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CONSERVATION STATUS OF LARGE BRANCHIOPODS IN THE WESTERN CAPE, SOUTH AFRICA

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Abstract: Temporary wetlands are an ecologically and economically important habitat in South Africa. They harbor large branchiopods, known to be flagship species of nonpermanent aquatic habitats, and sensitive to land use changes. In this study we review the current status of large branchiopods in the Western Cape, a South African province subject to increasing agriculture and urbanization. We studied the species diversity and distribution of large branchiopods by sampling 58 temporary wetlands in an area covering about 30% of the Western Cape. Information obtained from field samples was supplemented by incubating resting egg banks from the sampled wetlands. Our data were compared with all known distribution records for large branchiopods in the target region. Based on this combined information, the International Union for the Conservation of Nature and Natural Resources (IUCN) Red List category was assessed for each species. Four of the eight large branchiopod species known to occur in the sampling area were collected. Of all wetlands sampled, 40% harbored large branchiopods. Most anostracan populations were small, and species co-occurred in only one wetland. From the entire Western Cape, 14 species have been recorded in the past. Two of these are already included in the IUCN Red List. Insufficient data are available to determine the IUCN Red Data Category of six other species. A large variation in the telsonic appendages of *S. dendyi* was found across the studied area. In view of possible ongoing speciation and subsequent radiation, individual populations need protection. Since little information is available, it is difficult to evaluate recent changes in the conservation status of large branchiopods. Their populations are currently very low and have probably diminished in the last few decades. More knowledge about the functioning of temporary systems is needed to manage these vulnerable habitats and conserve their threatened species.

Key Words: Anostraca, biodiversity, distribution, temporary wetlands, threatened species

INTRODUCTION

The Western Cape of South Africa harbors the famous Cape Floristic Kingdom (CFK), known to hold a uniquely rich terrestrial flora with high levels of endemism (Balmford 2003). Its aquatic systems also have a remarkably high degree of endemism in their fauna and flora, perhaps as a result of the varied chemical and physical conditions among wetlands, as well as their oligotrophic and often seasonal or ephemeral state (Wishart and Day 2002).

Temporary systems in particular display various phenologies, depending on the local climate, soil characteristics, and hydrology. Different types of temporary wetlands in the Western Cape are vleis (general South African term covering different wetland types, such as temporary saline or freshwater systems), pans, ponds, and dams (Jones and Day 2003). They are filled with fresh or brackish water and house distinct communities, often containing not only endemic but also threatened species (Wishart and Day 2002). They have an essential ecological and socioeconomical function and are internationally and nationally renowned as important ecosystems in need of conservation (Convention on wetlands 1971, Water Act 1998).

The organisms occurring in temporary wetlands cope with their ephemeral habitat by structural, behavioral, and physiological adaptations (Wissinger et al. 1999, Schwartz and Jenkins 2000). The large branchiopods (Crustacea, Branchiopoda: fairy shrimps (Anostraca), clam shrimps (Spinicaudata and Laevicaudata), and tadpole shrimps (Notostraca)) are typical inhabitants of ephemeral wetlands in southern Africa and are considered by Belk (1998) to be flagship species of such systems. These organisms cope with the dry phases of the habitat by producing resting eggs, thus forming egg banks, which serve as a buffer against demographic catastrophes (Simovich and Hathaway 1997, Brendonck et al. 1998).

Temporary water bodies are severely threatened worldwide, endangering the persistence of many branchiopod species, as well as other members of the biota. Changes in land use (Belk 1998, Wissinger et al. 1999), pollution (Hamer and Brendonck 1997), and abstraction of water are the major causes of degradation or destruction of these habitats. King (1998) investigated the impact of agriculture and urbanization on temporary pools in the Central Valley of California. Human activities caused destruction of 50%–85% of available habitat, resulting in a loss of as much as 30% of the original crustacean biodiversity. Temporary aquatic systems are probably some of the most neglected and threatened ecosystems in South Africa (Davies and Day 1998), and are likely to have been drastically diminished over recent decades. Some wetlands have already been completely destroyed due to overextraction of water or poor conservation management (Martens and De Moor 1995). To our knowledge, no data have been published on the declining number of temporary wetlands in the Western Cape, but personal observation (J. A. Day) indicates that only a small proportion of natural temporary wetlands still remains in the greater Cape Town metropolitan area, for instance.

In 1998, the government of South Africa passed the National Water Act (Act 38 of 1998). One of its aims was to balance economic growth and development with the protection and conservation of water resources to facilitate their ecologically sustainable use and development. An important tool for the long-term management of water resources is known as the 'Resource Directed Measures' (RDM), set up by the Department of Water Affairs and Forestry (DWAF) to ascertain and maintain the quality and quantity of water required to protect aquatic and associated ecosystems and their biological diversity (DWAF 2003). A new understanding of the current state, structure, and functioning of all kinds of aquatic ecosystems is crucially needed in order to implement this Water Act through the RDM (DWAF 2003).

Since large branchiopods are typical representatives of temporary wetlands, knowledge of their biology and distribution is needed for their conservation. Large branchiopods, being restricted to temporary pools, are extremely vulnerable to habitat destruction because each population is contained totally within a relatively small, isolated wetland (Belk 1998). By protecting these flagship taxa, the vulnerable temporary wetlands will be secured as well. Despite their significance for conservation, only limited literature has been published on the distribution of branchiopods and the factors affecting their distribution, species richness, and conservation status in the Western Cape (e.g., Barnard 1929, Hamer et al. 1994, Hamer and Rayner 1995, Hamer and Appleton 1996, Hamer and Brendonck 1997).

In this article, we compare the current status of large branchiopods obtained from a field survey of 58 temporary wetlands in the Western Cape with their previously known distribution records, supplemented by incubation of resting egg banks from the sampled wetlands. The environmental factors explaining the occurrence of the large branchiopods are presented. Observed geographic variation in the morphology of *Streptocephalus dendyi*, one of the most common species in the region, is examined, taking possible ongoing speciation into account and its consequences for conservation measures. Furthermore, the most important characteristics of individual species are reviewed and the IUCN Red List Categories assessed.

STUDY AREA

The Western Cape, the southwestern province of South Africa (Figure 1), is diverse in climate, geology, land cover, land use, vegetation, soil, and ground-water characteristics (DEAT 2000, Meyer 2000). The mean annual rainfall varies from less than 100 mm in the north and east to more than 2,500 mm in the mountains near Stellenbosch

Figure 1. Geographical position of the Western Cape, South Africa.

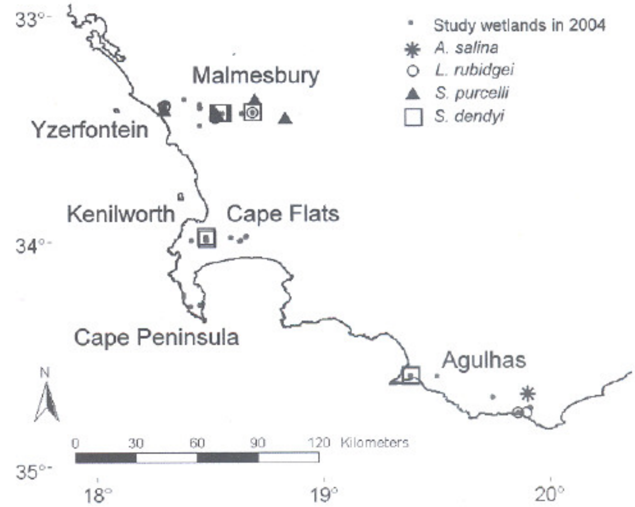

Figure 2. Locations of the study wetlands (dots) with indication of the large branchiopod species collected during July–September 2004 (black star = *A. salina*; open circle = *L. rubidgei*; black triangle = *S. purcelli*; open square = *S. dendyi*).

(Fuggle and Ashton 1979). The cold Benguela current along the west coast and the warmer Agulhas current along the east coast cause strong climatic gradients from north to south and from east to west (Hobbs et al. 1998). Land cover consists mostly of various forms of macchia-like shrubland and cultivated land. The continued urbanization in and around Cape Town has caused significant pollution and land use change in the region.

In a field survey carried out during July to September 2004, 58 temporary wetlands were sampled in the region around Yzerfontein-Malmesbury (28 wetlands), Cape Peninsula (six wetlands), Kenilworth (six wetlands), Cape Flats (six wetlands), and around Agulhas (12 wetlands) (Figure 2). Table 1 summarizes mean annual precipitation, lithology, and land use of each study area. Precise contributions of rainwater, run off, interflow, and ground-water discharge or recharge to the hydrology of the systems are largely unknown.

MATERIALS AND METHODS

Three hydrological categories of wetlands were distinguished: a long (seven to 11 months), a moderately long (four to six months), and a short (one to three months) wet phase. A total of 170 wetlands encountered during the exploration of potential wetlands were classified into these three categories, using information from landowners and maximum depth as an indirect relative measure for hydroperiod. Of these wetlands, 58 were selected randomly in a stratified manner, with the previously mentioned categories as strata. The coordinates of all selected wetlands were incorporated in a GIS framework and were linked with biological data (large branchiopod diversity) in order to facilitate the visualization of the results.

The sampling of large branchiopods was carried out semi-quantitatively by means of a five-minute collection effort with a 250-μm sweep net (catch-surface of 500 cm^2). Each system was surveyed once. At the time of sampling, the wetlands were already inundated for about three weeks (systems with a short hydroperiod) to four months (systems with a long hydroperiod), depending on the hydrological category of the wetland. The collected organisms were preserved in 70% ethanol, counted, and identified to species level using Day et al. (1999).

Resting eggs were collected with a core sampler (diameter 5.2 cm) from all 58 surveyed wetlands. Eight samples (upper 30 mm of the soil) were taken (four in the middle and four at the wetted edge of the wetland) and dried in the sun. In the laboratory, these samples were inundated with EPA medium (US-EPA/600/4-85/013 1985) with optimal conductivity and temperature conditions (predetermined by unpublished experiments), which are similar to the conditions in the field as the pools fill up. Two inundations per wetland were carried out: the fresher wetlands (< 900 μS/cm in the field) were inundated with 20 and with 200 μS/cm EPA at 15°C and the more saline wetlands (> 900 μS/cm in the field) with 200 and 1000 μS/cm EPA at 15°C. Hatched individuals were identified using Day et al. (1999).

The following environmental variables were measured in conjunction with branchiopod sampling.

Table 1. Mean annual precipitation, lithology, and land use of each studied region (from DEAT 2000).

Study area	Cape Flats Kenilworth	Yzerfontein-Malmesbury	Cape Peninsula	Agulhas
Precipitation	595–1015 mm	350–595 mm	595–1015 mm	350–595 mm
Lithology	sand	sand, phyllite, and biotite granite	quartzitic sands	sand, quartzitic sand, shale, and phyllite
Land use	built up; Kenilworth: conservation area	cultivated; Rondeberg: conservation area	conservation area	cultivated and fallow land

Dissolved oxygen concentration (Ox/330/SET-meter) was determined directly in the wetland. Conductivity (LF/330/SET-meter, with temperature compensation) and pH (pH/340-B/SET-1-meter) were measured by means of a mixed water sample, containing about 20 L of water collected at the edge and in the middle of the wetland. Water clarity was determined in the field with a Snells tube. Chlorophyll a concentrations were measured by filtering a maximum volume of water (until saturation of the filter) through a GF/C filter (mesh size: 1.2 µm) and extracting the pigment in methanol following the procedure of Talling and Driver (1963). The amount of suspended matter was analyzed by filtering a maximum volume of water through a previously dried and weighed GF/C Whatman filter, followed by drying the filter for at least 24 hours at 105°C and reweighing it. By subtracting the weight of the original clean filter, the amount of suspended matter (mg/l) was calculated. Chemical oxygen demand, total nitrogen, and total phosphorus were analyzed at the Scientific Services Branch of the Cape Town Unicity. Maximum depth of the wetlands was measured in the field. The surface area was estimated by measuring the length and width of wetlands and using area formuli for geometric features corresponding to the shape of the wetland.

If assumptions were met, parametric t-tests were used to determine the association between the occurrences of large branchiopods (presence/absence data) and selected biotic and environmental variables. If the assumptions of parametric t-tests were not met, logistic regressions were conducted. All tests were done in Statistica 6 (StatSoft Inc. 2001). Presence absence data were used because they are more robust (less subject to ecosystem variability) than abundance data.

All species were evaluated in accordance with the most recent IUCN Red List Criteria (IUCN 2001, 2003). Known geographic distributions over southern Africa were taken into account to determine appropriate categories. The IUCN Red List categories are: extinct (EX), extinct in the wild (EW), critically endangered (CR), endangered (EN), vulnerable (VU), near threatened (NT), and of least concern (LC). The category of some species could not be ascertained because of data limitations (indicated as data deficient: DD). The status of the species was indicated as: rare (R) = less than five individuals collected, uncommon (U) = between six and 20 individuals collected from at least one pool, and common (C) = more than 20 individuals collected from at least one pool. The number of localities in which the species was found and the year in which the species was last collected were also reviewed. The literature, as well as information from local scientists and museum collections, was used to reconstruct the known distribution patterns of large branchiopods in the Western Cape.

To illustrate geographical variation in the common species *S. dendyi*, telsonic appendages of a few individuals of each sampled population were preserved in 4% formaldehyde; subsequently they were dehydrated in an alcohol series (30 minutes in 50%, 75%, 90%, and 100% alcohol). Afterwards, appendages were dried, coated with gold, and photographed under a Philips ESEM XL 30 scanning electron microscope.

RESULTS

Previous and Current Distribution of Large Branchiopods

From literature and previous studies it is known that wetlands of the Western Cape harbored 11 species of Anostraca, two of Conchostraca, and one of Notostraca (Barnard 1929, Hamer and Appleton 1996, Hamer and Brendonck 1997, Day et al. 1999). During our survey, investigating other wetlands in the Western Cape, only the Anostraca *Streptocephalus dendyi*, *S. purcelli*, and *Artemia salina* and the Conchostraca *Leptestheria rubidgei* were collected (Table 2). Physical and chemical measurements of studied wetlands containing large branchiopods are presented in Table 3.

The distribution of the large branchiopod populations collected during our field survey is presented in Figure 2. *Artemia salina* was caught in one saltpan in Agulhas (Figure 2). *Streptocephalus purcelli* was collected from five wetlands and a rockpool in the Yzerfontein-Malmesbury region. Four populations

Table 2. Known distribution of large branchiopods in the Western Cape. Field data collected during July to September 2004 are marked as De Roeck, this study. Species previously collected in the region studied in 2004 are indicated with an asterisk.

Species	Locality	Reference
Artemia salina (Linnaeus)*	Cape Agulhas	De Roeck, this study
	Doornfontein	Jones 2002
	Veldrif Salterns	Triantaphyllidis et al. 1998
	Yzerfontein	Brooke and Day 1983, 1984, pers. obs.
Branchipodopsis dayae Hamer and Appleton	Elands Bay	Hamer and Appleton 1996
B. hodgsoni Sars*	Ashton	Barnard 1929
	Bredasdorp	Hamer and Appleton 1996
B. karroensis Barnard	Beaufort West, Hoogeveld	Barnard 1929
B. wolfi Daday	Beaufort West	Wirminghaus 1993, pers. obs.
Streptocephalus cafer (Loven)	Prince Albert	Adie 1995, pers. obs.
S. dendyi Barnard*	Brandfontein	Jones 2002
	Cape Agulhas	Hamer and Brendonck 1997
	Gansbaai	De Roeck, this study
	Kenilworth, Cape Town	De Roeck, this study
	Rondebosch, Cape Town	Barnard 1929
	West of Paarl	Hamer and Brendonck 1997
	Yzerfontein-Malmesbury	De Roeck, this study
S. gracilis Sars*	Cape Town	Sars 1898
S. ovamboensis Barnard	Beaufort West	Wirminghaus 1993, pers. obs.
	Oudsthoorn	Hamer and Brendonck 1997
S. papillatus Sars	Beaufort West, Hoogeveld	Barnard 1929
S. purcelli Sars*	Cape Town	Hamer and Brendonck 1997
	Blinkvlei	Jones 2002
	Cape Flats near Epping	Brendonck before 1994, pers. obs.
	Citrusdal	Hamer and Brendonck 1997
	Darling-Malmesbury	De Roeck, this study
	Green Point Common	Sars 1898, Stebbing 1910
	Palmiet Fontein	Jones 2002
	Rondeberg	De Roeck, this study
	Ronderug	Jones 2002
	Saint Helena Bay	Hamer and Brendonck 1997
	Sandvlei	Jones 2002
	Simonstown, Plumstead	Brendonck before 1994, pers. obs.
	Stellenbosch	Barnard 1929
	Stompneus Baai, Saldahna	Barnard 1930
	Yzerfontein	Hamer, pers. obs.
	Zuurvlakte	Jones 2002
Cyzicus australis (Loven)	Albertinia	Brehm 1951
	Beaufort West	Barnard 1929
	Langklip	Barnard 1929
	Prince Albert	Barnard 1929
Leptestheria rubidgei (Baird)*	Beaufort West	Barnard 1929
	Bushmanland	Sars 1900
	Cape Flats	Barnard 1930
	Cape Flats	Day 1983, pers obs
	Darling-Malmesbury	De Roeck, this study
	Gansbaai	De Roeck, this study
	Green Point Common	Sars 1898, Sars 1899
	Mosselbay-Albertinia	Barnard 1929
	Pacaltsdorp	Barnard 1928
	Palmiet Fontein	Jones 2002
	Prinskraal	Barnard 1929
	Rietfontein	Snow and Day, pers. obs. 1983

Table 2. Continued.

Species	Locality	Reference
	Rondeberg	De Roeck, this study
	Ronderug	Jones 2002
	Sandvlei	Jones 2002
	Zuurvlakte	Jones 2002
	Zwartrug	Jones 2002
Triops granarius (Lucas)*	Agulhas, Springfield	Day 1990, pers. obs.
	Beaufort West	Day 1985, pers. obs.
	Carnarvon	Barnard 1929
	Mosselbay	Barnard 1929
	Piquetberg	Barnard 1929
	Rietfontein	Snow and Day 1983, pers. obs.
	Ronderug	Jones 2002
	Sandvlei	Jones 2002

of *S. dendyi* were collected in Agulhas, three in Kenilworth, and four in the Yzerfontein-Malmesbury area. Two populations of *L. rubidgei* occurred in Agulhas and four in the Yzerfontein-Malmesbury area. Overall, Anostraca were found in 18 (31%) of the 58 study wetlands, and Conchostraca in six (10%); no Notostraca were collected at any of the sites. Inundation of the resting egg bank of all 58 sampled wetlands revealed eight new populations of large branchiopods, but no additional species were found.

In one wetland around Malmesbury, *S. dendyi* and *L. rubidgei* were found together. *Streptocephalus dendyi* and *S. purcelli* typically occurred at low densities. In nine (81%) of the 11 wetlands harboring *S. dendyi* and in four (67%) of the six containing *S. purcelli*, fewer than 15 individuals were found in the five-minute search.

The anostracans *S. gracilis*, *Branchipodopsis dayae*, and *B. hodgsoni*, and the notostracan *Triops granarius* were not found in our study, although they had previously been collected in the same region (Table 2, Figures 3, 4, and 5). Outside the regions we studied, the anostracans *Branchipodopsis karroensis*, *B. wolfi*, *S. ovamboensis*, *S. cafer*, and *S. papillatus* and the conchostracan *Cyzicus australis* were previously collected in the Western Cape (Table 2, Figures 3, 4, and 5). Distribution patterns of all large branchiopods from the whole Western Cape are summarized in Figures 3, 4, and 5.

Relation Between Environmental Variables and the Distribution of Large Branchiopods

Large branchiopods populated temporary wetlands with a variable inundation period of four weeks to about 10 months. Hydroperiod (estimated by maximum depth of the wetland) had no significant effect on the distribution of *S. dendyi* (logistic regression: df = 2, Wald stat = 5.801, $p > 0.05$), *S. purcelli* (logistic regression: df = 2, Wald stat = 1.214, $p > 0.05$), or *L. rubidgei* (logistic regression: df = 2, Wald stat = 0.174, $p > 0.05$). Over all 58 wetlands, *S. dendyi* had a significantly greater chance of occurring in habitats with a low chemical oxygen demand (logistic regression: df = 1, Wald stat = 4.443, $p = 0.035$), and the conchostracan *L. rubidgei* in wetlands with a large amount of suspended matter (logistic regression: df = 1, Wald stat = 3.960, $p = 0.047$) and a large surface (t-test: df = 48, t-value = 2.05267, $p = 0.046$). For the anostracan *S. purcelli*, no significant relationships with environmental characteristics were found.

Current Conservation Status of Large Branchiopods in the Western Cape

The current conservation characteristics of all species known from the Western Cape are summarized in Table 4. The populations hatched from the investigated resting egg banks are not incorporated in this table. To date, two species of large branchiopods from the Western Cape are recorded in the IUCN Red List: the endangered *S. dendyi* (EN B1+2bd, version 2.3 (1994)) and the critically endangered *S. gracilis* (CR A2c, B1+2bd, version 2.3 (1994)).

Intraspecific Variation in *Streptocephalus dendyi*

The anostracan *S. dendyi* showed considerable intraspecific variation in the number, distribution, and shape of the telsonic spines (Figure 6). Populations originating from the Agulhas region had two to three pairs of lateral spines on the telson. Populations from Kenilworth showed one pair of more strongly developed spines, which furthermore had two extra setae. *Streptocephalus dendyi* from

Table 3. The physical and chemical measurements of 22 wetlands containing large branchiopods. Indicated are: presence of the species *S. dendyi*, *S. purcelli*, *A. salina*, and *L. rubidgei*; hydroperiod class of the wetland (S: short, M: moderately long, and L: long); maximum depth (cm); surface area (m^2); chemical oxygen demand (COD; mg/l); chlorophyll a concentration (µg/l); total N (mg/l); total P (mg/l); pH; dissolved oxygen concentration (mg/l); conductivity (µS/cm); suspended matter (SuspMat; g/l); and water clarity (Snells tube value; cm).

Location	Code	*S. dendyi*	*S. purcelli*	*A. salina*	*L. rubidgei*	Hydro-period	Max Depth	Surface Area	COD	Conduc-tivity	Chloro-phyll	Total N	Total P	pH	Oxygen	Susp-Mat	Clarity
Agulhas	AgL1a	1	0	0	0	M	36	462	91	5310	9.73	2.62	0.49	8.3	11.0	0.01	19.0
Agulhas	AgL2a	1	0	0	0	L	80	551	92	7190	13.74	1.65	0.03	7.6	8.2	0.28	17.5
Agulhas	AgM1a	1	0	0	0	L	54	276	106	7970	12.88	1.85	0.03	8.2	9.4	0.61	28.5
Agulhas	AgM1b	0	0	1	0	S	9	2036	989	194000	68.57	4.82	0.33	7.9	8.3	0.01	4.5
Agulhas	AgM2a	1	0	0	0	M	26	241	121	5800	6.70	5.97	1.19	8.5	12.1	0.01	17.5
Agulhas	AgS2b	0	0	0	1	S	3	240	530	35800	111.20	5.53	0.73	7.5	8.5	0.51	4.5
Kenilworth	CfL2a	1	0	0	0	L	112	4097	114	390	4.39	1.80	0.06	7.1	8.2	0.00	22.0
Kenilworth	CfM1a	1	0	0	0	M	55	552	78	1052	10.43	1.70	0.03	7.4	9.0	0.01	22.5
Kenilworth	CfS2a	1	0	0	0	S	23	186	63	1426	18.49	1.76	0.10	7.5	6.7	0.09	22.0
Malmesbury	LaL1c	1	0	0	1	M	24	27770	108	437	92.67	7.34	7.28	7.2	9.3	3.28	0.8
Malmesbury	LaL2c	0	0	0	1	M	33	59301	95	3000	77.61	3.16	0.36	8.1	6.4	0.15	5.0
Malmesbury	LaM1b	0	1	0	0	M	61	240	28	458	23.17	1.03	0.06	8.0	6.5	0.08	6.5
Malmesbury	LaM2c	1	0	0	0	L	78	157	93	537	9.50	9.21	0.07	7.4	9.5	0.01	19.0
Malmesbury	LaM2d	0	1	0	0	M	42	421	68	533	4.17	1.14	0.09	8.3	9.2	0.01	18.5
Malmesbury	LaS1c	0	1	0	0	S	20	596	79	308	98.00	3.66	0.35	7.3	5.9	0.07	3.0
Malmesbury	LaS2c	0	1	0	0	S	21	353	115	219	227.45	10.07	3.48	6.8	9.0	0.31	3.0
Malmesbury	LaS3c	1	0	0	0	M	30	35	114	211	30.12	3.50	0.11	6.9	4.3	0.01	13.5
Malmesbury	LaS4c	1	0	0	0	S	7	49	134	225	136.22	5.85	1.51	6.9	6.2	0.12	5.5
Malmesbury	LaS6c	0	1	0	0	S	20	26	246	554	38.23	8.42	0.93	7.2	6.2	0.06	7.5
Yzerfontein	LaL1a	0	0	0	1	L	40	351	153	4440	17.14	3.42	0.20	8.4	8.6	0.18	10.0
Yzerfontein	LaM2a	0	0	0	1	S	25	75	111	275	81.94	0.74	0.33	7.4	6.9	0.11	7.5
Yzerfontein	LaSxa	0	1	0	0	S	4	7	279	1219	125.76	27.44	5.77	6.9	2.0	0.09	7.0

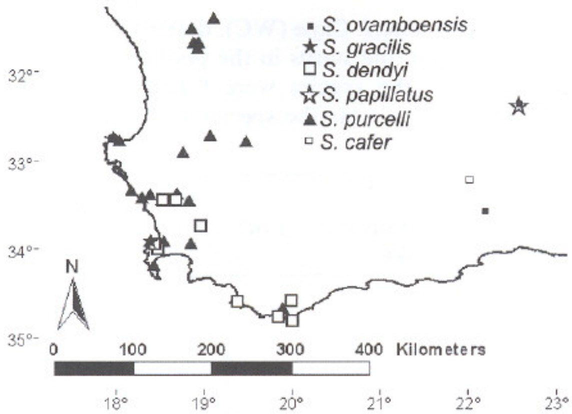

Figure 3. Distribution of the anostracan genus Streptocephalus in the Western Cape (black square = *S. ovamboensis*; black star = *S. gracilis*; large open square = *S. dendyi*; open star = *S. papillatus*; black triangle = *S. purcelli*; small open square = *S. cafer*).

Yzerfontein-Malmesbury had one strongly developed spine (0.9 mm) on the telson, carrying itself four to five spinal extensions (Figure 6).

DISCUSSION

Previous and Current Distribution of Large Branchiopods

To date, 14 species of large branchiopods have been recorded from the Western Cape. This species richness is not especially high compared to other areas in South Africa. In the much smaller Drakensberg region, for instance, 11 species were found (Hamer and Martens 1998). Our field survey covered about the same area as the Drakensberg study, but only four species were discovered. This is

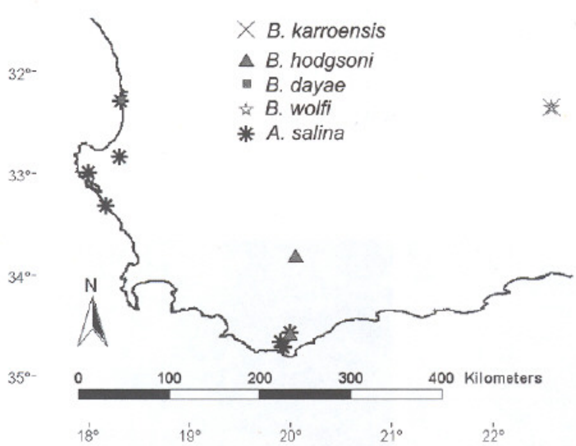

Figure 4. Distribution of the anostracan genus Branchipodopsis (cross = *B. karroensis*; grey triangle = *B. hodgsoni*; grey square = *B. dayae*; open grey star = *B. wolfi*) and Artemia (black star = *A. salina*) in the Western Cape.

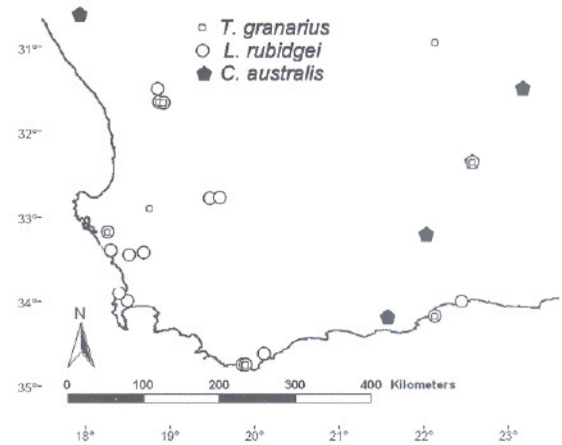

Figure 5. Distribution of Notostraca (small open square = *T. granarius*) and Conchostraca (open circle = *L. rubidgei*; black pentagon = *C. australis*) in the Western Cape.

only half the number of species previously recorded from the region, which suggests local extinctions of several species may be occurring in the Western Cape. However, the 2004 sampling year was relatively dry, and it is possible that we did not find some of the smaller, more pristine wetlands where many species are likely to occur. Moreover, the circumstances for hatching could have been suboptimal during 2004.

Streptocephalus gracilis was last found more than 100 years ago in Green Point, Cape Town. Although this species is recorded in the IUCN Red List as critically endangered, it is probably extinct. A similar situation exists for *B. karroensis*. Hamer and Appleton (1996) concluded that many anostracan species previously reported in southern Africa are probably already extinct because they are only known from type material collected in the early 1900s.

Anostraca were present in 18 (31%) and Conchostraca in six (10%) of the 58 study wetlands. Notostracans were absent from all localities. Hamer and Martens (1998) discovered a similarly low occurrence of large branchiopods (23% of the sampled pools) in the Drakensberg region. The small numbers of active large branchiopod populations in our field survey could possibly be explained by the presence of predators such as *Xenopus laevis* (Daudin) (African clawed frog) or *Platalea alba* Scopoli (African spoonbill). Because our samples were taken in a late successional phase, the effect of predators could be especially large (Corti et al. 1997, Spencer et al. 1999, Bilton et al. 2001). The inundation of resting egg banks from the 58 study wetlands only yielded eight extra populations of large branchiopods. Hence, predation is probably

Table 4. Conservation characteristics of large branchiopods occurring in the Western Cape (WC), determined the IUCN Red List Criteria (based on 2004 and all known previous surveys). Indicated are: the status in the pool (C: common, R: rare, U: uncommon); the number of localities in the Western Cape where the species were found; occurrence in conservation area (Y or N); endemic to the Western Cape (Y or N); and the last year the species was collected in the Western Cape. Uncertain characteristics are indicated with a question mark.

Species	IUCN Red List	Status in pool in WC	Number of localities in WC	Conservation area in WC	Endemic to WC	Last year of collection in WC
Anostraca						
Artemia salina	DD	C	9	N	N	2004
Branchipodopsis dayae	DD	R	2	N	N	1980
B. hodgsoni	VU	U	2	N	N	1990
B. karroensis	DD	U	1	N	Y	1929
B. wolfi	DD	U?	2	N	N	1993
Streptocephalus cafer	LC	U?	2	N	N	1995
S. dendyi	EN	C	16	Y	N	2004
S. gracilis	CR	R	2	N	N	1898
S. ovamboensis	LC	C	2	?	N	1994
S. papillatus	DD	C	1	N	N	1929
S. purcelli	LC	C	25	Y	N	2004
Conchostraca						
Cyzicus australis	DD	C?	5	N	N	1950?
Leptestheria rubidgei	LC	C	21	Y	N	2004
Notostraca						
Triops granarius	LC	U?	7	N	N	2002

not the main reason, as we might expect a buffering effect from the resting egg bank. Pollution might also negatively affect the distribution of vulnerable species. Many of the study wetlands are located in agricultural or urbanized land. Consequently, surface waters, especially in Cape Flats, were exposed to pollution by pesticides (Dalvie et al. 2004) and heavy metals (Brown et al. 1991). Some of these pollutants reduce growth and reproductive capacity of large branchiopods, leading to a possible failure of annual recruitment (Lahr 1997).

Ongoing destruction of wetlands could, furthermore, lead to greater isolation of populations, increasing the possibility of local extinctions (Belk 1998). With reduced connectivity between populations in a metapopulation configuration, the probability that a neighboring (source) population could rescue a (sink) population from extinction is diminished (Semlitsch and Bodie 1998). Habitat destruction is generally accepted as the main threat to the persistence of large branchiopods (Belk 1998, Brendonck and Williams 2000). Around Cape Town, large branchiopods only occurred in ponds on pristine areas of the Kenilworth Racecourse, which might indicate a sensitivity to pollution or land use changes.

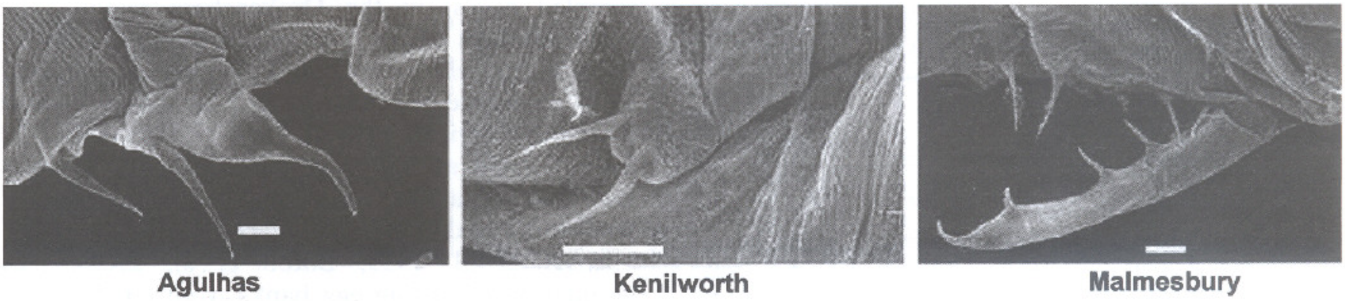

Figure 6. Geographical variation in telsonic spine number and morphology in *S. dendyi* from different locations in the Western Cape, with indication of a 100-μm calibration line (white line).

Co-occurrence of Large Branchiopods

Most wetlands that supported large branchiopods were inhabited by only one species. A single wetland contained both *S. dendyi* and *L. rubidgei*. Inundation of resting egg banks did not reveal additional cases of co-occurrence. A similarly low incidence of co-occurrence was observed in the Drakensberg region by Hamer and Martens (1998). In other parts of the world, large branchiopod species often co-occur, for instance, in the U.S. (Eng et al. 1990, Graham 1995, Hathaway and Simovich 1996, Maeda-Martinez et al. 1997), the Mediterranean (Beladjal et al. 2003), Morocco (Thiery 1991), Botswana (Brendonck and Riddoch 1997), KwaZulu-Natal (Hamer and Appleton 1991), the Northern Cape of South Africa (Hamer and Rayner 1996), and the Namib Desert (Day 1990). Hamer and Appleton (1991) and Thiery (1991) suggest that abiotic factors, different life history traits, and availability of biotopes influence the co-occurrence of large branchiopods.

Relation Between Environmental Variables and the Distribution of Large Branchiopods

There was a greater chance of finding *S. dendyi* in habitats with low rather than high chemical oxygen demand values, which might indicate a low tolerance to organic loads and associated low oxygen tensions. The conchostracan *L. rubidgei*, on the other hand, was found more commonly in relatively turbid water rather than clear water. Martin (1992) suggested that turbidity is caused by clam shrimps disturbing the substrate while feeding. This does not hold for all pools in our study as certain pools on clay substrata were perpetually turbid even in the absence of conchostracans. Regardless of the cause, turbidity can be an advantage, decreasing the risk of predation by visual predators like *Notonecta* (Woodward and Kiesecker 1994). *Leptestheria rubidgei* was also found more commonly in larger wetlands, possibly due to non-measured variables related to size.

Intraspecific Variation in *Streptocephalus dendyi*

A clear pattern of geographical variation in the position and morphology of telsonic spinulation was discovered between, but not within, *S. dendyi* populations. Characteristics of these structures can be species-specific (Hamer et al. 1994). Comparable variation in the arrangement of telsonic spines was observed by Hamer and Rayner (1995) in *Triops* and by Brendonck and Hamer (1999) in *S. vitreus*. This variation feeds discussion on species boundaries and speciation processes in these taxa and the utility of these morphological characters in species identifications. If *S. dendyi* is actually a species complex rather than a single species, its current conservation status should be reconsidered, and local populations need to be protected, as they could be hot spots from which new types/species could radiate.

Current Conservation Status of Large Branchiopods in the Western Cape

Of the 14 large branchiopod species known to occur in the Western Cape, only two anostracan species (*S. gracilis* and *S. dendyi*) are currently listed in the IUCN Red List, and no notostracans or conchostracans. We collected *S. dendyi* from 11 wetlands. Previously this species was only found in three wetlands and therefore categorized as endangered. Although we discovered additional populations, we suggest not changing the status of *S. dendyi* because, as mentioned before, taxonomic issues are not yet resolved.

Within the boundaries of the Cape Floristic Kingdom, only one (*B. karroensis*) of the 14 species of large branchiopods is endemic, in contrast to a high level of terrestrial plant endemicity (about 70% of approximately 9,600 species) (Goldblatt 1997) and a large proportion of endemics in other freshwater invertebrate and fish taxa (Wishart and Day 2002). Large variation in abiotic factors in the Cape Floristic Kingdom may not affect large branchiopods in the same way as it does plants and other freshwater species. The high degree of endemicity (64%) of Anostraca within South Africa as a whole has been partly explained by the high overall abiotic variation in this country (Brendonck and Riddoch 1997).

Over the whole Western Cape, only a few populations of large branchiopods occur in conservation areas (Table 4). However, even wetlands in conservation areas are not safe from habitat alteration or destruction. Climate change and ground-water extraction could potentially affect the hydrology of wetlands over large areas (Pyke and Fischer 2005). Hydrological change may result in reduced hydroperiods with increased chance of abortive hatching and ultimately exhaustion of resting egg banks and extinction of local populations. Due to the buffering and storage capacity of the resting egg bank, large branchiopods could hatch for years in wetlands where they can no longer successfully reproduce (Belk 1998, Brendonck and De Meester 2003), and thus effects of habitat change on large branchiopod populations might remain undetected for several years. Studies on climate change point out that the Western Cape will most likely get drier, which could cause changes in the wetlands hydrology (New 2002, Midgley et al. 2005). Van Jaarsveld and Chown (2001) predict that 44% of plant and 80% of animal species would undergo some alteration to their geographic ranges, and Midgley et al. (2002) estimate a loss of plant species in the Western Cape fynbos biome of between 51% and 65% by 2050. As temporary wetlands are very vulnerable habitats, the effect of climate change on the biota could be even more dramatic. Further knowledge of the effects of climate change and water extraction on temporary wetlands is crucial for applying regulations and for accomplishing suitable conservation management strategies.

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