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Pleurochrysis pseudoroscoffensis (Prymnesiophyceae) blooms on the surface of the Salton Sea, California

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Abstract

Dense populations of the coccolithophore *Pleurochrysis pseudoroscoffensis* were found in surface films at several locations around the Salton Sea in February–August, 1999. An unidentified coccolithophorid was also found in low densities in earlier studies of the lake (1955–1956). To our knowledge, this is the first record of this widespread marine species in any lake. Samples taken from surface films typically contained high densities of one or two other phytoplankton species as well as high densities of the coccolithophore. Presence or absence of specific algal pigments was used to validate direct cell counts. In a preliminary screen using a brine shrimp lethality assay, samples showed moderate activity. Extracts were then submitted to a mouse bioassay, and no toxic activity was observed. These results indicate that blooms of *P. pseudoroscoffensis* are probably not toxic to vertebrates and do not contribute to the various mortality events of birds and fish that occur in the Salton Sea.

Introduction

Coccolithophorids (Prymnesiophyceae) are common phytoplankters in marine habitats. Species in this group are characterized by an outer covering of small regular plates (coccoliths) consisting of calcium carbonate (Heimdal, 1993). Some species are known to form large and sometimes regularly occurring blooms in the world's oceans (Milliman, 1980; Honjo, 1982; Blackburn & Cresswell, 1993). Several genera consistently occur in near-shore marine waters including *Hymenomonas, Cricosphaera, Pleurochrysis, Ochrosphaera* and *Cruciplacolithus* (Johansen et al., 1988; Heimdal, 1993). Although coccolithophorids are a predominantly marine group, a few species have been found in inland waters (Green et al., 1990; Heimdal, 1993). Most coccolithophorids are thought to produce harmless blooms, but some species may be toxic (Moestrup, 1994).

This paper reports on blooms of *Pleurochrysis pseudoroscoffensis* Gayral et Fresnel observed in the Salton Sea, California, and on assessments of their pigment composition and toxicity. Small numbers of a coccolithophorid were observed during a plankton survey of the lake in 1955–1956 (Carpelan, 1961). The form, however, was not identified or described. Two prymnesiophytes, *Prymnesium* sp. and a second species, were observed in a microcosm study of salinity effects on Salton Sea phytoplankton (M. Gonzalez, unpublished data). The second species was originally identified as *Coccolithus* sp., but it is now thought to have been *P. pseudoroscoffensis* (M. Gonzalez, pers. comm.). The present study is the first to document the occurrence of *P. pseudoroscoffensis* in the Salton

Sea and to describe bloom occurrences there of any coccolithophorid. Of the five species in the genus *Pleurochrysis*, only one, *P. carterae* Braarud et Fagerland Christensen, has been previously described from an inland body of water, a saline pond in New Mexico (Johansen et al., 1988).

The Salton Sea is a 980 km^2 saline (44 g l^{-1}) lake located in arid southeastern California, U.S.A. It was created in 1905 due to an engineering accident. Although it has a mean depth only of 8 m and a maximum depth of 14 m, it is the largest lake in California (see Cohen et al., 1999; Watts et al., 2001 for maps of the Salton Sea). The lake is eutrophic largely because it is in a closed basin and most of its inflows are agricultural and municipal wastewaters (Bain et al., 1970; Cohen et al., 1999). Frequent algal blooms occur in the lake, some with chlorophyll *a* concentrations as high as 500 $\mu g\ l^{-1}$ (K. M. Reifel, unpublished data).

Materials and methods

Collection and preservation of phytoplankton

Several blooms of *P. pseudoroscoffensis* were observed during the spring and summer of 1999 at the Salton Sea. Samples were taken during three blooms (P2, P3, P4) for analysis of taxonomic and pigment composition. These three blooms and one additional bloom (P1) were also tested for toxic activity using two assays (brine shrimp and mouse). See Table 1 for geographic coordinates of sampling locations.

The first sample (P1) was collected on February 28, 1999. Conditions were calm and a surface film could be seen over much of the lake. The sample was collected 9–10 km offshore from surface water and contained mostly foam. In June 1999, conditions were generally calm and an extensive surface film was observed for several days. It was first seen on June 17 and sampled (P2) on June 20. The sample was collected 2–3 km offshore using a film-concentrating device. This device consisted of thin, 2 m-long strips of wood with polystyrene floats attached to either side of each wood strip. It was floated on the surface and acted as a barrier allowing surface film to be concentrated. Several foam accumulations were also seen on July 5. A sample of foam and surface film (P3) was collected mid-lake using the film-concentrating device. Conditions were calm on this date and the surface film appeared oily. On August 17, water supersaturated with oxygen was observed along the shoreline. Wind was present that caused moderate wave activity. A large (13 L) water sample (P4) was collected from the top 50–100 cm of the water column. All samples were centrifuged using an International Equipment Company HN-SII centrifuge at 2400 rpm to remove as much water as possible. The final concentrates were stored at −80°C until analyzed.

Physical properties (temperature, pH, specific conductance and dissolved oxygen concentration) of each collection site were measured using a YSI model UPG6000 Sonde. A factory-calibrated probe (accuracy: ± 0.15 °C) was used for temperature measurements. Measurements of dissolved oxygen (accuracy: ± 0.2 $mg\ l^{-1}$) were made using a probe that was calibrated using barometric pressure measured in the field and internally corrected for salinity using measurements of specific conductance (accuracy: ±5%). The pH electrode (accuracy: ±0.2 pH units) was calibrated in the laboratory using two standards of known pH (pH 7 and pH 10), and readings were corrected for temperature internally. The precision of each measured variable was greater than the number of decimal places reported in Table 1.

Sub-samples for enumeration and pigment analysis were taken from each sample collected prior to centrifuging. Samples for enumeration were preserved in 5% Lugol's solution. Because coccolithophorids will dissolve when preserved in Lugol's solution (Throndsen, 1978), a sub-sample was also preserved in 5% buffered formaldehyde solution. Samples for pigment analysis were filtered through Whatman GF/F (0.7 μm) filters using a syringe filter apparatus. Filters were stored in liquid nitrogen (−196°C) until analyzed.

Taxonomic and pigment analysis

Preserved samples were enumerated using the Utermöhl method (Lund et al., 1958). Lugol's preserved samples were settled in 25 ml settling chambers for at least 24 h and formalin-preserved samples were settled for at least 48 h before analysis (Hasle, 1978). Two crossed diameters were enumerated using a Leitz inverted microscope at a total magnification of 400×. All cells larger than 5 μm in length were counted and identified to genus or species.

Pigment analysis was done using high performance liquid chromatography (HPLC). Filters were extracted in 90% acetone for 24 h and then sonicated with a microprobe system to enhance extraction efficiencies. An internal pigment standard (canthaxanthin, which is

Table 1. Geographic locations, physical conditions, taxonomic and pigment compositions, and toxicity results for four bloom samples taken at the Salton Sea (nd = not detected)

Sample number	P1	P2	P3	P4
Date	28-Feb-99	20-Jun-99	05-Jul-99	17-Aug-99
Geographic coordinates	115° 38.6′	115° 48′	115° 45.3′	115° 54′
(N latitude; W longitude)	33° 16.2′	33° 23′	33° 17.5′	33° 30′
Physical conditions[a]				
Water temperature (°C)	20.7	34.5	30.6	—
Specific conductance (mS cm^{-1})	51.2	53.7	53.1	—
pH	8.8	8.5	8.8	—
Dissolved oxygen (mg l^{-1})	17.8	11.0	13.0	—
Estimated oxygen% saturation[b]	240%	190%	210%	—
Taxonomic composition		*density (cells ml^{-1})*		
P. pseudoroscoffensis	—	1 000 000	22 000	16 000
Gonyaulax grindleyi	—	nd	nd	160
Gymnodinium sp.	—	nd	130	nd
Gyrodinium uncatenum	—	97	nd	nd
Heterocapsa niei	—	nd	nd	17 000
Oxyrrhis marina	—	nd	320	64
scrippsielloid dinoflagellates	—	11 000	23 000	640
Cylindrotheca closterium	—	97	nd	260
Navicula sp.	—	1400	nd	nd
Pleurosigma ambrosianum	—	320	nd	130
Thalassionema sp.	—	1600	3600	640
Chattonella marina	—	nd	nd	12 000
Tetraselmis sp.	—	350	nd	3500
unidentified cryptomonads	—	710	nd	nd
Total number of cells counted	—	1 020 000	49 100	50 400
Pigment composition		*concentration ($\mu g\ l^{-1}$)*		
Chlorophyll *a*	—	403.9	181.6	423.9
		ratio: pigment – chlorophyll a		
Chlorophyll *b*	—	0.4	0.3	0.5
Chlorophyll *c*	—	7.6	4.9	15.8
Alloxanthin	—	19.3	3.2	1.3
19′-Butanoyloxyfucoxanthin	—	9.4	8.0	12.4
Diadinoxanthin	—	8.0	21.3	4.6
Fucoxanthin	—	24.8	11.7	14.4
Lutein+Zeaxanthin	—	7.9	1.3	4.1
Peridinin	—	4.8	25.5	6.6
Prasinoxanthin	—	12.3	2.0	9.6
Violaxanthin	—	nd	nd	2.4
Brine shrimp lethality assay		*% mortality*		
400 $\mu g\ ml^{-1}$	100	78	38	100
200 $\mu g\ ml^{-1}$	26	26	0	100
100 $\mu g\ ml^{-1}$	46	3	0	75
50 $\mu g\ ml^{-1}$	9	0	0	13
Mouse bioassay		*morbidity and mortality*		
	none	none	none	none

[a] Measured at 0.5 – 1 m below water surface.
[b] Estimated with UPG6000 Sonde calibrated using temperature, salinity and barometric pressure.

not normally found in samples) was used to correct for volume changes during the extraction and injection processes. The method of Wright et al. (1991) was used. Pigment compounds were separated on an ODS-2 column using a three solvent gradient system at a flow rate of 1 ml min^{-1}. Pigment peaks were detected by two absorption detectors; a ThermoQuest UV2000 which measures absorption at 436 and 450 nm and a ThermoQuest UV6000 which measures from 390 to 550 nm every 1 nm. In addition, a fluorescence detector (ThermoQuest FL3000, Ex 404 nm; Em 680 nm) was used to detect and quantify the various chlorophyll degradation products, which usually occur at low concentrations.

Toxicity assessment

The four bloom samples (P1, P2, P3 and P4) collected between February and August were analyzed for toxic activity using two assays. Samples were first screened using a brine shrimp (*Artemia salina* Leach) lethality assay. Extracts from the four samples were also tested using a mouse bioassay.

Extracts were prepared in the following manner at Scripps Institution of Oceanography (SIO). Frozen centrifuged algal samples were lyophilized and the dry residue subsequently weighed. The dried sample was triturated in methanol (ca. 100 ml g $sample^{-1}$) and the resulting suspension was filtered and then washed with methanol (ca. 200 ml g $sample^{-1}$). The filter plug was dried and washed with water (ca. 300 ml g $sample^{-1}$) and the filtrate was lyophilized. The methanol extracts were evaporated to dryness. The resulting residue was partitioned between ethyl acetate (ca. 200 ml g $sample^{-1}$) and water (ca. 200 ml g $sample^{-1}$). The ethyl acetate partition was dried over sodium sulfate and the solvent evaporated to obtain the crude ethyl acetate extract. After evaporation of the residual ethyl acetate, the aqueous fraction was lyophilized. The combined aqueous extracts were placed on a freshly prepared Amberlite^{TM} XAD-2 column (ca. 10 cm^2 packing material g $extract^{-1}$) and desalted by washing with water (ca. 80 ml g $extract^{-1}$). The organic compounds were then washed from the column with methanol. After weighing, each extract was assayed for brine shrimp lethality, and a ^1H NMR spectrum was recorded using a Varian Inova 300 MHz NMR spectrometer.

Brine shrimp lethality assays were performed at SIO using a modification of the methods of Meyer et al. (1982) and Solis et al. (1993). Extracts were dissolved in a 15% aqueous dimethyl sulfoxide (DMSO) or methanol solution to obtain a final concentration of 1.33 mg ml^{-1}. Replicates (2) were diluted to 400, 200, 100 or 50 μg ml^{-1} in the wells of a 96 well micro titer plate. Negative control sample wells (8) were created by duplicating the solvent system. Approximately 15 shrimp nauplii were added to each well. Mortality was monitored over intervals of 2, 4, 6, 12 and 24 h and is reported as percent mortality at 24 h.

Mouse (*Mus musculus* Linnaeus) bioassays were performed at the National Wildlife Health Center (NWHC). Sample extracts were diluted to 1 mg ml^{-1} in DMSO for inoculation into ICR female mice (15–20 g) purchased from Harlan Sprague Dawley. Using a 1 cc syringe and 25 g needle, 0.1 ml of each of the diluted extracts were inoculated intraperitoneally into each of three mice. Control mice were inoculated with 0.1 ml of DMSO. The mice were observed for signs of morbidity for 30 minutes post-inoculation and daily thereafter for 5 days. Samples were considered toxic if all three mice became sick or died.

Analysis of archived phytoplankton samples

A search was also made for *P. pseudoroscoffensis* in samples of phytoplankton taken as part of a biological limnology program during 1997–1999. Phytoplankton samples were collected at intervals of 2–5 weeks at 3–5 mid-lake stations at three integrated depths (0–3 m, 3–6 m, 6–9 m) using a 3-m long PVC tube sampler. The samples were preserved in 5% buffered formaldehyde or Lugol's solution. Enumeration of samples was done using the Utermöhl method as described above. Reports on the phytoplankton results will be given elsewhere. Here, we report on our search for *P. pseudoroscoffensis* in samples collected from the northern station, S-1 (see Watts et al., 2001 for a map of stations).

Results

Identification

Coccolithophores are typically identified through detailed observation of their coccoliths using a combination of light microscopy (LM) and electron microscopy (Heimdal, 1993). Individuals from a February 1999 sample were identified by Wuchang Wei (SIO, pers. comm.) as *Pleurochrysis pseudoroscoffensis* through whole cell observations using LM and through

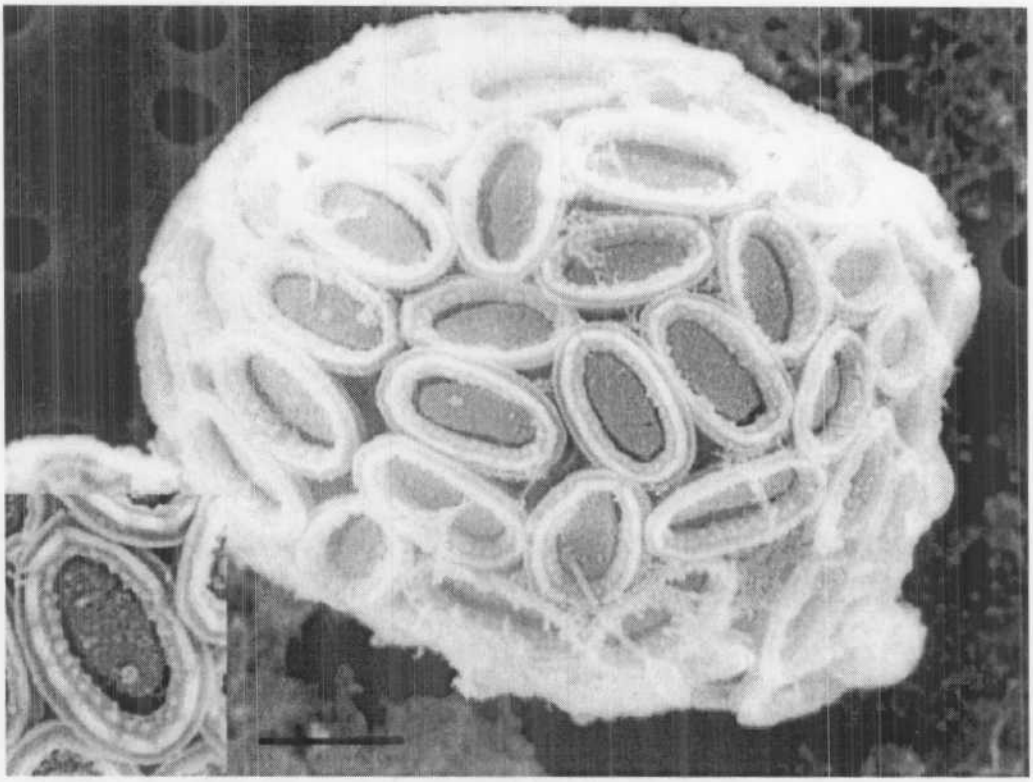

Figure 1. Whole cell of *Pleurochrysis pseudoroscoffensis*. The insert is an enlargement of a coccolith, showing the characteristic ornamentation. Bar = 2 μm. Photo by Steven Barlow.

observations of their coccoliths using scanning electron microscopy (Fig. 1). Cells of *P. pseudoroscoffensis* observed in samples from the Salton Sea tend to be spherical (10–15 μm in diameter) unlike the cells described by Gayral & Fresnel (1983), which were typically larger and more elongated (22–26 μm in length). The authors noted, however, that cells tended to become spherical in older cultures. Cells of other species in the genus *Pleurochrysis* can also be either spherical or oval (Johansen et al., 1988; Fresnel & Billard, 1991). *P. pseudoroscoffensis* sampled from the Salton Sea may have come from older blooms, or the difference between cells collected at the Salton Sea and those collected by Gayral and Fresnel may reflect natural variation within this species.

Abundance

Blooms of *P. pseudoroscoffensis* were observed between February and August 1999 when surface water temperatures ranged from 20 to 35 °C. These blooms typically occurred as oily-looking surface films that were either thin and widespread over large portions of the lake (February, June, July) or concentrated into foamy streaks (February, June). The surface films occurred on calm days. Blooms were also observed, however, during conditions of moderate wave activity (August 1999) when they were concentrated along the shoreline in the top 50–100 cm of the water column.

During blooms, pH and specific conductance were within normal ranges for the Salton Sea (Table 1) (Watts et al., 2001). High densities of phytoplankton present in surface waters are reflected in the high daytime dissolved oxygen levels. Due to high rates of photosynthesis, the surface waters were often supersaturated with oxygen (Table 1).

Samples analyzed from the June and July blooms (P2, P3) represent densities that were present in artificially concentrated surface samples. Densities of the species present were certainly lower in the water column itself. Values for the August bloom (P4) rep-

resent actual densities in the top portion of the water column. In samples collected from the three blooms, *P. pseudoroscoffensis* was abundant, but so were other species including dinoflagellates, diatoms and/or raphidophytes (Table 1). Typically, *P. pseudoroscoffensis* shared dominance with one or two other algal species.

In midlake samples collected during 1998 and 1999, densities of *P. pseudoroscoffensis* were highest between February and May (M. A. Tiffany, unpublished data). Although they reached a maximum of 1100 cells ml^{-1} in February 1999, densities normally ranged between 5 and 100 cells ml^{-1}. When present in detectable densities, they were most abundant in the surface layers (0–6 m). During 1998–1999, *P. pseudoroscoffensis* contributed >1% of total phytoplankton biovolume on only five dates: 6 January 1998 (2%), 6 February 1998 and 7 December 1999 (3%), 28 February 1999 (8%) and 10 May 1999 (16%).

Pigments

Pigment compositions of the three blooms sampled were similar (Table 1). All samples contained 19′-butanoyloxyfucoxanthin, which is characteristic of some prymnesiophytes, and diadinoxanthin and fucoxanthin, which are found in many groups including prymnesiophytes, dinoflagellates, diatoms, chrysophytes and raphidophytes. Pigment ratios were also calculated to further determine which algal groups were major contributors to total chlorophyll *a* (chl *a*).

Although all samples were similar in pigment composition, there were differences found for some pigments that are indicative of specific algal groups. Sample P3 had a high concentration of perdinin, a marker pigment for dinoflagellates. This sample contained a high density of an unidentified scrippsielloid dinoflagellate (Dinophyceae). Sample P4 contained a high density of the dinoflagellate *Heterocapsa niei* Loeblich. The lower concentration of peridinin in this sample, as indicated by the lower ratio of peridinin to chl *a*, may be due to the fact that *H. niei* is smaller than the scrippsielloid (13–25 μm vs. 20–35 μm in length). Sample P2 contained a high concentration of alloxanthin, a pigment restricted to cryptophytes. Several cryptomonad species have been recorded from the Salton Sea (Barlow & Kugrens, 2002). Cryptomonads, however, are often missed in field collections because their fragile cells can be destroyed during fixation (Jeffrey & Vesk, 1997). This may be why they were found in low numbers during phytoplankton enumeration. Samples P2 and P4 contained prasinoxanthin, a pigment marker for prasinophytes, which corresponds with *Tetraselmis* sp. (Prasinophyceae) being found in both samples. Sample P2 also contained a large amount of fucoxanthin, which is most likely due to the high density of diatoms found in this sample.

Although it did not contain the highest number of cells, sample P4 had the highest chl *a* concentration. Mostly likely, this is because this sample contained high numbers of *Chattonella marina* Subrahmanyan Hara et Chihara (Raphidophyceae). This species has numerous chloroplasts (Hallegraeff & Hara, 1995) and is larger (35–60 μm in length) than most other species found in the bloom samples. Because raphidophytes do not contain a marker pigment (Jeffrey & Vesk, 1997), the contribution of *C. marina* (the only raphidophyte known from the Sea) to total of chl *a* in this sample cannot be determined. Seasonal and vertical variations in abundance of *C. marina* in the Salton Sea are described in a companion paper (Tiffany et al., 2001).

Toxicity analyses

All samples showed some degree of toxicity to brine shrimp (Table 1). The level of activity, however, varied between the samples. The August bloom (P4) produced the highest amount of activity (100% mortality at both 400 and 200 μg ml^{-1}). A very low level of activity was found in sample P3 (no activity at concentrations lower than 400 μg ml^{-1}). Although these data may indicate the presence of a toxin, the brine shrimp assay is typically used only for screening purposes and additional tests are needed to determine the types and activities of any toxins that may be present. No sample showed any activity against mice (Table 1).

Discussion

Although *P. pseudoroscoffensis* was most likely present before 1998, this study represents the first definite report of the species from the Salton Sea. Only one species of coccolithophore has been identified to date, so Carpelan's (1961) "unidentified species of Coccolithophoridae" was most likely *P. pseudoroscoffensis*. Prior to 1998, however, the coccolithophore was observed only occasionally and in small numbers in water samples (Carpelan, 1961; M. A. Tiffany, pers. obs.) and in surface sediment samples (M. A. Tiffany, pers. obs.).

In 1999 at the Salton Sea, *P. pseudoroscoffensis* typically formed blooms in the surface layer on calm

days. Photo-inhibition is frequently observed in phytoplankton located near the surface due to high surface irradiance intensity (Reynolds, 1984). One suggested function of coccoliths (Fig. 1) is to serve as a light-scattering device providing protection from excessive illumination (Green et al., 1990). This may in turn provide a competitive advantage over other species in high-intensity light conditions (Berge, 1962). The high reflectance of blooms has been extensively documented by studies done through remote sensing (e.g. Holligan et al., 1983; Groom & Holligan, 1987). Diadinoxanthin, a photoprotectant pigment, was also present in samples collected from blooms of *P. pseudoroscoffensis* in the Salton Sea.

The low densities of *P. pseudoroscoffensis* observed from most of the archived samples may have several explanations. The life cycles of species in the family Pleurochrysidaceae have a diploid cricolith-bearing phase that alternates with a haploid benthic pseudofilamentous stage lacking coccoliths (Billard, 1994). The life cycle of *P. pseudoroscoffensis* is complex, but it is known to exhibit these two phases (Gayral & Fresnel, 1983; Green et al., 1990). Between blooms, *P. pseudoroscoffensis* may spend most of its time in the benthic pseudofilamentous stage of its life cycle. Such individuals have been observed in several sediment samples from the Salton Sea (M. A. Tiffany, pers. obs.). Some environmental trigger would then cause the formation of the motile diploid phase causing planktonic blooms, and only at these times would *P. pseudoroscoffensis* be present at the surface or in the water column in detectable densities. Also, the collection of phytoplankton samples with the 3 m long sampling tube would collect few individuals of phytoplankton species found predominantly on or near the surface, because of dilution through integration by the sampler of the top 3 m of the water column. The action of deploying the tube sampler may also disrupt the surface film enough to prevent collection of the coccolithophore.

While the sampling regime used to collect samples during 1997–1999 is useful for documenting species abundances in mid-lake areas, near-shore phytoplankton blooms can be missed. Dense blooms tend to occur more frequently near-shore, and localized blooms have also been observed (Carpelan, 1961; Reifel et al., 2002). A bloom of *Gyrodinium uncatenum* Hulburt, for example, occurred at the south end of the Sea along the shoreline during January–March 1999 with densities as high as 300 000 cells ml^{-1} (Reifel et al., 2002). Although this species was present at the mid-lake sampling stations, it was not found in bloom densities. When the sampling regime was expanded to include near-shore areas and to incorporate opportunistic sampling, blooms of *P. pseudoroscoffensis* were observed and adequately sampled.

Jeffrey & Wright (1994) separated prymnesiophytes into four pigment types based on the presence or absence of chlorophyll c_3, fucoxanthin and its derivatives. One species of *Pleurochrysis* that was studied (*P.* aff. *carterae*) was placed in the type 1 category based on the presence of fucoxanthin and absence of both 19′-hexanoyloxyfucoxanthin and 19′-butanoyloxyfucoxanthin. Based on the pigment compositions of three bloom samples at the Salton Sea (Table 1), *P. pseudoroscoffensis* seems to fall into the type 4 category. Both 19′-butanoyloxyfucoxanthin and fucoxanthin were seen in all samples, and 19′-hexanoyloxyfucoxanthin was absent. Jeffrey & Wright also found variations in pigment suites among closely related individuals and warned that the "range of pigment suites existing in the Haptophyta is not always strictly delimited by the present taxonomic assignments" (Jeffrey & Wright, 1994: 123).

Large mortality events in both fish and bird populations are common occurrences at the Salton Sea (Walker, 1961; Jehl, 1996). Algal toxins were hypothesized to be involved in die-off events involving large numbers (ca. 150 000) of eared grebes (*Podiceps nigricollis* Brehm) after all common bird diseases, pesticides and heavy metals were ruled out as causes (Reifel et al., 2002). Several prymnesiophyte species are known for producing toxic blooms. Species of *Prymnesium* and *Chrysochromulina* have been responsible for large fish die-offs in marine systems (Dahl et al., 1989; Green et al., 1990; Eikrem & Throndsen, 1993; Moestrup & Thomsen, 1995) and in inland water systems (Reich & Aschner, 1947; Shilo & Shilo, 1955; Hurlbert & Mulla, 1981; Hansen et al., 1994). The list of potentially toxic prymnesiophytes is likely to increase with further study of this group (Moestrup & Thomsen, 1995). Although *P. pseudoroscoffensis* initially showed some toxic activity when tested in the brine shrimp lethality assay, it showed no activity in a mouse bioassay. This species is probably not responsible for mortality events at the Salton Sea through production of a toxin. It may, however, affect organisms in other ways such as through production of dimethylsulfide (DMS) and/or its precursor dimethylsulphoniopropionate (DMSP). Production of DMS and DMSP is confined largely to the Dinophyceae and Prymnesiophyceae (Turner et al., 1988;

Iverson et al., 1989), and *P. carterae* has been shown to produce DMS and DMSP in laboratory cultures (Vairavamurthy et al., 1985). The exclusion of fish from some prymnesiophyte blooms may be due to the production of DMS (Sieburth, 1979). Blooms of coccolithophorids can also affect organisms by altering natural phytoplankton and zooplankton communities. Recent large-scale bird mortality in the Bering Sea was probably due to a shift in dominant zooplankton species caused by a large bloom of the coccolithophore *Emiliania huxleyi* (Saar, 2000). Further study is needed to document these possible effects of *P. pseudoroscoffensis* on birds and fish in the Salton Sea.

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