International Journal of *Artemia* Biology

ISSN: 2228-754X

2012, Vol 2, No 1: 3-8

Special Issue on Biogeography (I)

Review of the biogeography of *Artemia* Leach, 1819 (Crustacea: Anostraca) in Brazil

Marcos R. Camara*

Departmento de Oceanografia e Limnologia, Universidade Federal do Rio Grande do Norte, Natal, RN, 59078-900, Brazil

* Corresponding author:
Marcos R. Camara
Departmento de Oceanografia e Limnologia, Universidade Federal do Rio Grande do Norte, Natal, RN, 59078-900, Brazil
Tel.: +55 84 3342 4954
Fax: +55 84 3342 4951
E-mail: mrcamara@ufrnet.br

Abstract

The genus *Artemia* (Crustacea; Anostraca) is a complex of sibling species and superspecies defined by the criterion of reproductive isolation. Two bisexual species are represented in the New World: *Artemia persimilis* Piccinelli & Prosdocimi and *Artemia franciscana* Kellogg. In Brazil, *Artemia franciscana* populations have been recorded in coastal saltworks in the states of Rio Grande do Norte, Ceará, and Rio de Janeiro. However, several of the coastal saltworks previously indicated as *Artemia franciscana* sites have been transformed into aquaculture farms or have been subject to a strong process of urbanization. Thus, in order to provide a reference point for current and future assessments, this paper presents an updated list of *Artemia franciscana* sites in Brazil based on literature data and field surveys. Furthermore, an attempt is made to delineate the origin and the dispersal of this species in northeastern Brazil in connection to genetic and ecological data. Finally, the need for the conservation of Brazilian *Artemia franciscana* populations is emphasized.

Key Words: *Artemia*, biogeography, ecology, Brazil

Introduction

The genus *Artemia* (Crustacea; Anostraca) is a complex of sibling species and superspecies defined by the criterion of reproductive isolation (Browne & Bowen, 1991). Two bisexual species are represented in the New World: *Artemia persimilis* Piccinelli & Prosdocimi and *Artemia franciscana* Kellogg. *Artemia persimilis* is restricted to some localities in Argentina whereas the bisexual *Artemia franciscana* superspecies is endemic to the Americas and the Caribbean, with various populations established in South American countries, either by deliberate inoculation or natural dispersal (Lenz & Browne, 1991; Gajardo *et al*., 1999).

The diversification of *Artemia franciscana* environments in South America ranges from coastal saltworks (Macau, Brazil), coastal salt lakes (Boca Chica, Venezuela) and inland salt lakes (Atacama, Chile) to coastal hypersaline estuaries (Virilla, Peru) (Lenz & Browne, 1991). In Brazil, *Artemia franciscana* populations have been recorded in coastal saltworks in the states of Rio Grande do Norte, Ceará, and Rio de Janeiro (Camara & Castro, 1983; Vanhaecke *et al*., 1987; Triantaphyllidis *et al*., 1998; Camara, 2001; Van Stappen, 2002). However, several of the coastal saltworks previously indicated as *Artemia franciscana* sites have been transformed into aquaculture farms or have been subject to a strong process of urbanization. Thus, in order to provide a reference point for current and future assessments, this paper presents an updated list of *Artemia franciscana* sites in Brazil based on literature data and field surveys. Furthermore, an attempt is made to delineate the origin and the dispersal of this species in northeastern Brazil in connection to genetic and ecological data. Finally, the need for the conservation of Brazilian *Artemia franciscana* populations is emphasized.

Biogeography of *Artemia franciscana* in Brazil

The occurrence of the genus *Artemia* (Crustacea, Anostraca) in Brazil was first reported in the coastal saltworks of Cabo Frio, Rio de Janeiro (Costa, 1972). However, the origin of these brine shrimp populations in the southeastern coast of Brazil still needs clarification. By contrast, data about the existence of *Artemia franciscana* in northeastern Brazil have become increasingly vivid (Camara, 2001; Camara *et al*., 2003; Maniatsi *et al*., 2009).

Artemia franciscana, the dominant and most studied brine shrimp species in the New World (Triantaphyllidis *et al*., 1998), is found in northeastern Brazil as a result of inoculations made in a very large solar saltwork in Macau (Rio Grande do Norte) in April 1977 with cysts from a San Francisco Bay (California, U. S. A.) stock (Camara & Castro, 1983; Persoone & Sorgeloos, 1980). Through the years, introduced *Artemia* dispersed to neighboring saltworks by men (for aquacultural purposes and to aid in salt production) and presumably, by wind and by local waterfowl, and became an important asset in the development of a successful shrimp (*Litopenaeus vannamei*) culture industry in northeastern Brazil. On a yearly basis, all *Artemia* biomass and a substantial part of the cysts used by the Brazilian shrimp culture industry are currently harvested in local saltworks in Rio Grande do Norte (Wainberg *et al*., 2011).

The origin of the cyst material inoculated in Macau is well established. Initially, electrophoretic evidence (similarity of samples of Macau and San Francisco Bay) confirmed the proposed origin, from San Francisco Bay (California, U.S.A.) cysts, of the Macau population (Gajardo *et al*., 1995). Following, Camara *et al*. (2003) reported the molecular genetic diversity of three *Artemia franciscana* populations (Macau, Galinhos and Areia Branca/Grossos) from northeastern Brazil, by means of RFLP (Restriction Fragment Length Polymorphism) analysis of their mtDNA. Fragment patterns observed among these brine shrimp in part of the 16S RNA region showed a consistent homogeneity and again indicated that the feral populations of *Artemia franciscana* found in the state of Rio Grande do Norte, northeastern Brazil, belonged to the *Artemia franciscana* superspecies. In addition, their proposed origin, from San Francisco Bay cysts, as previously reported by Gajardo *et al*. (1995) based on allozymic evidence derived from the Macau population, was clearly

demonstrated. More recently, Maniatsi *et al*. (2009) compiled and derived sequence data for two mitochondrial (16S rRNA, COI) and two nuclear (ITS1, p26) markers in fourteen American populations of *Artemia franciscana*, including Brazilian populations from Rio Grande do Norte (Macau, Galinhos and Areia Branca). Cladistic analysis revealed three reciprocally monophyletic mitochondrial clades. The first clade consisted of the North American populations of San Francisco Bay (California) and Great Salt Lake (Utah), the Brazilian feral populations of Macau, Galinhos, and Areia Branca, and the northernmost Chilean population of Iquique. Bearing in mind that inferred genealogies reflect historical colonization patterns, Maniatsi *et al*. (2009) provided strong evidence for an advanced state of phylogenetic congruence across loci in the investigated lineages.

The magnitude of the regional dispersal of *Artemia franciscana* populations in the coastal saltworks of Rio Grande do Norte was documented about two decades after the original inoculation (Camara, 2001). For twelve months (July 1996 – June 1997), fifty-five saltworks located in the municipalities of Areia Branca, Grossos, Galinhos, Guamaré and Macau were visited and sampled for the presence of *Artemia franciscana* and the occurrence of its cysts. Interestingly, populations of *Artemia franciscana* were found in all fifty-five saltworks, although significant amounts of cysts were only found in six sites. The present of *Artemia franciscana* in all visited sites brought evidence to the ample dispersal of this anostracan throughout the saltwork region of Rio Grande do Norte. Furthermore, the relatively low incidence of cysts suggested that most of these populations were reproducing ovoviviparously (Camara, 2001).

The dispersal (or migration) of individuals from one locality to another is a fundamental ecological process which can also enhance gene flow within and between populations (Rankin, 1985). The principal dispersion mechanism of *Artemia* is transportation of cysts by wind and by waterfowl, as well as deliberate human inoculation in solar saltworks (Persoone & Sorgeloos, 1980). The fact that in most cases the cysts float at the surface of the water lays at the basis of transportation both by wind and waterfowl. The cysts adhere to the feet and the feathers of the birds which come down on the water or they are washed ashore where they dry and are carried away by the wind (Persoone & Sorgeloos, 1980). Considering that cyst production in Rio Grande do Norte was high for the first five years after inoculation, then declined by over an order of magnitude (Camara & Rocha, 1987), dispersal of *Artemia* to neighboring saltworks should have occurred primarily in the late 70's and early 80's. Furthermore, taking into account that coastal saltworks in Rio Grande do Norte act as wintering grounds or passage areas for a diverse and abundant avifauna, it is likely that the role of migratory birds in the dispersal of *Artemia franciscana* in northeastern Brazil might have been underestimated in the past (Larrazábal *et al*., 2002).

The relatively stable environmental conditions found in the coastal saltworks of Rio Grande do Norte might also explain why most of these brine shrimp populations are currently reproducing ovoviviparously. Cyst production is commonly seen in populations experiencing a seasonal cycle of either temperature or salinity, or living in ephemeral habitats (Browne & Bowen, 1991; Lenz & Browne, 1991; Gajardo *et al*., 2002). Ovoviviparity (nauplii production), on the other hand, is associated with stable environmental conditions (Lenz, 1984; Wear *et al*., 1986; Wear & Haslett, 1987; Dana *et al*., 1995; Mura, 1995; Van Stappen *et al*., 2001; Wurtsbaugh & Gliwicz, 2001; Torrentera & Dodson, 2004). In such conditions, it would be of selective advantage to produce the majority of offspring ovoviviparously in order to maximize success in intraspecific competition (Lenz & Browne, 1991).

Table 1 provides an updated list of *Artemia franciscana* sites in Brazil based on literature data and field surveys. *Artemia franciscana* populations have been recorded in coastal saltworks in the states of Rio Grande do Norte, Ceará, and Rio de Janeiro (Vanhaecke *et al*., 1987; Triantaphyllidis *et al*., 1998). It is interesting to note that several of the localities previously indicated as *Artemia franciscana* sites have been transformed into aquaculture farms. For example, several coastal saltworks in the

northeastern states of Rio Grande do Norte, Ceará, and Piaui are now shrimp (*Litopenaeus vannamei*) farms. The resulting scenario is that industrial salt production in Brazil (5,508, 859 million tonnes in 2010) is currently restricted to Rio Grande do Norte (92.61%) and Rio de Janeiro (7.39%). In addition, particularly in the southeastern state of Rio de Janeiro, coastal saltworks have been subject to a strong process of urbanization. Thus, it is appropriate to finalize the current review with a special focus on the conservation of Brazilian *Artemia franciscana* populations.

Table 1: List of *Artemia franciscana* sites in Brazil

State	Locality	Geographical coordinates	References
Ceará	Aracati	4º 33' S; 37º 46' W	1, 2, 3, 4
	Camocim	2º 54' S; 40º 50' W	4
	Fortaleza	3º 43' S; 38º 32' W	1, 3
	Icapuí	4º 42' S; 37º 21' W	1, 3, 4
	Mundaú	3º 16' S; 39º 24' W	1, 3, 4
Rio Grande do Norte	Areia Branca	4º 57' S; 37º 08' W	4, 6
	Galinhos	5º 05' S; 36º 16' W	4, 6
	Grossos	4º 58' S; 37º 09' W	4, 6
	Guamaré	5º 06' S; 36º 19' W	4, 6
	Macau	5º 06' S; 36º 38' W	1, 2, 3, 4, 5, 6
	Mossoró	5º 11' S; 37º 20' W	2
	Porto do Mangue	5º 04' S; 36º 46' W	This article
	São Bento do Norte	5º 10' S; 36º 05' W	4
Rio de Janeiro	Araruama	22º 53' S; 42º 20' W	7
	Arraial do Cabo	22º 57' S; 42º 01' W	7
	Cabo Frio	22º 51' S; 42º 03' W	1, 3, 4, 7, 8
	São Pedro da Aldeia	22º 50' S; 42º 06' W	7

References: 1: Vanhaecke *et al*. (1987); 2: Camara & Rocha (1987); 3: Triantaphyllidis *et al*. (1998); 4: Van Stappen (2002); 5: Camara & Castro (1983); 6: Camara (2001); 7: INEPAC (2004); 8: Costa, P. da (1972)

Biological invasions by marine organisms, as a result of human activities, are now frequent occurrences and a threat to biodiversity on a global scale. In marine environments, taxonomic diversity of invading species ranges from microbes to fishes and is mostly related to ballast water and aquaculture (Carlton, 1989). With the development of hatchery aquaculture in Brazil, especially marine fish and shrimp, the use of *Artemia* as a diet for larval culture is expected to increase significantly in the near future (Wainberg *et al*., 2011). In this context, aquaculture effluents, particularly from hatchery (fish and shrimp larviculture) operations located in areas close to hypersaline biotopes, are potential threats to *Artemia franciscana* biodiversity. This is particularly true when allochthonous *Artemia* species are used in such aquaculture ventures, as escapes of non-native *Artemia* species might impact autochthonous brine shrimp populations through competition, genetic introgression, and introduction of pathogens and parasites. Therefore, a strategic approach for the conservation of *Artemia franciscana* populations in Brazil should include a scheme for safe disposal of hatchery (fish and shrimp larviculture) effluents, particularly in areas close to *Artemia* biotopes; and the development of a code of conduct to regulate inoculation policies, in conformity with Beardmore (1987).

Acknowledgements

I thank Alireza Asem, Editor of the International Journal of *Artemia* Biology, for the invitation to write this essay, and my colleagues from the *Artemia* world family for fruitful discussions throughout the years.

References

Beardmore J.A. (1987) Concluding remarks for Symposium Session I: Morphology, Eco-toxicology, Radiobiology, Genetics. In: Sorge-

loos, Bengtson, Decleir and Jaspers (eds) *Artemia* Research and its Applications, 1. Universa Press, Wetteren, Belgium, 345-346.

Browne R.A. and Bowen S.T. (1991) Taxonomy and population genetics of *Artemia*. In: Browne, Sorgeloos and Trotman (eds) *Artemia* Biology, CRC Press, Florida, U.S.A., 221-235.

Camara M.R. (2001) Dispersal of *Artemia franciscana* Kellogg (Crustacea; Anostraca) populations in the coastal saltworks of Rio Grande do Norte, northeastern Brazil. Hydrobiologia, 466, 145-148.

Camara M.R. and Castro E.V. (1983) *Artemia salina* L. (Anostraca): uma opção para a aqüicultura do nordeste do Brasil. Rev. Bras. Zool., 1, 145-147.

Camara M.R. and Rocha R. de M. (1987) *Artemia* culture in Brazil: an overview. In: Sorgeloos, Bengtson, Decleir and Jaspers (eds) *Artemia* Research and its Applications, 3. Universa Press, Wetteren, Belgium, 195-200.

Camara M.R., Triantafyllidis A., Baxevanis A.D. and Abatzopoulos T.J. (2003) Preliminary characterization of Brazilian *Artemia franciscana* populations by means of mtDNA RFLP analysis. Regional Workshop on *Artemia* Biodiversity, Puerto Varas (Chile), 36-38.

Carlton J.T. (1989) Man's role in changing the face of the ocean: biological invasions and implications for conservation of near-shore environments. Conserv. Biol., 3, 265-273.

Costa P. da (1972) Nota sobre a ocorrência e biologia de *Artemia salina* (L.) na região de Cabo Frio (RJ). Seç. Publ. Inst. Pesq. Mar., 66, 1-14.

Dana G.L., Jellison R. and Melack J.M. (1995) Effects of different natural regimes of temperature and food on survival, growth and development of *Artemia monica* Verrill. J. Plankton Res., 17, 2117-2130.

Gajardo G., Conceição M. da, Weber L. and Beardmore J.A. (1995) Genetic variability and interpopulational differences in *Artemia* strains from South America. Hydrobiologia, 302, 21-29.

Gajardo G., Mercado C., Beardmore J.A. and Sorgeloos P. (1999) International study on *Artemia*. LX. Allozyme data suggest that a new *Artemia* population in southern Chile (50º 29' S; 73º 45' W) is *A. persimilis*. Hydrobiologia, 405, 117-123.

Gajardo G., Abatzopoulos T.J., Kappas I. and Beardmore J.A. (2002) Evolution and speciation. In: Abatzopoulos, Beardmore, Clegg and Sorgeloos (eds) *Artemia*: Basic and Applied Biology, Kluwer Academic Publishers, Dordrecht, The Netherlands, 225-250.

INEPAC (2004) Sal. Projeto Inventário de Bens Culturais Imóveis. Desenvolvimento Territorial dos Caminhos Singulares do Estado do Rio de Janeiro. Instituto Estadual do Patrimônio Cultural, Rio de Janeiro.

Larrazábal M.E., Azevedo Júnior S.M. and Pena O. (2002) Monitoramento de aves limícolas na Salina Diamante Branco, Galinhos, Rio Grande do Norte, Brasil. Revta. Bras. Zool., 19, 1081-1089.

Lenz P.H. (1984) Life-history analysis of an *Artemia* population in a changing environment. J. Plankton Res., 6, 967-983.

Lenz P.H. and Browne R.A. (1991) Ecology of *Artemia*. In: Browne, Sorgeloos and Trotman (eds) *Artemia* Biology, CRC Press, Florida, U.S.A., 237-253.

Maniatsi S., Kappas I., Baxevanis A.D., Farmaki T. and Abatzopoulos T.J. (2009) Sharp phylogeographic breaks and patterns of genealogical concordance in the brine shrimp *Artemia franciscana*. Int. J. Mol. Sci., 10, 5455-5470.

Mura G. (1995) An ecological study of a bisexual *Artemia* population from Sant'Antioco solar saltworks (south-western Sardinia, Italy). Int. J. Salt Lake Res., 3, 201-219.

Persoone G. and Sorgeloos P. (1980). General aspects of the ecology and biogeography of *Artemia*. In: Persoone, Sorgeloos, Roels and Jaspers (eds) The Brine Shrimp *Artemia*, 3, Universa Press, Wetteren, Belgium, 3-24.

Rankin M.A. (1985). Migration: Mechanisms and Adaptive Significance. Contributions in Marine Science, 27, The University of Texas, Marine Science Institute, Texas, U.S.A.

Torrentera L. and Dodson S.I. (2004). Ecology of the brine shrimp *Artemia* in the Yucatan, Mexico, salterns. J. Plankton Res., 26, 617-624.

Triantaphyllidis G.V., Abatzopoulos T.J. and Sorgeloos P. (1998) Review of the biogeography of the genus *Artemia* (Crustacea, Anostraca). J. Biogeogr, 25, 213-226.

Van Stappen G. (2002). Zoogeography. In: Abatzopoulos, Beardmore, Clegg and Sorgeloos (eds) *Artemia*: Basic and Applied Biology, Kluwer Academic Publishers, Dordrecht, The Netherlands, 171-224.

Van Stappen G., Fayazi G. and Sorgeloos P. (2001) International study on *Artemia*. LXIII. Field study of the *Artemia urmiana* (Günther, 1890)

population in Lake Urmiah, Iran. Hydrobiologia, 466, 133-143.

Vanhaecke P., Tackaert W. and Sorgeloos P. (1987) The biogeography of *Artemia*: an updated review. In: Sorgeloos, Bengtson, Decleir and Jaspers (eds) *Artemia* Research and its Applications, 1. Universa Press, Wetteren, Belgium, 129-155.

Wainberg A.A., Ribeiro F.A.S., Ribeiro K. and Camara M.R. (2011) Aquaculture in Rio Grande do Norte, NE-Brazil: past, present and future. World Aquacult., 42(1), 21-25.

Wear R.G., Haslett S.J. and Alexander N.L. (1986) Effects of temperature and salinity on the biology of *Artemia franciscana* Kellogg from Lake Grassmere, New Zealand. 2. Maturation, fecundity, and generation times. J. Exp. Mar. Biol. Ecol., 98, 167-183.

Wear R.G. and Haslett S.J. (1987) Studies on the biology and ecology from Lake Grassmere, New Zealand. In: Sorgeloos, Bengtson, Decleir and Jaspers (eds) The Brine Shrimp *Artemia*, 3, Universa Press, Wetteren, Belgium, 101-126.

Wurtsbaugh W.A. and Gliwicz Z.M. (2001) Limnological control of brine shrimp population dynamics and cyst production in the Great Salt Lake, Utah. Hydrobiologia, 466, 119-132.