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## Review

### ***Artemia* (Crustacea, Anostraca) in Chile: a review of basic and applied biology**

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**ABSTRACT.** The brine shrimp *Artemia* in Chile has been studied since the 1980s, initially on populations inhabiting shallow coastal and inland mountain ponds, and saltworks in northern and central Chile. Based on morphometric and molecular evidence, these populations were identified as *A. franciscana*. In the 1990s, *A. persimilis* was recorded from southern Patagonia, a species previously considered endemic to Argentina. Recently, two new populations of *A. franciscana* have been recorded, from one saline coastal pond in northern Chile and from a saltwork in central Chile. The scope for further research to increase both understanding of the strain characterization and basic population ecology descriptions of the Chilean brine shrimps and improve their conservation status is discussed. It is suggested that future studies should investigate first the management of local brine shrimp population for local aquaculture or conservation resources, other direction would be the effects of ultraviolet radiation (UVR) exposition that is notoriously high in brine shrimp habitats. This last factor is very important because the UVR is an important mutagen on the genetic structure of the populations. In this scenario, it is suggest a carefully management for introduced brine shrimp populations for local aquaculture for avoid alterations in native populations that due their genetic isolation would need conservation procedures for avoid local extinctions.

**Keywords:** *Artemia*, saline lakes, ultraviolet radiation, aquaculture, Chile.

### ***Artemia* (Crustacea, Anostraca) en Chile: revisión de la biología básica y aplicada**

**RESUMEN.** El camarón de salmuera o *Artemia* ha sido estudiado en Chile desde la década de 1980, las primeras descripciones de poblaciones fueron para lagunas someras en zonas costeras y de montaña, y en salinas artificiales en la zona central y norte de Chile. Sobre la base de evidencias morfológicas y moleculares estas poblaciones fueron descritas como *A. franciscana*. En la década de 1990, se describió la presencia de *A. persimilis* en la zona sur de la Patagonia, lo cual fue una ampliación del rango de distribución significativa, pues esta especie se le consideró endémica de Argentina. Recientemente dos nuevas poblaciones de *A. franciscana* fueron reportadas en una laguna somera en el norte y para una salina artificial en la zona central. El objetivo del presente estudio fue realizar una investigación para entender la caracterización de poblaciones y ecología básica de las poblaciones chilenas del camarón de salmuera y discutir como mejorar el estado de la conservación de estas. Se discute que a futuro los estudios se deberían enfocar primero al manejo de poblaciones nativas para acuicultura local o como un recurso para su conservación, otras orientaciones de estudio, podrían ser los efectos de la radiación ultravioleta (UVR) que es notoriamente alta en los hábitats del camarón de salmuera. Este último factor es importante porque la radiación ultravioleta es un agente mutágeno importante en la estructura genética de las poblaciones. En este escenario, se sugiere un manejo cuidadoso de las poblaciones introducidas del camarón de salmuera para la acuicultura local, con el fin de evitar alteraciones en las poblaciones nativas que debido a su aislamiento genético necesitarían procedimientos para su conservación con el fin de evitar extinciones locales.

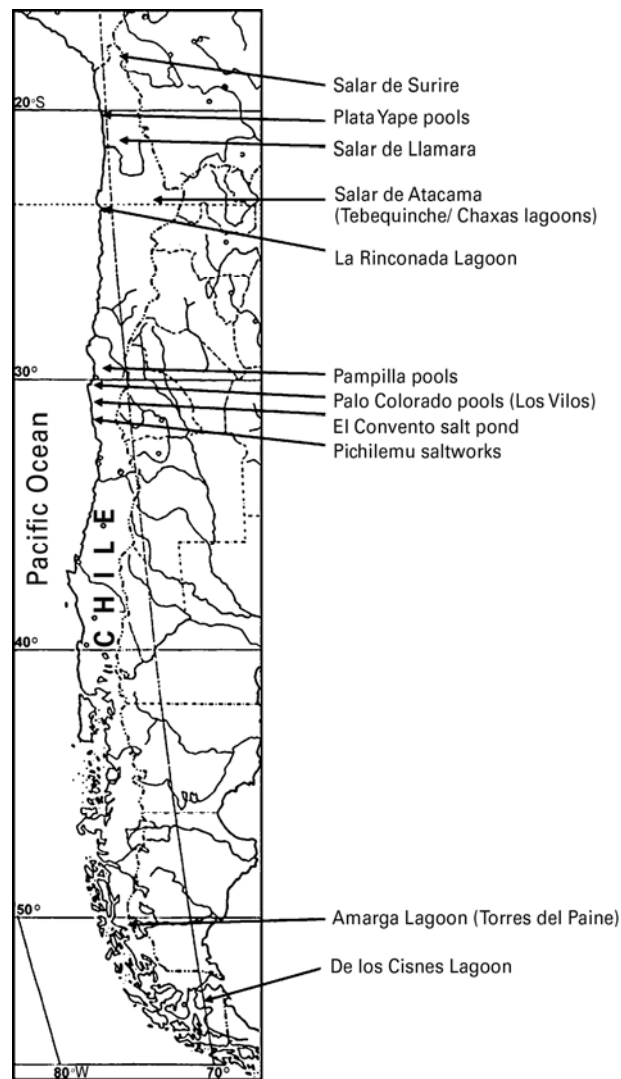
**Palabras clave:** *Artemia*, lagos salinos, radiación ultravioleta, acuicultura, Chile.

## INTRODUCTION

The brine shrimp *Artemia* is a cosmopolitan crustacean inhabiting saline lakes and ponds in all continents with the exception of Antarctica. In the New World, the genus is represented by the species *Artemia franciscana* Kellog, 1906, and *A. persimilis* Piccinelli & Prosdocimi, 1968 (Amat *et al.*, 1994a, 1994b; Triantaphyllidis *et al.*, 1998). The first descriptions of Chilean brine shrimp were published in the early 1990s (Zúñiga *et al.*, 1991, 1994; Gajardo *et al.*, 1992, 1995; Gajardo & Beardmore, 1993; Wilson *et al.*, 1993; Amat *et al.*, 1994b). Prior to 1996, *A. franciscana* was reported from inland and coastal shallow ponds and one saltwork (Amat *et al.*, 1994b, Table 1 and Fig. 1). In 1996, one population from a saline shallow pond in southern Patagonia (Campos *et al.*, 1996) was reported and identified as *A. persimilis* (Gajardo *et al.*, 1998, 2000; De los Ríos & Zúñiga, 2000; Table 1). More recently, two more populations of *A. franciscana* have been reported, from a saltwork in central Chile (De los Ríos, 2000, Table 1) and from one shallow coastal pond in northern Chile (Crespo & De los Ríos, 2004). Finally, one population of *A. persimilis* from a saline lake on Fireland Island (De los Ríos, 2005; Table 1) has been discovered.

## STRAINS CHARACTERIZATION

The two species in South America, *A. franciscana* and *A. persimilis*, were first recognised by Amat (1980) and Hontoria & Amat (1992). Gajardo *et al.* (1995), in a series of studies using allozymes and/or cytogenetics, investigated the genetic structure of *A. franciscana* (Gajardo *et al.*, 1992, 1995; Gajardo & Beardmore, 1993), and *A. persimilis* as well (Gajardo *et al.*, 2000, 2001) from Torres del Paine National Park in Chilean southern Patagonia. Gajardo *et al.* (1995) concluded that genetic differences between the strain affecting the individuals from all known Chilean populations of *A. franciscana* are correlated with the inter-population extent of its geographical distribution and ecological isolation. Later, Gajardo *et al.* (2001) showed that the chromocentre numbers of *A. franciscana* populations from Chile and other Central and South American localities relate directly with the latitude of the habitats (Table 2). Most recently Gajardo *et al.* (2004) have assessed the pattern of variation of mitochondrial DNA of Chilean brine shrimps by restriction fragment length polymorphism (RFLP) analysis. They have confirmed that the species *A. franciscana* occurs between latitudes 20° to 33°S and the species *A. persimilis* is distributed between latitudes 34° to 51°S.



**Figure 1.** Geographic locations in Chile with *Artemia* populations.

**Figura 1.** Localización geográfica de las poblaciones de *Artemia* en el territorio chileno.

There is some uncertainty concerning the species identity of the Salar de Atacama and Pichilemu populations. Gajardo *et al.* (1995) in a study of nine populations concluded that the individuals of brine shrimp at Pichilemu (38°48'S, 72°10'W) belong to *A. franciscana*. However, the results from subsequent morphological (Gajardo *et al.*, 1998), cytogenetic (Colihueque & Gajardo, 1996; Gajardo *et al.*, 2001), where chromosome and chromocentre complements of  $2n = 44$  and 0 to 6 respectively have been recorded), and mitochondrial DNA (Gajardo *et al.*, 2004) studies all yield evidences indicating that Pichilemu brine shrimps belong to *A. persimilis*. Gajardo *et al.* (2004) have suggested that the presence of *A. persimilis* at this locality is possibly indicative of an hybrid zone.

**Table 1.** List and geographical location of sites in Chile with presence of *Artemia* populations in according to the literature.**Tabla 1.** Lista y localización geográfica de sitios en Chile con presencia de poblaciones de *Artemia* según la literatura.

Name	Species	Geographical localization	Reference
Salar de Surire	<i>A. franciscana</i>	18°48'S, 69°04'W	Zúñiga <i>et al.</i> (1999)
Salar de Llamara	<i>A. franciscana</i>	21°18'S, 69°37'W	Zúñiga <i>et al.</i> (1999)
Plata Yape pools (Iquique)	<i>A. franciscana</i>	20°40'S, 70°15'W	Gajardo <i>et al.</i> (1998)
Salar de Atacama: Cejas Lagoon	<i>A. franciscana</i>	23°02'S, 68°13'W	Zúñiga <i>et al.</i> (1999)
Salar de Atacama: Tebenquiche Lagoon	<i>A. franciscana</i>	23°07'S, 68°16'W	Zúñiga <i>et al.</i> (1999)
La Rinconada Lagoon	<i>A. franciscana</i>	23°26'S, 70°30'W	Crespo & De los Ríos (2004)
Pampilla pools	<i>A. franciscana</i>	29°58'S, 71°22'W	Zúñiga <i>et al.</i> (1999)
Palo Colorado pools (Los Vilos)	<i>A. franciscana</i>	31°58'S, 71°35'W	Gajardo <i>et al.</i> (1998)
El Convento salt pond	<i>A. franciscana</i>	33°52'S, 71°48'W	De los Ríos (2000)
Pichilemu saltwork	<i>A. persimilis</i> (?)	34°48'S, 72°10'W	Gajardo <i>et al.</i> (1998)
Amarga Lagoon (Torres del Paine)	<i>A. persimilis</i>	50°29'S, 72°45'W	Gajardo <i>et al.</i> (1998)
De los Cisnes Lagoon	<i>A. persimilis</i>	53°14'S, 70°00'W	De los Ríos (2005)

**Table 2.** Cytogenetical characteristics of *Artemia* populations and frontal knob diameter described in the literature.**Tabla 2.** Características citogenéticas y diámetro del lóbulo frontal de poblaciones de *Artemia* descritas según la literatura.

Name	Species	Chromosome number	Chromocentre number	Diameter frontal knob
Salar de Surire	<i>A. franciscana</i>	No data	No data	No data
Salar de Llamara	<i>A. franciscana</i>	No data	13.8	194.3
Plata Yape pools (Iquique)	<i>A. franciscana</i>	42	14.82	211.0
Salar de Atacama: Cejas Lagoon	<i>A. franciscana</i>	44	4.36	196.4
Salar de Atacama: Tebenquiche Lagoon	<i>A. franciscana</i>	No data	No data	No data
La Rinconada Lagoon	<i>A. franciscana</i>	No data	No data	No data
Pampilla pools	<i>A. franciscana</i>	No data	No data	198.9
Palo Colorado pools (Los Vilos)	<i>A. franciscana</i>	42	10.09	183.9
El Convento salt pond	<i>A. franciscana</i>	No data	10.8	148.2
Pichilemu saltworks	<i>A. persimilis</i>	44	0	No data
Amarga Lagoon (Torres del Paine)	<i>A. persimilis</i>	No data	0	301.5
De los Cisnes Lagoon	<i>A. persimilis</i>	No data	No data	No data

The morphological study done by Gajardo *et al.* (1998), provides further evidence for the presence of both *A. franciscana* and *A. persimilis* in Chile. The size of the male frontal knob is an important distinctive character to distinguish *A. franciscana* from *A. persimilis* (De los Ríos & Zúñiga, 2000). The average diameter of the frontal knob in *A. franciscana* is 200 µm and in *A. persimilis* is 300 µm (De los Ríos & Zúñiga, 2000; Table 2). This structure is used in sexual coupling; with differences in shape allowing the reproductive isolation (Mura, 1989; Mura *et al.*, 1989).

## ECOLOGICAL STUDIES

*A. franciscana*: these populations are located in three main habitat types: the first comprises coastal shallow ponds; the second are found in artificial saltworks; and the third and better studied group comprises populations in inland saline shallow ponds (Amat *et al.*, 1994b; Zúñiga *et al.*, 1994, 1999; Gajardo *et al.*, 1998). There are three populations in coastal shallow ponds. The first population is in northern Chile, in Yape pools (20°40'S, 70°15'W). The second is located in central Chile in Pampilla (29°58'S, 71°22'W) and Palo Colorado pools (31°58'S;

**Table 3.** Chemical features of *Artemia* habitats described in the literature.**Tabla 3.** Características químicas de hábitats de *Artemia* descritos en la literatura.

Name	Salinity (ppt)	Percent of total major ions						
		Na <sup>+</sup>	K <sup>+</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	CO <sub>3</sub> <sup>2-</sup>
Salar de Surire	102	No data	No data	No data	No data	No data	No data	No data
Salar de Llamara	167	No data	No data	No data	No data	No data	No data	No data
Plata Yape pools (1)	52	169	680	660	202	30,400	4,720	No data
Salar de Atacama: Cejas Lagoon (2)	292	51.7	2.4	0.6	2.6	64.7	43.6	No data
Salar de Atacama: Tebenquiche Lagoon (1)	233	79,000	5,300	290	4,500	123,900	19,000	240
La Rinconada Lagoon	80	No data	No data	No data	No data	No data	No data	No data
Pampilla pools	45	No data	No data	No data	No data	No data	No data	No data
Palo Colorado pools (Los Vilos)	75	32.5	1.3	1.3	3.8	53.3	7.6	< 0.1
El Convento salt pond	No data	No data	No data	No data	No data	No data	No data	No data
Pichilemu saltworks	115	No data	No data	No data	No data	No data	No data	No data
Amarga Lagoon (Torres del Paine) (3)	123	3,661.6	187.6	14.7	1,729.3	8,084.4	359.9	2,148.0
De los Cisnes Lagoon	No data	No data	No data	No data	No data	No data	No data	No data

References: 1) Amat *et al.* (1994b), 2) Zúñiga *et al.* (1994); 3) Campos *et al.* (1996). All salinity data were obtained from Zúñiga *et al.* (1999), with exception of La Rinconada Lagoon (Crespo & De los Ríos, 2004) and Amarga Lagoon (Campos *et al.*, 1996).

71°25'W) (Amat *et al.*, 1994b; Gajardo *et al.*, 1998; Zúñiga *et al.*, 1999). The habitats in each of these areas are similar in being located in ephemeral habitats at the upper high tidal level of rock beaches and with chemical characteristics similar to seawater (Amat *et al.*, 1994b; Gajardo *et al.*, 1998; Zúñiga *et al.*, 1999, Table 3). The hydrological conditions of the shallow coastal ponds are an important factor regulating reproductive cycles of the brine shrimp. The brine shrimp reproduce oviparously, producing cysts in natural conditions of a strong salinity increase (Amat *et al.*, 1994b; Gajardo *et al.*, 1998; Zúñiga *et al.*, 1999). No ecological studies of brine shrimp have been undertaken in this habitat, but it is probable that the shrimps graze on bacteria and microalgae and simultaneously they would be grazed by occasional sea birds.

A population of *A. franciscana* described by Crespo & De los Ríos (2004) from a previously permanent pond near Antofagasta is a noteworthy example of how changeable shallow ponds habitats may be. This habitat initially was described as hypersaline, and the halophilic microalgae *Dunaliella salina* Teodoresco and *Halobacterium* were recorded from the site (Gomez-Silva *et al.*, 1990). However, following a strong earthquake that affected the area in 1995, the pond was flooded with fresh water. *A. franciscana* was subsequently recorded from the pond in the years 2000 and 2003 (Crespo & De los Ríos, 2004) probably as a result from artificial inoculation. *A. franciscana* probably has been introduced by human intervention into artificial saltworks (Gajardo *et al.*, 1995; De los Ríos & Zúñiga, 2000). Although neither saltwork population has been the subject of detailed ecological studies, according to Zúñiga *et al.* (1994). Both salt works have been operating during the last ninety years (De los Ríos & Zúñiga, 2000) and detailed studies into the dynamics of their resident brine shrimp populations, population succession and community structures are warranted.

The brine shrimp populations of inland saline lakes occur in shallow mountain ponds located mainly between 18° to 23°S (Zúñiga *et al.*, 1999). Northern Chile is markedly arid, experiencing weak rains during the "Bolivian winter" of January and February. The ponds of the mountain and plains are all associated with saline deposits of volcanic origin (Chong, 1984) and brines of these saline lakes have relatively high sulphate concentrations (Zúñiga *et al.*, 1991, 1994, 1999; Gajardo *et al.*, 1992, Table 3). The salinities of these ponds vary widely. In waters with salinity concentrations  $<90 \text{ g L}^{-1}$ , the calanoid copepod *Boeckella poopoensis* is the dominant member of zooplankton (De los Ríos & Crespo, 2004;

De los Ríos & Gajardo, 2010a, 2010b; De los Ríos-Escalante 2010). In lakes with water salinity concentrations  $>90 \text{ g L}^{-1}$ , members of the genus *Artemia* are the dominant member of the zooplankton (Hurlbert *et al.*, 1986; Williams *et al.*, 1995). Predation by adult *B. poopoensis* on *Artemia* nauplii is probably the main factor reducing the abundance of the brine shrimps with salinity concentrations  $<90 \text{ g L}^{-1}$  (Hurlbert *et al.*, 1986; Hammer & Hurlbert, 1992). Where *Artemia* do occur abundantly, the crustacean would play a key ecological role as the main grazer, through non selective filter feeding on the producer organisms (which includes halobacteria, cyanobacteria, diatoms and halophilic microalgae such as *Dunaliella salina* (Zúñiga *et al.*, 1991, 1994; Demergasso *et al.*, 2003). These upland *Artemia* habitats are sites for feeding and nesting of aquatic birds such as Chilean flamingo (*Phoenicopterus chilensis*), Andean flamingo (*Phoenicoparrus andinus*), James flamingo (*Phoenicoparrus jamesi*) and Wilson Phalarope (*Phalaropus tricolor*). The three species of flamingos are important for *Artemia* populations, because two of these species (*P. andinus* and *P. jamesi*) graze on phytoplankton and bacteria, and therefore probably compete directly with the brine shrimp for food sources. However, Chilean flamingos potentially would predate on brine shrimp because these waterfowl feed non selectively on zooplankton (López, 1990). Brine shrimp reproduce ovoviviparously only in permanent lakes with very high salinity concentrations. In these situations there is no cyst production and the population numbers decline over time with increasing salinity. The affected populations regenerate under optimal environmental conditions of low salinity concentrations from a few surviving individuals (Zúñiga *et al.*, 1994, 1999). Regarding dispersal, the inland saline lakes are located east and west of the Andes mountains between 18° to 23°S, an area within the migration route of flamingos. Flamingos have been implicated as an agent capable of dispersing brine shrimp. Indeed, dispersal by flamingos may explain the presence of *A. franciscana* in saline lakes of northern Chile (Gajardo *et al.*, 1998, De los Ríos & Zúñiga, 2000), Argentina (Papeschi *et al.*, 2000) and adjacent areas of Peru and Bolivia (Triantaphyllidis *et al.*, 1998).

*A. persimilis*: the Chilean populations of *A. persimilis* occur mainly in southern Patagonia (Gajardo *et al.*, 1998; De los Ríos & Zúñiga, 2000; De los Ríos, 2005; De los Ríos & Gajardo, 2010a, 2010b), with biological studies having focused on Amarga lagoon, inside Torres del Paine National Park. The water bodies in this area inhabited by *A. persimilis* have high chloride and sulphate concentrations

(Campos *et al.*, 1996). According to Campos *et al.* (1996), the biotic components are mainly cyanobacteria and a few diatoms grazed by rotifers and brine shrimp. Again, the predator of *Artemia* is probably the Chilean flamingo *P. chilensis* (Soto, 1990; Campos *et al.*, 1996). In the Patagonian sites, brine shrimp and copepods can coexist in spite of the different salinity tolerances of both groups (De los Ríos & Gajardo, 2010, De los Ríos-Escalante & Gajardo, 2010). The presence of *A. persimilis* in southern Patagonia may be due to dispersal via water birds migrating from central Argentina to southern Chile (Gajardo *et al.*, 1998; De los Ríos & Zúñiga, 2000). Certainly, the very low altitude of the Andes mountains in the region would not constitute a barrier to migrating water fowl, and therefore to dispersal of brine shrimp. Further, *A. persimilis* probably shows optimal survival and fecundity in lower salinity concentrations and temperatures than *A. franciscana* (Sorgeloos *et al.*, 1986). Lakes with low salinity concentrations and low temperatures are typically observed in southern Patagonia, and these conditions presumably suit better the presence of *A. persimilis*.

## FUTURE DIRECTIONS

This review is concluded by discussing directions for future studies on Chilean brine shrimps, mainly with respect to their ecology and management. At present time the ecological information available is restricted or relies on inferences. Also, little published information is available concerning the management and use of these biological resources (Zúñiga & Wilson, 1996). The effects of exposure to ultraviolet radiation (UVR) (Cabrera *et al.*, 1995; Villafañe *et al.*, 2001) needs to be investigated, particularly the impacts regulating zooplankton communities and affecting mutation rates (Hebert *et al.*, 2002; Friedberg, 2003).

**Management:** the increasing demand of *Artemia* cysts for aquaculture has caused high levels of cysts harvesting from the main source, Great Salt Lake, Utah, USA. A flow-on effect has been the artificial inoculation of cysts in saltworks in Brazil, Vietnam and other countries, and also the search for alternative brine shrimp strains and species to culture (Lavens & Sorgeloos, 2000). The increase of aquaculture activities had led to an increase in the importation of brine shrimp cyst into Chile. However, the uncontrolled use of exotic strains and species, may potentially pose a significant threat to many Chilean *Artemia* populations by displacement of native strains (De los Ríos & Gajardo, 2004). Unfortunately insufficient information is available on the use of Chilean brine shrimp populations for aquaculture,

although some populations have relative good growth and survival response in controlled and semi-controlled conditions (Zúñiga & Wilson, 1996; De los Ríos, 2001). Nevertheless, the best results in studies of mass culture of Chilean brine shrimp were obtained using populations from coastal shallow ponds, because shrimp from these sources produce cysts in natural conditions (Zúñiga *et al.*, 1999). Also, the brines of these habitats have ionic composition similar to seawater (Amat *et al.*, 1994b; Zúñiga *et al.*, 1999), representing favourable conditions for marine aquaculture because they do not need to divert energy to cope with different chemical conditions, and thereupon should grow and reproduce efficiently (Bowen *et al.*, 1985). The opposite situation was reported for populations from the sulphate-enriched brines of inland lakes. Shrimp from these sources have low fecundity and growth rates when reared in seawater (Zúñiga & Wilson, 1996).

Consequently, local aquaculture activities based on brine shrimp will, in all likelihood, use stock from habitats with high chloride concentrations, such as *A. franciscana* from coastal ponds or saltworks, or *A. persimilis* from southern Patagonian lakes. In the case of *A. persimilis* from southern Patagonia, the shrimp inhabit regions with difficult weather conditions, namely heavy rainfall in winter and strong 100 km h<sup>-1</sup> winds in summer (Soto *et al.*, 1994; Campos *et al.*, 1996). Aquaculture under such conditions may be economically difficult. Similar difficulties may apply for brine shrimp aquaculture based on saltworks in central Chile because the area sometimes experiences strong rains in winter (Niemeyer & Cereceda, 1984) that would generate considerable losses for aquaculture producers.

Finally, northern Chile presents at least two important advantages for brine shrimp aquaculture: low rainfall, and an environment rich in natural nitrate and phosphorus fertilizers (Chong, 1988). Another important advantage includes the abundance of native, high quality live foods for *Artemia* such as the halophilic microalgae *D. salina* (Gómez-Silva *et al.*, 1990; Araneda *et al.*, 1992a, 1992b). High yields have been achieved using shallow coastal strains in outdoor culture at intermediate production scales (Zúñiga & Wilson, 1996). The results from studies to date indicate that future directions for research into Chilean brine shrimp aquaculture must focus on achieving economical and technical advances for establishing intensive and extensive production scales.

**Ultraviolet effect on brine shrimp:** in recent years, levels of ultraviolet radiation (UVR) have been increasing substantially, in Chile (Cabrera *et al.*, 1995)

mainly in southern Patagonia (Villafañe *et al.*, 2001) but also in the tropical Andes (Villafañe *et al.*, 1999; Helbling *et al.*, 2002). Ultraviolet radiation is an important mutagen, changing the molecular structure of DNA (Friedberg, 2003). Consequently, the biota of shallow aquatic habitats lacking photoprotective strategies to avoid or repair the damage caused by exposure to UVR, may be particularly susceptible to UVR-induced damage (Villafañe *et al.*, 2001; Helbling *et al.*, 2002). Since brine shrimp have many advantages for use in culture and in genetics (Gajardo & Beardmore, 2001), three lines of study into effects of UVR on brine shrimp are likely to produce useful results.

a) Studies at the cellular scale into the mutagenic effects of UVR on the nucleotide sequence of DNA may reveal genetic changes in successive generations. Such changes are known to occur in halophilic crustaceans (Hebert *et al.*, 2002). Gajardo & Beardmore (1993) and Gajardo *et al.*, (1995, 2004) described genetic isolation and differentiation of Chilean brine shrimp populations. It may be important, with respect to conservation issues, to ascertain whether populations with year-round exposure to high UVR levels, for example in tropical zones, have substantially higher mutation rates compared with populations from areas with exposure to low UVR levels.

b) A second line of studies would investigate the effects of UVR on individual organisms. The shallow ponds inhabited by brine shrimps typically have a maximum depth between 1-15 m (Zúñiga *et al.*, 1999), and UVR penetrates to the bottom of the water column (Villafañe *et al.*, 2001). Consequently, the resident zooplankton is exposed to high levels of UVR against which the organisms require protection, such as provided by photoprotective photorepair or antioxidant substances such as melanin, carotenoid pigments or ascorbic acid (Villafañe *et al.*, 2001; Hessen *et al.*, 2002). For example, freshwater Arctic daphnid crustaceans are exposed to high levels of UVR during summer, and synthesise and accumulate substances which provide protection against high levels of UVR. *Boeckella titicacae* (= *B. gracilipes*) from Lake Titicaca, in the tropical Andes (Helbling *et al.*, 2002) synthesise a micosporine-like amino acid, and calanoids from shallow ponds in southern Patagonia also synthesise protective pigments (Rocco *et al.*, 2002), for example.

Although the response of *Artemia* to UVR has not been studied, it is likely that marked red or orange coloration of juveniles and adult specimens of tropical latitudes (Zúñiga & De los Ríos, personal observations) have a photoprotective or photorepairing

function. Thick chorionic membranes of cysts of brine shrimp from inland mountain habitats (Zúñiga *et al.*, 1999) may also constitute evidence of exposure to high levels of UVR. These inland shrimp does not produce cysts under natural conditions, but under extreme controlled conditions they can produce a few cysts with a thick chorionic membrane (Zúñiga *et al.*, 1999). This feature may be an adaptative response to high levels of insolation exposure and UVR, since similar results were described for cysts from tropical populations of brine shrimp (Amat, 1982). Elucidation of the effects of UVR on *Artemia* would seem to be a fruitful line of investigation to follow.

c) A third line of studies would investigate the effects of UVR on the population structure and dynamics of Chilean brine shrimp. In marked contrast to the information concerning the effects of UVR on brine shrimp, much information has been published concerning daphnid exposure to UVR from northern hemisphere freshwaters.

Presumably, exposure to high levels of UVR radiation involves individuals affected in expending energy and metabolites to produce photoprotective substances (Hessen, 1996; Hessen *et al.*, 1999). Given this possibility, exposure to UVR would cause mortality in different life stages, lower fecundity in adults, and slow growth rate of individuals. However, dissolved organic carbon (DOC) may be providing protection against UVR (Morris *et al.*, 1995; De los Ríos, 2003). Many of the saline and brackish aquatic ecosystems of the Atacama desert and in southern Patagonia have a wide gradient of concentrations of DOC (De los Ríos, 2003). Consequently, it is reasonable to predict that there would be marked differences in the energy spent by individuals in developing photo-protection that would affect fecundity, individual growth, and absolute abundance of various populations (Rautio, 1998; Winder, 2001; Rautio & Korkhola, 2002a, 2002b). Indeed, integrated laboratory and field studies involving an array of brine shrimp natural sites and investigating the effect of variation in levels of protection provided by different concentrations of DOC protection against UVR damage, may be an important line of research to pursue in Chile from the standpoint of conserving natural stocks of brine shrimp at a time of major changes in atmospheric conditions of planet Earth.

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