Distribution, habitats and role as intermediate host of the freshwater snail, *Bulinus forskalii*, in South Africa

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ABSTRACT

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This paper focuses on the geographical distribution and habitats of *Bulinus forskalii*, the snail intermediate host of the conical fluke of equids, *Gastrodiscus aegyptiacus* as reflected by the 1 209 samples in the database of the National Freshwater Snail Collection of South Africa. The 362 different loci on record represent an extensive distribution in KwaZulu-Natal Province, the Limpopo Province, the coastal areas of the Eastern Cape Province and the south-eastern part of the North West Province. Although it was recorded from all types of water-body represented in the database, the highest percentages of samples were recovered from dams (30.4 %) and brooks (28.2 %). The majority of samples came from perennial habitats (59.1 %), 60.7 % from habitats with standing water, 54.0 % from habitats with clear water and 71.8 % from habitats of which the water was described as fresh. The majority of samples (39.5 %) were collected in habitats of which the substratum was recorded as muddy. The highest percentage of samples, by far (81.5 %), was collected in habitats that fell within the mean yearly temperature interval ranging from 15–20 °C. An integrated decision tree constructed from the data in the database indicated that temperature and type of water-body played a decisive role in determining the presence of *B. forskalii* in a given area. The results of experimental exposure to miracidia of a local strain of both *Schistosoma haematobium* and *Schistosoma mattheei* in the laboratory indicated that a local strain of *B. forskalii* was incompatible with both these strains of parasite. Research to clarify the role of *B. forskalii* in the transmission of both *Calicophoron microbothrium* and *G. aegyptiacus* in South Africa, is recommended.

Keywords: *Bulinus forskalii*, *Calicophoron microbothrium, Gastrodiscus aegyptiacus*, geographical distribution, habitat types, temperature

INTRODUCTION

The oldest record of *Bulinus forskalii* (Ehrenberg, 1831) in the National Freshwater Snail Collection (NFSC) dates back to 1956. It was collected in the KwaZulu-Natal Province of South Africa. This investigation focuses on the geographical distribution and habitats of *B. forskalii* as reflected by the 1 209 samples on record in the NFSC. Details are given of the habitats as described by collectors at the time of collection and also of the mean altitude and mean annual rainfall and temperature of the loci ($^1/_{16}$ square degrees) in which the collections were made.

This species is well known as the intermediate host of *Gastrodiscus aegyptiacus*, the intestinal fluke of horses, donkeys and mules elsewhere in Africa (Malek 1980) and *B. forskalii* was also reported previously to be susceptible to this parasite in South Africa (Le Roux 1958). In view of the fact that *B.*

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forskalii is an intermediate host of a distinct strain of *Schistosoma intercalatum* in Cameroon (Wright, Southgate & Knowles 1972) and Gabon (Brown, Sarfati, Southgate, Ross & Knowles 1984), we evaluated the compatibility of a local strain of this snail species with a local strain of both *Schistosoma haematobium* and *Schistosoma mattheei* in the laboratory. The economic implications of its role as intermediate host of veterinary important helminth species are briefly discussed.

MATERIALS AND METHODS

Data on the geographical distribution and habitats of *B. forskalii*, which extend from 1956 up to the present, were extracted from the database of the NFSC. Only those samples for which the collection sites could be located on the 1:250 000 topo-cadastral map series of South Africa, were included in the analysis. The loci in which the collection sites were located, were grouped in intervals of mean annual rainfall and air temperature, as well as intervals of mean altitude to illustrate the frequency of occurrence in specific intervals. Rainfall, temperature and altitude data were obtained from the Computing Centre for Water Research, University of Natal. A temperature index was calculated for every species in the database by taking into account their frequencies of occurrence in the selected temperature intervals and these results were used to rank them in order of association with low to high climatic temperatures. This was done by allocating numeric values, ranging from one for the coolest to five for the warmest, to the five selected temperature intervals. The proportion of the total number of loci falling in a particular temperature interval for each species was then multiplied by the value allocated to that specific temperature interval. This was done for each temperature interval in which the species was recorded and the sum of these scores was then taken as the temperature index for that particular species (Brown, Dept of Zoology, The Natural History Museum, London, personal communication 2002).

Chi-square values were calculated to determine the significance of differences between the frequency of occurrence in, on, or at the different options for each variable, such as type of water-body, substratum or temperature. In addition, the effect size (Cohen 1977) was calculated for each variable to evaluate the importance of its role in governing the geographical distribution of this species. The effect size is an index which measures the degree of discrepancy between the frequency distribution of a given species in the set of alternatives of a given variable such as water-bodies, as compared to the frequency distribution of all other mollusc species in the database in the set of alternatives of the same variable. The data in the database were also further processed to construct an integrated decision tree (Breiman, Friedman, Olsen & Stone 1984). This multivariate analysis enables the selection and ranking of those variables that maximally discriminate between the frequency of occurrence of a given species under specific conditions compared to all other species in the database. This was done with SAS Enterprise Miner for Windows NT and *Decision Tree Modelling Course Notes* (Potts 1999).

To evaluate its compatibility with *S. haematobium* and *S. mattheei*, 30 specimens of *B. forskalii*, intended as breeding stock, were collected in a stream within the Potchefstroom Municipal area (26°42'34"S, 27°05'37"E). These specimens were maintained in the laboratory in stainless steel aquaria through which water was continuously circulated and temperature kept constant at 25 °C with custom-built programmable central processing units (De Kock 1985; De Kock & Van Eeden 1986). Snails required for exposure to *S. haematobium* and *S. mattheei* miracidia were cultured in the experimental set-up from eggs produced during a 24-h period by the parental snails and the hatchlings reared on "TetraMin® Baby Fish Food E" (Tetra Werke, Germany) (Joubert & De Kock 1988). At an age of 3 weeks 20 specimens of the F_1 offspring and nine of the 18 specimens of the parental generation still alive at that stage, were exposed to miracidia from a laboratory strain of *S. haematobium* and the procedure was repeated with a laboratory strain of *S. mattheei*. Both parasite strains were originally obtained from the Research Institute for Diseases in a Tropical Environment, Nelspruit, Mpumalanga Province. The protocol for exposure of the snails to miracidia, screening for the shedding of cercariae and maintenance of the exposed snails, entailed the following: each snail was individually exposed in 2 mℓ of water in a multi-well container to three miracidia for a period of 3 h (De Kock 1992). The four groups of exposed snails were kept in separate containers and maintained together at a constant temperature of 25 °C in the same aquarium in the experimental set-up. Mortalities were recorded daily. Members of each exposed group were screened together every third day from day 24 until day 72 post-exposure. All snails that died during this period were crushed between two slides and inspected under a microscope for immature parasite stages (Chernin & Dunavan 1962).

RESULTS

The 1 209 samples of *B. forskalii* which could be located on our maps were collected from 362 different loci (Fig. 1). It was recovered from all habitat types represented in the database, but the highest percentages were collected in dams (30.4 %) and brooks (28.2 %) (Table 1). However, the frequency of occurrence in dams differed significantly only from that of rivers (χ^2 = 85.30; *df* = 1; P < 0.05), swamps (χ^2 = 23.56; *df* = 1; P < 0.05) and ponds (χ^2 = 8.46; *df* = 1; P < 0.05). The nine times it was recovered from quarries represented just 0.7 % of the total number (1 209) of collections for this species, and it accounted for 7.4 % of the total number of collections (122) on record in the database for this type of water-body (Table 1).

Although the majority of samples (59.1 %) of this species were collected in habitats described as perennial, the 308 samples recovered from seasonal habitats accounted for a higher percentage (5.8 %) of the total number of collections of all molluscs in seasonal habitats (Table 2).

The largest number of samples by far (734) were collected in habitats with standing water (Table 2) and its frequency of occurrence under this condition differed significantly from its occurrence in slow-running (χ^2 = 63.04; *df* = 1; P < 0.05) and fast-running (χ^2 = 23.42; *df* = 1; P < 0.05) water. Fifty-four percent of the samples were collected in habitats of which the water was described as clear and in 71.8 % of the cases the water was recorded as fresh (Table 2).

Nearly 40 % of the samples were collected in habitats with a muddy substratum and this differed significantly from its frequency of occurrence in habitats with stony (χ^2 = 10.14; *df* = 1; P < 0.05) and sandy substratums (χ^2 = 13.80; *df* = 1; P < 0.05).

The largest number of samples by far (81.5 %), came from collection sites which fell within the mean annual temperature interval ranging from 15–20 °C (Table 4) and the frequency of occurrence differed significantly from all the other intervals (chi-square values ranging from χ^2 = 48.80; *df* = 1; P < 0.05, to χ^2 = 168.11; *df* = 1; P < 0.05).

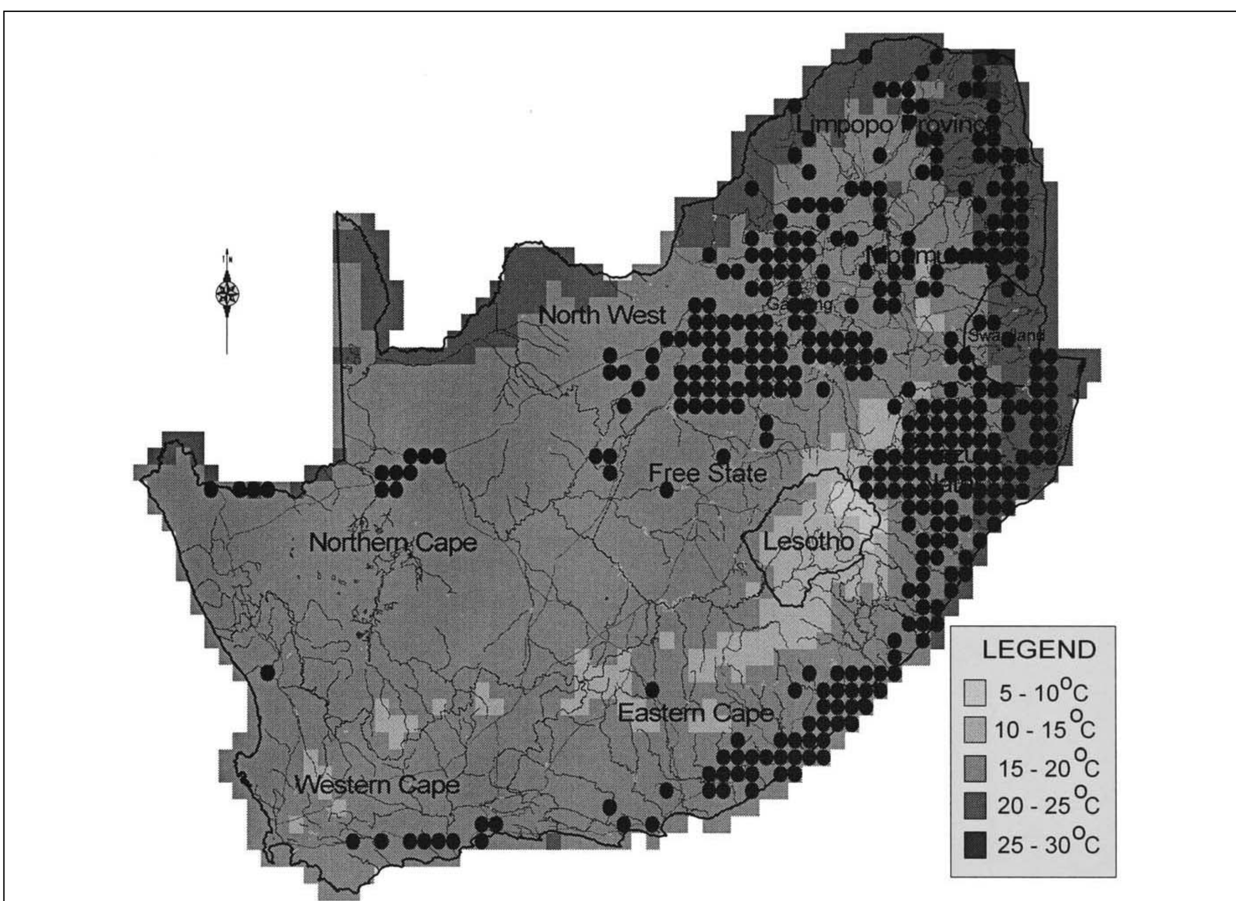

FIG. 1 The geographical distribution of *Bulinus forskalii* in 1/16 square degree loci and mean annual air temperature in South Africa

TABLE 1 Types of waterbody in which *Bulinus forskalii* was found in 1 209 collection sites recorded during surveys

Waterbodies	A	B	C	D
Brook	341	28.2 %	7 211	4.7 %
Channel	10	0.8 %	169	5.9 %
Concrete dam	5	0.4 %	221	2.3 %
Dam	368	30.4 %	8 400	4.4 %
Ditch	23	1.9 %	636	3.6 %
Irrigation furrow	6	0.5 %	113	5.3 %
Pan	11	0.9 %	306	3.6 %
Pond	95	7.3 %	1 566	5.6 %
Quarry	9	0.7 %	122	7.4 %
River	136	11.2 %	7 507	1.8 %
Spring	14	1.2 %	301	4.7 %
Swamp	47	3.9 %	2 179	2.2 %
Waterhole	10	0.8 %	225	4.4 %
Effect size	*w* = 0.37 (medium effect)			

A: Number of times collected in a specific waterbody
B: % of the total number of collections (1 209) on record for *B. forskalii*
C: Number of times any mollusc was collected in a specific waterbody
D: % occurrence of *B. forskalii* in the total number of collections in a specific waterbody

TABLE 2 Water conditions in the habitats of *Bulinus forskalii* as described by collectors during surveys

	Type		Velocity			Colour		Salinity	
	Perennial	Seasonal	Fast	Slow	Standing	Clear	Muddy	Fresh	Brackish
A	715	308	52	245	734	653	346	868	16
B	59.1%	25.5 %	4.3 %	20.3 %	60.7 %	54.0 %	28.6 %	71.8 %	1.3 %
C	22 432	5 350	2 229	9 501	16 147	20 408	6 438	24 098	657
D	3.2%	5.8 %	2.3 %	2.6 %	4.5 %	3.1 %	5.4 %	3.6 %	2.4 %
E	*w* = 0.28 (small to medium effect)		*w* = 0.27 (small to medium effect)			*w* = 0.25 (small to medium effect)		*w* = 0.06 (small effect)	

A: Number of times collected in a specific water condition
B: % of the total number of collections (1 209) on record for B. forskalii
C: Number of times any mollusc was collected in a specific water condition
D: % occurrence of *B. forskalii* in the total number of collections in a specific water condition
E: Effect size values calculated for each water condition

TABLE 3 Substratum types in the habitats of *Bulinus forskalii* as described by collectors during surveys

	Substratum types			
	Muddy	Stony	Sandy	Decomposing material
A	478	230	316	16
B	39.5 %	19.0 %	26.1 %	1.3 %
C	12 835	7 934	6 523	632
D	3.7 %	2.9 %	4.8 %	2.5 %
E	*w* = 0.19 (small effect)			

A: Number of times collected on a specific substratum
B: % of the total number of collections (1 209) on record for B. forskalii
C: Number of times any mollusc was collected in a waterbody with a specific substratum
D: % occurrence of B. forskalii in the total number of collections in a waterbody with a specific substratum
E: Effect size calculated for substratum types

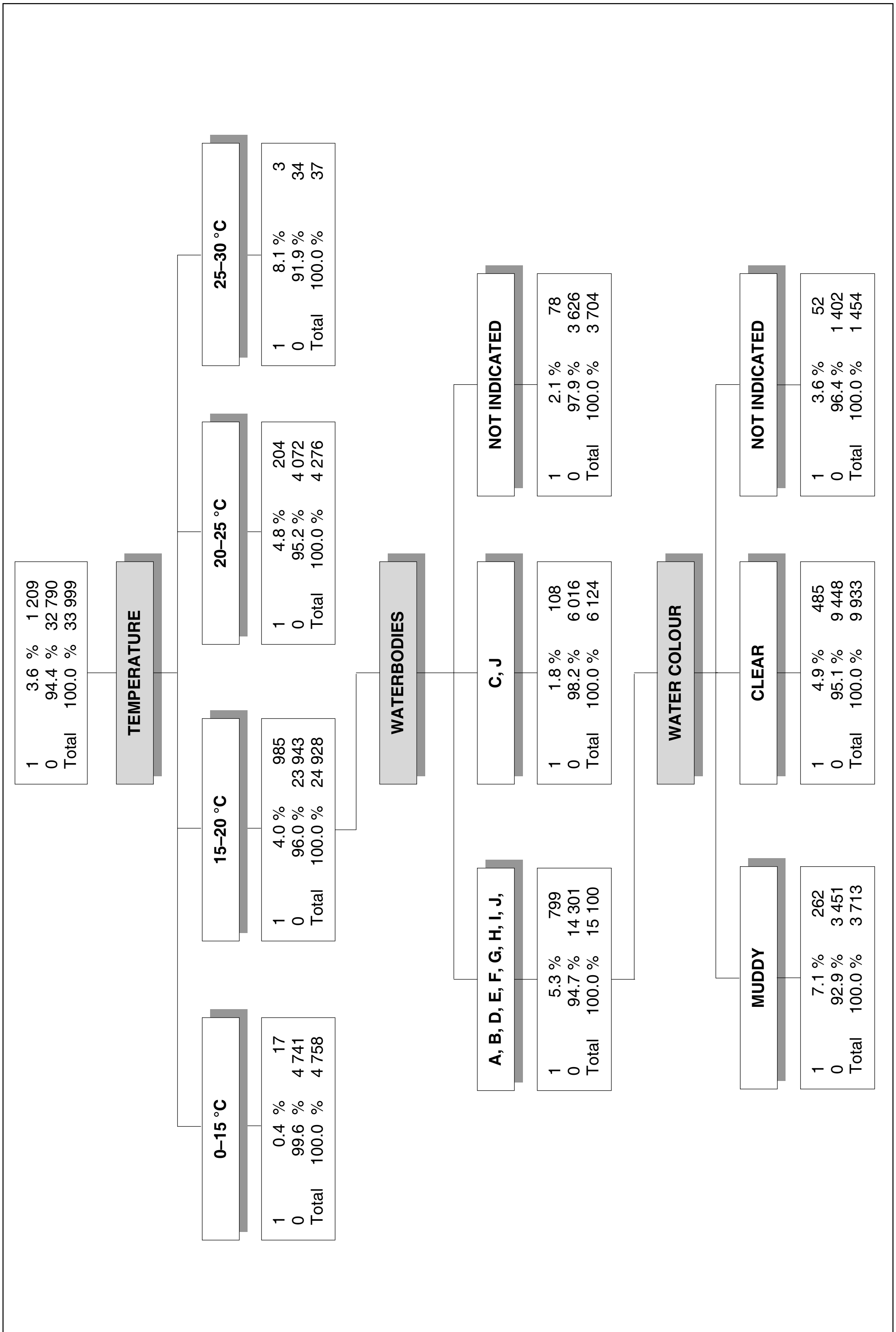

FIG. 2 Decision tree of the frequency of occurrence of *Bulinus forskalii* for each variable as compared to the frequency of occurrence of all the other species in the database of the NFSC. 0 = percentages and frequencies of all other species, 1 = percentages and frequencies of *B. forskalii*. Waterbodies: A = brook, B = channel, C = concrete dam, D = dam, E = ditch, F = irrigation furrow, G = pan, H = pond, I = quarry, J = river, K = spring, L = swamp, N = waterhole

TABLE 4 Frequency distribution of the 1 209 collection sites of *Bulinus forskalii* in selected intervals of mean annual air temperature and rainfall and mean altitude in South Africa

	Temperature intervals (ºC)				Rainfall intervals (mm)				Altitude intervals (m)			
	10–15	15–20	20–25	25–30	0–300	300–600	600–900	900–1 200	0–500	500–1 000	1 000–1 500	1 500–2 000
A	17	985	204	3	43	489	651	26	306	174	622	107
B	1.4 %	81.5 %	16.9 %	0.2 %	3.6 %	40.4 %	53.8 %	2.2 %	25.3 %	14.4 %	51.4 %	8.9 %
C	4 404	24 928	4 276	37	975	11 994	19 799	1 203	6 747	4 491	1 4918	6 998
D	0.4 %	4.0 %	4.8 %	8.1 %	4.4 %	4.7 %	3.3 %	2.2 %	4.5 %	3.9 %	4.2 %	1.5 %

A: Number of times collected in a locality falling within a specific interval
B: % of the total number of collections (1 209) on record for *B. forskalii*
C: Number of times any mollusc was collected in a locality falling within a specific interval
D: % occurrence of *B. forskalii* in the total number of collections within a specific interval
E: Effect size values calculated for each factor

TABLE 5 Frequency distribution in temperature intervals and temperature index of *Bulinus forskalii* as compared to all mollusc species in the database of the National Freshwater Snail Collection

Mollusc species	Number of samples	5–10 °C	10–15 °C	15–20 °C	20–25 ºC	25–30 °C	Index[a]	SD[b]	CV[c]	Effect size values
Pisidium viridarium	636	201	270	163	2		1.95	0.76	39.23	–1.59
Lymnaea truncatula	723	95	281	343	4		2.35	0.71	30.14	–1.14
Pisidium casertanum	5		2	3			2.60	0.55	21.07	–1.02
Pisidium costulosum	425	1	138	282	4		2.68	0.49	18.34	–0.98
Pisidium langleyanum	627	18	173	430	6		2.68	0.54	20.33	–0.89
Gyraulus connollyi	969		185	777	7		2.82	0.41	14.40	–0.84
Bulinus tropicus	8 448	32	2 326	5 860	230		2.74	0.50	18.31	–0.83
Ceratophallus natalensis	1797		299	1 430	68		2.87	0.43	15.09	–0.67
Burnupia (all species)	2778	7	287	2 384	100		2.93	0.38	12.97	–0.57
Ferrissia (all species)	540		72	420	47	1	2.96	0.48	16.09	–0.43
Bulinus reticulatus	296		6	287	3		2.99	0.17	5.83	–0.42
Assiminea umlaasiana	2			2			3.00	0.00	0.00	–0.39
Tomichia cawstoni	4			4			3.00	0.00	0.00	–0.39
Tomichia differens	10			10			3.00	0.00	0.00	–0.39
Tomichia lirata	2			2			3.00	0.00	0.00	–0.39

TABLE 5 (*Continued*)

Mollusc species	Number of samples	5–10 °C	10–15 °C	15–20 °C	20–25 °C	25–30 °C	Index[a]	SD[b]	CV[c]	Effect size values
Tomichia ventricosa	89			89			3.00	0.00	0.00	–0.39
Tomichia tristis	81			79	2		3.03	0.16	5.16	–0.33
Unio caffer	76		6	63	6	1	3.03	0.46	15.24	–0.29
Physa acuta	755			719	36		3.05	0.21	7.00	–0.28
Bulinus depressus	552			519	33		3.06	0.24	7.76	–0.25
Arcuatula capensis	15			14	1		3.07	0.26	8.42	–0.23
Lymnaea columella	2 302		81	1 977	243	1	3.07	0.37	12.07	–0.22
Lymnaea natalensis	4721		205	3 802	713	1	3.11	0.43	13.79	–0.12
Assiminea bifasciata	17			15	2		3.12	0.33	10.65	–0.10
Gyraulus costulatus	736		20	580	135	1	3.16	0.44	13.84	–0.00
Bulinus forskalii	1 209		17	985	204	3	3.16	0.41	12.95	0.00
Pisidium ovampicum	6			5	1		3.17	0.41	12.89	0.02
Sphaerium capense	25		1	17	7		3.24	0.52	16.14	0.15
Bulinus africanus spp. group	2 930		9	2 155	760	6	3.26	0.45	13.82	0.22
Corbicula fluminalis	390		1	291	94	4	3.28	0.44	13.38	0.25
Tomichia natalensis	23			16	7		3.30	0.47	14.24	0.31
Assiminea ovata	5			3	2		3.40	0.55	16.11	0.44
Thiara amarula	10			6	4		3.40	0.52	15.19	0.47
Septaria tessellaria	2			1	1		3.50	0.71	20.20	0.48
Melanoides victoriae	49			29	19	1	3.43	0.54	15.75	0.50
Biomphalaria pfeifferi	1 639		5	880	751	3	3.46	0.51	14.69	0.59
Coelatura framesi	6			3	3		3.50	0.55	15.65	0.62
Neritina natalensis	16			8	8		3.50	0.52	14.75	0.66
Bulinus natalensis	245		2	97	146		3.58	0.51	14.20	0.84
Segmentorbis planodiscus	27			9	18		3.67	0.48	13.10	1.06
Segmentorbis angustus	32			7	25		3.78	0.42	11.11	1.48
Melanoides tuberculata	305			64	237	4	3.80	0.43	11.31	1.50
Pisidium pirothi	23			4	19		3.83	0.39	10.13	1.63
Spathopsis petersi	39			1	36	2	3.93	0.40	10.11	1.89
Aplexa marmorata	9				9		4.00	0.00	0.00	2.05
Bellamya capillata	31				31		4.00	0.00	0.00	2.05
Eupera ferruginea	169			6	157	6	4.00	0.26	6.46	2.05
Lentorbis carringtoni	8				8		4.00	0.00	0.00	2.05
Lentorbis junodi	12				12		4.00	0.00	0.00	2.05
Segmentorbis kanisaensis	9				9		4.00	0.00	0.00	2.05
Spathopsis wahlbergi	36			7	28	1	4.00	0.27	6.80	2.05
Cleopatra ferruginea	73				71	2	4.03	0.16	4.08	2.12
Lanistes ovum	41				38	3	4.08	0.26	6.47	2.23

The majority of samples came from habitats which fell within the two mean annual rainfall intervals which ranged from 300–900 mm (40.4 % + 53.8 % = 94.2 %) and 51.4 % came from sites which fell within the mean altitude interval ranging from 1000–1 500 m (Table 4).

The frequency of occurrence in habitats falling within the five selected temperature intervals, the temperature indexes calculated from these data and the ranking of the species in order of their association with low to high temperatures, are presented in Table 5. The effect size values calculated for each factor are also listed in Tables 1–4.

The results of the integrated decision tree analysis, in which all the different variables were taken into account, are depicted in Fig. 2. The 985 times *B. forskalii* was collected in habitats falling within the temperature category, 15–20 °C represented 4.0 % of the total number of 24 928 collections recorded for this category (Fig. 2). However, the 204 times this species was collected in habitats within the 20–25 °C represented a higher percentage (4.8 %) of the total number of collections for this category. Concrete dams and rivers (C, J) were the only types of water-body pointed out as of minor importance for the occurrence of this species within the 15–20 °C temperature category (Fig. 2).

None of the exposed snails shed cercaria during the entire period of observation. Specimens that died during this period and were crushed between glass microscope slides to screen for pre-patent infections, also showed no evidence of immature parasite stages.

DISCUSSION

The distribution of *B. forskalii* is essentially Afrotropical. An account of its occurrence elsewhere in Africa and its presence in Madagascar was reported earlier (Mandahl-Barth 1957, 1965). Its range extends southwards to the lower Orange River and Eastern Cape Province, but it is not found in the cool highlands of eastern and southern Africa, nor in most of the Western Cape Province (Brown 1994). However, our data show that its range in South Africa is definitely more widespread than reported by Brown (1994), especially with regard to its distribution in the cooler areas of the North West Province and the north-eastern areas of the Free State Province (Fig. 1).

Effect size values in the order of 0.1 and 0.3 indicate small and medium effects, respectively, while values of 0.5 and higher indicate significantly large effects (Cohen 1977). From the values calculated for each factor separately (Tables 1–4), it can be deduced that only rainfall, salinity of the water and type of substratum, seemed to play a minor role in the presence or absence of this species in a particular site. This analysis indicated that temperature and type of water-body were the most important factors circumscribing the habitat of *B. forskalii* in South Africa. This is supported by the results of the multivariate decision tree analysis that also indicated temperature and type of water-body as the two most important factors circumscribing the habitat of this species and should consequently play a major role in determining its geographical distribution in South Africa.

The fact that *B. forskalii* was recovered from all types of water-body represented in our database is in accordance with the wide variety of habitats listed in the literature for this species. These are, amongst others, various natural and artificial situations, including swamps, irrigation systems and, above all, small water-bodies that may be flowing or stagnant (Brown 1994).

Although *B. forskalii* is listed as a good aestivator by Brown (1994), it does not occur in such briefly-filled rain pools as are inhabited by *Bulinus reticulatus.* Nevertheless, we have often found these two species together in ephemeral habitats in the North West and Free State Provinces of South Africa.

Bulinus forskalii is listed by Brown (1978) among the broadly tropical mollusc species of South Africa because it has a western arm in its range of distribution. It is therefore not surprising that the temperature index we calculated for this species does not differ significantly (effect value < 0.5; Table 5) from those of five of the seven other mollusc species also listed by Brown (1978) as broadly tropical in South Africa.

Our unsuccessful efforts to infect a local strain of *B. forskalii* with a local strain of *S. haematobium* support the results of earlier unsuccessful attempted experimental infections with the same species combination (Frandsen 1979). We also found a local strain of *B. forskalii* to be incompatible with a local strain of the indigenous bovine schistosome species, *S. mattheei*. However, *B. forskalii* was reported as one of the intermediate hosts of another bovine schistosome species, *S. bovis* in both eastern Africa (Kinoti 1964; Southgate & Knowles 1975; Mutani, Christensen & Frandsen 1983; Mwambungu 1988) and West Africa (Diaw & Vassiliadès 1987)

Although *B. forskalii* is involved in the natural transmission of the conical fluke, *Calicophoron microbothrium*, of cattle, goats and sheep in Ethiopia (Graber & Daynes 1974) and Niger (Tager-Kagan 1977), its role in this respect in South Africa, has not yet been established. This species was, however, reported as an intermediate host for the natural transmission in South Africa of another conical fluke species, *Gastrodiscus aegyptiacus*, also of the family Paramphistomatidae, of equids, pigs and warthogs, *Phacochoerus aethiopicus* (Le Roux 1958).

To our knowledge studies to establish the range of the geographical distribution of *G. aegyptiacus* in South Africa have not yet been reported in the literature. In a study which entailed the monthly monitoring of the helminth levels of 93 working donkeys in the Moretele 1 district of the North West Province, prevalence figures as high as 63.0 % were recorded (Wells, Krecek, Wells, Guthrie & Lourens 1998).

The pathogenicity to its definite hosts has also not yet been satisfactorily established, but it is commonly believed that it is relatively unimportant. However, a case of severe parasitism of the colon, associated with incoordination and collapse, was reported by Bracegirdle (1973) in a horse in Ethiopia and contrary to the common belief, it was concluded in a study of a particular stud farm of thoroughbred horses in South Africa by Azzie (1975), that *G. aegyptiacus* could be pathogenic to horses. *Bulinus forskalii* most probably also plays a role in the natural transmission of *C. microbothrium* in South Africa, which in its acute phase, could be lethal to domestic ruminants (Dinnik 1964).

The results of a recent survey of the freshwater molluscs in the Kruger National Park (De Kock, Wolmarans & Du Preez 2003) suggested that *B. forskalii* could be in the process of becoming more widespread in that area. The fact that this snail can exploit a wide variety of natural and artificial habitats, as reflected by the results in Table 1, and also has the ability to aestivate through long periods of drought, are factors which could contribute to the chances of this species extending its range of distribution in South Africa. In view of the possibility that this intermediate host snail could be in the process of becoming more widespread and the economic implications that might be involved, it is recommended that research should be focussed on establishing the geographical distribution of *C. microbothrium* and *G. aegyptiacus* in South Africa and on clarifying the role played by *B. forskalii* in their transmission.

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