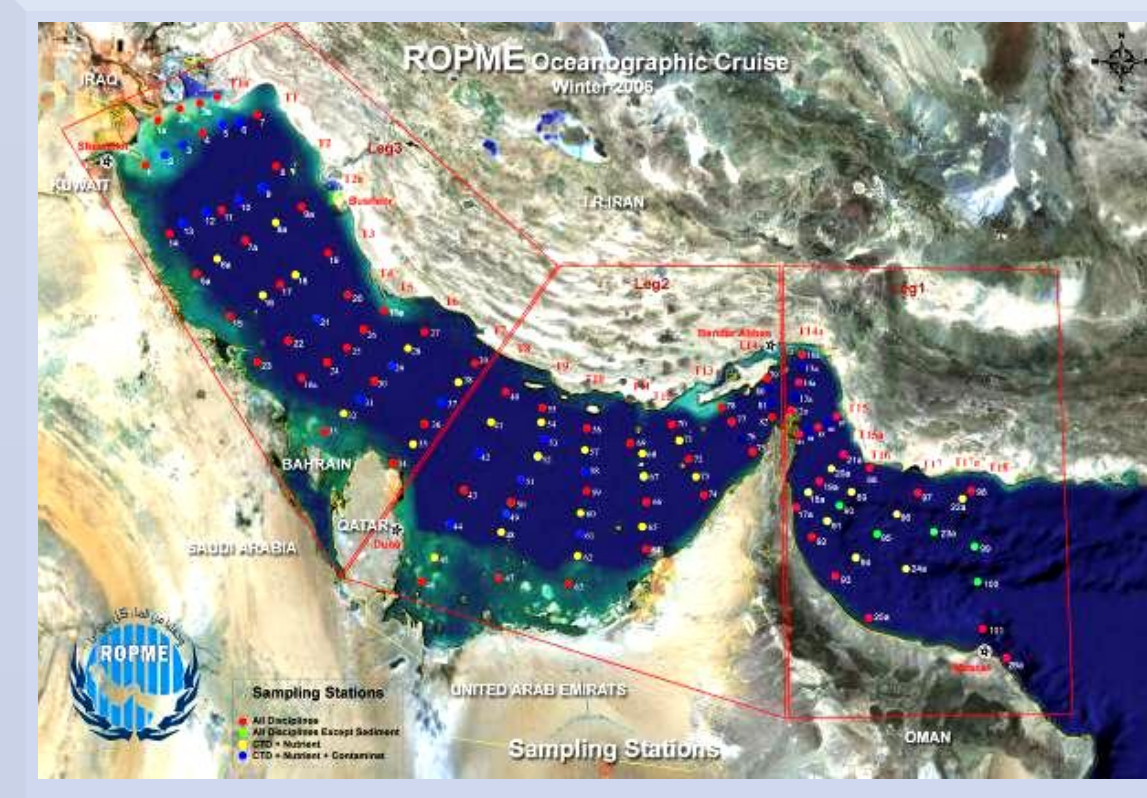


INTRODUCTION

The Arabian Gulf, also known as the Persian Gulf or the Inner ROPME Sea Area is a remarkable West Asian mediterranean-type marginal sea of the Indian Ocean, located in a region of the Middle East with subtropical hyper-arid climate.

The Gulf supports highly productive marine ecosystems including economically important species of fish, crustaceans and cephalopods. Over the past decades, marine environment of the Gulf has been changed rapidly under variety of anthropogenic and natural stresses, including salinity and temperature rise and nutrients loads increase. Invasive alien species and increased occurrence of algal blooms also could play an important role in ecosystems degradation in the Gulf.

The Regional Organization for the Protection of Marine Environment (ROPME) organized multi-disciplinary research cruise involving regional scientists and covering the Arabian Gulf and much of the Sea of Oman to obtain a unique basin-wide dataset on the oceanographic and biological variables. We explore the diversity, abundance and spatial distribution of the winter phytoplankton together with chlorophyll distribution in relation to local oceanographic processes across the Arabian Gulf and the Sea of Oman based on the data of the ROPME cruise in February and March 2006.



Map of the Arabian Gulf and the Sea of Oman and station locations during ROPME winter cruise, February-March 2006



MATERIALS & METHODS

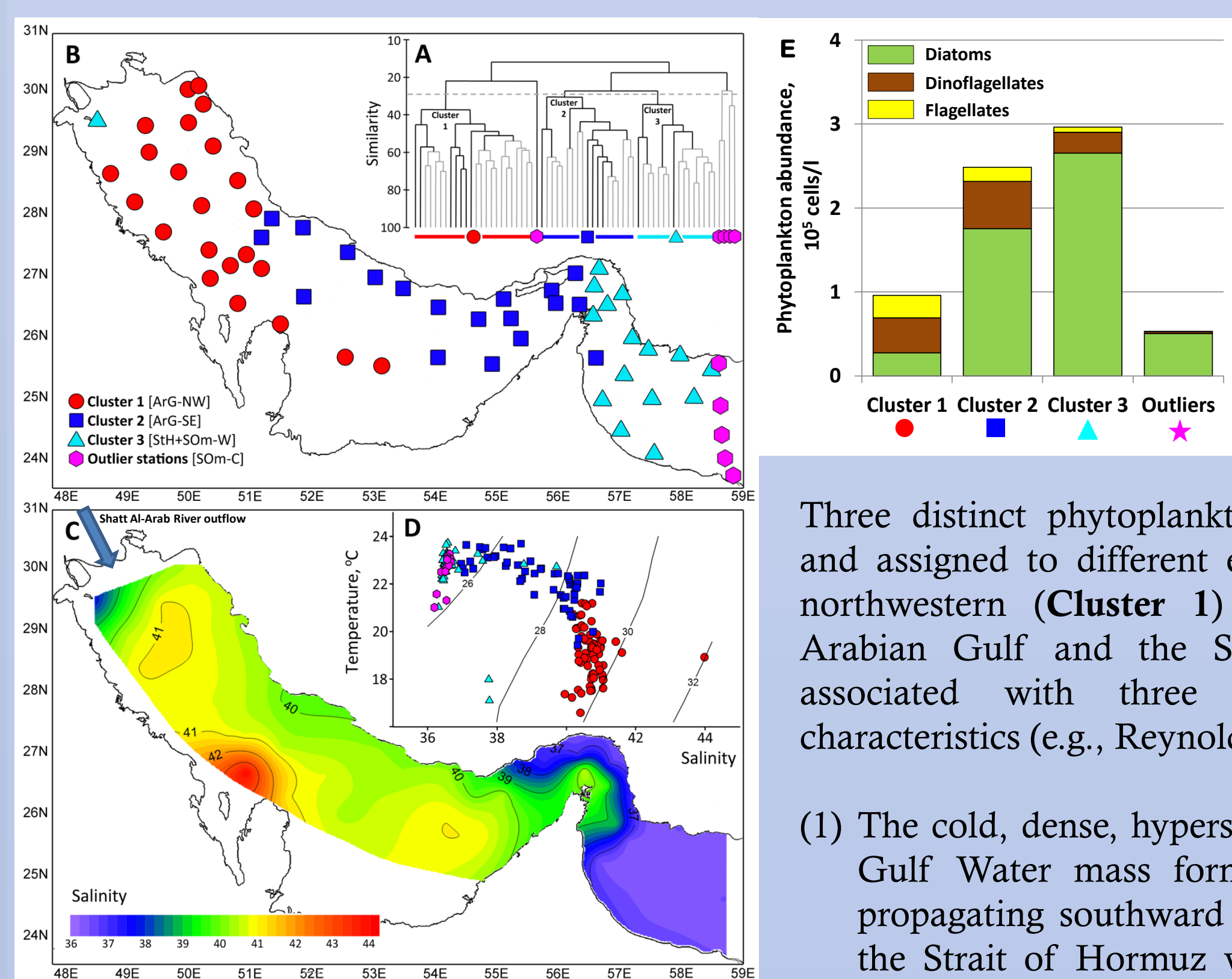
The basin-wide phytoplankton survey covering the Arabian Gulf and the Sea of Oman was performed aboard the M/V "Ghods" between 3 February and 9 March 2006 at 104 sampling stations. For quantitative analyses, one-liter water samples were collected by a Niskin bottle from the surface, middle, and bottom layers.

To quantify the phytoplankton taxa, a 25 ml sub-sample of Lugol-preserved water sample was settled in Utermöhl sedimentation chamber (Utermöhl, 1958) and examined with a Leica DMIL inverted microscope at 200× or 400× magnification.

Chlorophyll measurements were processed accordingly on the US EPA standard method 445.0 for aquatic fluorescence measurements (Arar & Collins, 1997) using acetone extraction and measuring of the fluorescence with Turner Designs TD-700 fluorometer. Preliminary calibration using Sigma Aldrich chlorophyll standard was applied. In total, 574 filters individually packed in foil were analyzed.

PHYTOPLANKTON: abundance & composition

During winter 2006, total phytoplankton abundance varied widely from 162 up to 1.86×10^6 cells·l⁻¹ ($1.87 \pm 2.76 \times 10^5$ cells·l⁻¹ on average) across the Arabian Gulf and the Sea of Oman. The lowest concentrations of phytoplankton ($< 10^3$ cells·l⁻¹) were associated with deep waters in the Sea of Oman. Rather low phytoplankton abundance was recorded in the Arabian Gulf along the Arabian coast. Phytoplankton blooms (1.75 - 1.86×10^6 cells·l⁻¹) coincided with the Strait of Hormuz and the adjacent waters of the Sea of Oman and the Arabian Gulf and were associated with Iranian shore. Phytoplankton abundances, which exceeded 10^6 cells·l⁻¹, were observed in the surface waters at the central part of the Arabian Gulf off Qatar.

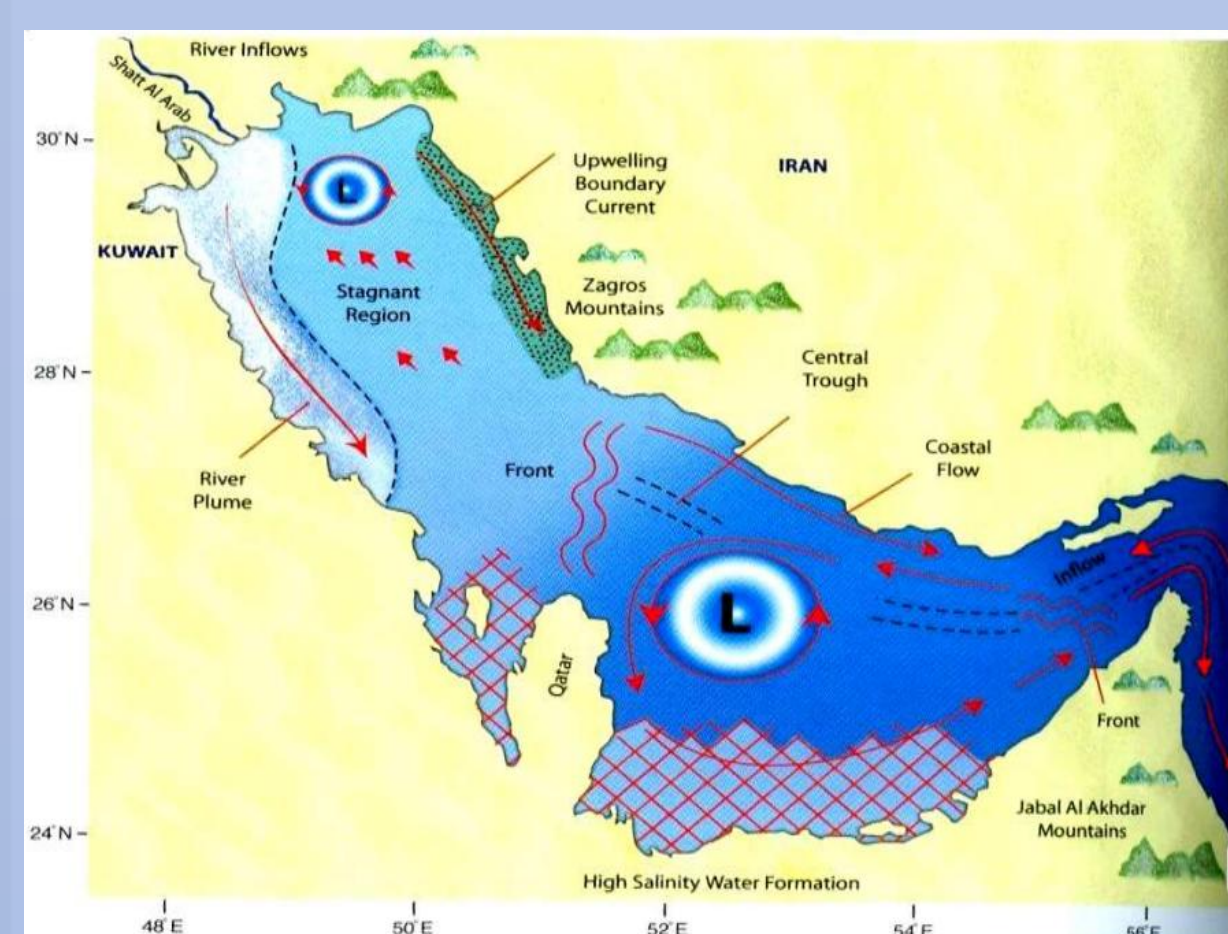


The hierarchical cluster analysis on inter-sample Kulczynski's similarities classified the sampling stations into three major clusters, which formed spatially coherent groupings in map view and differed in phytoplankton structure.

Three distinct phytoplankton assemblages were identified and assigned to different environmental conditions in the northwestern (Cluster 1) and southeastern (Cluster 2) Arabian Gulf and the Sea of Oman (Cluster 3) and associated with three water masses with unique characteristics (e.g., Reynolds, 1993).

- (1) The cold, dense, hypersaline, and nutrient poor Arabian Gulf Water mass formed in the northern Gulf and propagating southward along the Arabian coast toward the Strait of Hormuz was inhabited by low abundant, flagellate-dominated phytoplankton.
- (2) The cool and saltier modified Indian Ocean Surface Water entering the Arabian Gulf on its eastern side from the Sea of Oman through the Strait of Hormuz and spreading through the Gulf along the Iranian coast possessed abundant diatom-dominated phytoplankton and characterized by *Pseudo-nitzschia* spp. and *Skeletonema* sp.
- (3) The relatively fresh, warm and nutrient-rich Indian Ocean Surface Water coming into the Sea of Oman from the northern Arabian Sea was characterized by most abundant and strongly diatom-dominated phytoplankton assemblage with high contribution of the Chaetocerae and lower proportion of small flagellates relative to the Arabian Gulf phytoplankton.

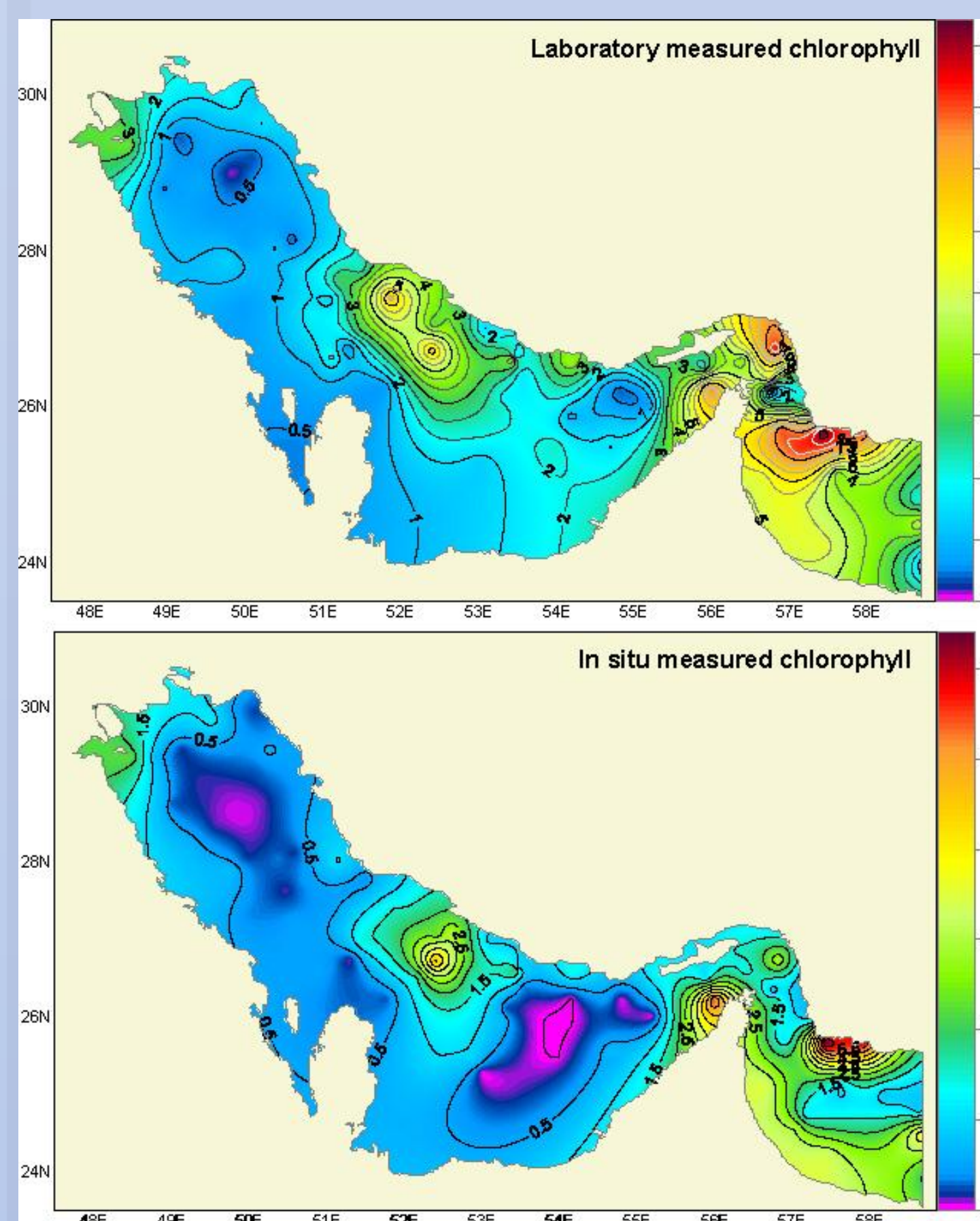
The revealed phytoplankton assemblages differed significantly from each other in terms of abundance, taxonomical distinctness and composition. Phytoplankton spatial distribution resembled the water circulation pattern across the Sea of Oman and the Arabian Gulf and followed a salinity gradient produced by the interaction of different water masses.



General pattern of water circulation in the Arabian Gulf (after Reynolds, 1993, modified; source: Al-Yamani et al., 2004).

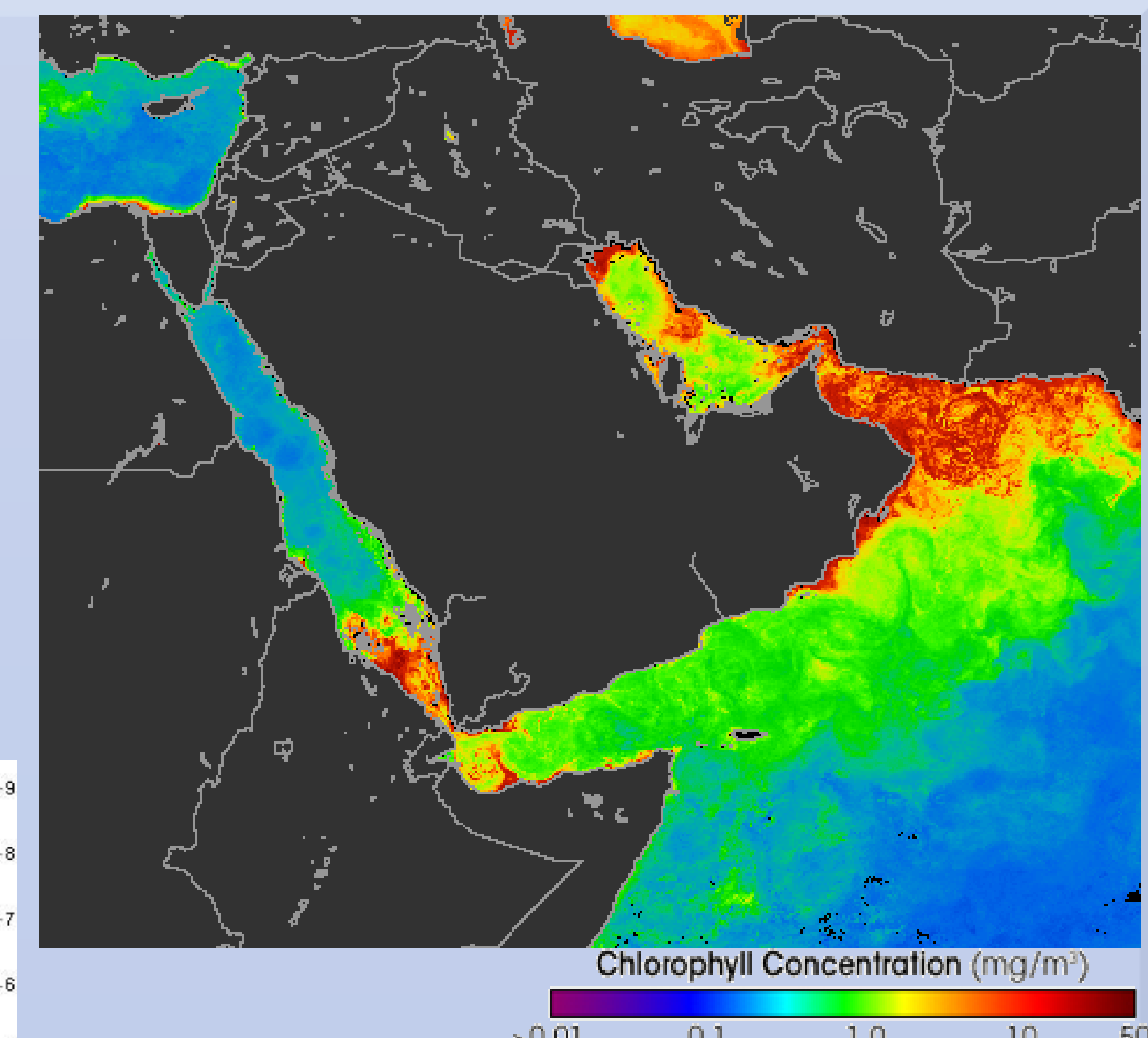
CHLOROPHYLL: spatial distribution

The mean concentration of chlorophyll-a for the water column was $2.09 \pm 1.92 \mu\text{g}\cdot\text{l}^{-1}$. The mean surface laboratory-measured chlorophyll value ($2.54 \mu\text{g}\cdot\text{l}^{-1}$) was in good agreement with satellite data obtained for February-March 2006, which has an average of $2.64 \mu\text{g}\cdot\text{l}^{-1}$ for the entire studied area. The chlorophyll concentration, determined by *in situ* fluorometer, was significantly lower than laboratory measured chlorophyll.

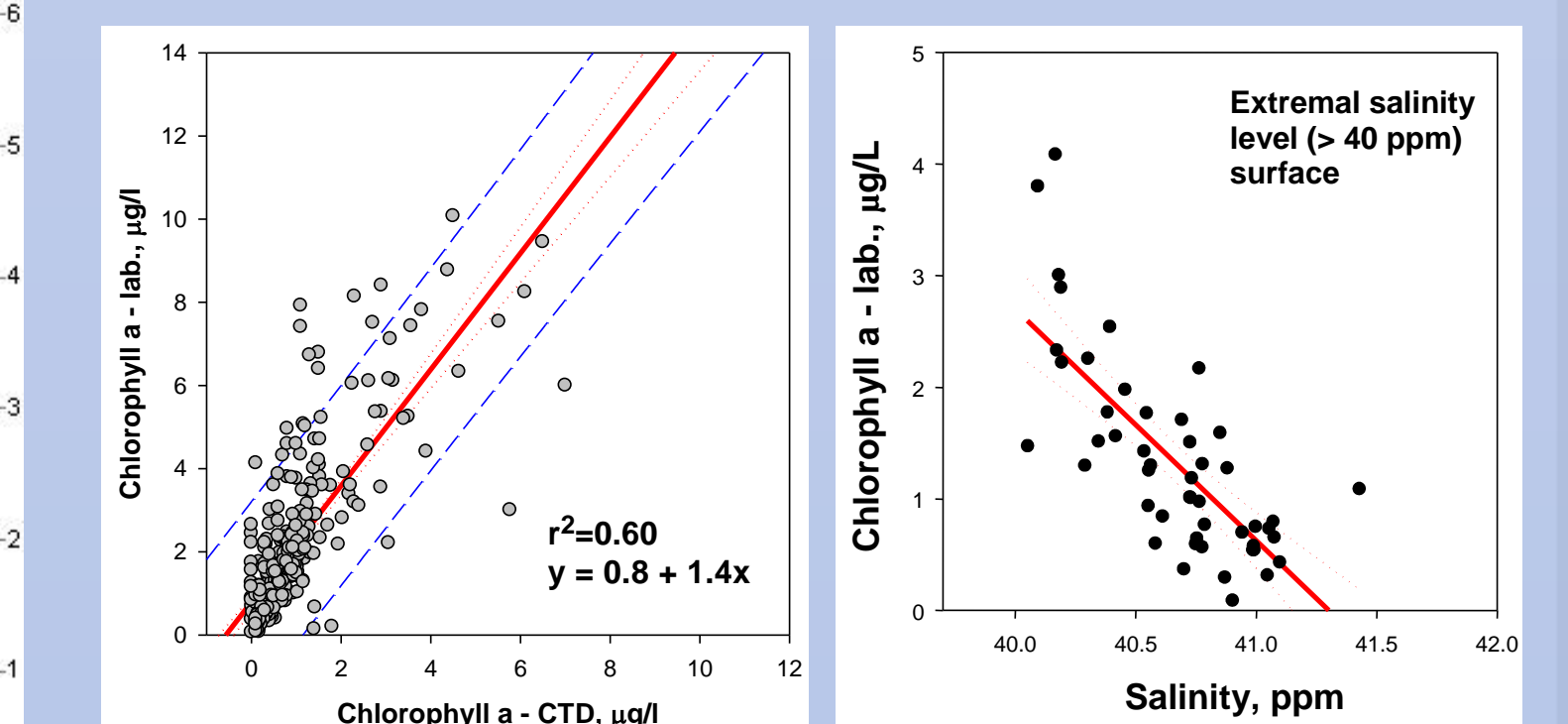


Spatial distribution of surface chlorophyll ($\mu\text{g}\cdot\text{l}^{-1}$), measured in laboratory and *in situ* during February-March 2006. Note that the variability is apparently lower for *in situ* measurements, suggesting that the profiling fluorometer could underestimate chlorophyll values significantly.

Statistic	Chlorophyll a, $\mu\text{g}\cdot\text{l}^{-1}$ (laboratory measurements)			
	Surface	Middle	Bottom	Total
Average \pm STD	2.54 ± 2.16	2.05 ± 1.79	1.68 ± 1.68	2.09 ± 1.92
Minimum value	0.09	0.15	0.07	0.07
Maximum value	9.45	8.77	10.08	10.08
Number of observations	104	103	104	311
Statistic	Phaeophytin, $\mu\text{g}\cdot\text{l}^{-1}$ (laboratory measurements)			
	Surface	Middle	Bottom	Total
Average \pm STD	0.44 ± 0.75	0.29 ± 0.38	0.29 ± 0.47	0.34 ± 0.56
Minimum value	0.00	0.00	0.00	0.00
Maximum value	4.30	2.12	2.95	4.30
Number of observations	104	103	104	311
Statistic	Chlorophyll a, $\mu\text{g}\cdot\text{l}^{-1}$ (CTD <i>in situ</i> measurements)			
	Surface	Middle	Bottom	Total
Average \pm STD	1.07 ± 1.25	0.97 ± 1.04	0.75 ± 0.83	0.93 ± 1.06
Minimum value	0.00	0.00	0.00	0.00
Maximum value	6.50	7.00	5.77	7.00
Number of observations	104	104	104	312



Mean surface chlorophyll concentration ($\text{mg}\cdot\text{m}^{-3} = \mu\text{g}\cdot\text{l}^{-1}$) in the ROPME Sea Area and adjacent waters during March 2006. Data are derived from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) using the standard OC3 chlorophyll algorithm (O'Reilly et al., 2000). (http://earthobservatory.nasa.gov/Observatory/Datasets/chlor_seawifs.html).



Results indicate the occurrence of high spatial variability in the studied regions of the Gulf and the Sea of Oman. Relatively few zones had pronounced low chlorophyll values ($< 1 \mu\text{g}\cdot\text{l}^{-1}$), while high concentrations ($> 4 \mu\text{g}\cdot\text{l}^{-1}$) were observed in central eastern side of the Gulf near the Iranian coast, in the southeastern part of the Gulf, Strait of Hormuz, and in the Sea of Oman.

Zones of high salinity (more than 40) correspond to low chlorophyll values, that is also confirmed by remote sensing.

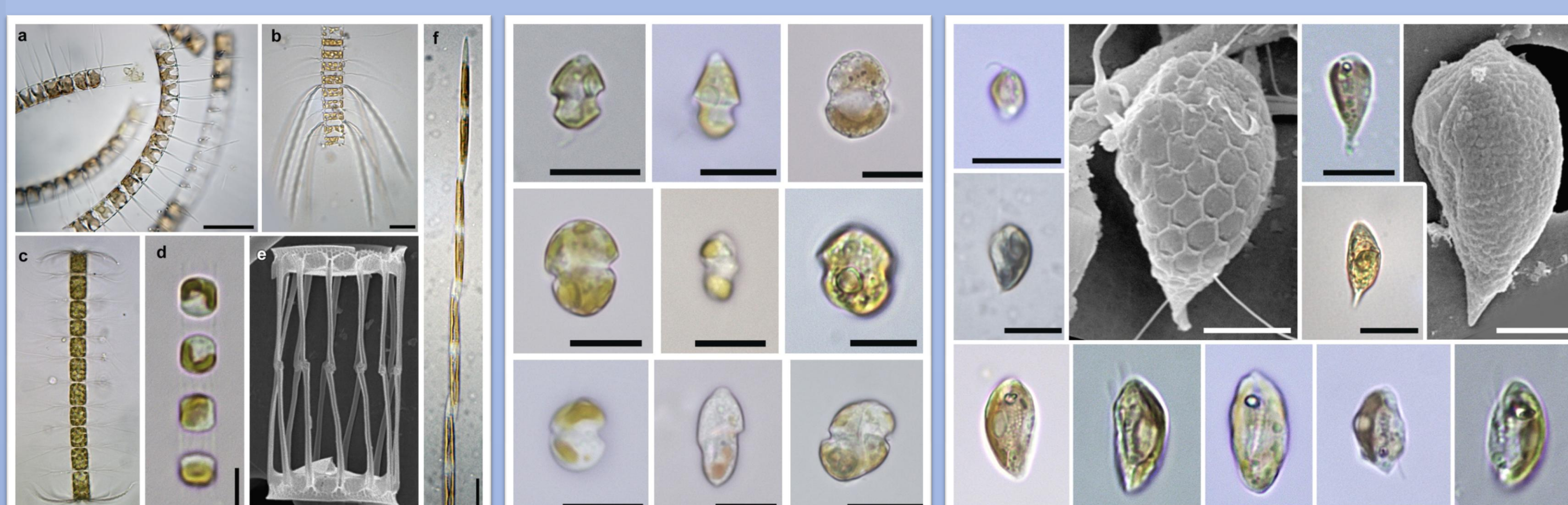
Data obtained from MODIS sensors and processed using OC3 algorithm were in good agreement with laboratory-measured chlorophyll. Differences were based on different spatial scale (MODIS sensor is registered 9×9 km spots as one point, basin-wide, while samples during cruise were taken usually within about ten kilometers intervals) and time scale.

Dominant phytoplankton taxa:

Diatoms

Dinoflagellates

Cryptophycean flagellates



Chaetoceros spp. (a, b); *Bacteriastrum furcatum* (c); *Skeletonema* sp. (d, e); *Pseudo-nitzschia* sp. (f).

Small-sized Gymnodinioids.

Plagioselmis prolonga and *Teleaulax acuta*.

CONCLUSION

1. The occurrence of high variability in horizontal and vertical distribution of chlorophyll concentrations was revealed across the Arabian Gulf and the Sea of Oman during February and March 2006. The highest mean concentrations for chlorophyll were recorded at the Sea of Oman, Strait of Hormuz, in the middle of the Arabian Gulf, and off Shatt Al-Arab (Tigris and Euphrates) and Karun river deltas.
2. The chlorophyll concentration, determined by *in situ* fluorometer, was significantly lower than laboratory measured chlorophyll.
3. The main outcome of this study was the first data set of acid-corrected *in vitro* chlorophyll concentrations and phytoplankton abundance and taxonomic diversity obtained simultaneously from the entire region of the Arabian Gulf and the Sea of Oman, which can be used as a baseline for validation of remote sensing measurements.

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