Lake and Reservoir Management 23:620-629, 2007

Dramatic blooms of *Prymnesium* sp. (Prymnesiophyceae) and *Alexandrium margalefii* (Dinophyceae) in the Salton Sea, California

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Abstract

Tiffany, M.A., J. Wolny, M. Garrett, K. Steidinger and S.H. Hurlbert. 2007. Dramatic blooms of *Prymnesium* sp. (Prymnesiophyceae) and *Alexandrium margalefii* (Dinophyceae) in the Salton Sea, California. Lake Reserv. Manage. 23:620–629.

In early 2006, unusual algal blooms of two species occurred in the Salton Sea, a large salt lake in southern California. In mid-January local residents reported bioluminescence in the Sea. Starting in February, large rafts of long-lasting foam, also bioluminescent, were observed as well. Microscopy investigations on water and sediment samples collected in March showed the marine dinoflagellate, *Alexandrium margalefii*, and the prymnesiophyte, *Prymnesium* sp., both previously unreported in the Salton Sea, to be abundant. Bioluminescence and foam production continued through March. Other dinoflagellate species, recorded during earlier studies, were rare or not detected during these blooms. Despite the fact that many *Alexandrium* species are known paralytic shellfish poison (PSP) producers, preliminary saxitoxin tests on this population of *A. margalefii* were negative. Previous reports on *A. margalefii* do not mention bioluminescence. It appears that the foam was caused by the *Prymnesium* sp. bloom, probably via protein-rich exudates and lysis of other algal cells, and its glow was due to entrained *A. margalefii*. This is the first report of *A. margalefii* in U.S. waters and the first report of it in a lake.

Key words: bioluminescence, dinoflagellates, foam, phytoplankton, salt lake, cysts, allelopathy

Introduction

The Salton Sea is a shallow eutrophic salt lake in the southeastern corner of California (area 980 km^2, mean depth 8 m). It began as a fresh water lake in 1905 and became saline over time due to lack of an outflow (Walker 1961). Marine fish and other organisms from the Gulf of California and the Pacific coast were deliberately introduced to establish a recreational fishery (Walker 1961). A hybrid tilapia, *Oreochromis mossambicus* Peters x *O. urolepis honorum* Trewavas, an omnivorous and planktivorous fish, invaded about 1970 (Costa-Pierce and Doyle 1997; Riedel and Costa-Pierce 2001; Hurlbert *et al.* 2007). Salinity in the lake is increasing due to evaporation and water transfer from agriculture to municipalities. For decades phytoplankton blooms have been a regular occurrence due to inputs of nutrient rich wastewater from agricultural fields and several cities in the watershed (Carpelan 1961; Bain *et al.* 1970; Tiffany *et al.* 2007). In 1997-1999, when the salinity measured 41-45 g l^{-1}, the phytoplankton community in the Salton Sea was dominated by dinoflagellates, diatoms, cryptomonads and a raphidophyte (Tiffany *et al.* 2007). By spring of 2005, filamentous cyanobacteria had became abundant after a collapse of the tilapia fishery (Anderson *et al.* 2007). The salinity is now (January 2008) at or approaching 50 g l^{-1}.

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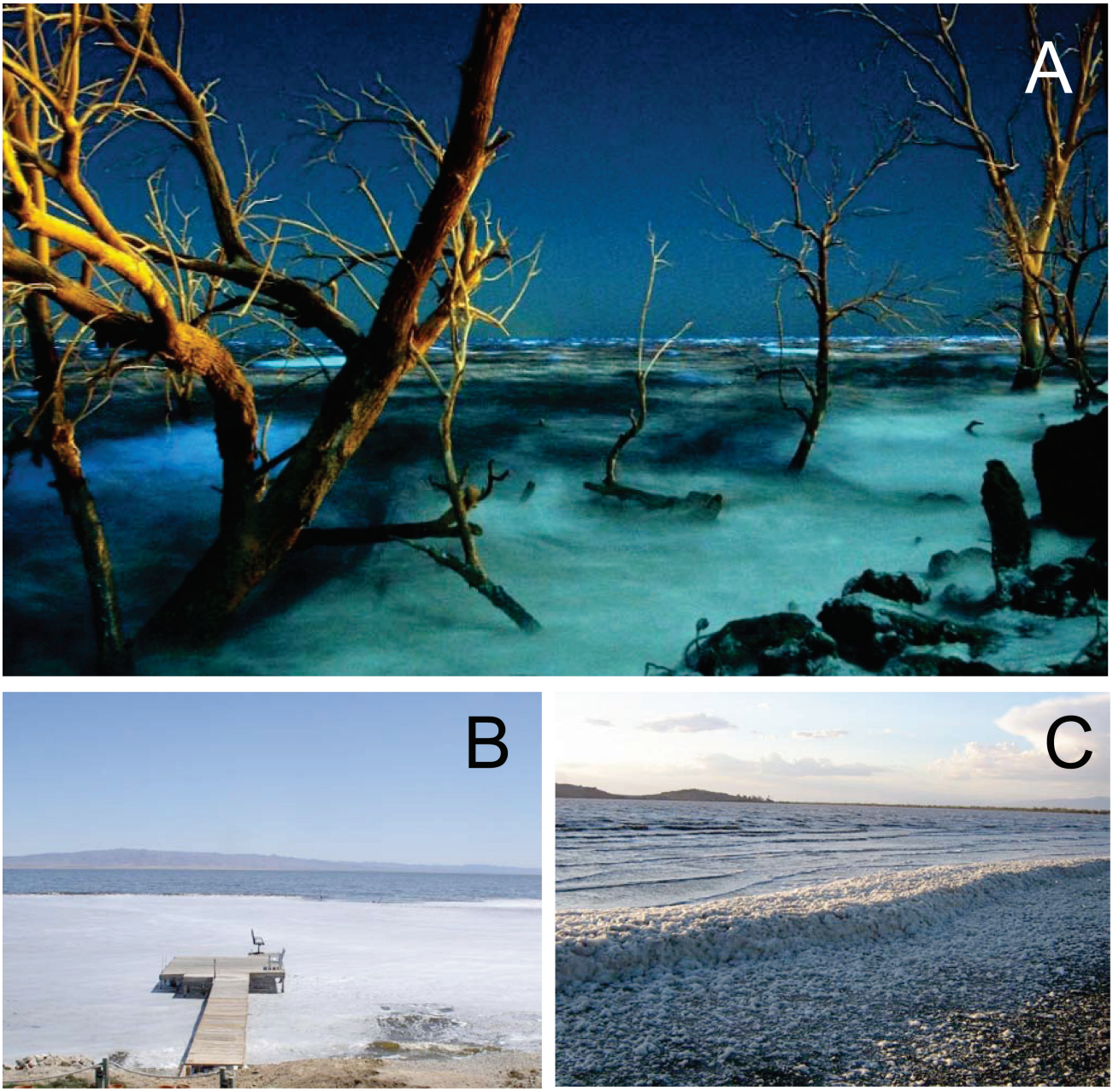

Figure 1.-Images of the Salton Sea in early 2006. (A). Southern shoreline on the night of January 15, 2006. The intense bioluminescence is presumed to be caused by *Alexandrium margalefii*. Trees illuminated with light from nearby geothermal plant. Photo taken at night with 8-second exposure by Kevin Marty, Imperial Valley Press. (B). Foam accumulation along western shoreline at Salton City in February 2006. Photo taken by Norm Niver. (C). Foam on the beach at Red Hill Marina, March 19, 2006.

The first indication of an unusual bloom event in 2006 at the Salton Sea came from local residents who reported blue glowing water in mid-January (Fig. 1A). This was followed closely by reports of large rafts of long-lasting foam after wind events (Fig. 1B, Norm Niver, personal communication). No fish kills were reported during this time. The bioluminescent and foam events in Jan-Feb 2006 were so extraordinary that an expedition was launched to study them on 31 Mar 2006. The objectives of this study were to determine the species present that could account for these phenomena, their abundance and other properties, and the limnological conditions accompanying the events.

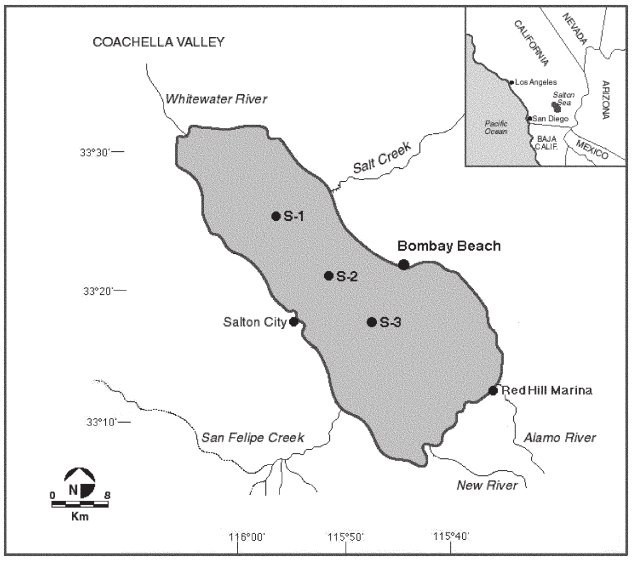

Figure 2.-Map of sampling locations.

Materials and methods

Phytoplankton and limnological measurements

We sampled the same 3 mid-lake stations used in the 1997-1999 monitoring study (Tiffany *et al.* 2007; Fig. 2). At each station water samples for phytoplankton analysis were taken from the depth strata 0-3 m, 3-6 m and 6-9 m using a 3 m long tube. 60 ml samples in duplicate were preserved in 1% Lugol's solution. Temperature and dissolved oxygen concentrations and specific conductance were measured at 1 m intervals starting at the surface as described in Watts *et al.* (2001). Salinity in g l^{-1} was determined from specific conductance using the conversion formula for the Salton Sea in Watts *et al.* (2001). Additionally, on two dates in 2006, 100 ml vials were used to collect surface water samples in 2006 at the southern (Red Hill Marina, 19 March, Fig. 2) and eastern shorelines (Bombay Beach, 31 March, Fig. 2) and 250 ml jars were used to scoop surface sediments to sample for cysts at the former location (31 March).

Enumerations of water samples were made using standard inverted microscope methodology as described in Tiffany *et al.* (2007). Twenty-five ml subsamples were settled for 24 hrs and ~ 1 ml was counted using cross diameters or, for abundant taxa, fields-of-view. Where possible, identifications were made to the species level. Taxonomic identifications were made using observations from light and scanning electron microscopy in consultation with Balech (1994), Balech (1995), Selina and Morozova (2005), Steidinger and Tangen (1997), and Throndsen (1997). The *Prymnesium* sp. failed to grow in culture and was only identified to the genus. Mean cell or colony biovolume was estimated for each species by measurement of at least 40 individual cells or colonies. These estimates were used to calculate biovolume densities for each taxon and for total phytoplankton.

Light and scanning electron microscopy preparations

Cells from field material were observed using an Olympus IX71 inverted microscope. Field material (live and Lugol's preserved) was examined within 36 hours of collection at 400× using glass bottom culture dishes (MatTek P35G-0-10-C). Photography was done using an Olympus DP70 digital camera. Living cells of *Alexandrium margalefii* and *Prymnesium* sp. were photographed at 960× using a water immersion objective and water immersion condenser. Drops of field material were placed on a No. 1 glass coverslip suspended between water droplets on the immersion condenser and objective.

For electron microscopy, *A. margalefii* cells were fixed overnight in a 1% osmium tetroxide solution at 4 °C and collected on a polycarbonate membrane filter (8 µm pore size, 13 mm diameter, Poretics #10573) by gravity filtration. Outer membranes were stripped from the cells in a secondary fixative bath of 70% EtOH made with Salton Sea water filtered through a 0.2 µm filter (FSW). The cells were held in the 70% EtOH bath for 48 hours at 4 °C. Cells were rinsed 2× for 5 minutes each with FSW (47 g l^{-1}, salinity measured with a Reichert hand refractometer using the correction factor of 1.13 from (González *et al.* 1998) and then FSW washes of decreasing salinity (40, 34, 28, 23, 17, 11, 6, and 0 g l^{-1}). The remainder of the fixation process followed Kempton *et al.* (2002). Observations were made using a Cambridge Stereoscan 240 scanning electron microscope.

Toxin assay

Field sediments containing *A. margalefii* cysts were tested for the presence of saxitoxin (STX). Samples were placed in an aluminum drying boat and dried overnight at 50 °C. Dried sediment was put in a plastic bag and broken into grain-sized pieces with a hammer. Five grams was added to a 200 ml glass beaker and mixed on a stir plate for 30 minutes in 10 ml of 0.1 N HCl. After mixing, the solution was poured into a 50 ml centrifuge tube, centrifuged for 10 minutes at 3,000 × g, and the supernatant was retained. This process was repeated with an addition of 5 ml of fresh acid. The supernatants were combined for STX testing. STX concentrations were measured using the Ridascreen STX ELISA (R-biopharm GmBH, Darmstadt, Germany). Samples were run in duplicate with STX standards provided in the Ridascreen kit and analyzed at a wavelength of 450 nm on a Spectracount plate reader (Perkin Elmer, USA).

Cyst concentration, isolation and incubation

Sediment samples were sealed, wrapped in aluminum foil, and kept in the dark at 22 °C until processed. Cysts were concentrated using the density-gradient technique (Bolch 1997). Purified cyst samples were placed in wells of a 6-well tissue-culture plate and were isolated following the micropipette technique described by Andersen and Kawachi (2005). Cysts and cyst-like cells from the concentrated sample were individually removed by micropipette using an inverted Olympus CK30 microscope at 40–100× magnification, and placed in FSW. Cysts were individually rinsed by sequential transfers between drops of FSW. Single cysts were placed into individual wells of 96-well tissue-culture well plates containing approximately 150 µl of FSW. Plates were incubated at 40 μEm^{-2} sec^{-1}, using full-spectrum fluorescent lights set for a 12:12:L:D cycle at 24 °C. Plates were examined for excystment 2× weekly during the first two weeks, then weekly for the third and fourth weeks using an inverted Olympus CK30 microscope at 40×. Excysted cells were allowed to multiply and transferred into larger volumes of FSW enriched with L1 media as needed.

Results

Field observations and measurements

The first indication that an unusual event was occurring in the Salton Sea came from local residents who reported blue glowing water in mid-January 2006 (Fig. 1A). This was followed closely by reports of large rafts of long-lasting foam after wind events, with shoreline foam accumulations >1 m high on western shorelines (*e.g.*, Fig. 1B; Norm Niver, Salton City, personal communication). No fish kills were reported during this time.

On a windy day, March 19, we observed extensive piles of foam ~0.5 m high, along the shore at Red Hill Marina (Fig. 1C). At night this foam and crests of breaking waves were bioluminescent.

On the night of March 30 we visited many points along the eastern shore of the Salton Sea and observed intense bioluminescence at every location. Spawning pileworms, *Neanthes succinea* Leuckart, a few cm long glowed as they darted about in the shallows near Bombay Beach, and damp shoreline sand glowed brightly when walked upon. Barnacles, *Balanus amphitrite* Darwin, on the dock pilings at Varner Harbor at the northeastern corner of the lake glittered as their filtering appendages disturbed the water. Stamping with our feet on the shorelines or dock caused sudden appearance of diffuse pools of light, ~5-15 cm across, deeper in the water. These 'pools' darted 1-2 m away and disappeared, and presumably were startled tilapia.

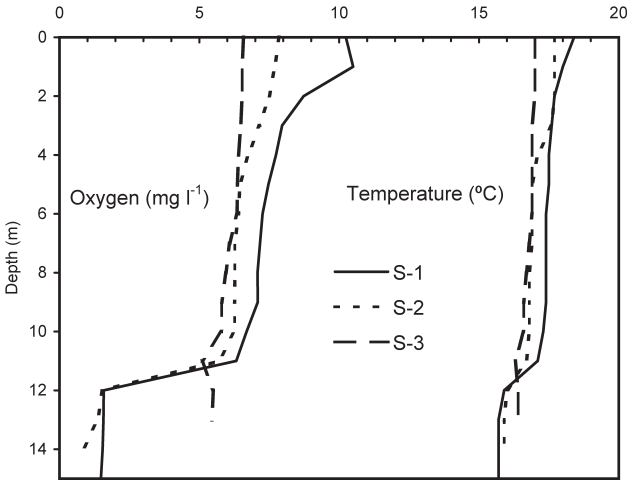

Figure 3.-Salton Sea temperature and dissolved oxygen profiles at mid-lake stations on 31 Mar 2006. For location of stations see Fig. 1.

On March 31 at lake center Secchi readings were 0.6 m at stations S-1 and S-2 and 0.8 m at station S-3. Temperature profiles showed slight stratification with very low oxygen levels (< 2 mg l^{-1}) at 11 m depth at stations S-1 and S-2 (Fig. 3). At all stations pH was 8.46-8.50 and salinity was 47.7-48.5 g l^{-1}. Water was orange-brown at all stations. During the return trip from lake center, the foam generated by our boat passage several hours earlier was still present on the lake surface.

Phytoplankton abundance

The highest abundance of *A. margalefii* (50,100 cells ml^{-1}) was found in the intensely bioluminescent shoreline sample taken at the Bombay Beach boat launch location on March 31. *A. margalefii* (Fig. 4A-C) completely dominated the phytoplankton here with *Prymnesium* sp. (Fig. 4D) occurring in lower abundance (Table 1).

Mid-lake, *Alexandrium margalefii* made up 22-81 percent of total phytoplankton biovolume density, with *Cyclotella* spp. dominating at station S-3. Numerical density of *A. margalefii* ranged from 190-2160 cells ml^{-1} and decreased with depth at all stations (Table 1). Other than a few cells of *Gonyaulax grindleyi* Reinecke, no other dinoflagellate species were detected in mid-lake. *Prymnesium* sp. constituted < 2 percent of total phytoplankton biovolume density at the mid-lake sites but was numerically abundant at 570-5,070 cells l^{-1} (Table 1). *Cyclotella* spp. completely dominated the mid-lake diatom community. The *Cyclotella* cells were primarily < 7.5 µm in diameter and thus most likely were *Cyclotella choctawhatcheeana* Prasad (see Lange and Tiffany 2002, for a detailed SEM analysis of Salton Sea *Cyclotella* spp.). *Pleurosigma ambrosianum* Sterrenburg, Tiffany and

Table 1.-Biovolume densities (B, $mm^3 l^{-1}$) and numerical densities (N, ind. ml^{-1}) of dominant species found in March 2006 at three mid-lake stations and two shore locations.

Location	Depth interval	Date	*Alexandrium margalefii*		*Cyclotella* spp.		*Prymnesium* sp.		Filamentous cyanobacteria*		Total biovolume
			B	N	B	N	B	N	B	N	B
S-1	0-3 m	31-Mar	44.1	1,690	13.4	48,500	0.3	3,490	0.4	9,720	58.4
S-1	3-6 m	31-Mar	33.2	1,270	15.3	53,500	0.1	1,560	0.3	6,280	48.9
S-1	6-9 m	31-Mar	27.3	1,040	14.9	51,500	0.1	1,270	0.2	5,160	42.5
S-2	0-3 m	31-Mar	56.5	2,160	12.5	48,300	0.4	3,950	0.3	7,460	69.8
S-2	3-6 m	31-Mar	51.5	1,970	14.3	48,900	0.3	2,890	0.9	22,700	67.1
S-2	6-9 m	31-Mar	9.5	360	11.5	40,200	0.1	570	1.2	30,500	22.3
S-3	0-3 m	31-Mar	9.8	377	14.8	46,600	0.4	4,440	3.4	80,500	28.6
S-3	3-6 m	31-Mar	7.6	289	14.9	48,400	0.2	2,430	1.5	31,900	24.4
S-3	6-9 m	31-Mar	5.0	190	14.5	53,700	0.5	5,070	2.5	59,700	22.6
S-1	0-9 m	31-Mar	34.9	1,330	14.5	51,200	0.2	2,110	0.3	7,050	49.9
S-2	0-9 m	31-Mar	39.2	1,500	12.8	45,800	0.2	2,470	0.8	20,220	53.1
S-3	0-9 m	31-Mar	7.4	285	14.8	49,600	0.4	3,980	2.5	57,400	25.2
Geometric mean of three stations	0-9 m	31-Mar	21.7	828	14.0	48,813	0.3	2,748	0.8	20,151	39.1
Red Hill Marina**	surface	19-Mar	24.8	950	47.2	208,000	7.7	82,000	0.0	0	79.7
Bombay Beach***	surface	31-Mar	1308	50,100	0.0	0	0.5	5,200	0.0	0	1309

*mostly *Geitlerinema* sp.

**2 m offshore of foam accumulation on beach (Fig. 1C)

***surface sample at boat launch in intensely bioluminescent water

Lange (up to 32 cells ml^{-1}) and *Nitzschia frustulum* (Kützing) Grunow (up to 5 cells ml^{-1}) were seen in low abundance at the mid-lake stations. These two diatoms contributed very little to the total biovolume density. Colonies of filamentous cyanobacteria, mostly *Geitlerinema* sp. plus a small amount of *Arthrospira* sp. and *Oscillatoria* sp., were also present but made up little of the total biovolume density except at station S-3.

The highest abundance of *Prymnesium* sp. (82,000 cells ml^{-1}) occurred at the Red Hill Marina site on March 19 where it accounted for almost 10 percent of the total biovolume density even though it is a very small cell (Table 1). The larger *Alexandrium margalefii* was present at a density of 950 cells ml^{-1}, about a third of the total biovolume density. Small *Cyclotella* spp. were abundant here at over 200,000 cells ml^{-1} and constituted over half of the total biovolume density.

Toxin assay

Tests using the Ridascreen STX ELISA on sediments containing *A. margalefii* cysts were negative for saxitoxin (STX). Work on detecting STX in cultured *A. margalefii* cells and cysts is on-going.

Cyst observations

The cysts produced by *A. margalefii* were small (~35 µm), spherical, and lacking ornamentation (Fig. 4B). They were discriminated from other cysts present in the sediment by a thick mucilage coating on the cell. Viable cysts had a granular appearance, sometimes with a yellow accumulation body. *A. margalefii* cysts made up ~70 percent of the cyst population found in the Red Hill Marina sediments collected on 31 Mar. *A. margalefii* cysts were easy to recover and incubate to excystment. After 3 days of incubation nearly 25 percent of *A. margalefii* cysts had excysted to form vegetative cells and after 2 weeks of incubation excystment had occurred in 50 percent of recovered *A. margalefii* cysts.

Discussion

Studies of the Salton Sea over the past decade illuminate the extremely dynamic nature of its ecosystem. Fish populations vary over orders of magnitude (Caskey *et al.* 2007; Hurlbert

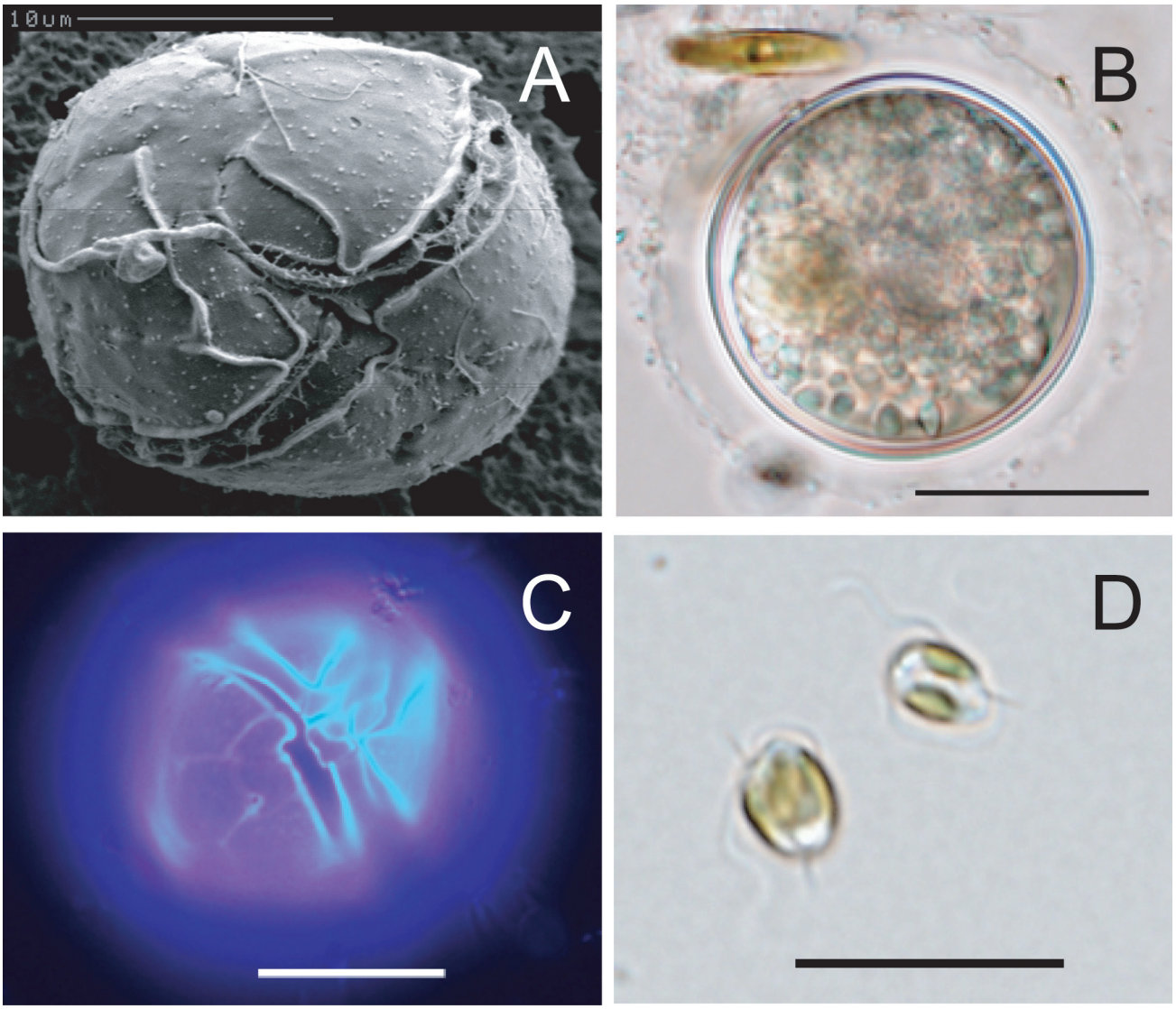

Figure 4.-*Alexandrium margalefii* and *Prymnesium* sp. from Salton Sea bloom. (A). SEM of *A. margalefii.* (B). Light microscope image of an *A. margalefii* cyst. (C). Calco-fluor image of an *A. margalefii* vegetative cell. (D). Light microscope image of several cells of *Prymnesium* sp. Scale bars = 10 µm (A) or 20 µm (B, C, D).

et al. 2007) and this may influence the composition and abundance of phytoplankton. Phytoplankton species that dominate in some years are undetected in others, and large year-to-year and spatial variation in total chlorophyll has been documented (Anderson *et al.* 2007; Reifel *et al.* 2007; Tiffany *et al.* 2007). The discovery of *A. margalefii* and *Prymnesium* sp. in the lake is only the latest example of this dynamism. Neither species was found during our intensive 1997-1999 monitoring of the Salton Sea (Tiffany *et al.* 2007), though a *Prymnesium*-like form and a *Chrysochromulina* sp. were observed occasionally in live samples during that period.

Alexandrium margalefii *and bioluminescence*

This is the first report of the marine dinoflagellate *A. margalefii* in U.S. waters, inland or marine, and the first report of it from any lake. Its type locality is marine waters at Rio de Vigo, Spain (Balech 1994). It was first reported from North America by Band-Schmidt *et al.* (2003) from Bahía Concepción, Gulf of California, and was germinated from cysts from this same location by Morquecho and Lechuga-Devéze (2003). The species has also been reported from the Pacific coastal waters of New Zealand (Mackenzie *et al.* 2004) and Russia (Selina and Morozova 2005).

Most of the phytoplankton species in the Salton Sea are of marine origin (Tiffany *et al.* 2007) though this lake has never

had a connection with the sea. That *A. margalefii* has now been detected in the Salton Sea is not surprising given that it forms cysts (Balech 1994; Morquecho and Lechuga-Devéze 2003; Bravo *et al.* 2006) and has recently been found along the Pacific flyway in the Gulf of California (Band-Schmidt *et al.* 2003; Morquecho and Lechuga-Devéze 2003). Birds are known to be dispersal vectors of algae (Schlichting 1960) and the Salton Sea has a history of deliberate introductions of marine fish and invertebrates which were always transported in tanks of water from the Gulf of California or the Pacific coast of California (Walker 1961).

A. margalefii possibly has been in the Salton Sea a long time as there are anecdotal reports of bioluminescence in the Sea as far back as the 1950s. Bill Karr, old time fishing guide and expert on the Salton Sea sport fishery (Karr 1985), offers this reminiscence (personal communication) of the period from the late 1950s to the late 1980s:

> *We used to surf at night in the big storms with the water lit all around us back in the early 60s. It has been a common occurrence for as long as I remember, going back to 1959. Annual, in fact. We used to fish under the lights at the North Shore Yacht Club [in Salton City] when it was open and in its heyday with yachts moored in the marina and partying going on overhead, catching corvina with the luminescence all around us. And even after the Yacht Club was history [late 1970s, 1980s], we used to fish under the lights at the Salton Sea State Recreation area launch ramp [northeastern corner of the lake] at night and had lit waters all around us…still catching fish…Last bioluminescence I saw there was around 1987-1989 during a huge windstorm at night,…[near the] defunct North Shore Yacht Club, with waves crashing over the breakwater and lit waters everywhere.*

When bioluminescent phytoplankters, whether *A. margalefii* or other taxa, are abundant, prey-predator dynamics in the Sea may be affected in important ways. Fish should have good nighttime success finding prey such as swarming pileworms or darting copepods when these can't move without signaling their location. Indeed, it has been hypothesized "that bioluminescence serves to increase the mortality rate of copepods grazing upon bioluminescent dinoflagellates" by increasing the conspicuousness of copepods to fish thereby favoring reduced copepod populations and increased dinoflagellate survival (Abrahams and Townsend 1993). Fishermen likewise can produce bursts of luminescence around their lure or baited hook by jigging their line a bit or otherwise keeping it in motion. Hundreds of thousands, occasionally millions, of Eared Grebes (*Podiceps nigricollis* Brehm) have for the last half century have used the Sea every year, mostly between January and March, where they feed almost exclusively on the pileworm (Jehl and McKernan 2002; Anderson *et al.* 2007). Numbers of grebes using the Sea have crashed in recent years apparently in response to greatly reduced pileworm populations. But when *A. margalefii* is abundant, nighttime feeding by the grebes on swarming pileworms would be greatly facilitated, just as in the case of pileworm-hunting fish. The ability of grebes to build up energy reserves and flight muscles for their northward spring migration may be enhanced during winters and early springs with strong phytoplankton bioluminescence.

None of the previous reports of *A. margalefii* record bioluminescent properties such as we observed. Dinoflagellates are the only photosynthetic organisms capable of exhibiting bioluminescence (Sweeney 1987), and a number of genera of marine dinoflagellates have been shown to produce light, including *Alexandrium* Halim. Species within this genus known to be bioluminescent are *A. fundyense* (Balech) Balech and *A. tamarense* (Lebour) Balech (Anderson *et al.* 1994), *A. affine* (Liu *et al.* 2004) and *A. catenella* (Sullivan and Swift 2003), however, not all clones in a species produce bioluminescence (Anderson *et al.* 1994).

Lack of reports for bioluminescence in *A. margalefii* may be due to the fact that bioluminescence is not detectable at low densities and high density blooms of this species had not been observed until now. The highest concentrations of *A. margalefii* reported in other studies has been ~1 cell ml^{-1}, in Minonosok Bight, Russia (Selina and Morozova 2005). Bioluminescence in inland waterbodies caused by dinoflagellates or any other taxa has not been previously reported, though it has been recorded in lagoons and lakes with at least a partial connection to the ocean (*e.g.*, Indian River Lagoon, Florida, Badylak *et al.* 2004; Lake Atawapaskat, St. Croix, Virgin Islands, Mauro 2006),

The cysts we observed for *A. margalefii* were similar to those described from southern Tasmania by Hallegraeff *et al.* (1991; as *Alexandrium* sp.) and Bahía Concepción by Morquecho and Lechuga-Devéze (2003). Morquecho and Lechuga-Devéze (2003) report successful excystment of *A. margalefii* cysts after 4 to 5 days of incubation. Our excystment studies show a similar capability for rapid excystment for *A. margalefii*. This was true both for sediments that were processed immediately after collection (August 2006) and those processed after being archived for 17 months (January 2008). The ability to quickly excyst time and time again into viable vegetative populations may be one of the factors in explaining the apparent geographical range expansion for *A. margalefii*.

Many species in the genus *Alexandrium* are known to produce the paralytic shellfish poisoning (PSP) toxin saxitoxin (STX). This makes species identification of members of this genus critical. MacKenzie *et al.* (2004) and Hallegraeff *et al.* (1991; as *Alexandrium* sp.) did not detect STX in *A. margalefii* during their studies. Our preliminary tests on field

and culture material of the Salton Sea strain of *A. margalefii* were also negative for STX production. However, whether this is genetically or environmentally controlled needs to be investigated.

Alexandrium spp. have also been shown to exhibit allelopathy, producing metabolites that inhibit or kill other algal species (Fistarol *et al.* 2004; Tillmann *et al.* 2007). This may partially account for the great scarcity of other phytoplankters in our 2006 samples (Table 1).

Prymnesium *sp., foam and allelopathy*

Although no *Prymnesium* species were unequivocally identified in our 1997-1999 monitoring of the lake (Tiffany *et al.* 2007) when salinity was ~41-45 g l^{-1} (Watts *et al.* 2001), a *Prymnesium*-like form and a *Chrysochromulina* sp. were occasionally observed in live samples during that period. A bloom of *Pleurochrysis pseudoroscoffensis* Gayral et Fresnel, another prymnesiophyte, occurred in early 1999 (Reifel *et al.* 2001) but it was not detected in our March 2006 sampling. The advent of *Prymnesium* blooms was foretold by an earlier experiment investigating the effects of salinity (30-65 g l^{-1}) on Salton Sea tank microecosystems (Hart *et al.* 1998). A *Prymnesium* sp. became very abundant at salinities >48 g l^{-1} (González 1997), the approximate salinity of the Salton Sea in 2006.

Blooms of ichthyotoxic *Prymnesium* have caused extensive fish kills throughout the world (Edvardsen and Paasche 1998). In the United States, blooms of *Prymnesium parvum* Carter have caused millions of dollars of damage to local economies due to fish kills in brackish lakes and rivers and freshwater reservoirs in Texas, Alabama, Arkansas, Georgia, North Carolina, and South Carolina (Tomas *et al.* 2004; Oh and Ditton 2005) and Arizona (Arizona Game and Fish, unpublished data). For example, the Texas Parks and Wildlife Department reported that in Jan 2001, a bloom of *P. parvum* resulted in a loss of 450,000 fish valued at $486,000 at Possum Kingdom Reservoir.

Prymnesium blooms are often characterized by golden yellow discoloration of the water and associated with intense production of foam and dissolved organic carbon (DOC) (Rhodes and Hubbs 1992; Roelke *et al.* 2007; Sager *et al.* 2007). It is not yet known if the *Prymnesium* population found in the Salton Sea can produce the hemolytic compounds (prymnesins) that cause fish kills, although no fish kills were reported during the 2006 bloom event. It is possible that at higher salinities and different nutrient regimes *Prymnesium* species produce less toxin (Baker *et al.* 2007; Roelke *et al.* 2007).

As in the case of the marine prymnesiophyte *Phaeocystis* (Richardson 1997), the massive development of foam over the surface of the Sea and eventual accumulation on shorelines is likely caused by the exudation of protein-rich materials by the algae, which are then whipped into foams by wave action. Lysis of other phytoplankters is another possible source of these materials. *Prymnesium* spp. are known to produce allelopathic substances that negatively impact other algal species (Fistarol *et al.* 2003). Under nutrient deficient conditions these substances lyse other phytoplankters and give *Prymnesium* spp. access to nutrient resources that would otherwise be unavailable (Granéli and Johansson 2003; Granéli and Hansen 2006). The highly eutrophic Salton Sea, of course, cannot be characterized as nutrient deficient!

Foam has also been postulated to be a dispersal mechanism for *Prymnesium* as wind can pick up bits of it and loft it to other locales (Thornton 1999). *Prymnesium* likely is already present in brackish and freshwater ponds and reservoirs in the Salton Sea region. Although no *Prymnesium* was detected in August 2006 (unpublished data) it is likely that it reappeared in February 2007, as long-lasting foam accumulations were then again reported from the lake.

Conclusions

We have documented the presence and high densities of two algal species not previously reported from the Salton Sea. *Alexandrium margalefii* and *Prymnesium* sp. may have important ecological roles in the Salton Sea and consequences for people and wildlife that utilize it. This is because of the potential for toxin production (PSP and prymnesins), the prevalence of resting stages that can lead to recurring blooms, capacity to bloom in high densities and outcompete other algal species, and the possible influence of bioluminescence on prey-predator relations. As several phytoplankton groups in addition to these may contain toxin producing species (Tiffany *et al.* 2001, 2007; Carmichael and Li 2006), monitoring efforts during the management and restoration of this lake should take into account both total phytoplankton, as measured by chlorophyll concentration, and species composition.

Acknowledgments

We thank Brian Brinegar for logistical support and Jay Abbott for assistance with the STX assays, Kevin Marty of the Imperial Valley Press and Norm Niver for providing photographs of the Salton Sea, and four anonymous reviewers for helpful suggestions on the manuscript. This work was supported in part by the NASA Earth System Science Fellowship Program under grant no. NNG05GB55H to M.A. Tiffany.

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