



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

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Abstract

There are several studies on the brine shrimp *Artemia* genus in order to understand the distribution of the different species across all continents. The *Artemia* distribution in Portugal is mainly located in coastal saltworks, and there is only one inland location where *Artemia* appears. Until now, in Portugal there were only two *Artemia* species recorded, the bisexual *Artemia franciscana* and a diploid parthenogenetic one. One of the problems of the *Artemia* genus in Portugal is the invasive role played by *A. franciscana* native from the American continent. Another threat to the biodiversity of *Artemia* in Portugal is the progressive loss of its natural habitats. From this vulnerable

situation arose the need to make a review of the *Artemia* presence in Portuguese hypersaline environments. In the Algarve region and in the Sado and Tagus estuaries, there is the exclusive presence of *A. franciscana*. The saltworks in the Aveiro region do still harbor populations of the diploid parthenogenetic *Artemia* strain. The "Rio Maior" saltworks are the only inland ones in Portugal and are inhabited by a diploid parthenogenetic *Artemia* strain. Policies to preserve these hypersaline environments must be established, since they might be subject of abandonment due to the devaluation of their economic activities, increasing the risk of loss of *Artemia* biodiversity in Portugal.

Key Words: *Artemia*, Biogeography, Portugal

Introduction

Over the last decades, with the growing threat of biodiversity loss worldwide, one of the greatest challenges in the scientific community is the need to record all the existing biodiversity. The genus *Artemia* has already been widely described in what concerns their biology, physiology, toxicology, genetics, ecology, biogeography and aquaculture applications (Persoone *et al.*, 1980; Amat, 1985; Sorgeloos *et al.*, 1987; Abatzopoulos *et al.*, 2002).

Several studies have already been conducted over the last few decades, in order to investigate the biogeography of the genus *Artemia*, which allowed us to know the worldwide distribution of this genus, verifying its presence in all continents except the Antarctica, as Triantaphyllidis *et al.* (1998) documented in their work.

The genus *Artemia* is already well studied taxonomically, although its systematics is still in constant evolution due to new lineages that have recently been discovered, suggesting a taxonomic reevaluation (Pacios and Muñoz, 2010).

Regarding the diversity of species found in the genus *Artemia*, it currently comprises six sexual species: *A. franciscana*, *A. persimilis*, *A. salina*, *A. urmiana*, *A. sinica* and *A. tibetiana*, as well as several parthenogenetic populations of *Artemia* with different ploidy (2n, 3n, 4n, and 5n) distributed through diverse hypersaline ecosystems (Pacios and Muñoz, 2010).

In Portugal the *Artemia* is mainly located in coastal saltworks, which are distributed from the Portuguese Atlantic north coast to the south coast of Algarve, quite close to the beginning of the Mediterranean Sea. There is only one inland location ("Rio Maior" saltwork), where *Artemia* appears. Until now, there are reports of only two *Artemia* species in Portugal, *A. franciscana* and parthenogenetic population of *Artemia*.

The work of Triantaphyllidis *et al.* (1998) is a reference with regard to the *Artemia* distribution worldwide. Its statement on the *Artemia* distribution in Portugal is based on an old work by Vanhaecke *et al.* (1987), which was not exhaustive about the distribution of *Artemia* in this country. After that,

several studies drew a more detailed description of the *Artemia* distribution in Portugal (e.g. Hontoria *et al.*, 1987; Narciso, 1989; Vieira, 1989 and Amat *et al.*, 1995). These could eventually have enriched the work of Triantaphyllidis *et al.* (1998).

Much of what we know about the distribution and biodiversity of *Artemia* in Portugal, comes from Vieira and Amat (1985), Vieira (1989), Amat *et al.* (2005, 2007). They succeeded in describing the distribution of *Artemia* in the Iberian Peninsula and the influence of invasive species in western European hypersaline systems.

As a result of these works developed in the last decades, Pacios and Muñoz (2010), on their recent study about the global biodiversity and geographical distribution of the genus *Artemia*, were quite extensive in relation to Portugal. However, there are still some Portuguese saltworks where the presence of *Artemia* populations was not yet verified.

Accordingly to what is occurring throughout the Mediterranean basin, one of the problems of the *Artemia* genus in Portugal is the invasive role played by the *A. franciscana* species native from the American continent (Amat *et al.*, 2005, 2007). This worldwide invasive phenomenon has been recently well described by several studies (e.g. Amat *et al.*, 2005; Green *et al.*, 2005; Abatzopoulos *et al.*, 2006; Mura *et al.*, 2006). The key factor in the decline of several native *Artemia* populations, by introducing the *A. franciscana* species, is the greater reproductive competence of the invasive one, in terms of the reproductive period duration or in terms of the number and quality of their offspring (Amat *et al.*, 2007). The exotic *Artemia* species also displays wider eurythermal and euryhaline capabilities (Browne and Wanigasekera, 2000), as well as several other characteristics which strongly contribute to its invasive success (Ruebhart *et al.*, 2008).

The work of Ruebhart *et al.* (2008) gives extensive information about the *A. franciscana* worldwide expansion, making it possible to realize that this species is currently present in all continents where the *Artemia* genus is described. This is quite important because these invasive events affect the endemic lineages and the native *Artemia* species.

The surveys performed in Portugal confirm this phenomenon and provided us with important and updated data of the biogeography of *Artemia* in this country.

The invasive process sometimes occurs very quickly and, therefore, rapid changes of the community's constitution can occur as soon as contamination by invasive strains takes place (Amat *et al.*, 2005). Given this, it is imperative to keep a close monitoring of these sites to promote the maintenance of native *Artemia* strains in Portugal, as well as the preservation of biodiversity in its hypersaline environments.

Another threat to the biodiversity of *Artemia* in Portugal is the progressive loss of saltworks, their natural habitat (Amat *et al.*, 2007). Having represented in the past great economic value, in recent decades these sites suffered from the abandonment they have been subjected to, which in some way led to the destruction of these hypersaline environments (Cunha *et al.*, 2001; Hortas *et al.*, 2006). However, the effort of several European entities that continue taking protective measures in these habitats must be noted; see Website: <http://ecosal-atlantis.ua.pt/>.

From the vulnerable situation of genus *Artemia* in Portugal arose the need to make a review of the *Artemia* presence in Portuguese hypersaline environments. With this aim, the currently existing bibliography was assessed and the data we collected in recent years through several monitoring campaigns was added.

Such knowledge of biodiversity and biogeography of *Artemia* in Portugal is extremely important and can be a valuable tool in the construction of political decisions led to the protection of these hypersaline environments.

Biogeography of *Artemia* in Portugal

The data we collected *in situ* and the information from selected bibliography for this review are listed in Table 1, providing substantial and updated information on *Artemia* biogeography in most Portuguese hypersaline environments.

In Algarve, the most southern region of Portugal, there are evidences of the exclusive presence of *A. franciscana*, being this region entirely

occupied by the invasive species. The first records of this species in this region date from the 80's (Hontoria *et al.*, 1987), having assumed over the decades its exclusive presence in the whole area. A monitoring campaign performed by our team in 2011, at "Tavira" and "Castro Marim" saltworks, showed the presence of a bisexual species in these saltworks, which is not surprising, since after the disappearance of native species due to the dominance of invasive ones, the reappearance of the former is not expected.

The saltworks in the Sado and Tagus estuaries, according to the bibliography, are fully occupied by *A. franciscana*, however there is evidence of a previous presence of diploid and tetraploid parthenogenetic *Artemia* populations at this area. This information was obtained by studying the diameter of cysts collected at these sites (Hontoria, 1990).

The further northern region of the country where *Artemia* can be found is the Aveiro district. The existing data indicate that this region might be dominated by parthenogenetic populations. The first characterizations of the *Artemia* in this region were made by Vieira and Amat (1985), having found a diploid parthenogenetic *Artemia* population in some local saltworks. Samples collected in "Esmolas" saltwork, revealed the presence of *A. franciscana*, thus alerting the scientific community to the spread of the invasive problem already reported in the most southern regions of Portugal.

Until now, we only have records of the diploid parthenogenetic population of *Artemia* in "Esmolas" (Amat *et al.*, 2005), and "Senitra" saltworks (Amat *et al.*, 2007), but recent prospects conducted in the "Troncalhada" (Pinto *et al.*, 2012) and "Grã Caravela" saltworks, showed the exclusive presence of a parthenogenetic population in these two locations.

The Aveiro saltwork complex is currently composed by nine saltworks. The "Esmolas" saltwork, where *A. franciscana* was found, is no longer part of this complex. Nowadays the parthenogenetic *Artemia* population has only been confirmed in three of the nine saltworks of this region ("Senitra", "Troncalhada" and "Grã Caravela"). Expanding the studies to the other saltworks of the region is imperative, in order to fully understand the

Tab. 1. *Artemia* sites in Portugal

Region	Saltwork Complex	Geographical Coordinates	Mode of Reproduction	Species	Ref.
Algarve Province	Olhão salterns	37°01'27"N 7°51'21"W	B.	<i>A. franciscana</i>	1
	Faro Ludo salterns	37°00'25"N 7°57'54"W	B.	<i>A. franciscana</i>	1
	Castro Marim salterns	37°13'10"N 7°25'11"W	B.	<i>A. franciscana</i>	1
	Castro Marim (MarVaz Saltern)	37°13'4"N 7°26'16"W	B.	<i>A. franciscana</i>	2
	Tavira (Santa Luzia Saltern)	37°06'25"N 7°38'38"W	B.	<i>A. franciscana</i>	2
	Olhão (Belamandil Saltern)	37°01'27"N 7°52'03"W	B.	<i>A. franciscana</i>	2
Sado Estuary	Rio Frio salterns	38°24'21"N 8°34'36"W	B.	<i>A. franciscana</i>	1
	Bonfim salterns	38°24'21"N 8°34'36"W	B.	<i>A. franciscana</i>	1
	Alcochete (Marinha Brito Saltern)	38°44'44"N 8°58'37"W	B.	<i>A. franciscana</i>	2
Tejo Estuary	Esmolas salterns	40°39'25"N 8°41'26"W	B.	<i>A. franciscana</i>	1
	Senitra Saltern	40°38'37"N 8°39'57"W	P.	Parth. P. (diploid)	2
	Troncalhada Saltern	40°38'40"N 8°39'43"W	P.	Parth. P.	3
	Grã-Caravela Saltern	40°38'38"N 8°39'51"W	P.	Parth. P.	3
Santarém District	Rio Maior Salterns	39°21'47"N 8°56'33"W	P.	Parth. P. (diploid)	2

B. = Bisexual; P. = Parthenogenetic; Parth. P. = Parthenogenetic population

Ref.: 1: Amat *et al.*, 2005; 2: Amat *et al.*, 2007; 3: This study

Artemia biodiversity in the entire Aveiro saltworks complex.

In the district of Santarém the "Rio Maior" saltworks are the only inland Portuguese saltworks. The first record of the *Artemia* presence here and its characterization was done by Amat *et al.* (2007).

This place (together with Aveiro salines) has a great ecological importance because it is one of the few Portuguese hypersaline environments with the exclusive presence of a native *Artemia* strain. Consequently, many studies have been undertaken recently in this saline (e.g. Pinto *et al.*, 2012), allowing to carry out periodic monitoring activities in this site. So far only a parthenogenetic population of *Artemia* was found in this saltwork, showing an apparent protection of this site to invasive events that have occurred in the majority of Portuguese hypersaline systems.

There is another saltwork complex in Portugal, located at the estuary of the Mondego River, specifically in Figueira da Foz. Until now there are no

records confirming the presence of *Artemia* in these saltworks, making them the only Portuguese hypersaline environments without any kind of information about it.

Over the last few decades the effort to achieve a greater knowledge of the biogeography and biodiversity of *Artemia* in Portugal has been notorious. This effort, nevertheless, is not over: there are still places in Portugal to explore, as well as an invasive process (already installed in Portuguese territory) to monitor, aiming to avoid the extinction of native species. Policies must be established to preserve these hypersaline environments, since due to the devaluation of their economic activities they may be subject of abandonment, increasing the risk of loss of biodiversity.

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