively affecting watersheds and associated water sources. These mixed experiences concerning the plant are leading to different management practices, in turn inducing some conflicts among various actors. Based on our findings, we suggest more should be done to better manage this invasive alien plant in the region before negative impacts become too great, particularly in protected areas.

**Keywords** Invasive alien plants · Socio-ecological systems · Socioeconomic · Livelihoods management · National park · Chimanimani Transfrontier Conservation Area

L. Kachena
Centre for Applied Social Sciences, University of Zimbabwe, Harare, Zimbabwe

R. T. Shackleton (✉)
Swiss Federal Institute for Forest, Snow and Landscape Research, WSL, Zürcherstrasse 111, CH-8903 Birmensdorf, Switzerland
e-mail: ross.shackleton@wsl.ch; rtshackleton@gmail.com

R. T. Shackleton
Department of Botany and Zoology, Centre for Invasion Biology, Stellenbosch University, Stellenbosch, South Africa

## Introduction

Anthropogenic activities agriculture, trade, recreation, and development - are key drivers and pathways behind the introduction of invasive alien species (Hulme, 2009; Turbelin et al. 2022). Some plant species have been accidentally introduced as stowaways

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through trade and tourism activities; for example, *Parthenium hysterophorus* which is invading several Asian and African countries (Adkins and Shabbir 2014; Makoni 2020). Species are also introduced on purpose for a variety of reasons, such as timber production, shelter, hedging, fodder, ornamental use, and bee fodder and later on, a subset of these become invasive. A decade ago, there were around 751 invasive alien trees listed (Rejmánek and Richardson 2013), and currently there are now over 1061 invasive alien plants globally (Intergovernmental Platform on Biodiversity and Ecosystem Services IPBES 2023). Research is progressively revealing the adverse effects of invasive alien plants on ecosystem stability and human well-being (livelihoods, health and social relations) (van Wilgen et al. 2017; Pratt et al. 2017; Shackleton et al. 2017b; Mazza and Tricarico 2018; Witt et al. 2018; Bajwa et al. 2019; Shackleton et al. 2019; Linders et al. 2019; Rai and Singh 2020; Reynolds et al. 2020). Despite the impacts of invasive alien plants and them being labelled as "dangerous aid" (Low 2012), there are some that provide benefits to local communities (Kull et al. 2011; Kull and Tassin 2012; Hirsch et al. 2020) and, on the bases that they are utilized by people, and can be considered as 'multiple purpose species' (Rejmánek and Richardson 2013; Shackleton et al. 2015). Further, some invasive alien plant species can provide services and have functions that are not readily available from local species (Shackleton et al. 2017a). This combination of benefits and costs can foster conflicts of interest (Kull and Tassin 2012; Zengeya et al. 2017) relating to how invasive alien plants should be used and controlled, especially in developing countries where invasions are spreading widely. Like elsewhere in the global south, there is a growing focus on the impacts of invasive alien plants in Zimbabwe. Recently, Tarugara et al. (2022) observed socio-economic impacts associated with *Lantana Camara* which include loss of grazing areas and poisoning of livestock when the leaves are ingested. This is in addition to harbouring insect vectors like mosquitos and tsetse flies which can cause health issues to both people and animals. Likewise, Chatanga et al. (2008) observed that massive spread of *L. Camara* in Gonarezhou National Park, is (in)directly transforming native vegetation structure and composition through changes in soil properties such as nutrient status, pH, moisture levels, and such changes are reducing native species diversity and richness. The impacts of invasive alien plants on soil properties is widely recorded; for instance, Kundhlande et al. (2012) and Jimu et al. (2020) observed soil nutrient depletion, acidity across and altered mycobiomes in *Pinus patula* forests in Afromontane region. Commercial woody invasive alien plants spreading in Afromontane regions in Zimbabwe are transforming fire regimes by promoting outbreaks of fires, including in protected areas (Jimu 2011). Given the high plant diversity in the eastern highlands of Zimbabwe, several studies have recently focused on emerging dynamics of invasive alien plants in the region, including their associated impacts on ecosystem services. More recently, Chakuya et al. (2023) observed that in Bvumba Mountains, *Hedychium gardnerianum* (*H. gardnerianum)* species (wild ginger) infestation is threatening the growth of shrubs, saplings, and juveniles of native forests because its larger leaf area suppresses penetration of sunlight for understorey plants. Additionally, apart from other ecological impacts such as death of mature trees since it grows parasitically on other trees, *H. gardnerianum* is distorting the scenic views of tourism sites in upper Bvumba.

Despite an increasing understanding of the implications of invasive alien plants, most of the literature still generally focuses on well-established invasive alien plants, with relatively little information available on emerging invasive alien plants that are rapidly spreading. We acknowledge that a lack of detailed assessments of the benefits and costs of invasive alien plants can directly affect management options (Vimercati et al. 2022) and that delayed assessments of an emerging invasive alien plant species affect management practices.

In southeast Africa, an emerging invasive alien plant of concern is *Vernonanthura polyanthes*, a shrub native to Bolivia and Brazil (Vega and Dematteis 2010). In its native region, it is widely known as "assa-peixe" and is often used to make cough syrups and useful in honey production (Vega and Dematteis 2010; Leitão et al. 2014; Guerra-Santos et al. 2016). *Vernonanthura polyanthes* was introduced into Mozambique by Portuguese commercial farmers in the 1990s for apiculture (Sukhorukov et al. 2017; Hyde et al. 2016). The species has been invading the eastern highlands of Zimbabwe and central Mozambique for over 2 decades (Mujaju et al. 2021; Clark et al. 2019). While limited scientific research and

media reports are hinting at the capacity of the species to invade different social-ecological landscapes along the Zimbabwe and Mozambique borderland (Timberlake et al. 2016; Lisboa et al. 2022; Gonye 2019), the governments of the two countries are yet to officially declare it as an invasive alien plant. To make matters more complex, others are embracing and promoting the non-timber forest products (NTFPs) that the plant offers.

This article utilised participatory qualitative methods to explore the perceived implications of *V. polyanthes* on biodiversity and ecosystem services that are critical for livelihoods. The central objective of this study is to determine the impact of *V. polyanthes* on ecological diversity and the relationship between its spread and socio-economic well-being of the region. Beyond this objective, the paper further explores strategies currently used by various groups to manage the species' spread within the region.

## Study site: The Chimanimani borderland region

The Chimanimani Mountains form part of the Manica Highlands which are shared between Zimbabwe and Mozambique (Fig. 1). In this study, we conduct work on the Zimbabwean side. The region is characterised by a rugged quartzite mountainous range that is over 530km$^2$ long ranging from an average of 500–700 m a.s.l in the northeast to 1000–1200 m a.s.l in the northwest. The Chimanimani Mountains are formally conserved under Chimanimani National Park of Zimbabwe and Chimanimani National Park of Mozambique. The two parks are combined to form the Chimanimani Transfrontier Conservation Area. The region is characterised by montane grasslands and ericaceous shrublands, as well as some patches of montane woodlands and moist, evergreen forests in its lower-lying parts (Childes and Mundy 2001). Additionally, the Chimanimani uplands are part of the Eastern Afromontane Biodiversity Hotspot (Shah et al. 2018) and it was recently declared a Biosphere Reserve (UNESCO 2022). The physical setting of the phytoregion favours plant diversity with more than 1000 plant species, of which 60 are endemic and are found mostly in the Chimanimani Mountains, Nyanga area, and Chirinda Forest. The abundance of vegetation attracts mountain-loving wildlife and birds such as the eland, blue dicker, bushbuck, sable and the elephants which is found on the Mozambican side.

The region is underdeveloped and the majority of the inhabitants undertake mainly subsistence land-based activities. Across the region, local communities are dependent on forests for NTFPs (e.g. wild roots, medicinal plants, wild fruits, fuelwood etc.) which are all critical for household income and livelihoods (Hudson et al. 2020) as well as shifting cultivation (particularly small grains, maize, legumes, and sesame). As a primary habitat for multiple species, the local forests promote biodiversity conservation, in addition to stabilizing stream flows and maintaining water runoff. While local communities traditionally practice shifting cultivation (Virtanen et al. 2021), the terrain of the region discourages many from using cattle-drawn power in land tillage. Beyond this subsistence, agriculture is also conducted at the commercial level in the region. Historically, during colonialism, white settlers (both British and Portuguese) transformed some of the forests into upland commercial forest plantations populated mainly by exotic trees—*Acacia mearnsii*, *Eucalyptus globulus*, and *P. patula*—and dairy farms, in the process displacing Indigenous People to peripheral zones. However, following land reform programme in Zimbabwe, several Indigenous communities have reclaimed the land they lost from white settlers and now practice semi-commercial agriculture in these areas. Over the years, disturbed forest margins and other landscapes have been susceptible to invasions by trees introduced for timber purposes (*A. mearnsii*, *E. globulus*, and *P. patula* species), and more recently by *V. polyanthes* (Chikowore et al. 2023).

Forests, mountains, and watershed areas in the region also serve as sites of aesthetic, recreational, and spiritual value on both sides of the border. Ndau communities utilise forests and watersheds as areas for ritual performances such as rainmaking. The scenic, mountainous terrain and waterfalls, wildlife, and forests have become a centre of attraction for tourists, and unsurprisingly, many people's livelihoods in the region rely on eco-tourism.

The region is also rich in precious stones. Over the past years, gold and diamonds have been mined in both Zimbabwean and Mozambican rivers and forests, including within some parts of the protected area (Kachena and Spiegel 2019, 2023; Gandiwa and Gandiwa 2012). Following

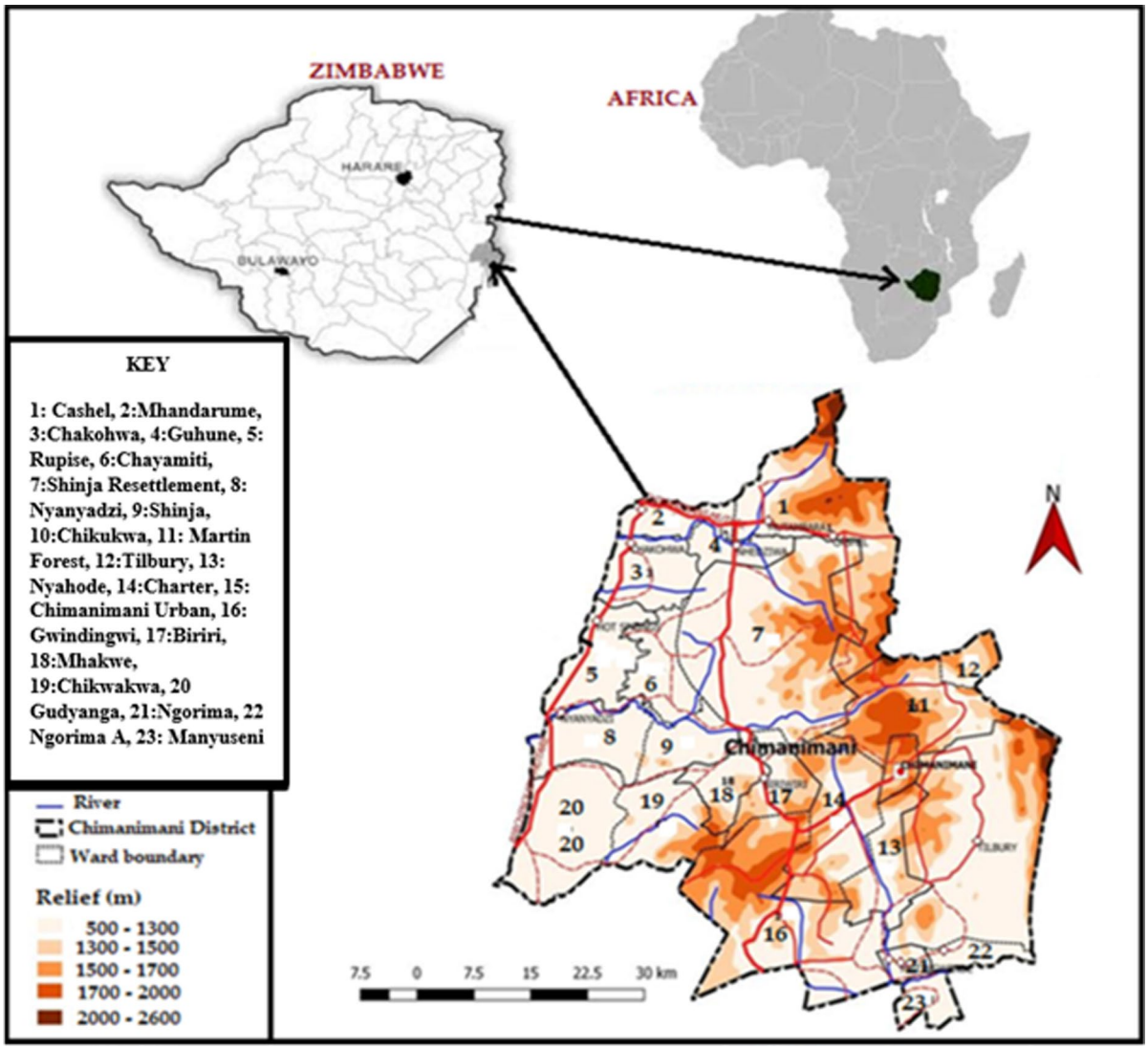


**Fig. 1** An overview of the study site where we consulted with seven communities on the Zimbabwean side of the Chimanimani region in southeast Africa. The visited communities in this study include; Chikukwa (10), Martin Forest (11), Tilbury (12), Nyahode (13), Charter (14), Ngorima (21) and Ngorima B (22). Map adapted from Chingombe and Musarandega (2021)

socio-ecological pressures (tropical storms and COVID-19), artisanal mining has become a major livelihood activity to both locals and foreigners—and the latter are acquiring land for settling, therefore encroaching on the few remaining patches of native and commercial forests (Spiegel et al. 2022).

## Methods

In this study, we employed exploratory participatory qualitative methodologies, including community mapping (CM) exercises, time series analysis (TSA) as well as key informant interviews (KIIs). This was

done from June to July 2021, in December 2021 and March 2022 with communities in the Eastern part of Chimanimani (Fig. 1). To get a holistic and representative view, we engaged different groups of people (including, women, youths, migrants and elders) and people with different primary livelihood strategies (including these with a focus on agro-pastoralism, agro-forestry, artisanal mining, and tourism activities). In total we engaged 375 participants (129 men, 142 women and 104 youths) from 8 communities, namely the rural settlement, peri-urban settlement, and commercial timber companies (see Table 1). We conducted 25 community mapping activities (with between 8 and 12 participants in each group) at different sites, to identify where *V. polyanthes* was invading within the community, and how its invasions in these areas translated into benefits and or costs for different local involved actors. Maps were first drawn individually, then participants were asked to present their maps to the group. Map presentations were also associated with some discussions that were meant to deepen understanding of the value of community resources and how they are affected by *V. polyanthes* invasions. Following this, a small group of volunteers (4–6) (normally consisting of a mix of youths, women and elders) were chosen to draw a final map reflecting on *V. polyanthes* in their community, taking into consideration comments and highlights made during the discussion phase. Key resources mapped or identified commonly included forests (native and commercial), croplands, grazing pastures, roads, and watershed areas (springs, river banks, and wetlands). We further conducted 16-time series analyses activities with community groups to establish a timeline of *V. polyanthes* invasions in the area. In addition to all this, participatory time series analysis was also conducted to assess how changes in seasonality and concurrent natural disasters (tropical storms and droughts) are shaping the spread and impacts of *V. polyanthes* for the 20 years from when *V. polyanthes* was first identified in the region. Key discussions were on how seasonal variances, changing climatic conditions and changes in land use patterns are promoting *V. polyanthes* invasiveness and distribution, together with a focus on the losses and benefits it brings under these conditions.

Separately, we carried out 28 key informant interviews with subsistence farmers, park rangers, community health workers, traditional leaders, foresters, forest company managers, representatives of government agencies (e.g. people from the Environment Management Agency (EMA), Forest Commission, Ministry of Lands, Agriculture and Rural Resettlement**,** Ministry of Health and Child Care), NGOs (e.g. Towards Sustainable Use of Natural Resource Organisation (TSURO), Chikukwa Ecological Land Use Community Trust (CELUCT)), and, local council members of Chimanimani Rural District Council

**Table 1** Number of participants engaged for fieldwork activities (♂ = men ♀ = women). KIIs (key informant interviews); CM (community mapping exercises), TSA (time series analysis)

| Community | Background of participants | KIIs | CM | TSA | No of participants | | |
|---|---|---|---|---|---|---|---|
| | | | | | ♂ | ♀ | Youths |
| Ngorima A | Pastoralists, resettled & subsistence farmers, beekeepers, artisanal miners, traditional leaders, and apiculturists | 2 | 8 | 4 | 29 | 36 | 25 |
| Ngorima B | Subsistence farmers, pastoralists, apiculturists, traditional leaders | 2 | 4 | 4 | 23 | 27 | 20 |
| Chikukwa | Pastoralists, subsistence farmers, apiculturists, artisanal miners, foresters, traditional leaders, CBOs, government representatives, health workers (environmental health technician) | 3 | 8 | 4 | 34 | 39 | 31 |
| Nyahode | Artisanal miners, pastoralists, horticulturalists, traditional leaders, and apiculturists | 1 | 5 | 4 | 30 | 37 | 24 |
| Chimanimani Village | NGOs, Government and private company representatives, park rangers, and tour guides | 8 | 0 | 0 | 3 | 2 | 3 |
| Charter | Foresters, managers and supervisors | 4 | 0 | 0 | 3 | 0 | 1 |
| Martin Forest | Foresters, managers and supervisors | 3 | 0 | 0 | 3 | 0 | 0 |
| Tilbury | Foresters, managers and supervisors | 3 | 0 | 0 | 3 | 0 | 3 |
| Roscommon Tea Estate | Forester and supervisor | 2 | 0 | 0 | 2 | 0 | 3 |
| Total | | 28 | 25 | 16 | 129 | 142 | 104 |

(RDC). Questions and topics of discussion in these interviews related to the respondents' knowledge of *V. polyanthes*, the perceived or known impacts on community livelihoods of the species and engaged management strategies being implemented on landscapes under different uses. These experts deepened and triangulated the information gathered through discussions with locals on how *V. polyanthes* is shaping socio-ecological and economic dynamics in the region. Additionally, participants shared vast knowledge of different possibilities for managing the plant and some of the challenges often encountered in the process. Throughout the data gathering process, we conducted discussions after obtaining both verbal and written consent from participants. Furthermore, to maintain confidentiality, the personal identities of participants were intentionally excluded throughout the findings section and this guaranteed their anonymity. Our data analysis approach was informed by a thematic approach which involved combining data with coherent themes, which would then be later on compared with and supported through document and literature review.

## Results

### Introduction and spread of *Vernonanthura polyanthes* in Chimanimani region

A total of 375 participants engaged for KIIs, CM and TSA proved to have an in-depth local knowledge of *V. polyanthes* introduction and spread in the region and were able to map this well (Fig. 2). In all 5 communities engaged, participants associated *V. polyanthes* with colonial histories of the Chimanimani Zimbabwe and Mozambique region. A local elder in Chikukwa explained that "as an exotic shrub, it means that the history of *V. polyanthes* is associated with western settlers who brought it in the region". While locals agreed that *V. polyanthes* is associated with white settlers, there were different views on how it ended up in the region. Participants reflected that *V. polyanthes* was first introduced in Sussundenga Farms by Portuguese who were experimenting with apiculture production. Since this first introduction, participants further reflected on two key mechanisms of further spread in the region.

Participants, engaged in 25 CM, 16 TSA, and 28 KIIs associated its spread in and subsequent invasions of the region with storm events (Fig. 2). A total of 5 environmental and livelihoods officers for a local NGOs revealed that *V. polyanthes* was spread from Sussundenga by successive harsh climatic events, particularly tropical storms that include Cyclone Eline which occurred in the early 2000s. Supporting this, 90 participants (artisanal miners, pastoralists, horticulturalists, traditional leaders, and apiculturists) in Nyahode agreed that they first witnessed *V. polyanthes* after cyclone Eline. Likewise, an Agritex Officer in the region reasoned that *V. polyanthes* seeds are very light, therefore, it was possible that they could have been swept by storms such as Cyclone Eline of 2000 and Cyclone Japhet of 2003. While historical storms

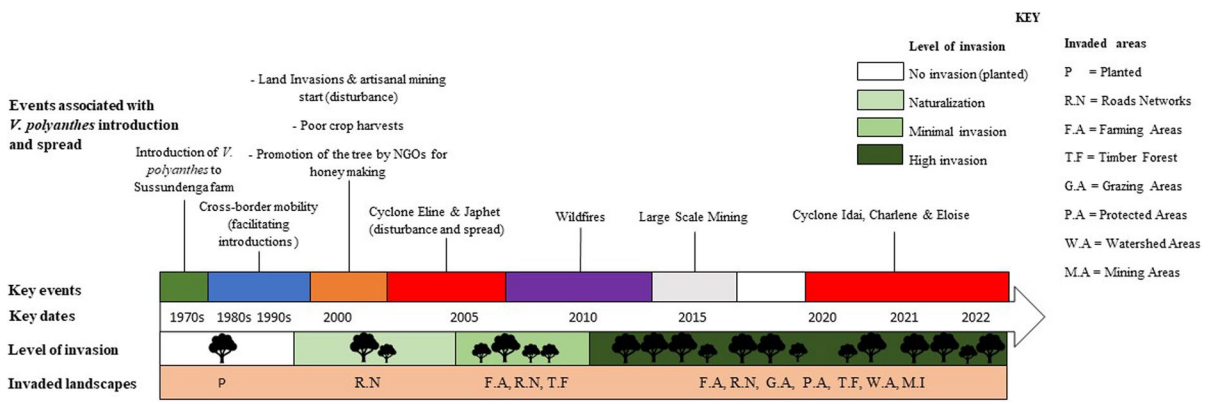


**Fig. 2** A reflection and aggregation of information gathered through community mapping and time series analysis associated with the spread of *V. polyanthes* in the region

are closely associated with the first introductions of *V. polyanthes* in the region, locals are also observing that recent storms like Cyclone Idai 2019 are promoting the species' localised spread and its increasing invasions across the region. Others also linked environmental disturbances like mining and fire with the establishments of *V. polyanthes.*

However, a sizeable number of participants highlighted the more purposeful and utility-inspired spread of the tree. Local apiculturists engaged in 8 community mapping workshops in Chikukwa reflected that *V. polyanthes* was introduced into the region and spread by people in the early 2000s as bee fodder to promote apiculture projects. People highlighted that local planting of *V. polyanthes* was initiated by livelihood-focused NGOs following the successive poor crop harvests in 2000. Closely reflecting on this, 10 female apiculturists in Chikukwa agreed that in the mid-2000s, and following apiculture training by a local NGO, a helicopter dispersed *V. polyanthes* seeds to foster the apiculture project.

Some less likely reasons for introduction and spread were also raised. Considering that *V. polyanthes* surfaced concurrently with the chaotic land reform programme, resettled farmers engaged in 4 CM and TSA workshops conducted in Ngorima A, harbor suspicions that the species might be a bioweapon which was intentionally spread by evicted white commercial farmers who were disgruntled by the land reform programme.

Different views on how the plant was introduced and spread into the region help to directly inform how *V. polyanthes* is perceived, utilised, and managed in the region. For example, many local names given to *V. polyanthes* relate to its introduction and spread. Recognised for its use in honey production, the plant is colloquially known as the Beebush by local apiculturists (see also Timberlake et al. 2020). However, it was also assigned other various vernacular names, including *Mupesepese* (the plant that grows everywhere) and *chimuCyclone Eline* (the Cyclone Eline tree) as well *Mutsurahondo* (the war plant) owing its rapid proliferation after cyclone Eline and chaotic land reform programme, respectively.

## Observed socio-ecological implications associated with *Vernonanthura polyanthes*

*Vernonanthura polyanthes* was observed to have various social-ecological implications on the region, including what people viewed as positive and negative impacts (Fig. 3).

## Perceived social-ecological implications

*Vernonanthura polyanthes* is perceived by all groups we engaged to have a variety of socio-ecological implications when it interacts with people and landscapes across the study region (Fig. 3). These include implications for biodiversity and associated NFTPS, as well as for fire, water and soil systems.

### *Biodiversity (flora and fauna) and natural products*

*Vernonanthura polyanthes* is perceived to be causing severe impacts on the region's ecological status and integrity. Local environmentalists observed that *V. polyanthes* is outcompeting numerous native species. A local tour guide explained that, "following disturbances like fire, it takes time for native trees to regrow but not *V. polyanthes*; under such conditions, it is suppressing forest regeneration". A total of 60 villagers including banana farmers, beekeepers, and artisanal miners in both Ngorima A and B unanimously identified several tree species (*Mudembesese, Mugurarwizi, Musapotwa, Mutsungunu* (*Bridelia micrantha*)) that serve as essential sources of NTFPs (banana ripening agent, fruits, wild insects, natural soap etc.) as being among those trees species being displaced by *V. polyanthes* infestation. Further, the 36 female participants we engaged for CM and TSA in Nyahode exercises testified that *V. polyanthes* infestation is leading to the depletion of traditional resources which are critical for household construction and maintenance. Specifically, one woman shared her experience following Cyclone Idai which severely destroyed her hut. She described how the infestation of *V. polyanthes* in grasslands led to a prolonged search for thatching grass (*Hyparrhenia hirta*), commonly known as yellow-spike grass, which challenge ultimately led her to use a donated tent to cover her hut's rooftop.

To emphasize this impact, 10 experts, including a senior Agritex Officer, stressed during KIIs that the extensive spread of *V. polyanthes* is leading to the loss of vital grass species for livestock such as *pfupfu* (*Pennisetum purpureum*, elephant grass). Additionally, in 7 TSA workshops conducted in Chikukwa, Nyahode and Ngorima B, local conservationists revealed how *V. polyanthes* is contributing to

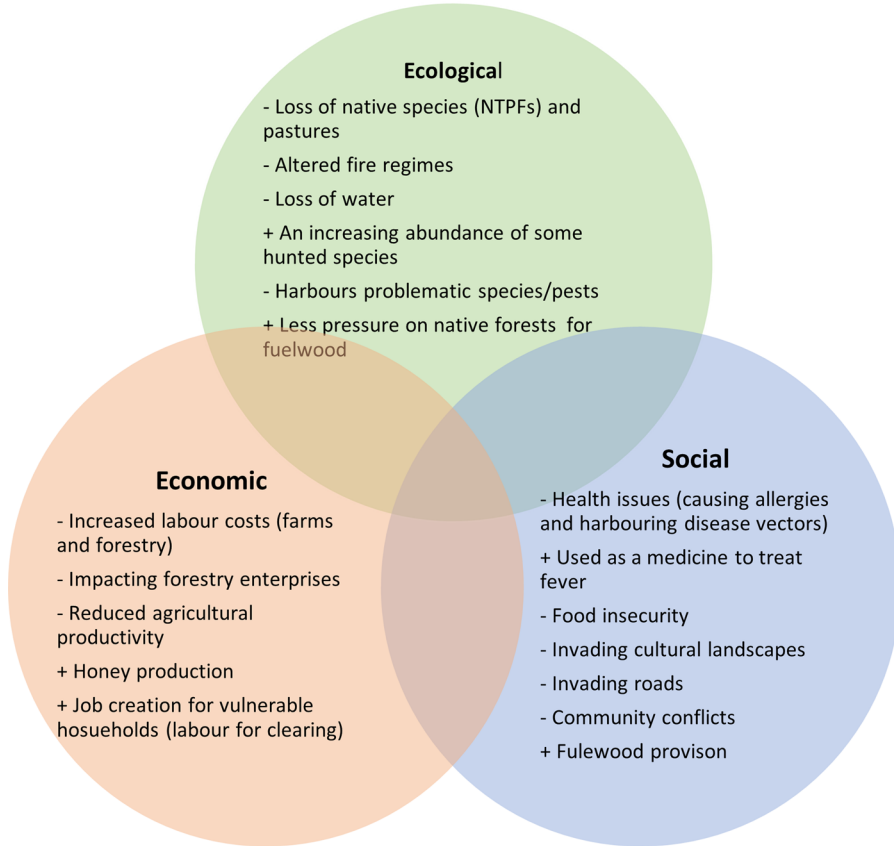


**Fig. 3** A summary of the primary socio-ecological implications of *Vernonanthura polyanthes* based on the outcomes of the particular CM and KIIs. Note that some aspects fall in multiple captures but were forced into one (the overlapping circles, however, illustrate the integrated and complementary nature of different aspects of the social-ecological system)

the decline of endemic butterflies and bird species, especially those reliant on wetland areas for foraging or habitat. This observation was also validated by a senior tour guide who noted that endemic bird species like Gakamiro and Hwitsoriro (Black Dove) are among the species losing their natural habitats to *V. polyanthes* thickets, and this has seen their population noticeably decreasing in the region.

Apart from outcompeting native endemic species, key informant experts and participants engaged community mapping exercise observed that *V. polyanthes* is attracting new species with some consequences for local livelihoods in the region. A local ornithologist highlighted that *V. polyanthes* thickets are now attracting qualia birds into the region, and that the thickets are serving as habitats to these birds. In turn, qualia birds are causing severe damage to crops (especially wheat) in the Rusitu Valley. A traditional leader in Ngorima highlighted that *V. polyanthes* thickets are also attracting damaging-causing wild animals such as warthogs that frequently invade and destroy vegetable gardens. However, a male farmer in Rusitu mentioned, for instance, that *V. polyanthes* thickets are attracting wildlife closer thus improving hunting experiences for locals. Apart from being a habitat, certain wildlife species also forage on *V. polyanthes* trees. A local artisanal miner, who often conducts his operations in Haroni, revealed that primates are feeding on *V. polyanthes* leaves, and this practice was more common in 2019 when several crop fields which they used to invade were affected by Cyclone Idai floods.

*Water*

Furthermore, *V. polyanthes* commonly invades watershed areas (streams, springs, natural wells, and small dams) therefore affecting water quantity and quality (Fig. 4). Female participants engaged for CM workshops in Chikukwa agreed that *V. polyanthes* is invading springs and other watershed areas and impacting both water access and security. Locals are now forced to frequently visit these springs to clean out *V. polyanthes* leaves which are affecting water quality.


**Fig. 4** Some negative effects of *V. polyanthes* Photo A: a deserted field after the owner failed to control *V. polyanthes* infestation; Photo B: a stream that is heavily infested by *V. polyanthes*; Photo C: a pathway facing closure following *V. polyanthes* infestation; Photo D: a spring that is regularly drying up due to increasing *V. polyanthes* infestation which then limits its use for cultural rituals

Additionally, it was pointed out that *V. polyanthes* leaves are blocking pipes, therefore causing water shortages. For instance, during TSA in Charleswood, Ngorima A, resettled farmers revealed that aquatic weeds and *V. polyanthes* are affecting irrigation activities by blocking irrigation pipes as well. Interestingly, in drier regions like some parts of Nyahode where *V. polyanthes* is less common, agro-pastoralists engaged in both CM and TSA acknowledge that they are using *V. polyanthes* as an underground water indicator and use the tree's presence as a guide on where to dig new wells.

*Fire and firewood*

The spread of *V. polyanthes* was also observed by participants sharing boundaries with commercial timber compartments in Chikukwa, Ngorima A and B as exposing several landscapes in the region to wildfires (Fig. 5). Both native and commercial forests are severely exposed to wildfire, as a result of fire regimes altered by *V. polyanthes.* Participants engaged in 3 CM exercises in Jihwo village, Ngorima A, unanimously welcomed an explanation provided by a local conservationist who likened *V. polyanthes* to petrol due to its ability to fuel the spread

**Fig. 5** A timber compartment destroyed by fire where *V. polyanthes* is an issue

of rapid fires that are exceptionally challenging to control. As an illustrative example, he narrated how native thickets forests like Makurupini, Matsatsakata, and Mugazhani were massively consumed by fires in less than 2 days due to the proximity of *V. polyanthes* bushes in their edges.

However, during different discussions, women engaged for CM and TSA in Chikukwa, Ngorima A and B seemed to like *V. polyanthes* because it is a readily available source of firewood (Fig. 6). For


**Fig. 6** Some bee fits of *V. polyanthes.* Photo A: a vegetable garden fenced using *V. polyanthes* poles; Photo B: white honey from *V. polyanthes*; Photo C: fuelwood or fencing poles of *V. polyanthes*

example, one woman stated that "We are happy because we have this tree in our community, we can easily harvest it for firewood, therefore save us time and hassles to walk long distances to indigenous forests." Likewise, a Headman in Rusitu reasoned that *V. polyanthes* is saving native forests that were often encroached on for firewood. He further testified that cases of people caught cutting down indigenous forests for firewood have decreased over the past 5 years.

*Soils*

Experts engaged for KIIs also highlighted that *V. polyanthes* can alter soil conditions and many views this as a benefit for agriculture. A forester for a timber company highlighted that, with the increasing spread of *V. polyanthes* in the region, some people are now reviving shifting cultivation methods. He disclosed that people are allowing *V. polyanthes* to invade their fields to improve the soil condition and such people then go on to conduct slash and burning control to recover fields for cropping. Similarly, some villagers are utilizing *V. polyanthes* to promote agro-ecology in their farms. In Chikukwa, for instance, we observed farmers planting their crops in fields sparsely infested by *V. polyanthes* because the plant is capable of conserving moisture as well as reducing runoff or erosion in the event of storms. Similarly, participants who were engaged in 4 TSA workshops in Ngorima B revealed that they are relying on *V. polyanthes* for dead leaves which serve as mulching and compost material which ultimately improves soil fertility. In one of our CM workshops, 6 female farmers in Rujeko village, Chikukwa demonstrated how *V. polyanthes* leaves can be used in combination with other materials, to make bio-fertiliser which locals are applying in maize crops. However, while these women using *V. polyanthes* for bio-fertilisers are claiming that it is a success, a local Agritex officer questioned the value of the bio-fertiliser under different conditions.

Perceived socio-economic implications

Participants engaged in KIIs, CM, and TSA associated *V. polyanthes* with a number of socio-economic implications where it invades (Fig. 3). These include implications for agriculture and food security, incomes and economics, and human health among many others.

*Agriculture and food security*

Given that Chimanimani is an agro-based economy that is strongly informed by crop production, it was witnessed that the spread of *V. polyanthes* in active agricultural lands is directly affecting productivity, increasing agricultural costs and food insecurity (Fig. 4). In Chikukwa Villages, 25 female farmers who took part in CM and TSA reflected that their yam gardens are becoming severely invaded by *V. polyanthes* species that are spreading in wetlands across the community. For instance, one female farmer, directly indicated that a portion of land that used to fetch her US$50–US$150 was severely infested by the *V. polyanthes*, and she now only harvested less than 40 kg of

yams which fetched her a mere US$20. In Nyahode, 41 participants engaged for 5 CM and 4 TSA revealed how *V. polyanthes* invades crops. Likewise, a male farmer highlighted that in 2015 his two-hectare banana plantation with 200 plants was invaded by *V. polyanthes* leading to estimated losses of US$2 000.

While estimating monetary agricultural losses associated with *V. polyanthes* invasions was difficult for most local famers, participants for CM in Ngorima A and B were aware of how much they spent in their bid to control *V. polyanthes* invasions on their farms. A local Headman in Ngorima A reflected that during each farming season, he pays US$200 to hire labour to clear *V. polyanthes* in his fields. A local youth explained that, per hectare, he charges US$25 for slashing, US$50 for weeding and US$250 for stumping (digging out *V. polyanthes*). Some poorer subsistence farmers engaged for 4 CM in Ngorima B revealed, however, that they cannot afford to pay hired labour in monetary forms. Instead, they often pay in kind or in exchange for other resources. A female banana farmer in Rusitu village, Ngorima B, revealed that though people who engage in manual labour often want to be paid in foreign currency which is inaccessible, they often pay them with grain, small livestock or clothes which labourers can utilize or resell later if they want money. A farmer in Vhimba village, Ngorima B, mentioned in one of the TSA exercises that each year she weeds out *V. polyanthes* for a family in her village and, in return, they plough her farm since she does not have cattle to do it. However, in 2 TSA in Ngorima B, it was mentioned that labourers are poorly paid; for instance, to weed one hectare they are paid with 10 kg of fertilizer or 40 kg of maize which are valued at US$20 and US$10 respectively.

In the region, *V. polyanthes* is observed to be reducing crop productivity and quantity of harvests, therefore, affecting the physical, social, and economic access to sufficient, safe, and nutritious food that is critical in meeting needs and food preferences for an active healthy life as recommended by the Food and Agriculture Organization of the United Nations (FAO 2013). A female farmer in Nyahode reflected that; "I barely harvested anything from my maize field last season, it was heavily infested by *V. polyanthes*, this was worsened by lack of labour since for one to harvest well you need to weed *V. polyanthes* three times since the plant regenerates quickly." In addition, *V. polyanthes* is affecting the diversity of food produced and consumed. In 8 CM engagements in Chikukwa, farmers expressed that they have already given up growing groundnuts, cowpeas, and sweet potatoes because they do not perform well in *V. polyanthes* infested fields. It was also mentioned that some farmers have abandoned wetlands they used to grow traditional rice because of severe infestation by *V. polyanthes*.

*Timber industry/forestry*

Private companies are also impacted economically by *V. polyanthes* invasions. Forestry companies reflected on the severe costs they have incurred associated with *V. polyanthes* related to the impacts of fire and control costs. Given that *V. polyanthes* is (in)directly linked with fire outbreaks that destroy timber forests, managers estimated that they have lost millions of dollars of revenue due to such fires—a view shared by multiple forestry companies. Numerous foresters from various agroforestry companies also mentioned that *V. polyanthes* is affecting the growth rates of timber species, although they have not yet established the monetary value of such disturbances.

Control costs for *V. polyanthes* are better understood. A line manager at Border Timbers stated that as a result of *V. polyanthes* invasions in timber compartments, the company has increased the number of seasonal workers for weeding purposes in plantations. Additionally, the company is spending more than $5000 per hectare to clear *V. polyanthes* and each hectare must be cleared at least three times a year. Given the high costs associated with managing *V. polyanthes*, an Allied Timber forester indicated that with the current *V. polyanthes* infestation, the company needs 200 workers who will be focused solely on managing the spread of the plant. A manager for a local tea estate hinted that they have increased the seasonal wage bill as a result of *V. polyanthes* invasions. He mentioned that where, previously, one person used to weed 100 units per day, the increasing presence of *V. polyanthes* means now that one person is weeding 60–80 units per day, and on the back of this, the company has recruited more people.

*Ecotourism*

Additionally, *V. polyanthes* is directly affecting tourism which is a key livelihood source for a significant proportion of the population in the region, especially youths. Invasions of *V. polyanthes* are deemed to be directly affecting the attractiveness of the general landscape and in particular some watershed areas. A government environmentalist stated; "we are assuming that, among other reasons, *V. polyanthes* is contributing to low tourist turnout in the region". In addition, roads that lead to key touristic sites are often blocked by the species. Elaborating on this, a local tour guide described that *V. polyanthes* is invading forests, in the process closing off trails of indigenous forests and making certain areas like Python Pool inaccessible to tourists (Fig. 4). This, therefore, is affecting visitors' chances of seeing specific endemic birds. Overall, the effects of the evasive species are to compromise the tourist satisfaction which hits their spending and impacts the whole region and the industry.

*Apiculture*

People engaged for both CM and TSA exercises in Ngorima A and Chikukwa reflected that some locals are economically benefiting from *V. polyanthes*. The flowers of *V. polyanthes* are rich in nectar, therefore local farmers, especially women and youths in Rusitu and Munaka villages under Ngorima A and Chikukwa respectively, are immensely benefiting from apiculture projects they have set up. A Livelihoods Officer for a local NGO indicated that following the increase in *V. polyanthes,* they have trained and handed over beehives to more than 800 apiculturists across the region. Likewise, a female lead apiculturist whom we interviewed in Ngorima A indicated that he earns between US$ 1500–2500 per year from honey sales and US$ 800–1200 from wax. Honey produced from *V. polyanthes* is deemed to be of high quality and it fetches higher prices at the market as compared to eucalyptus honey (Fig. 6). Explaining this, a local honey producer stated that *V. polyanthes* nectar produces clear and transparent honey which is sweeter than other tree flowers in the region. The honey is thus more attractive to customers and this is augmented by the fact that it is also believed to have medicinal properties that cure lung and chest pains. Commenting on the gains accrued from apiculture, a field officer for a local Community Based Organization (CBO) highlighted that the thriving *V. polyanthes* honey production business also capacitated vulnerable women and youths to secure a stable source of income, consequently improving household livelihoods. However, resettled crop farmers and pastoralists have a different view and believed the benefits from honey do not outweigh the losses in agricultural productivity. Commenting on this, a renowned farmer resettled in the region, mentioned that "food security cannot be measured by harvesting good honey, [and] if our crops fail as a result of *V. polyanthes*, the whole region will starve including those with plenty of beehives." This highlights some economic trade-offs and potential conflicts of interest in the region.

*Health*

Participants engaged in TSA, CM, and KIIs which included 6 environmental health technicians and 10 community health workers in Ngorima A, Nyahode and Chikukwa discussed public health implications associated with *V. polyanthes*. They highlight that there is a positive association between *V. polyanthes* abundance and certain illnesses, particularly malaria and allergies. Numerous female participants engaged in CM mentioned that *V. polyanthes* thickets are facilitating mosquito breeding. An Environmental Health Technician (EHT) at local a clinic revealed that statistics for patients treated for malaria between June 2020 and June 2021 were from villages that are severely infested by *V. polyanthes*. A number of female participants engaged in 8 CM also described being exposed to allergens associated with *V. polyanthes*. For instance, a female villager showed us her health card reflecting that each year, between 2015 and 2020 and around July–August when *V. polyanthes* is at the flowering stage, she frequently sought medical attention when her eyes and skin reacted to *V. polyanthes* pollen. Three Community Health Workers in Masiza, Jihwo, and Nyahode mentioned that they frequently request heat rubs from the District Hospital after they have observed that children in their villages were frequently stung by wasp, hornets, and bees attracted to *V. polyanthes* flowers and thickets in the locale.

However, some locals engaged in 8 CM and 4 TSA in Ngorima B revealed how they are embracing the *V. polyanthes* for health purposes, especially following

Cyclone Idai and Covid-19 when assessing public health centres was proving to be difficult. Locals who participated in 2 CM and 2 TSA in Jiho and Charleswood villages under Ngorima A revealed that boiled *V. polyanthes* leaves can help to treat diseases such as diabetes, stomach pains, and chest pains. An elderly man in Jihwo, stated that, through local wisdom that includes relating the smell of the plant to native species with medicinal properties, and observing the pigment of leaves and growth rate of this *V. polyanthes*, they found out that the species likely has the capacity to boost immune systems and taking it regularly can help fight diseases and aid body functioning, especially in diabetic patients. However, local health practitioners in Chimanimani are hesitant to recommend *V. polyanthes* as a medicinal remedy, stating that more studies must be carried out to understand its medicinal properties.

*Cultural*

Given that Chimanimani communities are closely connected with nature and ancestral spirits, locals dislike that *V. polyanthes* is encroaching on places of aesthetic and cultural value which are critical for the community's well-being and social capital. During a trip to Jihwo in Ngorima A, we witnessed locals slashing *V. polyanthes* at an ancestral graveyard for the Ngorima Chiefs in Jihwo area. Commenting on this, a well-known *Svikiro* (Spirit Medium) in Ngorima A stated that; "after every 3 months villagers living nearby the graveyard take turns to slash encroaching *V. polyanthus* at this site which is a symbol of sacredness and power, so we cannot watch it being in mess because of this tree." Likewise, in other areas such as Chikukwa, we also learnt that certain cultural forests are being invaded by *V. polyanthes*. A community forester shared that multiple community forests where ritual ceremonies for rainmaking are often conducted are now inaccessible following severe infestation by *V. polyanthes*.

*Conflict*

It was noted that *V. polyanthes* is associated with social conflicts in the region. It has triggered some disputes among different land uses and people with different livelihood interests. A community leader in Ngorima B highlighted that some villagers are embracing the plant by using it as a hedge or natural fence to restrict livestock from gaining entry into their properties (yards, gardens, and fields). However, this often results in micro-disputes between neighbours sharing boundaries since *V. polyanthes* attracts predators that feed on small livestock or crops and invade people's land. Likewise, a Headman in Vhimba testified that few years ago he resolved a conflict between two villagers who shared a boundary. In this case "Villager A was keeping some *V. polyanthes* at the boundary of the gardens which Villager B did not like and when a snake at one time appeared on the *V. polyanthes* boundary, Villager B approached Villager A to cut off the *V. polyanthes* so that the boundary will become open and the thickets could not harbour snakes. Villager A, however, refused to consider Villager B's plea, and when, coincidentally, that snake was later seen again on a different day, Villager B accused Villager A of being a witch and of owning the snake". Apart from inducing micro-conflicts, *V. polyanthes* is also associated with ongoing tensions between agro-forestry companies and communities along the buffer of timber compartments across the region. A supervisor for Allied Timbers revealed that "illegal settlers invading timber compartments are causing wildfires in the region because when they clear *V. polyanthes* shrubs for farming [they] are allowing fire to spread into timber compartments". Similar conflicts were also unfolding between communities, as villagers who survive on apiculture want *V. polyanthes* for honey production while agro-pastoralists are vehemently against the species which they accuse of disturbing their livelihood activities.

Current and proposed management mechanisms

Formal and informal management of *V. polyanthes* invasions are common in the region, especially when it spreads into landscapes critical for local economies, livelihoods or those with socio-cultural importance. We ascertained that people have very limited capacity and few options at hand to control *V. polyanthes* invasions. People in Chimanimani rely mainly on mechanical methods which at times have limited effects on preventing the spread of the tree. Although this will never lead to eradication, some people are utilizing it for firewood which might help to slow its spread across the region. Below we discuss local management of the species, the effectiveness of these

methods, and some of the challenges encountered in the process as presented by local communities and key informants.

*Mechanical control*

Farmers—both subsistence and resettled—as well as commercial forest estates often control *V. polyanthes* through mechanical means. This method is commonly used given its affordability. Some of the mechanical techniques used include digging out of *V. polyanthes* plants (locally called stumping), slash and burn clearing, or simply cutting down trees. The use of these different manual control methods is normally determined by the growth stage of the plant and/or by the value or status of the invaded landscape. Banana farmers in Rusitu Valley (Ngorima A) engaged in 2 TSA exercises, for instance, reflected that they commonly dig out *V. polyanthes* trees when they are at the early stages of invasion. One of the farmers stated that "*V. polyanthes* is very weak, so when it is less than 12 months old, you can easily dig it out, or hand-pull it, especially when the ground is wet." Stumping was also done when farmers are clearing land for cultivation, especially when the land was left idle for years. A resettled migrant farmer in Ngorima recalled that when he started living in Jihwo, the area was severely infested by *V. polyanthes* so he had to mechanically dig out large trees to avoid future regeneration of the plant on the same land. However, a group of 13 resettled farmers in Chitsa, engaged for TSA in Chikukwa, reflected that while stumping is the most effective way of controlling *V. polyanthes*, stumping a fully-grown *V. polyanthes* on dry land was laborious especially if large portions of land needed clearing. An Agritex officer stated that they encourage farmers to clear *V. polyanthes* fields during winter when it is wet, which, besides making it easier to dig trees out, also controls *V. polyanthes* at its flowering stage, therefore, curtailing the spread of new seeds.

Another method that was often used was slashing and burning. This method was often used to control *V. polyanthes* where it is sparsely populated in landscapes meant for farming or those being converted for farming. However, a Headman in Chikukwa, explained that slash and burning is often behind the outbreak of wildfires, so community regulations were made that no one is allowed to use fire to control *V. polyanthes*. The use of fire is also limited when controlling *V. polyanthes* in cultural landscapes and watershed areas where fire is culturally prohibited. Due to the increasingly limited use of fire, simply slashing trees is becoming more common. A forester at Allied Timbers explained that they often control *V. polyanthes* through slashing and do not burn the residues because it can lead to wildfires that will destroy the forest. Likewise, a supervisor at a tea estate hinted that the slashing method is a very temporal way of reducing *V. polyanthes* thickets as it does not stop the species from sprouting again and regenerating. The Forest Commission Officer explained that slashed *V. polyanthes* regenerates fast, especially during the summer, and control is becoming very costly especially to commercial timber companies because are frequently hiring workers to slash the *V. polyanthes* after every 3 months.

*Chemical control*

The use of chemicals and herbicides to control *V. polyanthes* was also highlighted by 20 KII respondents. When the plant was first observed in the region, some forestry companies used herbicides in their bid to control the species. A forester for Allied Timbers, for instance, recalled that in early 2005, his company purchased glyphosate to apply in plantations that were infested by *V. polyanthes*. However, the herbicides proved to be ineffective because after spraying, *V. polyanthes* just lost its leaves but regenerated a few months later. Similar stories were shared by other local farmers and forestry representatives. For instance, a manager for Border Timbers revealed that they once sprayed paraquat on young *V. polyanthes* trees but this did not affect the plants. Commenting on the use of chemicals, an EMA officer argued that besides having negative impacts on biodiversity, all tried herbicides have failed to control the spread of *V. polyanthes*. On the other hand, a lead farmer explained that even if herbicides were effective, it was going to be too costly for farmers to regularly buy these chemicals for usage on their farms.

*Utilization*

Conservationists and apiculturists—benefiting from *V. polyanthes* for honey production—strongly opposed the use of chemical control of the plant, fearing loss of biodiversity and their incomes

respectively. Instead, both advocates for an alternative solution, suggesting managing of *V. polyanthes* by utilising it as source of energy. Female apiculturists in Chikukwa and Ngorima pointed out that though purchasing herbicides to control *V. polyanthes* is costly, they suggested discontinuing use by individuals and forest companies. Their rational was that herbicides could negatively impact bees and honey quality, subsequently affecting honey production. In connection to this, a Headman in Ngorima stated that: "we used to get firewood from timber sawmills across the region; however, over the past years we were struggling following the closure of many sawmills, [and] as a result, many families are now resorting to the use *V. polyanthes"*. He further mentions that the species is a blessing in disguise has rescued local indigenous forests, as many of them were being targeted for firewood before. in 8 TSA exercise in Nyahode and Ngorima B suggested cutting down *V. polyanthes* for fuelwood just after the flowering stage, but before the seeds ripen. This approach aims to curtail excessive regeneration of new plants while balancing it with honey production. It was, however, highlighted by resettled farmers that promoting utilization will not lead to the eradication of *V. polyanthes* in the region. Furthermore, it could potentially worsen conflicts within communities.

## Future directions and conclusion

In this paper we assessed the social-ecological impacts of *V. Polyanthes*, an emerging invasive alien plant which is believed to have been introduced into central Mozambique in the early 1970s by Portuguese farmers as bee fodder (Clark et al. 2019; Timberlake et al. 2020; Lisboa et al. 2022). Invasion science often prioritises quantitative methodologies to numerically reflect impacts and trends of invasive alien plants (Shackleton et al. 2019), but in this article we extend the outlook through adopting participatory designs to explore lived experiences and local ecological knowledge of communities exposed to invasive alien plant species. Through participatory qualitative methodologies, the study explores how Indigenous Ecological Knowledge is being used by local communities in Chimanimani to understand processes associated with the spread, impacts, and management of *V. polyanthes*. Through exploratory participatory engagement, the paper shows how *V. polyanthes* invasions are shaped by socio-ecological changes which include seasonal variance, changing climatic conditions, and changes in land use patterns. In particular, this study established that local knowledge has identified successive tropical storms that hit Chimanimani region as promoting the spread of *V. polyanthes* from one location to another within and outside the region. Climatic changes and hazards have also been shown as a key driver of invasions in more ecologically focused research as well (Bellard et al. 2018; Lamsal et al. 2018).

This paper also advances knowledge on socio-ecological complexities associated with invasive alien plants and how they are often classified as either 'dangerous aid' (see also Low 2012) or 'multiple purpose species' (see also Kull and Tassin 2012). This study has ascertained that there are mixed feelings over the plant in Chimanimani. This is similar to earlier observations that the interplay between invasive alien species and livelihoods is highly complex (Shackleton et al. 2011; Shackleton and Shackleton 2018), and that they can be perceived to have both positive and negative impacts.

The implications of *V. polyanthes* invasions vary in different contexts; for example, with regard to the ecological status of the landscape and the socioeconomic background of communities exposed to it. We observed that *V. polyanthes* is strengthening livelihood diversity for some households by promoting honey production and associated projects that are empowering local female farmers, especially those living in reserves. Furthermore, women across the region are embracing *V. polyanthes* as a source of firewood, similar to other communities in southern and eastern Africa that are using invasive alien plants like *Prosopis* fuelwood (Chikuni et al. 2004; Mwangi and Swallow 2008). Further, the utilisation of *V. polyanthes* for fuelwood and construction may be saving native forests that were previously targeted for such purposes. People are also adapting to having the species and learning new uses. Through indigenous knowledge, local farmers in Chimanimani have identified some medicinal properties that *V. polyanthes* offers. The species is now used to treat several ailments, similar to how it is used as medicinal plant in its native range (Guerra-Santos et al. 2016; Almeida et al. 2021). On the other hand, *V. polyanthes* invasions, like other invasive alien plant species (Mwangi

and Swallow 2008; Shackleton et al. 2019) are inducing some negative implications on the local rural economy, negativity impacting ecosystems and biodiversity as well as people's livelihoods and well-being. Local respondents identified that *V. polyanthes'* spread is severely affecting subsistence agricultural livelihoods which are the keystone of community well-being in Chimanimani. Such compounds local food insecurity on already vulnerable populations. Likewise, the spread of *V. polyanthes* in commercial forestry landscapes is directly increasing monetary costs and losses for timber companies operating in the region. Timber companies are struggling to meet the labour costs required to manage *V. polyanthes* invasions. Given its capacity to alter fire regimes, timber companies are losing thousands of hectarages of plantations to wildfires associated with the presence of *V. polyanthes*. Additionally, these fires are bearing observable ecological losses. The region is witnessing the loss of native forests which are habitats to multiple endemic bird and amphibian species. Notably, *V. polyanthes* suppress the regeneration of endemic trees species that offer habitats and irreplaceable NTFPs. Invasions are also associated with serious negative health outcomes that include promoting the breeding of mosquitos that carry malaria and causing allergies, with similar implications observed from other invasive alien plant species (Muller et al. 2017; Hussain et al. 2020). Climatic changes and associated disturbances add to the spread of this invasive alien plant species, which might lead to more negative impacts on people and the environment in the future.

Like other invasive alien plant species (van Wilgen and Richardson 2014; Zengeya et al. 2017), there are clear conflicts of interest arising among those utilising *V. polyanthes* and those being negatively affected by it, with the latter wanting it to be better controlled in the region and the earlier wanting it to stay to promote honey production and fuelwood supply. This suggests important considerations for management. Currently, there is no agreed way of managing the plant when it encroaches on certain landscapes although some cultural practices and regulations may limit the use of some methods (e.g. fire). While chemical methods have been tried over years, they have been deemed ineffective, and some local conservationists are hesitant of their use due to non-target effects. Currently, the plant is mainly managed through mechanical means, although this is ineffective and costly to multiple stakeholders over the long run.

There is a need, therefore, for other management options including biological control mechanisms. Additionally, we propose for integrated invasive alien plant management initiatives that combine chemical, mechanical, biological, and policy related management strategies to supress *V. polyanthes* (van Wilgen et al. 2011). We further, recommend that more in-depth quantitative social and ecological research is carried out to better understand the implications of *V. polyanthes* on people and biodiversity. To reduce impacts and to get an early handle on the management of this invasive alien plant species, collaborative actions between various stakeholders in both Zimbabwe and Mozambique, are needed. As a starting point, the governments of these two countries need to develop adequate legislation. Likewise, already existing institutional collaborations that include the Chimanimani TFCA, should be at the centre stage to promote collaborative engagements to reduce the impacts of invasions.

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