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Research Article

The invasion status of *Myriophyllum spicatum* L. in southern Africa

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Abstract

The submerged aquatic macrophyte *Myriophyllum spicatum* L. (Haloragaceae) has been recorded in southern Africa since 1829. It was first considered problematic in 2005 on the Vaal River, which has highlighted the need for an assessment of the invasion status and an appropriate management strategy to be identified. We used a unified invasion framework to categorise *M. spicatum* in southern Africa and define appropriate management strategies. Historical records and field surveys were used to assess the invasion status. Populations were considered established if collection records from a particular catchment or river system spanned at least 10 years and in some cases several localities. Of the 21 river systems where it has been recorded, it was evaluated as established in 13 and in the D1-E category of invasion. The disjunct populations suggest that it was point source introductions and thus the major barrier that prevents *M. spicatum* from proceeding along the invasion framework is its inability to naturally disperse the greater distances between catchments. Appropriate management strategies need to be catchment or river system based depending on the stage or state and category of invasion. Where *M. spicatum* is in the D1-E stage – established and potentially spreading, the appropriate management strategies include containment, and where possible, mitigation.

Key words: Unified invasion framework, submerged macrophyte, management strategy, introduced, casual, established

Introduction

In the Haloragaceae, the genus *Myriophyllum* is considered cosmopolitan, and comprises approximately 60 species, all of which are aquatic macrophytes (Cook 2004). Only two *Myriophyllum* species occur in southern Africa, *Myriophyllum spicatum* L. (Haloragaceae) and *Myriophyllum aquaticum* (Vell.) Verd. (Haloragaceae). Both are thought to be introduced (Mendes 1978). Since the introduction of *M. aquaticum* from South America in the early 1900s, it has spread throughout southern Africa and is considered one of South Africa's worst aquatic weeds (Coetzee et al. 2011a). On the other hand, *M. spicatum* was first recorded in South Africa in 1829, but was only considered problematic on the Vaal River as recently as 2005 (Coetzee et al. 2011b). Its impacts include, clogging of irrigation pipes and pumps, and preventing water access by boaters and fishermen (Coetzee et al. 2011b). In North America where it has invaded several hundred water bodies, its impacts include reduced biodiversity, and shading of native plants, which has implications for ecological functioning (Madsen et al. 1991).

There is a general consensus that *M. spicatum* is native to Europe, some parts of Asia and North Africa (Reed 1977; Cook 1985; Couch and Nelson 1985) and that it was accidentally introduced into India, North America and southern Africa (Holm et al. 1979). *Myriophyllum spicatum* is often considered a significant weed in areas or regions where it is introduced (Patten 1956; Reed 1977; Couch and Nelson 1985; Smith and Barko 1990; White et al. 1993, Johnson and Blossey 2002). In the United States of America, removal from waterways costs the country millions of dollars annually (between 37 000–500 000 US\$ per km^2) (White et al. 1993). In South Africa, *M. spicatum* is listed under the Conservation of Agricultural Resources Act, 1983 as a Category 1 weed, which is the highest category an exotic weed can attain. This was done as a precautionary measure due to

Table 1. The invasion stage and the relevant categories as outlined and defined in the unified invasion framework proposed by Blackburn et al. (2011).

Stage	Category
Transport	**A** Not transported beyond limits of native range
Introduction	**B1** Individuals transported beyond limits of native range, and in captivity or quarantine (i.e. individuals provided with conditions suitable for them, but explicit measures of containment are in place)
	B2 Individuals transported beyond limits of native range, and in cultivation (i.e. individuals provided with conditions suitable for them but explicit measures to prevent dispersal are limited at best)
	B3 Individuals transported beyond limits of native range, and directly released into novel environment
	C0 Individuals released into the wild (i.e. outside of captivity or cultivation) in location where introduced, but incapable of surviving for a significant period
Establishment	**C1** Individuals surviving in the wild (i.e. outside of captivity or cultivation) in location where introduced, no reproduction
	C2 Individuals surviving in the wild in location where introduced, reproduction occurring, but population not self-sustaining
	C3 Individuals surviving in the wild in location where introduced, reproduction occurring, and population self-sustaining
Spread	**D1** Self-sustaining population in the wild, with individuals surviving a significant distance from the original point of introduction
	D2 Self-sustaining population in the wild, with individuals surviving and reproducing a significant distance from the original point of introduction
	E Fully invasive species, with individuals dispersing, surviving and reproducing at multiple sites across a greater or lesser spectrum of habitats and extent of occurrence

the plant's weedy behaviour in other parts of the world, especially the USA (Henderson 2001). In light of the problems being experienced in the Vaal River, the southern African populations of *M. spicatum* have the potential to become problematic and appropriate management strategies need to be explored.

Appropriate management action requires defining invasion status. To do this several authors have suggested the use of invasion frameworks for several taxa (Gozlan et al. 2010; Richardson et al. 2000) which have recently been revised into a proposed unified invasion framework (Blackburn et al. 2011). The unified invasion framework aligns terminology and categorises introduced populations according to the invasion stage and has appropriate management strategies for each of these. The framework uses four stages to characterise the invasion process which include transport, introduction, establishment and spread, with each stage having specific barriers that the introduced species needs to overcome to proceed to the next stage. Within these stages, there are different categories which a species can attain depending on the criteria that define each category. These categories range from A through E, with each having a specific definition outlined by Blackburn et al. (2011) (Table 1). This framework has already been applied to characterise and identify appropriate management strategies for several invasions in Africa, including *Banksia ericifolia* (Proteaceae) (Geerts et al. 2013), Australian *Acacia* species (Richardson et al. 2011) and an invasive loricariid catfish (Jones et al. 2013).

The invasion framework proposed by Blackburn et al. (2011) was applied to *M. spicatum* in a similar way to that of the loricariid catfish in Jones et al. (2013) because the same limitations apply to submerged macrophytes and fish in terms of their ability to survive and spread between catchments. The aim of this study was to characterise the invasion of *M. spicatum* and assess potential management strategies for it in southern African systems.

Data collection

In order to characterise the invasion status of *M. spicatum* in southern Africa, historical records were collected from herbaria in the region (Appendix 1). Each specimen was carefully examined and photographed to ensure correct identifications and to assess the reproductive state of the plants (i.e. presence of flowers and seeds) to determine the potential for reproduction. In addition to this, all the southern African records of *M. spicatum*

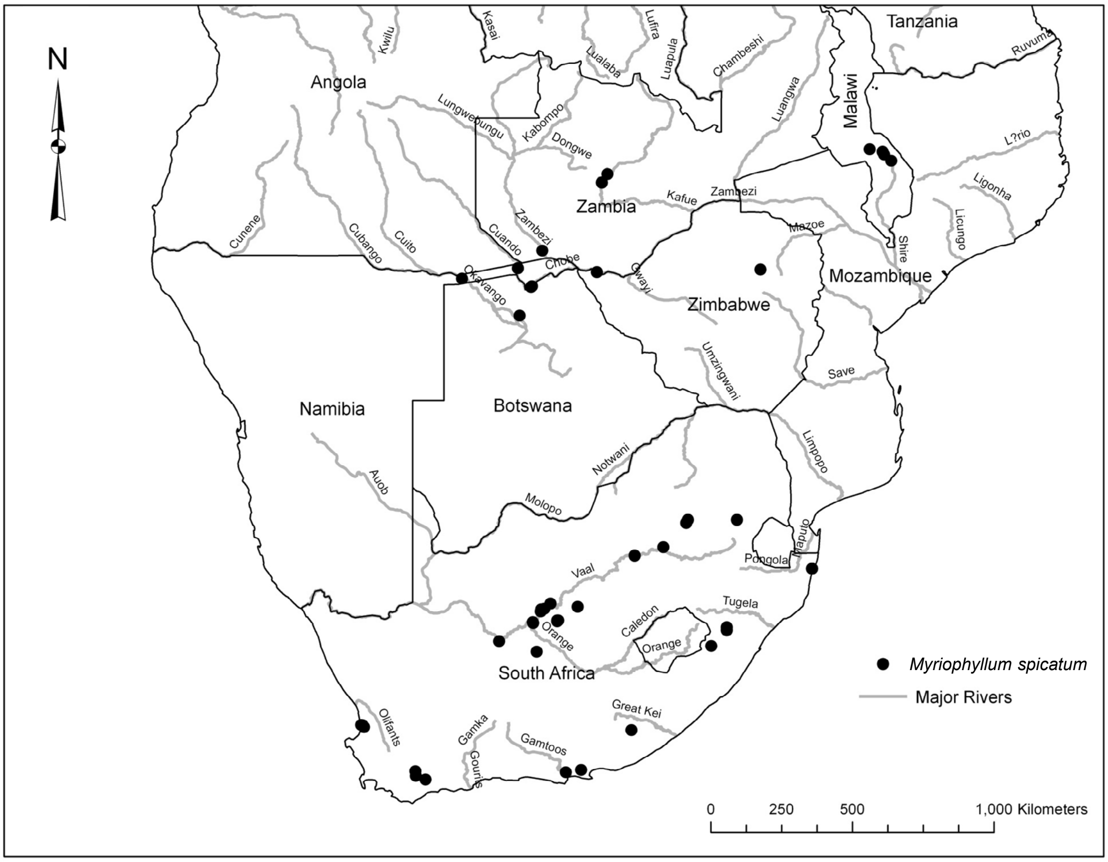

Figure 1. The distribution of *Myriophyllum spicatum* in southern Africa from verified herbarium specimens housed in southern African herbaria.

were downloaded from the GBIF database (Global Biodiversity Information Facility; http//.www.gbif.org) as supplementary or additional records. The records between the different herbaria and GBIF were then cross referenced and any duplicates were removed from further analysis. Observational records were also removed due to the possibility of misidentifications.

To determine the extent of establishment and/or invasion, existing localities as well as new water bodies were surveyed. In South Africa, we have conducted extensive annual field surveys since 2008 to assess the distribution and populations of all known aquatic weeds, as well as survey for the early detection of new emerging aquatic weeds. In addition to this, we have been on several surveys specific to localities where *M. spicatum* has been recorded in South Africa, Botswana and Namibia (Appendix 2.).

Stage based characterisation of *Myriophyllum spicatum* in southern Africa

Stage 1: Transportation

The introduction pathway from its native range, Europe, North Africa and Asia to southern Africa is unclear. The first published record and lodged specimen of *M. spicatum* in South Africa was in November 1829 from the Swartkops River (-33.73°, 25.32°), when the plant collectors C.F. Ecklon and K.L.P. Zeyher surveyed the Uitenhage area in the Eastern Cape, South Africa, between July 1829 and February 1830. Ecklon (1830) stated that: "*a most striking feature of the Uitenhage district (Eastern Cape, South Africa) is the abundance of many of the European water plants, viz:* Chara, Typha, Potamogeton *and* Myriophyllum spp. *which were found, but rarely in the other districts*"(pp 360).

Table 2. The records and localities of *Myriophyllum spicatum* in southern Africa, including the invasion stage as either established or introduced, as well as the invasion category according to the framework proposed by Blackburn et al. (2011). A list of herbarium specimens is in Appendix 1.

Country	Province	River system	Years of records	# of records	localities	Herbaria	Stage	Invasion category
South Africa	Eastern Cape	Swartkops River*	1829-1830	2	1	SAM	Casual	C0
		Wetland near Hankey	1927	1	1	PRE	Casual	C0
		Klipplaat River+	1968-2013	3	1	PRE; GRA	Established	D1-E
	Kwa-ZuluNatal	Mooi River	1885-1967	5	2	BOL; NH; PRE; NU; UDW	Established	D1-E
		Umzimkulu River	1958	1	1	PRE	Casual	C0
		Lake Sibaya+	1965-2012	9	1	PRE; GRA; NH	Established	D1-E
	Western Cape	Cogmans Kloof River*	1922	2	1	BOL; PRE	Casual	C0
		Breede River*	1923-1938	2	2	PRE; SAM	Established	D1-E
		Verlorenvlei*	1938-1994	6	1	BOL; NBG; GRA; PRE	Established	D1-E
	Northern Cape	Vaal and Orange River below the confluence*+	1877-2012	20	Several	PRE; BOL; NGB; SAM; GRA; UDW	Established	D1-E
		Modder River*	1908-1919	4	1	SAM; BOL; PRE; KMG	Established	D1-E
		Riet River*	1936-1963	3	2	PRE	Established	D1-E
	Gauteng	Bronkhorstspruit River	1934-1990	2	1	PRE	Established	D1-E
Zimbabwe		Zambezi River, vicinity of Victoria Falls*	1913-1949	4	1	GRA; BOL; PRE; SRGH	Established	D1-E
		Harare	1919	1	1	PRE	Casual	C0
Botswana		Chobe River	1930	1	1	J	Casual	C0
Botswana and Namibia		Linyanti River	1972-1999	4	4	SRGH; PSUB; PRE	Established	D1-E
		Singalamwe District	1975-1983	2	2	PRE	Casual	C0
Malawi		Lake Malawi	1969-1986	4	3	SRGH; GRA; PRE	Established	D1-E
Zambia		Lake Tanganyika	1947-1961	2	1	PRE; SRGH	Established	D1-E
		Kafue River+	1959-1960	2	1	PRE; SRGH	Casual?	C0

* Indicates flowering/fruiting individuals in the herbarium records and + indicates the river systems where populations of *Myriophyllum spicatum* that have been found during field surveys and are currently surviving. ? - The records for the Kafue system would indicate that the plant failed to establish, however this is the only other system where *M. spicatum* has been referred to as having a high abundance (Wild 1961) and is still surviving.

The aquarium trade has been implicated in many of the more recent aquatic macrophyte introductions (Martin and Coetzee 2011), however it is unlikely that this could be the cause of the first introductions as early as the 1820s. The transportation of fish from the native range of *M. spicatum* such as common carp from Europe or goldfish from Asia could account for its introduction into southern Africa (de Moor and Bruton 1988). The time of introduction of both these fishes, early 1800s for European common carp and 1726 for Asian goldfish (Bruton and Merron 1985), would be early enough for the associated introduction of *M. spicatum*. Aquatic vegetation is a well-known spawning medium for several fishes including goldfish (Battle 1940), which could explain the associated transportation and inadvertent introduction of *M. spicatum*.

Stage 2: Introduction

The mode of and potential motive for the transport of *M. spicatum* from the native range to southern Africa is likely to be associated with the introduction and spread of exotic fishes. Since the first record in the 1820s, there have been a total of 80 verified records (Table 2, Appendix 1) of *M. spicatum* in 21 independent river systems in southern Africa (Figure 1). This suggests that *M. spicatum* has overcome the barriers that would limit its survival in a novel habitat and is likely to have established in several systems throughout southern Africa.

Stage 3: Establishment

A species is considered established in a novel habitat when a population persists for several generations (for plants, 10 years (Richardson et al. 2011)), however if a species cannot persist for whatever reason in the novel habitat, it is considered casual (Blackburn et al. 2011). In order to assess establishment of *M. spicatum* in river/catchment systems, the plant was considered to be established when records spanned at least 10 years (Richardson et al. 2011) and in some cases several localities within the system (Table 2). In eight of the 21 river/catchment systems in southern Africa where *M. spicatum* has been reported, there was no evidence of establishment and its local invasion stage was C0 - casual (Table 2). In the other 13 systems, the records spanned at least 10 years so it is considered established (Table 2). The field surveys to locate currently established populations of *M. spicatum* identified only three in South Africa: the Vaal River -26.9374°, 27.0559°, Lake Sibaya -27.3504°, 32.6862° and the Klipplaat River -32.49387°, 26.94959°; and one in Zambia, the Kafue River -14.913846°, 25.928701°. This is not to say that *M. spicatum* has gone locally extinct, submerged plants can be extremely difficult to find and it is possible that it may have been overlooked.

With regard to population persistence, sexual reproduction is considered relatively insignificant by several authors, with auto-fragmentation as the main mode of reproduction which usually occurs at the end of the growing season (Aiken et al. 1979; Smith and Barko 1990). However there were a number of flowering specimens recorded in the southern African herbarium material, from several of the systems (Table 2) which is further evidence that the plants have established and have the potential to sexually reproduce.

Stage 4: Spread

Information on the motive for the introduction of exotic species is lacking, especially for introductions pre-1900s. *Myriophyllum spicatum* is no exception with no records for the intentional spread in southern Africa. The current disjunct distribution in southern Africa would suggest anthropogenic point source introductions with the dispersal over the considerable distances between and across major catchments in southern Africa is likely to be linked to an anthropogenic pathway. The most recent new population of *M. spicatum* to be found in southern Africa was in 1975 in the Singalamwe District, Northern Botswana which suggests that dispersal in southern Africa is limited. The most common mode of spread in the introduced range (North America) is the movement of viable vegetative fragments between catchments by recreational water users, such as boaters and fishermen (Aiken et al. 1979; Smith and Barko 1990; Smith et al. 2002). This suggests that the major barrier for *M. spicatum* in southern Africa is its inability to spread naturally across the greater distances between catchments or major river systems. Despite this, in southern Africa, *M. spicatum* has spread a considerable distance from the putative point of introduction (assuming that the Swartkops River is the first point of introduction) and therefore is considered to be a fully invasive species in the category of E according to Blackburn et al. (2011).

Category of invasion

In southern Africa there are several populations and locations where *M. spicatum* has been recorded over a wide geographical distribution, so the categorisation needs to be done on a regional scale, as well as each individual system (Table 2). On a regional scale, using the unified framework proposed by Blackburn et al. (2011), *M. spicatum* has dispersed a considerable distance from the point of introduction and has managed to invade a wide spectrum of habitats and therefore is categorised as an **E** invasion. When each system is considered individually, the systems where *M. spicatum* is considered casual were categorised as **C0** invasion with establishment failure, while the systems where *M. spicatum* has established, is reproducing (either sexually or vegetatively) and spreading within the system, the populations could be categorised as a **D1-E** invasion. The limiting factor for *M. spicatum* within each system is its inability to spread unaided between catchments and river systems.

Management

Blackburn et al. (2011) propose appropriate management strategies for the control of invasive species depending on the invasion stage. In the case of *M. spicatum* where it is considered in the C0 stage, the suggested management action is either containment or eradication. In these systems where *M. spicatum* was considered casual, long term establishment has probably failed and therefore any further management is unnecessary. However, in the systems where *M. spicatum* has established and between the D1-E category, eradication is usually not a viable option due to the logistics around the large size of some of these systems. For example *M. spicatum* is currently found along the majority of the 800km Vaal River (Coetzee et al. 2011b). Containment, and in some cases mitigation, are viable options, and priority should be given to systems where the populations of *M. spicatum* are either problematic or the likelihood of breaching the dispersal barrier through anthropogenic means is high. In both of these cases, the Vaal River would be on the highest priority due to the high number of commercial and recreational water users such as farmers, boaters and fishermen whom are likely to encounter *M. spicatum*.

Potential management strategies

Management options for *M. spicatum* in southern Africa are limited due to the given infrastructural and logistical limitations that the region has to offer. This is further complicated by the fact that no herbicides are registered for use against *M. spicatum* in the region, and the sensitive nature of many of the systems in which it occurs (Lake Sibaya: pristine natural lake, Klipplaat River: pristine mountain stream, the Vaal River: important source of irrigation for food crops, and the Kafue River: large tropical river with significant ecological services for the area). There has been some success in southern Africa in terms of awareness and education with other submerged aquatic weeds (e.g. *Hydrilla verticillata* (L.f.) Royle in the Pongolapoort Dam) and the implementation of inspection and cleaning bays for boats at slipways (Coetzee et al. 2009). The suitability of a biological control programme using the North American weevil *Euhrychiopsis lecontei* Dietz (Coleoptera: Curculionidae) is being investigated for southern Africa with the hopes of implementation in the near future (Coetzee et al. 2011b).

Conclusion

Myriophyllum spicatum has established and is spreading in southern Africa. This is the first attempt at using a unified invasion framework to categorise the invasion of a freshwater macrophyte and identify appropriate management strategies. However there is scope for future studies on specific management practices that would be suitable for southern Africa. In addition to this monitoring the dynamics of the systems (biotic and abiotic) where *M. spicatum* is established to determine any negative ecological impacts in southern Africa.

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Supplementary material

The following supplementary material is available for this article:

Appendix 1. A list of the *Myriophyllum spicatum* specimens and the herbaria where they are housed.

Appendix 2. Summary of all the *Myriophyllum spicatum* specific field surveys that have been conducted in southern Africa.

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