Geographic range extension of *Anorthoneis dulcis* Hein in Oases of Baja California Peninsula, México

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ABSTRACT - We provide the first record of *Anorthoneis dulcis* Hein in México in two Oases of the southern Baja California Peninsula, thus extending the geographic distribution of this species in North America from East (Florida) to West (Baja California Sur). The pH values observed at one of the Oases (7.1-8.9) show that *A. dulcis* may thrive in a wider range of pH variation than previously cited. We propose that, although records of *A. dulcis* are scarce it has a wide distribution, from East to West in North America, to South America as far as the Patagonia.

Key words: diatoms, freshwater, biogeography, first record

RESUMO – **Extensão da área geográfica de *Anorthoneis dulcis* Hein em oásis da Península da Baixa California, México**. Apresentamos o primeiro registro de *Anorthoneis dulcis* Hein para o México. A espécie foi encontrada em dois oásis da Península Sul da Baixa Califórnia. Amplia-se desta forma a distribuição geográfica da espécie na América do Norte da região leste (Flórida) à região oeste (Baixa Califórnia). Os valores de pH observados em um dos oásis (7,1-8,9) demonstra que *A. dulcis* pode resistir a maior variação de pH do que foi anteriormente citado. Consideramos que embora os registros de *A. dulcis* sejam escassos, a espécie possui ampla distribuição, de leste a oeste da América do Norte ao sul da América até a Patagônia.

Palavras-chave: diatomáceas, águas continentais, biogeografia, primeiro registro

INTRODUCTION

The species of *Anorthoneis* Grunow are generally marine littoral, epiphytic or epipsammic forms that have been reported as rare or scarce for several coastal areas of temperate and warm waters (Hustedt, 1955; Giffen, 1970; Sterrenburg, 1988). Solely twelve *Anorthoneis* taxa have previously been described, even though three of these are invalid, *A. excentrica* var. *ornate* Takano, *A. maculata* M. Peragallo in Tempère & Peragallo and *A. striata* M. Peragallo in Tempère & Peragallo, and one (*A. tenuis* Hustedt) is dubious. Considering *A. tenuis* Hustedt as valid there are, therefore, eight marine species of *Anorthoneis*: *A. eurystoma* Cleve, *A. excentrica* (Donkin) Grunow, *A. hyalina* Hustedt, *A. hummii* Hustedt, *A. minima* Foged, *A. pulex* Sterrenburg, and *A. vortex* Sterrenburg, plus one from freshwater habitats *A. dulcis* Hein (Hein, 1991).

With respect to other records of *Anorthoneis* species from the peninsula of Baja California, López-Fuerte *et al*. (2010) reported *A. eurystoma*, *A. excentrica* and *A. hummii*, all found in sediments associated with mangroves in Bahía Magdalena, Baja California Sur (BCS).

Anorthoneis dulcis Hein was described in 1991 from three rivers in Northern Florida, USA, as a periphytic species in subtropical waters in the autumn and winter. It has also been found in South Korea (Kwang River) (Lee *et al*., 1994) on stones at a depth of 30 cm, in areas with slightly brackish water and apparently free from major pollution sources in spring and summer periods. In South America the first records were made by Maidana *et al*. (2005) in the southern Santa Cruz province, Argentina, and in Brazil by Tremarin & Ludwig (2008) in sediments of the fluvial island of Mosqueiro, State of Pará, and on sand grains in lentic estuarine and freshwater areas by Garcia & Talgatti (2008) in Patos Lagoon, Rio Grande do Sul.

This paper describes the first record of *A. dulcis* in Mexico, in two Oases of the southern Baja California Peninsula, which extends the geographic distribution of the taxon. Data on relative abundance, frequency and environmental data are provided.

MATERIAL AND METHODS

Study Area

The Baja California Peninsula is located in the NW of México between 23° and 32.5° N, and 109° and 114° W. It is limited to the north by the state of California, USA, to the west by the Pacific Ocean, and to the east by the Gulf of California (Fig. 1).

The geomorphology and hydroclimatic evolution of the Baja California Peninsula generated a series of environmental humid (mesic) relics that are currently found in the high mountainous regions or as Oases, which are characterized by a discontinuity in their distribution (Arriaga & Rodríguez-Estrella, 1997; Díaz *et al*., 2004). Even though the Oases of BCS represent less than 1% of the state surface, these concentrate a remarkable proportion of biodiversity and endemism (Rodríguez-Estrella, 2004).

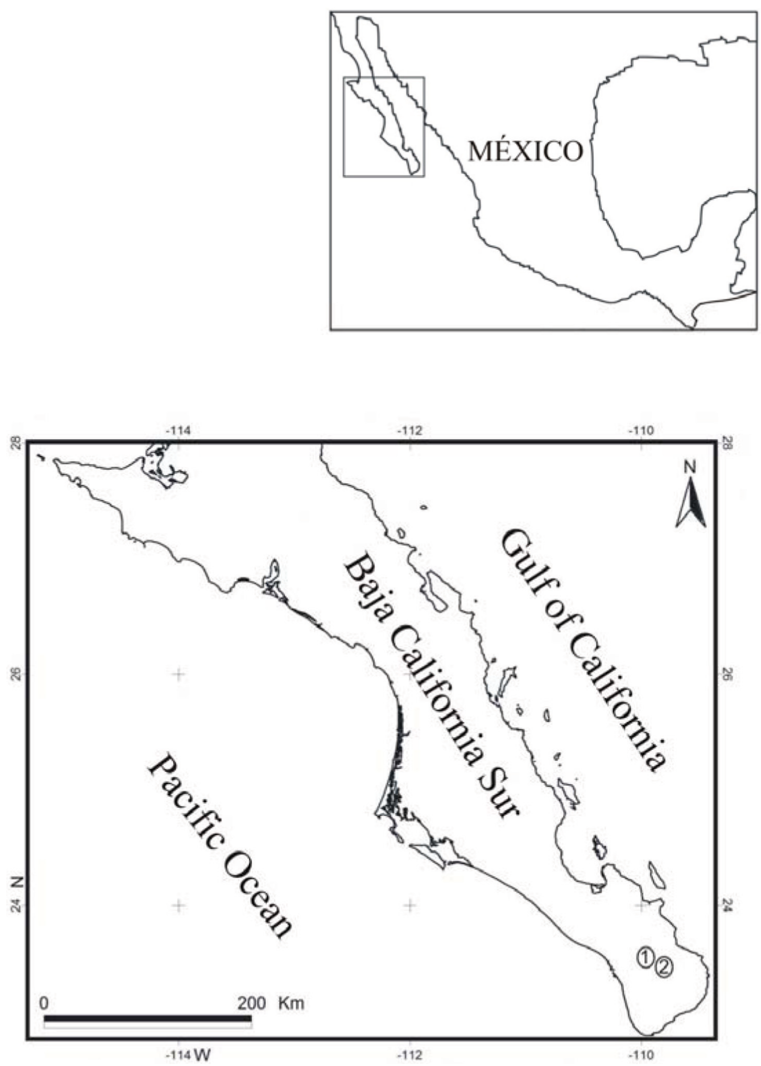


Fig. 1. Location of the studied Oases in the Baja California Peninsula: 1) Agua Caliente; 2) San Bartolo.

San Bartolo Oasis (23° 44' 09" N, 109° 50' 37" W) is found in a streambed that flows through a gully formed with abrupt slopes. In the southern slope the gully reaches an aquifer that reaches the surface in a small spring, the water emerging from the spring runs permanently by the streambed until reaching the phreatic mantle. The Agua Caliente Oasis (23° 32' 54" N, 109° 58' 13" W), covers a surface of 1.47 km² and is located within a zone of dissective plateaus formed by way of ancient sand material deposits derived from the Sierra de La Laguna. It is tributed by the Agua Caliente and San Jorge streams (Díaz & Troyo, 1997).

Sampling

Epilithic diatom samples were collected in seven sampling sites from the Agua Caliente Oasis and in nine sampling sites at San Bartolo´s in November 2009. In March 2008, only samples from San Bartolo were collected in four sites. A toothbrush was used to scrape an area of 5 cm^2 of each substrate from two rocks (> 25 cm), or two cobblestones (< 15 cm) at each site. The samples were deposited in vials and transported to the laboratory in ice and in the dark.

At each site *in situ* physical and chemical data were collected such as pH and water temperature, using a potentiometer Testr10 with 1.0-15.0 interval and resolution of 0.1 with an integrated thermometer. Electric conductivity was measured with an EC-Testr11 conductometer with a 2000 µS/cm a 20.00 µS/cm interval and a resolution of 0.1-10.

Sample processing

The diatom samples were processed to digest the organic matter both from inside and outside the diatom frustules using nitric acid and commercial alcohol (ethanol) at a ratio of 1:3:1 (sample-acid-alcohol) as in Siqueiros-Beltrones (2002). After rinsing the oxidized samples with distilled water to a pH > 6, the clean diatom valves were mounted permanently (by triplicate) using Pleurax (RI = 1.7). At least two slides per site were examined under a phase contrast Zeiss microscope. Following Siqueiros-Beltrones *et al*. (1991) 500 valves were identified and counted for each slide at 1000x. Then, the frequency $fi = ni/N$ with which *A. dulcis* occurred (percentage) and the relative abundance $\%Spi = n \times (100/N)$ were estimated.

RESULTS AND DISCUSSIONS

The specimens of *A. dulcis* (Figs. 2-5) showed the following dimensions: 13.3-16.3 µm length; 10-11.7 µm width; 13-18 striae in 10 µm. This dimensions agree in general with those recorded by Hein (1991), Lee *et al*. (1994), Tremarin & Ludwig (2008), Garcia & Talgatti (2008), except for the length of the apical axis (13.3 µm) which was somewhat shorter. But in general it shows the typical morphology given for the species.

Environmental data and distribution

Table 1 shows the physical and chemical measurements of the water from the San Bartolo and Agua Caliente Oases where *A. dulcis* was found. In the former, electric conductivity varied between 370-500 and 520 µS/cm for spring and winter, respectively. In the Agua Caliente Oasis conductivity was lower, ranging from 220 and 250 µS/cm. Mean temperature values in San Bartolo were 25°C and 26°C, for spring and winter, respectively; in the Agua Caliente Oasis a value of 23°C was recorded.

Measured pH values may be considered circumneutral to slightly alkaline (7.1-8.0 and 8.0) in spring and winter, respectively in San Bartolo. Whilst, in Agua Caliente, pH values varied from slightly alkaline to alkaline (8.3-8.9). The pH values recorded at the Agua Caliente Oasis suggests that *A. dulcis* may thrive in a wider range of pH variation than previously recorded for Florida, South Korea and Brazil 7.5-8.1 and 7.5-8.8 (Hein, 1991, Lee *et al*., 1994, Tremarin & Ludwig, 2008, Garcia & Talgatti, 2008) and in southernmost Argentina (Maidana *et al*., 2005), (Tab. 2).

The quantitative study of *A. dulcis* at San Bartolo Oasis revealed a high value of relative abundance (2.8%) in spring, while in winter it was only 0.3%, even though 10,617 diatoms valves were counted and identified in 21 permanent slides (Tab. 3).

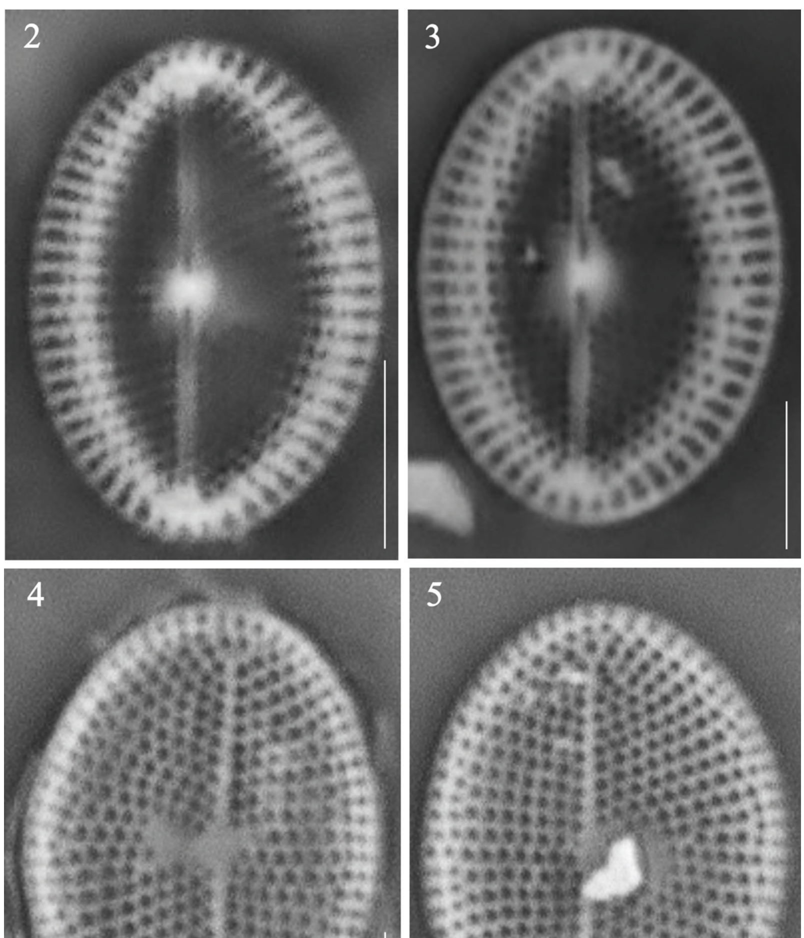
In winter, the floristic composition of the diatom assemblages in the San Bartolo Oasis where *A. dulcis* was found were characterized by the higher abundance of *Achnanthidium exiguum* (Grunow) Lange-Bertalot (19% relative abundance) and a 100% frequency.

In the Agua Caliente Oasis on the other hand, the species was found with *Gomphonema pumilum* (Grunow) Reichardt & Lange-Bertalot that showed a 19% relative abundance and a 100% frequency, while *Ulnaria* sp. and *Cocconeis placentula* var. *euglypta* (Ehrenberg) Cleve were also abundant.

The low frequency of *A. dulcis* in spring and its high abundance in winter (in the San Bartolo Oasis) could suggest a seasonal pattern. However, even though Hein (1991) observed that the abundance of *A. dulcis* diminished in winter and Lee *et al*. (1994) recorded it only in spring and summer, Garcia & Talgatti (2008) reported no seasonal variation for *A. dulcis* which remained throughout the year. This report and our (frequency and abundance) observations during winter in the Agua Caliente Oasis, leads us to refute the existence of such a pattern. The above consideration require that further observation of live material be carried out in order to determine if the specimens are alive during the sampling periods, inasmuch diatom frustules may endure intact even though the cells are not alive.

On the other hand, the low abundance and frequency of *A. dulcis* in both Oases similar to that of other species of *Anorthoneis* reported by Sterremburg (1988) for marine forms, and for other species of *Anorthoneis* in BCS, which show a similar pattern, as in *A. eurystoma* and *A. hummii* in winter, and of *A. excentrica* during spring in sediments associated to mangroves of Bahía Magdalena, where their occurrence was below 1% (López-Fuerte *et al*., 2010).

Currently, the records for *A. dulcis* are still scarce, although it seems that this species may grow as an epipsammic, free-living form (Tremarin & Ludwig, 2008; Garcia & Talgatti, 2008), or as an epilithic form attached by mucilage stalks (Lee *et al*., 1994). Our observations show that both rocks and cobblestones are a suitable substrate for its growth.



Figs. 2-5 Valve view of *Anorthoneis dulcis* LM. **2, 3**. Raphe valves; **4, 5**. Rapheless valves. Bars = 5 µm.

Table 1. Environmental data of the sites where *Anorthoneis dulcis* was found at the Oases of San Bartolo and Agua Caliente BCS (México).

Oasis	Date	Site	Substrate	Water temp. °C	pH	Conductivity (μs/cm)	Altitude (m)
Agua Caliente	winter	S1	Rock	21	8.3	230	1746
		S3	Rock	22	8.4	220	1700
		S5	Rock	23	8.4	220	226
		S7	Rock	26	8.9	250	227
		S1	Cobblestone	26	7.1	370	353
		S3	Cobblestone	26	7.2	500	353
San Bartolo	spring	S4	Cobblestone	26	7.2	500	353
		S5	Cobblestone	26	7.2	500	353
		S6	Cobblestone	27	7.7	490	353
		S7	Cobblestone	26	7.2	500	353
San Bartolo	winter	S4	Rock	25	7.8	520	237

Table 2. Range of the physicochemical variables in Northern Florida, South Korea, Laranjal Bay (Brazil) and BCS Oases (México).

Physicochemical variables	Florida[1]	South Korea[2]	Laranjal Bay[3]	Oases
Temperature (°C)	15-27	21.2-23.8	14-31(air)	21-27
pH	7.5-8.1	7.8-8.1	6.0-8.0	7.1-8.9
Electric conductivity (μs/cm)	318-497	432-480	100-2000	230-520

[1]Hein (1991); [2]Lee et al; [3]Garcia & Talgatti (2008).

Table 3. Abundance of *Anorthoneis dulcis* at San Bartolo and Agua Caliente Oasis during winter and spring seasons.

Oasis	Season	Valves observed	Relative abundance (%)	Relative Frequency (%)
San Bartolo	winter	7	0.3	25
San Bartolo	spring	129	2.8	67
Agua Caliente	winter	31	0.8	50

Other freshwater species were identified along with *A. dulcis*, such as: *Eunotia minor* (Kützing) Grunow, *Nitzschia sigmoidea* (Nitzsch) W. Smith, *Sellaphora pupula* (Kützing) Mereschkovsky, *Encyonema neogracile* Krammer and *Epithemia* spp. Likewise, where *A. dulcis* is found other taxa of marine/brackish water affinity have been recorded as common such as *Actinocyclus normanii* Hustedt and *Delphineis surirella* (Ehrenberg) G.W. Andrews (Lee *et al*., 1994). In particular, along with *A. dulcis* typically halophytic or brackish forms were found, such as *Pleurosira laevis* and *Nitzschia denticula*, respectively.

This is the first record of *A. dulcis* for México. However, although records of *A. dulcis* are scarce the species has a wide distribution, from East to West in North America, to South America as far as the Patagonia and Asia. It can also live in typical continental waters, either lentic or lotic as a part of the periphyton, as in Florida, as an epipsammic form as in Brazil, and as an epilithic form in the estuarine habitats of South Korea. Also, our findings show that it dwells on cobblestones and rocks in lotic and semi-lentic environments, and that its tolerance to pH and conductivity may be wider than hitherto recorded.

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