

Distribution of Clam Shrimps (Crustacea: Laevicaudata and Spinicaudata) in South Africa, with New Records from the Northern Cape Province

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The ephemeral waterbodies of southern Africa are regarded a global hotspot for large Branchiopod diversity. Although the distributions and systematics of Anostraca and Notostraca have been fairly well defined, clam shrimps have received much less attention. So far, 18 clam shrimp species are known from the sub-region, but none of the available published literature defines their distribution in South Africa. Furthermore, most of the recent studies were concentrated in the mesic provinces, while very little information is available from the Northern Cape, where most ephemeral waterbodies in the country occur. This study reviews the distribution of clam shrimps in South Africa by reviewing published distribution records and contributing novel data from surveys in the Northern Cape. We found that 13 of the 18 species from the sub-region occur in South Africa, of which four are restricted to their respective provinces. We further clarify the current state of endemism patterns in South Africa and provide novel findings from the Northern Cape, including three new range extensions. The Northern Cape hosts the highest species richness, with nine species, followed by the Eastern Cape, where seven species have been recorded so far. Most other provinces have low species richness and endemism, while no species records have been published from the Limpopo province yet. Surveys over large geographical scales are important, and more research is needed on clam shrimp systematics in South Africa.

Key words: Wetlands, Ephemeral, Endemism, Richness, Branchiopoda.

BACKGROUND

Ephemeral water bodies include a diverse array of intermittently inundated wetland systems that support unique and specially adapted aquatic invertebrates (Calhoun et al. 2017). They are especially conspicuous in semi-arid and arid landscapes (Atashbar et al. 2014), but their sporadic nature causes them to be neglected

in research and conservation efforts (Herremans 1999). Ephemeral wetlands are particularly vulnerable to alterations in land use patterns, because any hydrological modifications in the neighbouring landscape ultimately affect their ecological functioning (Calhoun et al. 2017). However, during their desiccated phases, which can last for years (Brendonck et al. 2008), these systems are often either completely overlooked or regarded as

lifeless and unimportant. This state of ignorance causes anthropogenic disturbances and changes to continuously pressure the unique biodiversity of these temporary waterbodies and renders their associated species vulnerable to decline and extinction (De Roeck et al. 2007; Amis et al. 2009; Atashbar et al. 2014; Dalu et al. 2017).

Large Branchiopods are the flagship aquatic invertebrates of ephemeral waterbodies globally (Brendonck et al. 2008). The orders Notostraca (tadpole shrimps) and Anostraca (fairy shrimps) are the two most well-known branchiopod crustacean groups and have been fairly well studied (Bird et al. 2019). The order Diplostraca with suborders Laevicaudata, Spinicaudata and Cyclestherida, make up the third major group of large Branchiopods, colloquially known as clam shrimps (Bird et al. 2019). Collectively, clam shrimps consist of five extant families, 19 genera and ~155 species; and even though they are widespread and abundant globally, they have not been well studied (Brendonck et al. 2008; Bird et al. 2019).

The ephemeral waterbodies of southern Africa are regarded a global hotspot for large Branchiopod diversity (Bird et al. 2019) and yet these systems have been neglected, especially in terms of their associated species (Martens and De Moor 1995; Mlambo et al. 2011). Clam shrimps have received much less attention than other associated fauna in the region (Bird et al. 2019). Eighteen clam shrimp species are known from the sub-region (Brendonck 1999; Bird et al. 2019), but none of the available published literature defines the distribution of clam shrimps in South Africa. Brendonck (1999) provided an authoritative summation on the clam shrimps in Southern Africa, but a number of faunistic inventories pre-dating his analysis (Hamer and Appleton 1991; Seaman et al. 1995; Hamer and Martens 1998) were not included. Furthermore, most of the recent studies (De Roeck et al. 2007; Vanschoenwinkel et al. 2008; Ferreira et al. 2012; Mabidi et al. 2016), were concentrated in mesic regions. These include areas in Western Cape, Free State, Mpumalanga and Eastern Cape, which receive average annual rainfall of 400 - 1000 mm. Conversely, the Northern Cape is the largest, most arid (MAP < 350 mm) province in South Africa, with the most pronounced occurrence of ephemeral waterbodies, but very little information is available on these systems or their associated biodiversity (Meyer-Milne and Mlambo 2019). This limits our understanding on the richness patterns and conservation status of clam shrimps in the country, which in turn causes concerns regarding land use management. Therefore, we review the distribution of clam shrimps in South Africa, by providing an overview of published distribution records and contributing novel data from the Northern Cape.

We aim to depict the known geographical distribution, richness and endemism patterns of clam shrimps in South Africa and highlight opportunities for future research focus.

MATERIALS AND METHODS

We examined the peer reviewed published literature for clam shrimp records from South Africa, and also include additional data from our own surveys across the Northern Cape Province (Fig. 1). Our surveys were conducted during 2017 and 2018 in 18 wet locations, using a square frame 500- μ m aquatic sweep net (30 cm wide), of which 13 sites produced clam shrimps. Hatching experiments were conducted in 2018 from sediment collected from 98 desiccated locations during 2017, of which clam shrimp species from 15 locations were successfully reared for identification. This entailed inundating the sediment in 2L plastic containers and allowing species to hatch and grow over a 28 days period (Henri et al. 2014) from nutrients that naturally occur in the sediment. Hatching was performed in a semi-controlled environment using a temperature exposure that simulates the average temperature for the region (26–28°C) and a 24 hour photoperiod. All *Triops* were removed to prevent predation. Identifications were made by direct comparison with the primary taxonomic literature, existing keys (Barnard 1929; Brendonck 1999), and previously identified reference material. All species currently considered valid from South Africa were included in the species richness and endemism analysis. The undetermined *Eulimnadia* spp. were excluded from these counts. Species richness is defined as the number of species that have been recorded in a given province, while endemic species include those known only from South Africa or a specific province. Species are considered to have restricted distributions if they are known from only one of the nine provinces, even though they are not endemic to South Africa.

RESULTS

The specific results are presented in table 1. A total of 13 clam shrimp species including five endemics are recognised from South Africa to date, all of which are from the suborders Laevicaudata and Spinicaudata. No species of Cyclestherida have been recorded in South Africa yet and only Spinicaudata species have so far been recorded in the Northern Cape. The Northern Cape has the highest species richness and endemism, hosting nine species of which three are restricted- and one is endemic to the province. No species records have so

far been published from Limpopo Province. *Ozestheria australis* (Loven, 1847) is the most widespread species with a distribution across eight of the nine provinces, followed by *Leptestheria rubidgei* (Baird, 1862) which occurs across six provinces. Four species have restricted distributions, including *Lynceus triangularis* Wolf, in litteris: Daday, 1927 (Eastern Cape), *Eocycticus dentatus* Barnard, 1929 (Northern Cape), *E. gigas* Barnard, 1924 (Northern Cape) and *Gondwanalimnadia alluadi* (Daday, 1926) (Northern Cape). Of these, *L. triangularis* and *E. dentatus* are also endemic to their

respective provinces.

Five species were found during our surveys (Table 1), all of which belong to Spinicaudata. Of these, *Leptestheria striatoconcha* Barnard, 1924 was recorded for the first time in the Northern Cape at four locations, with a fairly disjunct geographic distribution (Fig. 2). *Eocycticus obliquus* (Sars, 1905) had the most widespread distribution in the province compared to the other species and was recorded from 11 locations, over a large geographical range (Fig. 2). *Ozestheria australis* was common, with nine records, but had a smaller

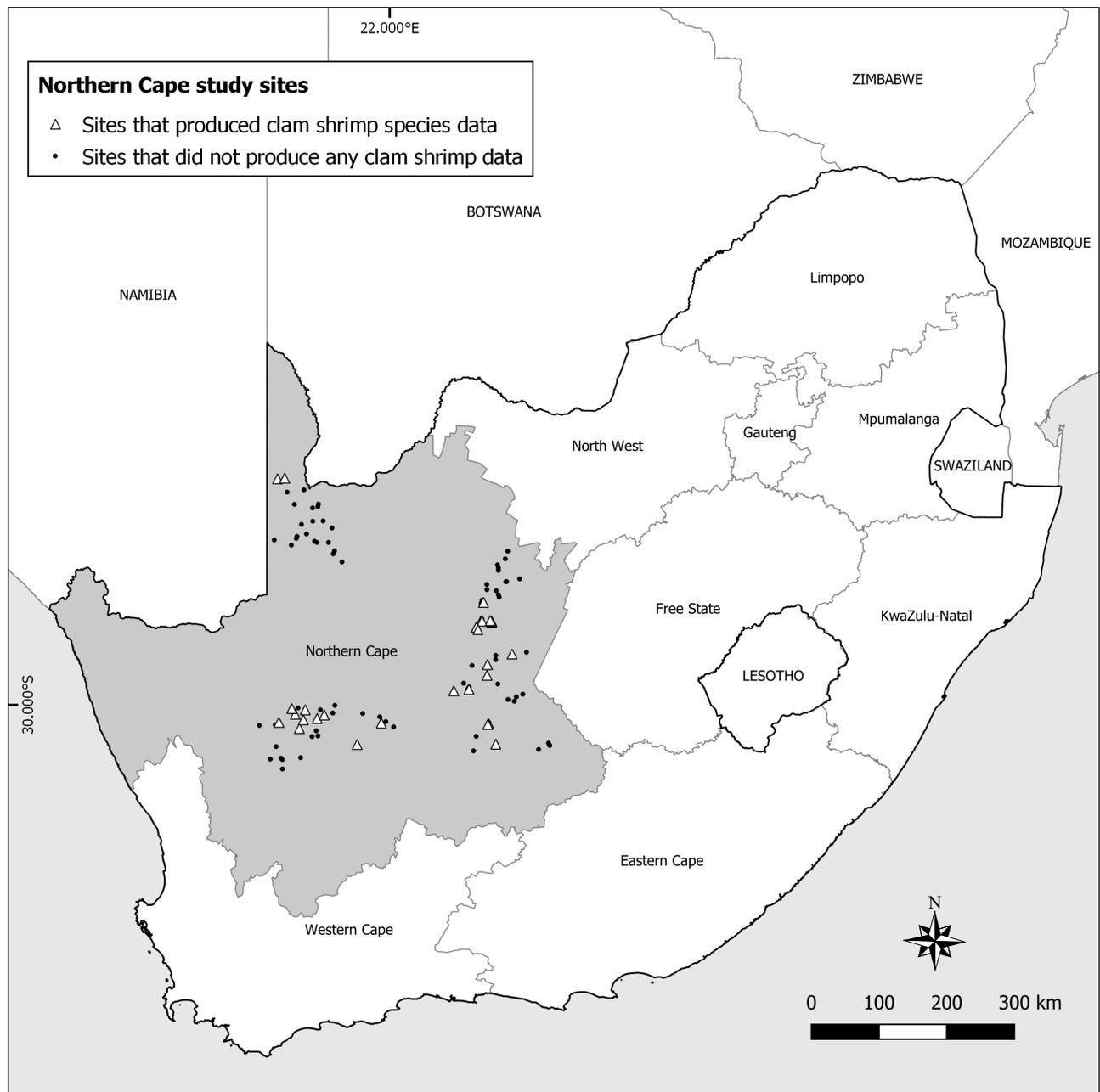


Fig. 1. Map of the study area, including the study sites in the Northern Cape from the current study.

distribution within Northern Cape (Fig. 2), while *L. rubidgei* Baird, 1862 had a restricted distribution towards the eastern parts of the Northern Cape and was only found at two locations. *Eocyclus gigas* Barnard, 1924 was only found in one location and was found for the first time outside its type locality. The taxonomy for *Eulimnadia* sp. still needs to be determined, but it was fairly common and restricted to the eastern parts of the Province.

DISCUSSION

The 14 clam shrimp species recorded in South Africa represent over 70% of those recorded from the sub-region and compares to the diversity of neighbouring Namibia, where Curtis et al. (1998) reported 15 clam shrimp species. However, the diversity of clam shrimps in South Africa is far lower compared to countries such as Australia (Timms 2018) and India (Rogers and Padhye 2015; Padhye et al. 2018), from which 71 and 27 species have been recorded (Rogers 2020). *Ozestheria australis* is the most widely distributed clam shrimp in South Africa, and has been recorded in neighbouring Namibia, Botswana and Zimbabwe, but has never been found beyond the sub-region (Brendonck 1999). Similarly, the widespread *Leptestheria rubidgei* (Baird, 1862) has also been found in neighbouring countries Namibia, Botswana and Lesotho, but has not been recorded beyond the sub-region (Brendonck 1999).

The endemic distribution of *Lynceus triangularis* Wolf, in litteris: Daday, 1927 (Eastern Cape) was reflected in Brendonck (1999) and has not been recorded since. *Gondwanalimnadia alluaudi* (Daday, 1926) (restricted to the Northern Cape) was only found again near Postmasburg by Buschke et al. (2012). *Eocyclus gigas* was believed to be endemic to Namibia (Brendonck 1999), but a recent review by Rogers et al. (2017) suggested *E. minor* is a junior synonym. Therefore, the type locality for *E. minor* depicted in Brehm (1958), extends the distribution of this species into South Africa. We report it for the first time, almost 200 km north from where it was first collected in South Africa.

Eocyclus dentatus Barnard, 1929 and *E. obliquus* (Sars, 1905) were previously considered absent in the Northern Cape, due to the erroneous inclusion of its type locality (Hanover) in the Eastern Cape (Brendonck 1999). Hanover is in the Northern Cape. *Eocyclus dentatus* was known from its type locality near Hanover, but was later also found near Kimberley (Northern Cape) by Herrmann et al. (2004). Therefore, it is endemic to the Northern Cape and not the Eastern Cape

as previously reported. Similarly, *E. obliquus* was only found twice before; near Hanover (Northern Cape) and Potchefstroom (North West). Its widespread occurrence in the Northern Cape, based on our records, elucidates that this species may be common.

New localities for four South African species previously believed to have limited distribution in South Africa (Brendonck 1999) were discovered. *Lynceus pachydaetylus* Barnard, 1929 previously thought to be endemic to Gauteng, was discovered by Ferreira et al. (2012) in Mpumalanga. Mabidi et al. (2016) recorded *Lynceus truncatus* Barnard, 1924 and *Leptestheria inermis* Barnard, 1929 for the first time in the Eastern Cape. *Leptestheria striatoconcha* Barnard, 1924 was believed to be restricted to its type locality near Heidelberg (Gauteng), but was reported by Vanschoenwinkel et al. (2008) on the Korannaberg Mountains (Free State), and also by Mabidi et al. (2016) near Jansenville (Eastern Cape) and in our study at several localities. Similarly, *Lynceus bicarinatus* Barnard 1924 was thought to be restricted to Free State, but its distribution in KwaZulu-Natal, reported by Hamer and Appleton (1991) was omitted from Brendonck (1999).

The Cyclestheriidae, which was shown to contain numerous cryptic species (Schwentner et al. 2013), has been reported (as *Cyclestheria hislopi* (Baird, 1859)) from neighbouring Namibia, Botswana and Zimbabwe (Brendonck 1999; Nhiwatiwa et al. 2011). This taxon is circumtropical (Sonia et al. 2010), which suggests its absence in South Africa.

Our study and that of Mabidi et al. (2016) found undetermined *Eulimnadia* specimens. Rabet (2010) argued the different morphological variations typically found in Spinicaudata causes species level confusion and therefore additional parameters such as egg morphology and molecular characters should be used. He further speculated that each locality for the southern African *Eulimnadia* population could represent a separate species.

The higher species richness in the Northern- and Eastern Cape provinces could be attributed to the fact that these two regions have recently been surveyed extensively, including the artificial hatching of specimens from dry soil (Sars' Method). Van Damme and Dumont (2010) revealed that their total species numbers were substantially (44%) supplemented through hatching experiments. Apart from our study, which is the first to cover a large geographical area in the Northern Cape, Mabidi et al. (2016) studied 22 waterbodies across the Eastern Cape Karoo. De Roeck et al. (2007) and Mlambo et al. (2011) respectively surveyed 58 and 138 temporary wetlands in the Western Cape and both still found low clam shrimp diversities.

Table 1. Clam shrimp species recorded from South Africa based on literature records and the current study. Provinces include the Western Cape (WC), Northern Cape NC, Free State (FS), North West (NW), Gauteng (GT), Limpopo (LP), Mpumalanga (MP), KwaZulu-Natal (KZN) and Eastern Cape (EC). National endemics are indicated by ^E, while province endemics are highlighted in grey. Demographics are depicted as (species richness, no. of restricted species)

Suborder/Family/Species	Distribution across provinces									
	WC (2,0)	NC (9,3)	FS (4,0)	NW (2,0)	GT (5,0)	LP (0,0)	MP (3,0)	KZN (5,0)	EC (7,1)	
LAEVIKAUDATA										
Lynceidae										
<i>Lynceus bicarinatus</i> Barnard, 1924			Brendonck (1999)		Brendonck (1999)		Ferreira et al. (2012)	Hamer and Appleton (1991)		
<i>Lynceus pachydaetylus</i> Barnard, 1929 ^E					Brendonck (1999)					Brendonck (1999) Mabidi et al. (2016)
<i>Lynceus triangularis</i> Wolf, in littoris: Daday, 1927 ^E										
<i>Lynceus truncatus</i> Barnard, 1924								Hamer and Appleton (1991); Brendonck (1999)		
SPINICAUDATA										
Cyzicidae										
<i>Ozestheria australis</i> (Loven, 1847)	Brendonck (1999)	Hamer and Rayner (1996); Brendonck (1999); Herrmann et al. (2004); Current study	Brendonck (1999)	Brendonck (1999)	Brendonck (1999)		Brendonck (1999)	Hamer and Appleton (1991)		Hamer and Martens (1998); Brendonck (1999); Mabidi et al. (2016)
<i>Eocyclus dentatus</i> Barnard, 1929 ^E		Brendonck (1999); Herrmann et al. (2004)								
<i>Eocyclus gigas</i> Barnard, 1924		Brehm (1958); Current study								
<i>Eocyclus obliquus</i> (Sars, 1905) ^E		Brendonck (1999); Current study		Brendonck (1999)						Mabidi et al. (2016)
Leptestheriidae										
<i>Leptestheria inermis</i> Barnard, 1929 ^E		Brendonck (1999)	Seaman et al. (1995)							Mabidi et al. (2016)
<i>Leptestheria rubidgei</i> (Baird, 1862)	Brendonck (1999); De Rooeck et al. (2007); Mlambo et al. (2011)	Brendonck (1999); Herrmann et al. (2004); Current study		Brendonck (1999)			Ferreira et al. (2012)	Hamer and Appleton (1991)		Brendonck (1999); Mabidi et al. (2016)
<i>Leptestheria striatoconcha</i> Barnard, 1924										
Limnadiidae										
<i>Eulimnadia africana</i> (Brauer, 1877)		Brendonck (1999)			Brendonck (1999)			Hamer and Appleton (1991); Hamer and Martens (1998)		
<i>Eulimnadia</i> sp. (undetermined)		Current study								
<i>Gondwanalimnadia alluandi</i> (Daday, 1926)		Brendonck (1999); Buschke et al. (2012)								Mabidi et al. (2016)



Fig. 2. The distribution of clam shrimp species in the Northern Cape, derived from the current study.

The complicated and problematic systematics of the clam shrimps (Bird et al. 2019) might have also resulted in less species information being published for the other provinces, even though extensive surveys for large Branchiopods have been conducted. For example, Henri et al. (2014) performed extensive aquatic sampling and hatching experiments from 30 ephemeral pans across Mpumalanga, North West and Free State; however, no clam shrimp species data were published from these studies. This reinforces the statement from numerous authors (Hamer and Martens 1998; Rogers et al. 2012; Bird et al. 2019) that there is a desperate need for systematic research on clam shrimps in South Africa. Even though this study covered an extensive geographic range in the Northern Cape, the unpredictable climate and complexities relating to hatching experiments still rendered less desirable species distribution information, which demonstrates a fairly low return on effort. We appeal to all scientists that work on temporary wetlands in the region, to collaborate with professional taxonomists, so that robust taxonomic information can be obtained. We further appeal to prioritise the ephemeral wetlands in the Northern Cape and Eastern Cape as hotspots for clam shrimp diversity, and to navigate research efforts towards the ephemeral waterbodies of least surveyed provinces, such as the Limpopo Province. We especially encourage survey attempts on a large geographical scale and implore researchers to publish species data that has already been collected.

CONCLUSIONS

Until now, no cohesive literature was available on the distribution of clam shrimps in South Africa. We reviewed available publications and surveyed an extensive area in the Northern Cape Province to clarify the geographical distribution, richness and endemism patterns of clam shrimps in the country. We discuss the current state of endemism patterns in South Africa and provided novel findings from the Northern Cape, including three new range extensions. We suggest that the Northern Cape and Eastern Cape be regarded as hotspot regions for clam shrimp diversity in South Africa. This study further revealed the deficiency in species information in most provinces, especially for the Limpopo Province and appeal for more research on the systematics of clam shrimps from South Africa and for species data to be published.

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Authors' contributions: E. Meyer-Milne is the lead author on this paper and was responsible for field work and research design. M.C. Mlambo is another co-author on this paper and was responsible for identifying samples from one locality in the Northern Cape. D.C. Rogers is a co-author on this paper and was responsible for identifying most samples from the Northern Cape and provided research guidance throughout the project.

Competing interests: The authors declare that they have no competing of interests.

Availability of data and materials: This paper does not contain any personal data beyond that belonging to the authors. The specimens are kept in the collections of Christopher Rogers (Kansas Biological Survey) and the Freshwater Invertebrates collection at the Albany Museum (South Africa). Information gathered from literature is cited in text. For future use of datasets presented in this paper, please contact the corresponding author.

Consent for publication: Not applicable.

Ethics approval consent to participate: No ethics approval needed for clam shrimps in South Africa, but permits were obtained for the purpose of this study from the local authorities. Permit information is presented in the acknowledgments section.

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