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Evaluating the efficacy of invasive plant control in response to ecological factors

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ABSTRACT

Biological invasions have increased dramatically in the past centuries and are one of the greatest threats to biodiversity today. *Chromolaena odorata*, a herbaceous shrub from the Americas, is one of the most widespread and problematic invasive plant species in the tropics and sub-tropics. The plant is a serious problem in South Africa, where invasive species threaten biodiversity and use up water resources. This study combines data on the distribution of *C. odorata* with ecological and clearing management data to evaluate the efficacy of an invasive plant clearing program over its decade of operation in the Hluhluwe-iMfolozi Park in KwaZulu-Natal, South Africa. Densities and local extent of the *C. odorata* invasion were significantly reduced during the period of operations of the clearing program. Seasonal effects impacted clearing efficacy, namely a reduction in efficacy during the seed dispersal period. Clearing success was positively associated with clearing effort and fire frequency and negatively associated with rainfall. Management implications drawn from the results include halting clearing during the seed-drop period, giving extra attention to areas with more rainfall and other water availability, and incorporating fire with other clearing methods where possible.

1. Introduction

Over the past few centuries, biological invasions have become increasingly more prevalent. Using humans as a dispersal agent through transport and commerce, a rising number of species have traversed natural bio-geographical barriers and spread to areas outside of their native ranges (D'Antonio and Vitousek, 1992; Vitousek et al., 1997; Mack et al., 2000). Invasive species comprise of a small fraction of all alien species introduced outside of their native ranges that “proliferate, spread, and persist to the detriment of the environment” (Mack et al., 2000; Richardson et al., 2000). Invasive species can disrupt disturbance regimes, ecosystem productivity, nutrient cycles, hydrology, community structure (Vitousek et al., 1997; Levine et al., 2003; Gaertner et al., 2014), and are considered the greatest threat to biodiversity worldwide after land-use change (Millennium Ecosystem Assessment, 2005). In addition to the detrimental effects that invasive species have on the flora and fauna of the systems they invade, their impact can have deleterious consequences to human health and well-being (Vitousek et al., 1997). The invasion of ecosystems can severely threaten the availability of ecosystem services and can diminish the production of agricultural goods, silviculture, and natural goods (Mack et al., 2000; Van Wilgen et al., 2008).

South Africa spends a considerable amount of resources combating invasive species (Van Wilgen et al., 2008). Having an economy relying heavily on farming, ecotourism, and timber production makes the control of invasive species critical for the country. More importantly, South Africa is a water-stressed nation, and many regard water scarcity as the biggest limitation to development in South Africa today (Turpie et al., 2008). A large number of alien plant species in South Africa consume more water than native vegetation, and as a result, there is an estimated reduction of 7% of the country's total water runoff being wasted by current invasions (Gorgens and Van Wilgen, 2004; Van Wilgen et al., 2008). Shockingly, reductions could advance to eight times that amount if invasive species were to cover their entire potential range in South Africa. The sobering threat of invasive species to the nation's water supply prompted the government to establish the Working for Water (WfW) program in 1995. This flagship program focuses on removing alien invasive plants to increase water resources and serve conservation efforts, while simultaneously alleviating poverty by employing individuals from underprivileged local communities on the clearing teams (Van Wilgen et al., 1998). The WfW program invests heavily in research

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and has developed norms and standards for invasive alien plant clearing that are available to be used by other programs.

One of South Africa's many problematic invasive species, and a major target of the Working for Water program, is *Chromolaena odorata* (L.) King & Robinson, a perennial, herbaceous shrub of the family Asteraceae, known among many names as Siam weed or Triffid weed. It originates from the Americas, with a native range spanning from the south-eastern U.S. to northern Argentina, including the Caribbean islands. *Chromolaena odorata* grows to a height of 1.5–2 m, but can reach heights up to 10 m when acting as a creeper, using other vegetation for support (Zachariades and Goodall, 2002). In South Africa, *Chromolaena odorata* is a category 1(b) invasive species under the National Environmental Management: Biodiversity Act 2004 (NEMBA), which came into force as of 1 October 2014, and prior to that was classed a category 1 noxious weed under the Conservation of Agricultural Resources Act 43 (1983). These declarations carry the legal requirement for immediate removal from both private and public lands (Van Gils et al., 2004), although in many cases, this is difficult to enforce.

The main objective of South Africa's Working for Water program is to reduce the density of invasive species in South Africa by 22% per annum (Department of Environmental Affairs, 2015). The program spent 171.8 million ZAR (24.5 million USD) fighting *C. odorata* alone from the program's founding in 1995 to 2008 (Van Wilgen et al., 2012). Despite this effort, of all the country's invasive plant species, *C. odorata* moved from ranking 14th in 2000 to 4th in 2010 in terms of occupied area (Van Wilgen et al., 2012), highlighting the difficulties involved in controlling this species.

Since 2004, a large-scale control program focused on clearing *Chromolaena odorata* has been operational in Hluhluwe-iMfolozi Park (HiP), KwaZulu-Natal, South Africa. This program was modeled after the WfW programme and followed their standard procedures. Over the decade of operations of the program, it has hired a large workforce of laborers from communities surrounding the park and successfully brought the species down to maintenance level (<5% park-wide cover), albeit at a cost of 103 million ZAR (15 million USD) (te Beest et al., 2017). However, as the species is still present in the park, continued monitoring is fundamental to prevent re-invasion and maximize the successes of past clearing efforts. Therefore, this study seeks to assess current densities of the species, to compare them to past densities, and to analyze the extent to which ecological factors and management practices may have aided the control program of *Chromolaena odorata* in HiP. This information might benefit future clearing programs for this species elsewhere, as the limited resources available for invasive alien plant control require research into factors improving efficacy and prioritization of areas that facilitate success (Van Wilgen et al., 2016). The current study evaluates management decisions, such as time between clearing treatments, amount of effort exerted, clearing methods utilized, and time of year clearing takes place, as well as ecological factors, such as rainfall, fire regime, temperature, and topography. Data sources include invasion density estimates obtained from transect sampling, clearing data from the park's alien plant control program, and ecological data from park records and climate databases.

2. Methods

2.1. Study area

Hluhluwe-iMfolozi Park (HiP) is a 90,000 ha reserve in the KwaZulu-Natal province of South Africa. It is situated between 28°00′–28°26′ S and 31°09′–32°43′ E. Elevation in the park varies from 60 to approximately 600 m above sea level and experiences a strong rainfall gradient with around 1000 mm annually in the higher altitudes in the north of the park, to 600 mm annually in the lower altitudes in the south of the park (Balfour and Howison, 2001). Rainfall is seasonal with most rain falling in the spring and summer months of October through March. Mean maximum temperature ranges from 23 °C in July to 29 °C in January and mean minimum temperature ranges from 13 °C to 19 °C. Habitat types range from open grasslands and woodlands that are frequently burned to closed acacia, broad-leafed woodlands and forests that are generally fire excluding (Whateley and Porter, 1983). Approximately one-quarter of the park area is burned annually (Balfour and Howison, 2001). HiP has a heterogeneous landscape and a high diversity of flora and fauna. There have been over 1250 recorded vascular plant species, and the park is home to many species of high conservation value, including the white rhinoceros *Ceratotherium simum* (Burchell, 1817), black rhinoceros *Diceros bicornis* (Linnaeus, 1758), and the African wild dog *Lycaon pictus* (Temminck, 1820) (see Macdonald, 1983). HiP is enclosed with a game-proof fence and is surrounded by rural communities and communal agricultural lands (Whateley and Porter, 1983).

2.2. Study species

Chromolaena odorata was first recorded as naturalized in South Africa near Durban in 1947 and has become widespread and abundant in the subtropical eastern and north-eastern parts of the country (Paterson and Zachariades, 2013). The first documentation of *C. odorata* in HiP was in 1961 (Macdonald, 1983). The species spread rapidly through the more mesic northern region of the park and in 2001 more than 20% of the area of the northern sections (Hluhluwe) was covered with dense monospecific infestations (Howison, 2009). In the remainder of HiP *C. odorata* is more restricted to riverine habitats and was shown to occur at the lower limits of its tolerance to water stress (te Beest et al., 2013). *Chromolaena odorata* commonly invades everything from roadsides, communal lands, pastures, croplands, and plantations to riverine areas, grasslands, savannas, forest edges, and disturbed forests (Zachariades et al., 2011). Southern African populations represent a distinct biotype that tolerates cooler temperatures than most biotypes found elsewhere, including in the native range, but the invasion is nonetheless restricted to frost-free areas (Kriticos et al., 2005; Paterson and Zachariades, 2013; te Beest et al., 2013). The plant can produce up to 260,000 wind-dispersed seeds per m^2 per year and has very few natural enemies outside of its native range (Witkowski and Wilson, 2001; Qin et al., 2013). It forms thick, monospecific stands that can shade out native vegetation and create restrictive barriers to animal and human passage (Goodall and Erasmus, 1996; te Beest et al., 2015a). *Chromolaena odorata* preferably grows in woodlands and on forest edges, where it can act as a fire ladder, turning surface fires into high-intensity canopy fires in habitats that would normally exclude fire (Macdonald, 1983; Macdonald and Frame, 1988; te Beest et al., 2012). The species can sprout quickly after fire and thereby outcompete native vegetation (te Beest et al., 2012, 2015b). Biocontrol of *C. odorata* has been investigated for many years, but has yet to be implemented in an effective manner in South Africa (Goodall and Erasmus, 1996; Zachariades et al., 2011).

2.3. Control program

In 2003/4, a large-scale control program funded by Ezemvelo KZN Wildlife (EKZNW), the provincial nature conservation authority, and the KwaZulu-Natal Department of Agriculture, Environmental Affairs and Rural Development (DAEA&RD) was initiated to target the *C. odorata* invasion in HiP. The program had strong links to the Working for Water program and adopted their standardized methodology. In recent years, the Invasive Alien Species Programme (IASP) has been expanded to include other alien species. The IASP contracted out clearing duties of different areas to teams of around 9–10 people. Being a community poverty-relief program, people were hired from local communities surrounding the park. At the height of operations, nearly 1000 laborers were clearing in the park at a time. Prior to forming a contract, the IASP would estimate the density of an area to determine