# Review of the African distribution of the brine shrimp genus *Artemia*

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## Abstract

Brine shrimp (genus *Artemia*) are small (8 to 12 mm long) cosmopolitan crustaceans (Anostraca) found predominately in hypersaline water bodies such as inland salt lakes and pans, coastal lagoons, and salt works at salinity levels above 40 $g \cdot \ell^{-1}$. They have been extensively studied due to their high monetary value as food for larval fish in aquaculture and their unique reproductive strategies. Brine shrimp occur as either bisexual species or as parthenogenetic populations. Despite published reviews of their world-wide distribution little is known about their occurrence in Africa. This review adds new information about 70 African *Artemia* sites and lists 26 potential sites and their coordinates. Sixteen sites in Southern Africa and Namibia were visited during a collecting trip, and new information on the reproductive mode of nine of these sites is given. Several South African populations exhibit bisexual reproduction. In Namibia there are two parthenogenetic populations (Walvis Bay and Swartkops) and an additional bisexual population (Hentie's Bay). A mixed population (bisexual and parthenogenetic reproduction at the same site) was found at Coega, South Africa.

**Keywords:** Biogeography, brine shrimp, site description, hypersaline water bodies

## Introduction

Brine shrimp of the genus *Artemia* (Crustacea, Anostraca) are of interest to both biologists studying their evolution and developmental biology (Abatzopoulos et al., 2002) and aquaculturists using them as live food in fish and shrimp larviculture (Dhont and Sorgeloos, 2002). The life cycle of *Artemia* can begin as an embryo within a dormant cyst. Depending on environmental conditions, embryos can enter into diapause and arrested development for many years and are capable of surviving a very wide range of environmental conditions (Clegg and Trotman, 2002). *Artemia* nauplii can be easily hatched from cysts and have various applications in aquaculture, for example: they can be enriched with nutrients, i.e., essential fatty acids and vitamins to improve their nutritional value to cultured fish larvae or juveniles (Dhont and Sorgeloos, 2002); they have been used as carriers of spawning hormones to treat fish diseases or induce spawning in adult fish (Burton et al., 1998); and they have been tested as a promising vehicle for probiotics in marine fish larviculture (King, 2002).

The genus is cosmopolitan and comprises both sexually reproducing species and parthenogenetic populations. Salinity is the most important environmental factor governing *Artemia* distribution with populations being found in salt lakes and pans at salinity levels above approximately 40 $g \cdot \ell^{-1}$ (Vanhaecke et al., 1987) where fish and many predatory invertebrates are absent (Browne and MacDonald, 1982). Information from reviews (Persoone and Sorgeloos, 1980; Browne and MacDonald, 1982; Vanhaecke et al., 1987 and Triantaphyllidis et al., 1998) suggests that reproduction is sexual in the new world/western hemisphere (Americas), while in the old world (Europe, Asia, and Africa) *Artemia* populations can reproduce either sexually or parthenogenetically (Browne and MacDonald, 1982).

*Artemia* cysts can be naturally dispersed over long distances by becoming attached to the feathers of wading birds (Green et al., 2005) or being carried by wind. However, due to their high commercial value, *Artemia* cysts have also been inoculated into salt pans throughout the world, for example in Kenya (Rasowo and Radull, 1986) and Vietnam (Vu Do Quynh and Nguyen, 1987). Unfortunately, inoculation harbours the danger of introducing invasive species that may establish themselves in the new environment and replace local species. For instance, Van Stappen (2002) suggested that *Artemia franciscana* may replace other species, such as *A. salina* which is known to occur on the African continent from Tunisia to Southern Africa.

Despite their wide distribution, very little is known about the distribution of *Artemia* in Southern Africa (Van Stappen, 2002). For example, Persoone and Sorgeloos (1980) listed nine *Artemia* sites for sub-Saharan Africa, a number that was increased to only 15 sites 18 years later in a review by Triantaphyllidis et al. (1998). In comparison, the number of records for China increased from 2 to 73 sites and in Central America from 18 to 57 (Van Stappen, 2002). Thus, for more than 20 years little progress has been made in our understanding of African *Artemia* distribution. There is, however, an increasing interest in *Artemia* research in Africa (Triantaphyllidis et al., 1998). This review contributes to the biogeography of *Artemia* by presenting information about the presence of *Artemia* in Africa. We report new sites visited and/or sampled as part of a sampling trip through South Africa and Namibia. Hence, the lists previously provided by Triantaphyllidis et al. (1998) and Van Stappen (2002) were updated.

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## Methods

The sampling trip through parts of South Africa and Namibia was conducted in July/August 2003. Salt pans were visited and GIS coordinates were recorded. Either live *Artemia* or *Artemia* cysts were collected. Adult *Artemia* were preserved in alcohol (>95% ethanol) and kept frozen at -20°C. Cysts were cleaned and dried and kept at -20°C and used for genetic analyses. The approximate size of the pans and the water depth (m) at the time of sampling were estimated, and the salinity ($g \cdot \ell^{-1}$) was recorded using an Atago Hand Refractometer (Model S-10E). Annual average temperature records were taken from information available in GIS databases pertaining to the respective coordinates. Adult *Artemia* were sexed by using a dissection microscope to discern the egg sacs of females or the claspers of males.

## Results and discussion

### *Artemia* populations in Africa

Most African *Artemia* populations have been recorded from countries bordering the Mediterranean (Table 1). Although the

**TABLE 1**
**Locations of *Artemia* populations on the African continent**

| Country | | Locality | Geographical coordinates | Reproductive mode/species | *Artemia* research centre number | Reference number |
|---|---|---|---|---|---|---|
| **Algeria** | # | ? | | | 1285*, 1182*, 1127*, 1098*, 1066*, 1065* | 2 |
| | | Chegga Oase | 34°29'N-05°53'E | | | 1 |
| | | Chott Djeloud | 34°03'N-06°20'E | | | 1 |
| | # | Chott Merouan | 34°00'N-06°10'E | B | | 3 |
| | | Chott Ouargla | 31°57'N-05°20'E | | | 14, 15 |
| | | Dayet Morselli | 35°30'N-00°46'W | | | 15 |
| | # | El-Menaceria | | | 1097 and 1091* | 2 |
| | | Gharabas Lake | 35°35'N-00°25'W | | | 1 |
| | # | Mellaha Guergour El-Amri | 35°59'N-05°15'E | B | | 3 |
| | | Salin de Bethioua | | | 1129* | 2, 4 |
| | | Sebket Djendli | 35°43'N-06°32'E | | | 1 |
| | | Sebket Ez Zemouk | 35°53'N-06°33'E | | | 1 |
| | | Sebket Oran | 35°32'N-00°48'W | | | 1 |
| | # | Sebkha Azrew | 35°43'N-00°08'W | B | | 3 |
| | # | Sebkha d'Arzeut | | | 1119 | 2 |
| | # | Sebkha N'zouri | 35°50'N-06°35'E | B | | 3 |
| | # | Sebkha Sidi Bouzian | 35°52'N-00°35'E | B | | 3 |
| | | Tougourd | 33°06'N-06°07'E | | | 16 |
| Cape Verde | # | Santa Maria | | | | 30 |
| | | Cape Verde Islands | | | | 4 |
| Egypt | # | Bourg El-Arab | | P | 1497*,1146*, 1136*, 1131*, 1063 | 2, 31 |
| | # | El Max Saline (Alexandria) | | P | 1142*, 1132*, 1115*, 1064* | 2, 31 |
| | | Ismailia | 30°36'N-22°15'E | | | 1 |
| | | Port Fouad | | P | | 4 |
| | # | Port Said | | P | 1152, 1144*, 1140*, 1134*, 1133*, 1114 | 2 |
| | | Qarun Lake | | P | 1139*, 1137, 1118* | 2, 4, 31 |
| | # | Rassoua | | | 1145* ,1143, 1141*, 1138 | 2 |
| | | Solar Lake (Sinai) | 29°10'N-34°50'E | P | | 4, 15, 17, 18, |
| | | Wadi Natron | 30°10'N-30°27'E | *A. salina* | * | 1 |
| | # | Wadi el Natrun | | *A. salina* (B [31]) | 1290*, 1147, 1117, 1026*, 576, 358 | 2, 4, 6, 31 |
| Kenya | | Elmenteita | 00°27'S-36°15'E | | | 1 |
| | # | Fundisha | | | 1035* | 2 |
| | # | Fundisha | | *A. salina* | | 5 |
| | # | Kensalt Saltworks | | | 1036* | 2 |
| | # | Kensalt Saltworks | | *A. franciscana* | 1439* | 2 |
| | # | Kurawa Saltworks | | *A. franciscana* | 1441* | 2 |
| | # | Kurawa Saltworks | | *A. salina* | | 5 |
| | # | Malindi Saltworks | | *A. franciscana* | 1440* | 2 |
| Libya | # | ? | | | 339, 1437* | 2 |
| | # | Abu-Khammash | | *A. salina* | | 6 |
| | | Gabr Acun (Fezzan) | 27°'N-13°'E | | | 16, 19, 21 |
| | | Mandara | 26°40'N-13°20'E | B | | 16, 19 |
| | | Mandara | | B | 341, 1459 | 2 |
| | | Quem el Ma | 26°41'N-13°22'E | | | 16, 19 |
| | | Ramba-Az-Zallaf (Fezzan) | 27°'N-13°'E | | | 20 |
| | | Trouna | 26°50'N-13°30'E | | | 19 |
| | | Trouna | | | 340 | 2 |
| Madagascar | | Ankiembe Saltworks | | P | 1314* | 2, 4, 7 |
| | | Ifaty Saltworks | | *A. franciscana* | | 4 |
| | | Salins de Diego Suarez | 12°19'S-49°17'E | | | 1 |
| Mocambique | | Lagua Quissico | 24°41'S-34°46'E | P | | 23, 26 |
| Morocco | # | Chemmaiaa | | *A. salina* | | 6 |
| | | Larache | 35°12'N-02°20'W | P | | 8, 22 |
| | | Moulaya Estuary | 35°07'N-02°20'W | | | 1 |
| | | Qued Ammafatma | 28°18'N-12°00'W | | | 16 |
| | | Qued Chebeica | 28°25'N-11°50'W | | | 16 |
| | | Sebket Bon Areg | 35°10'N-02°50'W | | | 1 |
| | | Sebket Zima | 32°05'N-08°40'W | | | 1 |
| | # | Souzamma | | | 1427* | 2 |


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| | | | | | | |
|---|---|---|---|---|---|---|
| Namibia | # | ? | | | 1418* | 2 |
| | # | Henties Bay Salt Refineries | 22°00'S-00°14'E | | | 28 |
| | # | Swakopmund Saltworks | 22°40'S -14°34'E | | | 28 |
| | | Vineta Swakopmund | 22°40'S-14°34'E | P | | 1, 4 |
| | | Vineta Swakopmund | | P | 1186*, 480*, | 2, 6, 7, 9 |
| | # | Walvis Bay | 22°56'S-14°30'E | | | 28 |
| Niger | | Teguidda In Tessoun | 17°26'N-06°39'E | | | 1 |
| Senegal | | Dakar | 14°34'N-17°29'W | | | 1 |
| | | Lake Kayar | 14°55'N-17°11'W | | | 1 |
| | | Lake Retba | 14°50'N-17°20'W | | | 16 |
| South Africa | # | ? | | | 1267, 1170, 1159 | 2 |
| | # | Bloemfontein Saltworks | | P | | 10 |
| | # | Brandtvlei Saltworks | 30°22'S-20°13'E | | | 29 |
| | # | Brandtvlei Saltworks | 30°26'S-20°44'E | | | 28 |
| | | Coega Salt Flats | 33°46'S-25°40'E | P | | 1 |
| | # | Driehoekspan | 29°45'S-23°14'E | | | 29 |
| | # | Haaegestad Pan | | | | 30 |
| | # | Hayfield Saltpan | 29°15'S-24°13'E | | | 29 |
| | # | Holpan Saltworks | 30°22'S-20°30'E | | | 29 |
| | # | Holpan Saltworks | 30°12'S-20°40'E | | | 29 |
| | # | Jonkerwater Saltworks | 30°05'S-22°36'E | | | 29 |
| | # | Kaalpan Saltworks | 30°00'S-20°03'E | | | 29 |
| | # | Klein Soutpan | 30°27'S-22°24'E | | | 29 |
| | # | Klipfontein Saltworks | 32°57'S-18°13'E | | | 28 |
| | # | Kliphoek Salina | | | | 27 |
| | # | Missionvale Salina | 33°52'S-25°32'E | | | 27 |
| | # | Paternoster Salt Pan | 33°47'S-17°55'E | | | 29 |
| | # | Playas | | | 1169 | 2 |
| | # | Rietfontein se Pan | 30°16'S-20°07'E | | | 29 |
| | # | Reynekespan Saltworks | 33°41'S-25°47'E | | | 28 |
| | # | Reynekespan (2 populations) | 29°43'S-24°15'E | | | 29 |
| | # | Saldanha Steel | 33°00'S-18°02'E | | | 28 |
| | # | Salt Lake | 29°17'S-24°00'E | | | 29 |
| | # | Hopetown Salt Pan | | | 1121* | 2 |
| | # | Hopetown | | | | 30 |
| | # | Sodium Saltworks | 30°10'S-23°08'E | | | 29 |
| | # | Soutpan area | 28°42'S-26°03'E | | | 29 |
| | # | Soutpan Saltworks | 28°44'S-26°04'E | | | 29 |
| | # | Sundays River Saltworks | 33°38'S-25°43'E | | | 28 |
| | | Swartkops | 33°52'S-25°36'E | | | 1, 2 |
| | | Swartkops | | *A. salina.* | 1179* | 30 |
| | # | Swartkops Marina | 33°51'S-25°34'E | | | 28 |
| | # | Swartkops Cerebos | 33°47' S - 25°32'E | | | 28 |
| | # | Uniesoutpan | 29°36'S-24°26'E | | | 29 |
| | | Velddrif | | *A. salina* | 1289 | 2, 13 |
| | # | Velddrif Saltworks | 32°43'S-18°12'E | | | 28 |
| | # | Velddrif Saltworks | 32°47'S-18°10'E | | | 28 |
| | # | Vermeulenspan | 29°45'S-24°20'E | | | 29 |
| | # | Wintersdam Farm | 28°45'S-26°08'E | | | 12 |
| | # | Witkraal Saltpan | 28°58'S-25°31'E | | | 29 |
| | # | Witpan Saltworks | 29°53'S-24°03'E | | | 29 |
| | # | Yzerfontein Saltworks | 33°19'S-18°10'E | | | 28 |
| | # | Zoutaar Saltworks | 30°19'S-23°05'E | | | 29 |
| Tunisia | # | ? | | | 465, 2, 3 | 2 |
| | | Bekalta | 36°48'N-10°20'E | *A. salina* | * | 24 |
| | | Bekalta | | *A. salina* | 363* | 2 |
| | | Chott Ariana | 36°54'N-10°18'E | *A. salina* | * | 24, 25 |
| | | Chott Ariana | | *A. salina* | 360* | 2 |
| | | Chott El Djerid | 33°42'N-08°26'E | | | 1 |
| | | Megrine | 36°47'N-10°14'E | *A. salina* | * | 24 |
| | | Megrine | | *A. salina* | 1268*, 361, 466* | 2 |
| | | Sebket Kowezia | 36°26'N-09°46'E | | * | 1 |
| | | Sebket Mta Moknine | 35°39'N-10°53'E | *A. salina* | * | 24 |
| | | Sebket Sidi El Hani | 35°31'N-10°27'E | | * | 1 |
| | # | Sfax | 35°45'N-10°43'E | *A. salina* | * | 24, 32 |
| | | Sfax | | *A. salina* | 1493*, 1492*, 1269*, 506, 362 | 2, 9 |

***Legend**: (B) = bisexual but species not known; (P) = parthenogenetically reproducing population; * = cysts are available at the Artemia Reference Center (ARC), Ghent, Belgium; # = a new Artemia population added to the list since the last general review by Triantaphyllidis et al. (1998).*
*The number in the last column indicates the reference in which the Artemia population was first reported; ? = Site name not known or not given.*

### References for Table 1

*1. Vanhaecke et al. (1987); 2. ARC table; 3. Zemmouri (1991); 4. Triantaphyllidis et al. (1998); 5. Rasowo and Radull (1986); 6. Triantaphyllidis et al. (1997b); 7. Triantaphyllidis et al. (1996); 8. Hontoria and Amat (1992); 9. Triantaphyllidis et al. (1997a); 10. Williams and Mitchell (1992); 11. Seaman et al. (1991); 12. Mitchell and Seaman (1988); 13. Amat et al. (1995); 14. Cole and Brown (1967) cited in Vanhaecke et al. (1987); 15. McCarraher (1972) cited in Vanhaecke et al. (1987); 16. Dumont (1979) cited in Vanhaecke et al. (1987); 17. Por (1968) cited in Vanhaecke et al. (1987); 18. Por (1969) cited in Vanhaecke et al. (1987); 19. Monod (1969) cited in Vanhaecke et al. (1987); 20. Ghannudi and Tufail (1978) cited in Vanhaecke et al. (1987); 21. Beadle (1974) cited in Vanhaecke et al. (1987); 22. Amat Domenech (1980) cited in Vanhaecke et al. (1987); 23. De Pinho Canelhas (1971) cited in Vanhaecke et al. (1987); 24. Van Ballaer et al. (1987) cited in Vanhaecke et al. (1987); 25. Clark and Bowen (1976) cited in Vanhaecke et al. (1987); 26. Sousa (1994) cited in Triantaphyllidis et al. (1998); 27. Du Toit (2001); 28. Present study – cyst/nauplii samples collected.; 29. Present study – personal communication; 30. Van Stappen (2002); 31. Baxevanis et al. 2004. 32. Toumi et al. (2005).*

**TABLE 2**
**Abiotic characteristics of 16 sites from South Africa[a] and Namibia[b] from which adult *Artemia* and/or *Artemia* cysts were collected during July/August 2003**

| Site name | Type | Elevation (m) | Approximate size (km²) | Temperature in °C (average; min/max) |
|---|---|---|---|---|
| Brandtvlei[a] | I | 940 | 4 | 20.2; -8 / +42 |
| Coega Cerebos[a] | C | 1 | 10 | 19.1; 0 / +32 |
| Henties Bay[b] | C | 0 | 5 | 20; 0 / +34 |
| Kleinzee Yacht Club[a] | N | 0 | 3 | ?; 0 / +40 |
| Klipfontein Salt[a] | C | 15 | 5 | 23.6; 0 / +40 |
| Missionvale Salt[a] | C | 4 | 5 | 18.3; 0 / +35 |
| Reynekespan[a] | I | 1149 | 0.5 | 22.2; -6 / +40 |
| Saldanha Steel[a] | S | 40 | 0.5 | 23.6; 0 / +40 |
| Sundays River[a] | I | 30 | 5 | 20.2; -1 / +36 |
| Swakopmund[b] | C | 0 | 4 | 20; 0 / +34 |
| Swartkops Cerebos[a] | I | 10 | 4 | 18.8; 0 / +35 |
| Swartkops Salt[a] | I | 3 | 4 | 18.2; 0 / +35 |
| Velddrif Cerebos[a] | C | 12 | 5 | 24.6; 0 / +40 |
| Velddrif Salt[a] | C | 12 | 5 | 24.6; 0 / +40 |
| Walvis Bay[b] | C | 0 | 10 | 20; 0 / +34 |
| Yzerfontein[a] | S | 80 | 0.5 | 20; -2 / +38 |

***Legend**:*
*I = Inland salt works; C = Coastal salt works; N = Natural coastal lagoon; S = Salt pan.*

climate of this region is well suited to the development of an *Artemia* biotope (Vanhaecke et al., 1987), the high number of records for this region is probably a result of a relatively higher collection effort.

The reproductive mode for most *Artemia* populations in Algeria has not been established. Populations with a confirmed reproductive mode are bisexual, but their species status is either not known or has not been published. One bisexual population was recorded at a salt works and others were found in natural salt lakes (Zemmouri, 1991). In Libya one population was confirmed as bisexual (Triantaphyllidis et al., 1997b), but the reproductive mode of the other populations was not given. Records from Morocco show one population of *A. salina* (Triantaphyllidis et al., 1997b), one occurrence of a parthenogenetic population, and populations of unknown reproductive mode. Most Egyptian *Artemia* populations are parthenogenetic. *A. salina* was found at the Wadi Natron site and a permanent population of *A. franciscana* was discovered at a salt works (Triantaphyllidis et al., 1998). All Tunisian populations have been reported as *A. salina*. Dumont (1979) reported an *Artemia* population from Lake Retba, Senegal. Only personal communications account for the records of all other *Artemia* populations in Niger and Senegal (Table 1), and their reproductive mode is not known.

Records available prior to our sampling trip show the existence of both bisexual species and parthenogenetic populations in sub-Saharan Africa (Table 1). These populations were located at salt works, some of which were operating at the time of sampling, others had been abandoned. In addition, a number of personal communications report the existence of *Artemia* populations which required further investigation. For example, for three of six South African populations listed by Van Stappen (2002) the information is based on personal communications, thus their species status was undetermined. *Artemia salina* is reported to have been inoculated into Kenyan salt works (Rasowo and Radull, 1986; see Table 1), but the *Artemia* Reference Centre in Ghent, Belgium, identified *Artemia* from those salt works as *A. franciscana*. Both Mozambique and Namibia have parthenogenetic *Artemia* populations occurring at salt works. A parthenogenetic population as well as *A. franciscana* have been found in Madagascar, with an unidentified population occurring in the northern part of the island. The *A. franciscana* population was not permanent, and had to be inoculated annually (Triantaphyllidis et al., 1998).

The low number of recorded *Artemia* populations in Africa does not reflect *Artemia* distribution on the continent. Large areas of Africa, (i.e., Mauritania, Somalia, Ethiopia, Sudan, and southern Africa) are considered potential *Artemia* habitat (Vanhaecke et al., 1987). However, very few collections have been reported for these areas. Vanhaecke et al. (1987) suggested that 97% of the known *Artemia* populations in Africa are in areas where yearly evaporation exceeds yearly precipitation. Williams (1996) estimated that 37% (11.3 x$10^6$ km$^2$) of the African continent can be categorised as arid and semi-arid where salt lakes are likely to occur.

Salt lakes of northern Africa were among the first on the continent to be investigated, followed by locations in East Africa (Hammer, 1986; Seaman et al., 1991). More recently, the salt pans of Southern Africa have come under investigation (Seaman et al., 1991). Studies of these saltwater bodies have mainly focused on geological and chemical characteristics, with few biological surveys. Thus, the presence or absence of *Artemia* in most of these water bodies remains unclear. Saline water bodies in East and Southern Africa with salinities greater than 40 g·ℓ$^{-1}$ (Table 3) may contain populations of *Artemia* and should be the focus of further investigations. Lists of salt pans or lakes with salinities below 40 g·ℓ$^{-1}$ can be found in Seaman et al. (1991), Hammer (1986), Shumway (1999) and Williams (1996).

### Addition of new *Artemia* sites in sub-Saharan Africa

During July and August 2003, adult *Artemia* and cysts were collected from nine and five sites, respectively. For most adult specimens gender could be determined, but as the sample sizes


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**TABLE 3**
**Salt pans, salt works and lakes in East and Southern Africa with salinity values known to be greater than 40 g·ℓ$^{-1}$ (some sites have water only seasonally)**

| Name | Position | Country | Salinity | Reference |
|---|---|---|---|---|
| Annaspan[b] | 28°31'S - 25°48'E | South Africa | | Present study |
| Banksdrifpan[b] | 28°56'S - 25°14'E | South Africa | | Present study |
| Bogoria | - | Kenya | 50 | Williams (1996) |
| Britten Pan | 27º45'S - 25º21'E | South Africa | 181.6 | Seaman et al. (1991) |
| Dealsville[b] | 28°40'S - 25°41'E | South Africa | | Present study |
| Delareyville area[a] | 26°41'S - 25°27'E | South Africa | | Present study |
| Etosha Pan | 18º40'S - 16º40'E | Namibia | 62.0 | Seaman et al. (1991) |
| Florisbad Pan[a] | 28º45'S - 26º05'E | South Africa | 197.3 | Seaman et al. (1991); Present study |
| Gannaleegte (3 sites)[a] | 28°42'S - 25°52'E | South Africa | | Present study |
| Holfontein[a] | 28°42'S - 25°52'E | South Africa | | Present study |
| Hosabes Pool | 23º30'S - 15º05'E | Namibia | 115.9 - 161.7 | Seaman et al. (1991) |
| Karee Pan[b] | 27º30'S - 25º35'E | South Africa | 41.8 | Seaman et al. (1991); Present study |
| Kimberley area[b] | 28°53'S - 24°15'E | South Africa | | Present study |
| Koppieskraal Pan | 26º55'S - 20º18'E | South Africa | 48.6 | Seaman et al. (1991) |
| Magadi | - | Kenya | 114 | Williams (1996) |
| Mollerspan[b] | 28°53'S - 24°14'E | South Africa | | Present study |
| Natron | - | Tanzania | 340 | Williams (1996) |
| Oranjemund Pan | 28º35'S - 16º35'E | Namibia | 302.4 | Seaman et al. (1991) |
| Rensburg Salt Pan | 28º55'S - 26º05'E | South Africa | 102.4 | Seaman et al. (1991) |
| Skietbaana[a] | 26°43'S - 25°28'E | South Africa | | Present study |
| Skoppan[b] | 28º40'S - 26º05'E | South Africa | 160.1 | Seaman et al. (1991); Present study |
| Soutbron[a] | 28°41'S - 25°50'E | South Africa | | Present study |
| Soutpan area (15 sites)[a] | 28°42'S - 26°03'E | South Africa | | Present study |
| Stink Pan | 27º46'S - 26º40'E | South Africa | 51.1 | Seaman et al. (1991) |
| Tara[a] | 28°42'S - 25°49'E | South Africa | | Present study |
| Wadrif Soutpan[a] | 32°12'S - 18°21'E | South Africa | | Present study |

***Legend**:*
*a = indicates sites visited where no Artemia were found*
*b = indicates sites which were dry at the time of the visit during the present study*

were low, only numbers of males and females in parentheses, rather than percentage values, will be reported. These results can be used as an indication of the most likely reproductive status of the population since parthenogenetic populations do not have males, except for the rare occurrence of non-functional males (MacDonald and Brown, 1990). Therefore, these figures do not allow an estimation of the gender ratio in the population as this would require a larger sample size and repeated sampling at different times. They provide, however, a basis for hypotheses regarding a population's reproductive mode.

In South Africa the sites Brandtvlei (10:47), Yzerfontein (13:33), Reynekespan (30:17), Swartkops Marina Salt (9:5), Swartkops Cerebos (7:7) and Missionvale (3:10) were inhabited either by sexually reproducing *Artemia* only, or they had at least one bisexual species. The presence of males in a population suggests the existence of a bisexual species, but the same site may also contain a parthenogenetic population. For example, Van Stappen (2002) listed the population from Coega saltworks as parthenogenetic. Unpublished work using genetic markers confirmed that this site had both a sexually reproducing species and parthenogenetic component. Genetic analyses are required to distinguish populations at one site from each other and to identify species. We suggest that the six South African populations exhibited sexual reproduction and, except for the population at Velddrif described by Amat et al.(1995), this is the first survey to include these South African populations.

At two sites in Namibia no males were recorded. These sites were Swakopmund (0:30) and Walvis Bay Salt Pan (0:42). Previously recorded Namibian populations (see Table 1) were parthenogenetic, and our recent records from the population at Swakopmund suggested the existence of a parthenogenetic population, thus confirming this reproductive mode for both sites using samples taken in 2003. Results from collections at Henties Bay (14:5) provide the first record of bisexual reproduction for Namibian *Artemia* although the species status of this population has not yet been determined.

Additional information (Table 2) was collected for some new southern African *Artemia* sites investigated as part of this study. This information included site management, GIS data relating average temperatures and their ranges, as well as elevation and the approximate area of the sites at the time of sampling. The latter value fluctuates strongly depending on season and rainfall and records should be taken repeatedly during the year.

Several other sites were visited but no *Artemia* or cysts were found (see Table 3). Of the 47 sites in South Africa and Namibia, 24 were at an elevation of above 1 000 m, with the highest elevation being 1 556 m a.m.s.l. Four sites were at sea level. The average elevation of the other sites was 793 m a.m.s.l. The average annual ambient temperature was 18.2°C (-8 to +42°C). The average minimum and maximum ambient temperatures of these 47 Southern African sites were -0.4°C and 36°C, respectively.

### Site names

There are two South African populations at Swartkops; these are at Swartkops Marina and Swartkops Cerebos. These sites belong to different salt production companies and, although geographically close to each other, were not listed as being the same due to different management. Similarly, sites listed under the name Velddrif do not all belong to the same salt company. In addition, very similar names have been given to different sites; for example, the name Soutpan (Afrikaans for salt pan) appears as part of several composite names. Spelling may differ between Afrikaans and English (i.e., Coega or Koega).

## Conclusion

There are 127 records of either sexually reproducing or parthenogenetic populations of *Artemia* on the continent, but reproductive mode has only been given for 41 populations. An estimated 32% of the populations appear to be parthenogenetic and 68% are bi-sexual species. However, only a tentative species list can be presented due to the uncertainty and paucity of published and anecdotal information. Most work on African *Artemia* populations needs verification using molecular techniques. Thus, applying caution with regard to the precision of the data, and considering that relatively few records are available, it is estimated that about 50% of the identified populations are *A. salina*, 12% can be hypothetically assigned to *A. franciscana*, and 38% of the populations so far described appear to be parthenogenetically reproducing *Artemia*.

By combining the information obtained during the sampling trips and climatic and GIS data available for South Africa with information provided in the literature the number of potentially available *Artemia* biotopes was updated (Table 3). These sites deserve further investigation. In order to obtain a representative picture of South African populations, sampling should be done repeatedly over several years and throughout the year since distinct dry seasons occur.

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