Temporal and Spatial Changes in the Abundance and Biomass of Pico (Heterotrophic Bacteria & *Synechococcus*) and Nanoplankton (Flagellates) of the Mersin Bay – Relationships with Ambient Physical, Chemical and Biological Parameters

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

Temporal and Spatial Changes in the Abundance and Biomass of Pico (Heterotrophic Bacteria & *Synechococcus*) and Nanoplankton (Flagellates) of the Mersin Bay – Relationships with Ambient Physical, Chemical and Biological Parameters

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The eastern Mediterranean has been known as the most oligotrophic water body among the worlds oceans and as a result of limited nutrient inputs from terrestrial sources primary productivity and plankton succession are restricted by lack of nutrients especially by phosphorus and nitrogen. Within this domain, Mersin bay forms a so called *hot spot* (highly sensitive) area where a sharp contrast exists between the coastal area supplied by land-based nutrient sources and the nutrient limited open sea. Excess nutrient enrichment lead for eutrophication in the inner Mersin bay while altering the quality and quantity of flora from shore to offshore. Microorganisms are highly sensitive and profoundly affected by environmental disturbances and are widely used to assess the impact of environmental changes on ecosystem functioning. With this study, it is aimed to investigate responses of the smaller fractions of phytoplankton composed of heterotrophic bacteria, *Synechococcus* and flagellates to rapidly changing ambient biological, chemical and physical properties of shelf waters over an extended period between 2008 and 2010. Epiflourescence microscopy and image analysis setup were used to enumerate and measure size of cells for biomass estimates.

Both the abundance and biomass of heterotrophic bacteria, *Synechococcus* and flagellates made peaks in inner bay, nearby the discharge points, while decreasing gradually towards offshore. Average abundance of heterotrophic bacteria in 0-20 m depth stratum was 2.3, 3 and 3.2 times higher than those calculated for the 20-50, 50-100 and 100-200m depth strata. These ratios were 2.8, 5.5 and 6.2 for *Synechococcus* and 2.4, 3.3 and 5 for flagellates.

Results clearly indicate that nearshore and offshore waters are completely distinct in their biology and chemistry and contain contrasting populations.

Throughout the study, heterotrophic bacteria dominated both in terms of abundance and biomass over *Synechococcus* and flagellates in Mersin bay. During the study period abundance of heterotrophic bacteria varied in the range 1.3 x 10^5 cells/ml (0.71 μg C/l) and 1.3 x 10^7 cells/ml (80.42 μg C/l) at surface. Bacteria showed strong seasonality being least abundant during winter and spring and most abundant during summer and fall. They mostly occupied the warmer upper water column during summer and fall. *Synechococcus* abundances varied in the range 1.2 x 10^3 cells/ml (0.07 μgC/l) and 1.2 x 10^6 cells/ml (129.69 μgC/l) at surface. Similar to heterotrophic bacteria, significant seasonality was also observed with *Synechococcus* displaying winter-spring minima and summer-fall maxima. Abundance profiles mimicked temperature profiles during summer and fall. In case of flagellates, their abundance and biomass values reached peak levels of 1.2 x 10^4 cells/ml and 11.15 μgC/l, respectively. Apart from heterotrophic bacteria and *Synechococcus* they did not show any significant seasonality and distributed more homogenously in the water column.

Based on Spearman rank correlation analysis, highly significant relationships were observed within the organism groups studied (heterotrophic bacteria and *Synechococcus* $n = 820$; $r = 0.703$; $p < 0.0001$; heterotrophic bacteria and flagellates $n = 820$; $r = 0.675$; $p < 0.0001$; *Synechococcus* and flagellates $n = 820$; $r = 0.635$; $p < 0.0001$) indicating collective responses to changing environmental conditions. Similarly, significant correlations have been obtained between biological groups and nutrient levels. Significant relationships were also observed between temperature and all groups.

Keywords; NE Mediterranean, Mersin Bay, heterotrophic bacteria, *Synechococcus*, flagellates, abundance, biomass, distributions.

ÖZ

Mersin Körfezi'nde Piko (heterotrofik bakteri ve *Synechococcus*) ile Nanoplanktonik (Kamçılılar) Organizmaların Bolluk ve Biyokütlesinin Zamana Bağlı ve Bölgesel Değişimleri - Ortamın Fiziksel, Kimyasal ve Biyolojik Parametreleri ile İlişkileri

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Doğu Akdeniz dünya denizleri arasında en oligotrofik su kütlesi olarak bilinmektedir. Karasal kökenli besin tuzu girdisinin az olması nedeniyle birincil üretim özellikle fosfor ve azot tuzları eksikliğinden dolayı sınırlanmaktadır. Bu bağlamda Mersin Körfezi'nde karasal kökenli nutrient kaynakları ile beslenen kıyısal alan ile besin tuzlarının sınırlı olduğu açık sular arasında belirgin bir farklılığın gözlendiği "Sıcak Nokta (Hassas Alan)" oluşur. Mersin Körfezi'nin iç kısmındaki aşırı besin tuzu zenginliği ötrofikasyona neden olur ve kıyıdan açığa doğru floranın niteliğini ve niceliğini değiştirir. Mikroorganizmalar çevresel etkenlerden dolayı oluşan değişikliklere karşı oldukça hassastırlar ve çevresel etkilerin ekosistem işleyişi üzerindeki etkisini belirlemek için yaygın olarak kullanılırlar. Bu çalışmayla planktonun küçük bileşenleri olan heterotrofik bakteri, *Synechococcus* ve kamçılı organizmaların Mersin Körfezi kıta sahanlığının hızlı şekilde değişim gösteren fiziksel, kimyasal ve biyolojik özelliklerine karşı verdikleri tepkiler incelenmiştir. Epifloresans mikroskop ve görüntü analiz sistemi hücrelerin sayımı ve karbon bütçelerinin hesabında kullanılmıştır.

Heterotrofik bakteri, *Synechococcus* ve kamçılı organizma bolluk ve biyokütle değerlerinin deşarj noktalarına yakın olan körfezin iç kesiminde en yüksek miktarlara ulaştığı ve açığa doğru giderek azaldıkları gözlenmiştir. 0-20 metre derinlik tabakası aralığındaki heterotrofik bakteri bolluğu 20-50, 50-100 ve 100-200 m derinlik tabakası aralıklarına kıyasla sırası ile 2.3, 3 ve 3.2 kat daha fazla bulunmuştur. Bu oranlar *Synechococcus* için 2.8, 5.5 ve 6.2, kamçılı organizmalar için 2.4, 3.3 ve 5 olarak hesaplanmıştır. Sonuçlar, kıyıya yakın ve

kıyıdan uzak bölgelerin biyolojileri ve kimyaları bakımından oldukça farklı olduğunu ve farklı yoğunluklarda populasyonlar içerdiğini göstermiştir.

Çalışma süresince Mersin Körfezi'nde heterotrofik bakteriler *Synechococcus* ve kamçılı organizmalara oranla hem bolluk hem de biyokütle açısından baskın bulunmuşlardır. Heterotrofik bakteriler yüzey suyunda 1.3 x 10^5 hücre/ml (0.71 µgK/l) ve 1.3 x 10^7 hücre/ml (80.42 µgK/l) aralığında değişim göstermiştir. Kış ve ilkbahar aylarında düşük değerlerde, yaz ve sonbaharda yüksek değerlerde gözlenen bakterilerin mevsimlere bağlı değişiklik gösterdiği bulunmuştur. Yaz ve sonbahar süresince daha sıcak olan su kolonunun üst kısmında yoğun olarak bulunmuşlardır. *Synechococcus* ise yüzey suyunda 1.2 x 10^3 hücre/ml (0.07 µgK/l) ve 1.2 x 10^6 hücre/l (129.69 µgK/l) değerleri arasında değişim göstermiş, heterotrofik bakterilere benzer şekilde kış ve ilkbahar aylarında az, yaz ve sonbaharda yüksek değerlerde bulunmuştur. Su kolonundaki bolluk dağılımları yaz ve sonbaharda sıcaklık ile benzerlik göstermektedir. Çalışma süresince kamçılı organizmaların bolluk ve biyokütleleri ise sırasıyla en yüksek 1.2 x 10^4 hücre/ml ve 11.15 µgK/l değerlere ulaşmıştır. Heterotrofik bakteri ve *Synechococcus*'dan farklı olarak bolluk ve biyokütleleri belirgin bir mevsimsel değişim göstermemiş ve su kolonunda daha homojen bir şekilde dağılmıştır.

Spearman rank korelasyonu analizine göre çalışılan organizma grupları arasında gözlenen yüksek düzeyde önemli ilişkiler, değişen çevre koşullarına karşı bu organizmaların verdiği ortak tepkiyi ortaya koymaktadır (heterotrofik bakteri ve *Synechococcus* $n = 820$; $r = 0.703$; $p < 0.0001$; heterotrofik bakteri ve kamçılı organizmalar $n = 820$; $r = 0.675$; $p < 0.0001$; *Synechococcus* ve kamçılı organizmalar $n = 820$; $r = 0.635$; $p < 0.0001$). Benzer şekilde heterotrofik bakteri, *Synechococcus* ve kamçılı organizmalar ile besin tuzları ve sıcaklık ile de yüksek düzeyde önemli ilişkiler bulunmuştur.

Anahtar Kelimeler; KD Akdeniz, Mersin Körfezi, heterotrofik bakteri, *Synechococcus*, kamçılı organizmalar, bolluk, biyokütle, dağılım.

“In memory of my dad,

whom I love and miss so much..”

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1. INTRODUCTION

The roots of marine microbiology were originated from Robert Hooke who had published a monograph, Micrographia, in 1665 showing drawings of microbes that he had seen with his compound microscope and the Dutch draper, and amateur lens maker, Antony van Leeuwenhoek, who had been able to achieve the magnification enough to observe bacteria in seawater in 1688. After 300 years, Francisco and Hobbie provided a method for the quantitative estimation of bacteria in the sea (Francisco et al., 1973; Hobbie et al., 1977). Before this, bacteria were suggested to be rare in oceans due to under-estimations via culturing studies (few or almost no colonies were able to grow on culture mediums that time) and hence they had been considered to be inconsequential part of the ocean's food web.

Francisco and Hobbies' contribution on direct observation of marine bacteria led for a revolution in marine microbial ecology emphasizing that pelagic bacteria are hugely abundant (10^6 cells/ml^{-1}) and account for most oceanic biomass and metabolism (Azam, 1998). 50% of the total marine biomass was suddenly discovered and their role in the decomposition of organic material and the demineralization of inorganic nutrients became fully accepted in the 1980s (Carl and Proctor, 2007).

Results showed that bacteria are major biological force in oceanic carbon cycle and ecosystem structure (Carl and Proctor, 2007; Pomeroy et al., 2007). Microbial oceanography has made remarkable strides towards system inventory, exposing tremendous diversity of microbial capabilities, and spatial and temporal dynamics (Azam and Worden, 2004).

"… This field is fascinating, not only because it is the study of that which cannot be seen with the naked eye but also because it is the study of organisms that are fundamental to the functioning and health of the oceans …" (Page 15; Proctor and Carl, 2007).

1.1. Microbial food web

In order to amplify the importance and function of microorganism groups that were studied within the scope of this thesis, the term "microbial food web" has to be discussed in detail prior to it. Microbial loop can be described as a complicated network of biota and processes based on the flow of detritus based energy through the food web and microorganisms are capable of creating a sustained cycle of production and decomposition of organic matter, requiring only the input of sunlight or the chemicals released from rivers and from hot vents that occur near undersea volcanism (Pomeroy et al., 2007). Whitman et al., (1998) suggested that the upper 200 m of the ocean houses a total of 3.6×10^{28} cells, of which 2.9×10^{27} cells are autotrophs, while the ocean water below 200 m contains 6.5×10^{28} prokaryotic cells from global estimates of volume. This biomass often is a major fraction of total biomass and has a very large ratio of production and respiration to biomass (Pomeroy, 2001). Carbon and mineral nutrient flows in the microbial loop are tightly connected and information on the nature of this coupling is thus essential for an understanding of the microbial loop (Azam et al., 1983).

"Microbial loop" has a dynamic behavior which is a result of several interacting ecological relationships: commensalism, competition and predation (Azam et al., 1983). Carbon dioxide or bicarbonate, inorganic nitrogen and phosphorus are converted by phytoplankton and photosynthetic and chemosynthetic bacterioplankton into the organic constituents of their cells. Heterotrophic and the smaller autotrophic bacteria are eaten by microflagellates which control the numbers of bacteria in the sea and microflagellates are consumed by larger protozoa. Ciliates constitute the main food for copepods and other mesozooplankton that are the food of larval fishes (Figure 1.1) (Pomeroy et al., 2007). A complex feedback system exists between these cells and their immediate surroundings (Armbrust et al., 1989).

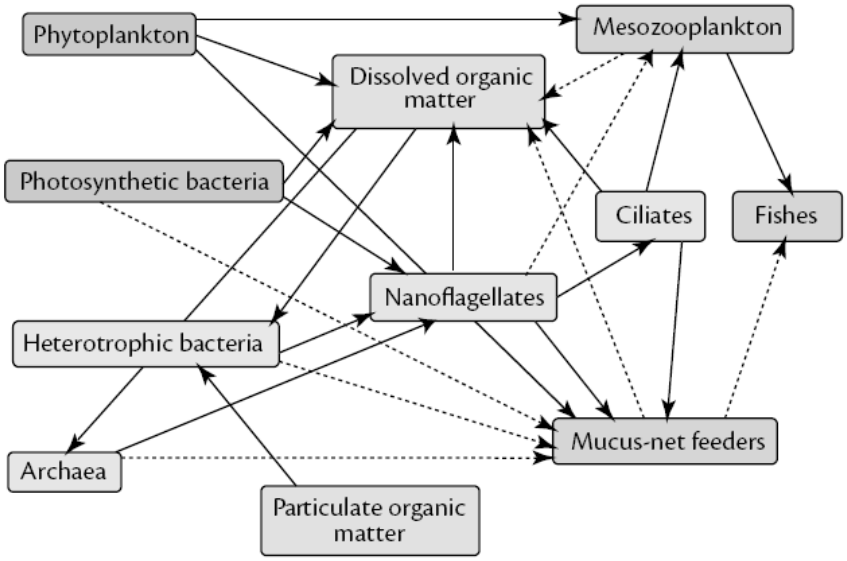

Figure 1.1. Simplified diagram of the oceans food web showing the dominant roles of the microbial loop. The major fluxes of carbon and energy are delineated by continuous lines; fluxes usually of lesser magnitude are delineated by broken lines (Pomeroy et al., 2007).

The microbial plankton consists of a wide range of prokaryotic and eukaryotic species. Sieburth et al., (1978) divides these microorganisms into the picoplankton (0.2-2.0 μm), nanoplankton (2-20 μm) and microplankton (20-200 μm). Based on this simple criteria, the microorganisms contained within these categories roughly correspond to the chroococcoid cyanobacteria, prochlorophytes and bacteria in the picoplankton, the flagellated protozoa and smaller microalgae in the nanoplankton, and the ciliated protozoa, larger dinoflagellates, diatoms and larvae of metazoa in the microplankton. For this reason, knowing the absolute and relative contributions of the various components of the microbial food web to total biomass is critical for understanding and modeling the biogeochemical cycling of carbon and other nutrients (Gin et al., 1999).

1.2. Microorganism groups studied in this work

In addition to picoplanktonic heterotrophic bacteria and cyanobacterium *Synechococcus* nanoplanktonic flagellates were also studied within the scope of this thesis study.

1.2.1. Heterotrophic bacteria

Heterotrophic bacteria are at the center-stage of nutrient cycling in the water column and in sediments of aquatic ecosystems (Azam, et al., 1983; Caron et al., 1988). They are found almost everywhere in the upper ocean (Li, 1998) and their standing stocks are remarkably similar throughout the world ocean in euphotic zones ranging 35-135 m deep, at least outside the polar seas (Ducklow, 1999). Microorganisms constitute the majority of living biomass especially in oligotrophic oceanic environments (Cho and Azam, 1990; Fuhrman et al., 1989; Gasol et al., 1997).

The size range of heterotrophic bacteria vary between 0.1 to 4 μm and they can be found in spherical (cocci) forms, rod forms and spiral shapes in the environment (Figure 1.2). They are important in marine food webs and biogeochemical cycles with large surface to volume ratios and shape the biology and chemistry of the oceans (Ducklow et al., 2001).

Heterotrophic bacteria are involved in a number of interrelated processes such as decomposition of complex molecules, respiration, mineralization, remineralization and uptake of dissolved organic compounds and their conversion to particulate matter as a result of their high growth rate and activity (Landry, 2001). They make contribution to the nutrient and carbon cycles in two major ways: by the production of new bacterial biomass (secondary production) and by the remineralization of organic carbon and nutrients (Giorgio and Cole, 98). The role of heterotrophic bacteria as remineralizers of inorganic nutrients has been challenged in the last two

decades, primarily as an outgrowth of an increased appreciation of the importance of microbes as competitors for essential nutrients (Azam et al., 1983).

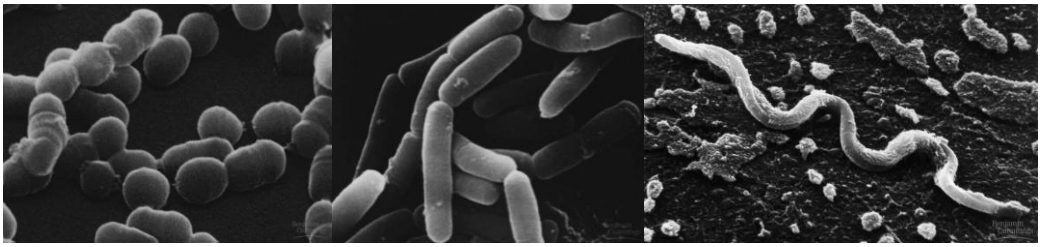

Figure 1.2. Morphologically different type of heterotrophic bacteria; Spherical "Cocci" bacteria, rod shaped "Bacillus", spiral shaped "spirella" (from Munn, 2004).

Growth and multiplication are the fundamental property of bacteria (Landry, 2001). There are several aspects of heterotrophic bacterial growth in aquatic systems that make them particularly adept at consuming organic and inorganic nutrients. In low productivity open ocean systems where bacteria constitute a relatively high proportion of biomass and activity, they are the major consumers of organic carbon and place constraints on inorganic nutrient availability (Biddanda and Benner, 1997; Cotner et al., 1997).

They are able to increase or decrease their activity over wider ranges of chemical and physical settings than any other group of organisms. High levels of primary production (Turley et al., 2000), quality of dissolved organic matter (Carlson and Ducklow, 1996; Cherrier et al., 1996; Kirchman, 1990), inorganic nutrients (Rivkin and Anderson, 1997; Thingstad et al., 1997), temperature (Kirchman and Rich, 1997; Shiah and Ducklow, 94), viral infection (Proctor and Fuhrman, 1990), micronutrients such as iron (Pakulski et al., 1996) and grazing on picoplankton (Calbet et al., 2001; Christaki et al., 2001; 2002) facilitate their growth and abundance (Wright and Coffin, 1984).

They are extremely important in the cycling of carbon between atmosphere and the ocean (Ducklow et al., 2000). Most portions of the photosynthetically formed carbon compounds including the particulate, detrital and dissolved organic carbon are utilized by heterotrophs as energy sources and remineralized to CO_2 via respiration (Azam et al., 1994). Dissolved organic carbon (DOC) generated from primary production by a variety of means is taken up by bacteria and used for their growth and metabolism (Azam et al., 1992). Heterotrophic bacteria are efficient in direct uptake of low-molecular weight (< ~500 Daltons) DOM with highly variable carbon assimilation efficiency of 10-70% (Azam et al., 1994). They also assimilate DIN as well as organic nitrogen compounds (Munn, 2004). The realization that natural assemblages of planktonic bacteria may acquire a significant fraction of their nitrogen and phosphorus via the uptake of dissolved inorganic nutrients has modified the traditional view of these microorganisms as nutrient remineralizers in plankton community (Caron, 94). Heterotrophic bacteria account for a large portion of total uptake of both phosphate (60% median) and ammonium (30% median) in freshwaters and marine environments (Kirchman, 94).

In addition to major nutrients such as carbon, oxygen, hydrogen, nitrogen, sulfur and phosphorus, most bacteria require small quantities of a range of trace elements, such as manganese, cobalt, zinc, molybdenum, copper and nickel. Some heterotrophs also require low concentrations of preformed growth factors or micronutrients, such as amino acids, pyrimidines, purines and vitamins, because they lack the biochemical pathways for the synthesis of key intermediates. Heterotrophs require preformed organic compounds and these include carbohydrates, amino acids, peptides and organic acids. Generally, macromolecules cannot be assimilated by prokaryotic cells, so many marine bacteria produce extracellular enzymes such as chitinases, amylases and proteases for their degradation into monomers of complex macromolecules. Chitinase is especially significant in marine bacteria; since chitin (a polymer of N-acetyl glucosamine, NAG) is such an abundant compound in the sea (Munn, 2004).

Bacteria are responsible for chemical conversions between the various oxidation states of nitrogen including ammonium, nitrogen gas, nitrite and nitrate. The given amount of organic nitrogen is repeatedly recycled through decomposer microbes and most of the nitrogen used by plants comes from mineralization of existing organic material. The ability of such heterotrophic prokaryotes to transform many highly toxic wastes to substances that are nontoxic, bioavailable and utilizable by other forms of life is very important in ecosystem stability. Many heterotrophic bacteria including actinomycetes can oxidize H_2S, the chemosynthetic bacteria are far more important (Munn, 2004).

Physiological processes such as individual cell-specific bacterial production and respiration are strongly affected by temperature (White et al., 1991, Pomeroy and Wiebe, 2001, Kirchman et al., 2005). Other environmental parameters such as UV radiation, H_2O_2, superoxide and hydroxyl radicals (called reactive oxygen species) and ferric ion concentrations are known to exert significant influence on bacterial growth.

Heterotrophic picoflagellates (0.2 to 2 μm) and nanoflagellates (2 to 20 μm) are currently thought to be the main consumers of bacterial production in aquatic ecosystems (Fenchel, 1988).

In conclusion, the roles heterotrophic bacteria play, are profound in the overall normal functioning, stability and continuance of the marine ecological processes. Assessing the global influence of these microbes requires, amongst other information, knowledge of their abundance at the largest possible spatial scale.

1.2.2. Cyanobacteria (*Synechococcus* spp.)

Cyanobacteria have an ancient marine history which can be traced back almost three billion years in the fossil record (Brock, 1973). They are a simple, but primitive and diverse group of microorganisms, with characteristics in common to both

bacteria and algae. They are one of the most ubiquitous and diverse groups of photosynthetic organisms, and the versatility of their light-harvesting systems, their unique physiological characters and high adaptive ability under a wide range of environmental conditions has contributed to their ability to success as a group in a wide range of habitats (Ting et al., 2002; Prasanna et al., 2010).

Simple and unicellular phycoerythrin-containing cyanobacteria with more or less rod-like cells are usually classified into *Synechococcus* genus which is known as the major component of primary production (Waterbury et al., 1979, 1986; Johnson and Sieburth, 1979) especially in the more oligotrophic regions such as the Mediterranean (Magazzu and Decembrini, 1995; Agawin and Agusti, 1997). They are commonly distributed, easily grown in cultures and many of strains have been isolated (Komárek, 2010). In natural water samples examined by epiflourescence microscopy, marine *Synechococcus* cells are predominantly coccoid in shape and range in size from 0.6 to 1.6 μm in diameter (Murphy and Haugen, 1990; Figure 1.3).

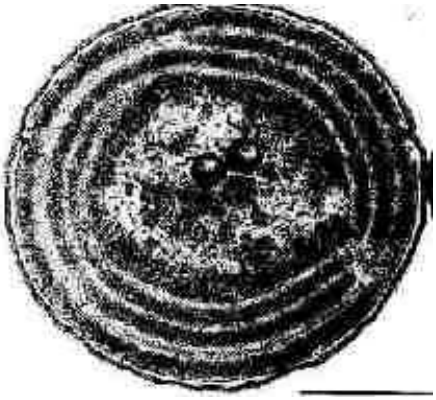

Figure 1.3. Transmission electron microscopy image of *Synechococcus* spp. (Johnson and Sieburth, 1979).

The strains in the marine *Synechococcus* cluster, like all other cyanobacteria, contain chlorophyll-a as their primary photosynthetic pigment and phycobiliproteins as accessory light harvesting pigments. All the open ocean isolates of *Synechococcus* are reddish-orange due to predominance of phycoerytrin (Waterbury et al., 1986).

Synechococcus has a much wider distribution ranging from waters in the (sub)tropics, temperate, and even polar regions and is often the dominant phytoplankter in both nutrient-deplete stratified, and nutrient-rich mixed waters (Waterbury, 1986; Partensky et al., 1999; Legendre et al., 1999; Vincent, 2000; Zubkov et al., 2000). The versatility of marine *Synechococcus* spp. has been related to its ability to grow over a wide range of light intensities and spectral quality and to utilize a wide variety of nitrogen (N) resources (Waterbury et al., 1986; Glibert et al., 1986). Different isolates of marine *Synechococcus* can utilize nitrate and ammonia as their sole nitrogen source for growth and approximately one half the strains tested can utilize urea as the sole nitrogen source (Waterbury, 1986; Moore et al., 2002). Under N deprivation, *Synechococcus* will degrade the abundant light-harvesting pigment protein phycoerythrin as an internal N source (Wyman,. 1992).

Synechococcus has specific mechanisms of photo-protection, it can rapidly change the expression of genes encoding photosystem II D1 proteins, avoiding photosynthetic inhibition (Llabres et al., 2010). Vertical distribution of these organisms is limited to the upper 100 m of the water column and primarily determined and controlled by the light and nutrients (Partensky et al., 1999).

Synechococcus is capable of contributing significantly to primary productivity in both coastal waters and the open ocean during certain periods of the year as a result of high in situ growth rates. They are being actively grazed at rates comparable to their growth rates that the cell division rate increased during the light period, reach a maximum at the end, and decline during the dark (Campbell and Carpenter, 1986).

The annual cycle of *Synechococcus* was found repeatable from year to year and closely correlated with the annual cycle of water temperature. There is a strong correlation between *Synechococcus* and water temperature. *Synechococcus* has also been shown to have a dramatic diel cycle of cell abundance characterized by a repeatable pattern of discontinues growth. Optimal growth temperature was found

as 28^0C, the light saturated maximum growth rate was 1.0 ± 0.1 d^{-1} for *Synechococcus* (Moore et al., 1995).

This group can dominate ≥ 50% of the biomass and production in oligotrophic (chlorophyll-a < 0.3 mg m^{-3}), nutrient poor (NO_3 + NO_2 < 1 μM), and warm (>26 ^{0}C) waters, but represent < 10% of autotrophic biomass and production in rich (Chlorophyll-a > 5 mg m^{-3}) and cold (<3 ^{0}C) waters (Agawin et al., 2000).

The natural abundance of *Synechococcus* results from a complex interaction of a number of physical and biological factors. Properties such as light quantity and quality, water temperature, mixing and nutrient availability are the factors affecting the growth whereas grazing is primarily responsible for the removal of individuals from the population. Grazing, viral lysis, and sedimentation constitute the three known removal processes for photosynthetic picoplankton (Christaki et al., 2002). *Synechococcus* distribution throughout the water column is generally controlled by three main factors, namely temperature, nitrate availability and light conditions (Lantoine and Neveux, 1997).

1.2.3. Flagellates

Photosynthetic and heterotrophic flagellates with their important roles in the trophodynamics of the food web (Burney et al., 1981; Davis and Sieburth, 1984) are known as the major numerical and biomass components of marine plankton (Beers et al., 1982). In contrast to the bacterial assemblage, nano-sized flagellates displayed considerable variability in abundance (Calpet et al., 2001). Flagellates are found in all marine biotopes from the oligotrophic open oceans to eutrophic inshore waters (Throndsen, 1997). They typically occur at densities of around 10^3 cells/ml in surface (0-30m) waters (Fenchel, 1988).

Movement of these species within a water column depends upon the presence of a flagellum. Motility may have a great impact on the ability of a cell to react to environmental conditions as well as enhancing their nutrient uptake (Throndsen, 1997).

Most of the flagellates encountered in the plankton from open waters belong to the nanoplankton (2-20 μm) (Throndsen, 1997). The majority of flagellates are often less than 5 μm in size (Beers et al., 1982; Sorokin, 1979), which presents difficulties to investigators attempting to determine taxonomic and trophic characteristics (Davis and Sieburth, 84; Figure 1.4).

Cryptophyceae, Dinophyceae, Prymnesiophyceae (=Haptophyceae) and Prasinophyceae are the four phytoplankton classes in which the flagellate stage either is dominant or plays an important part in the life cycle of the phytoflagellates. Zooflagellates are included in the class Zoomastigopherea and Choanoflagellidea, Kinetoplastida and Ebriida are the three classes in which flagellates are frequently found (Throndsen, 1997).

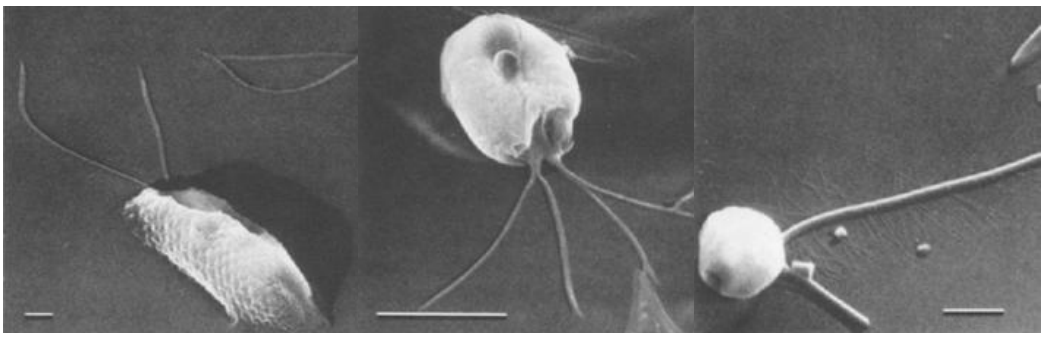

Figure 1.4. Scanning electron microscopy images of some marine flagellates (Scale bars represent 1.0 μm) (From Davis and Sieburth, 1984).

Basically three trophic types are common in this diverse group. They can be phototrophic (phytoflagellates) which rely solely on photosynthesis for their survival, heterotrophic (zooflagellates) which depend on the uptake of organic

material from the sea and mixotrophic (a combination of phototrophic and phagotrophic nutrition) (Throndsen, 1997). For flagellates capable of photosynthesis, mixotrophy has been considered as a strategy to either acquire carbon under low light conditions or to acquire nutrients in short supply (Nygaard and Tobiesen, 1993). Average concentrations of mixotrophs, heterotrophs and autotrophs were found as 0.09, 1.14, and 0.66 × 10^3 cells ml^{-1}, respectively, in the southern Mediterranean Basin and 0.09, 1.1, and 0.98 × 10^3 cells ml^{-1}, respectively, in the northern basin (Christaki et al., 1999). The presence or absence of chloroplast is the most obvious criterion for distinguishing between phototrophic and heterotrophic flagellates (Throndsen, 1997).

Heterotrophic flagellates are significant members of the microbial communities which are important and possibly dominating elements of the biota of natural aquatic ecosystems (Azam et al., 1983; Sherr and Sherr, 1988). They function as major grazers of bacteria and prey for metazoa, and catalyze the recycling and remineralization of nutrients (Jurgens and Gude, 1990; Kirchman, 1994; Sherr and Sherr 1988). In contrast, a substantial deficiency in the relative abundances of heterotrophic flagellates and bacteria would imply predator control of bacterivorous flagellates, and therefore substrate regulation of bacterial abundance (Gasol, 1994). The direct consumption of primary production by heterotrophic flagellates was calculated to be 13 % (Kuosa and Kivi, 1989).

1.3. The study area

The name Mediterranean is derived from the Latin mediterraneus, meaning "inland" or "in the middle of the earth" (from medius, "middle" and terra, "earth"). The Mediterranean occupies a huge depression which reaches a depth of 5.093 meters at its deepest point and measures almost 4.000 kilometers from east to west, covering a surface area of around 3 million square kilometers. The roots of the genesis and evolution of this environment, a natural laboratory which has drastically changed appearance more than once, even in the last 10-20 million years, lie in the

beginnings of the big oceans and have a central position in the history of the world (Mojetto, 1996).

The Mediterranean has a narrow connection to the Atlantic Ocean through the Strait of Gibraltar. Also, in the south-east, The Mediterranean connects with the Red Sea via man made Suez Canal. The Mediterranean consists of two main parts; Eastern Mediterranean and Western Mediterranean which communicate through the relatively shallow Strait of Sicily (Figure 1.5).

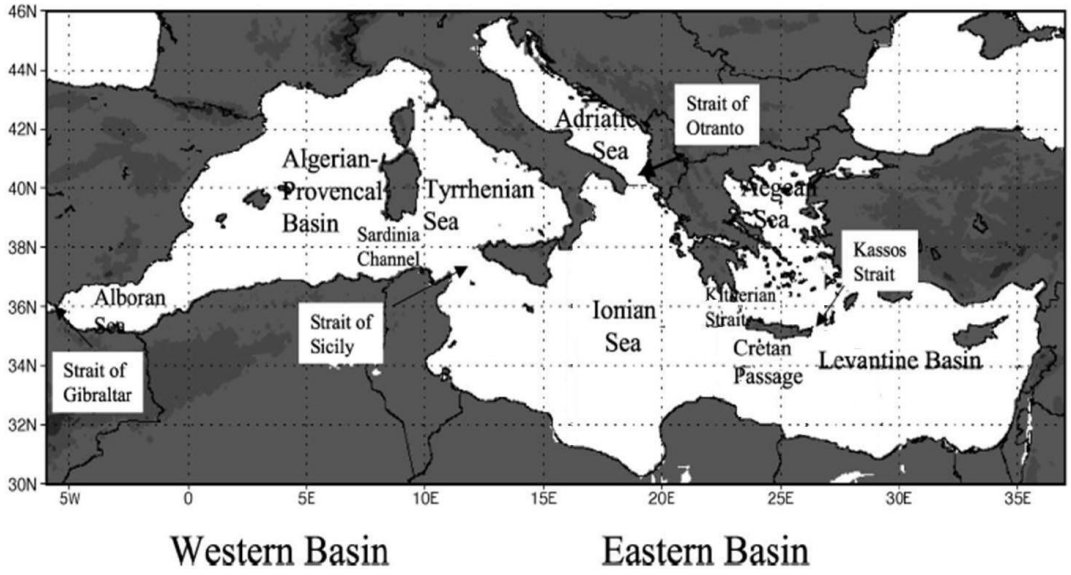

Figure 1.5. The configuration of Mediterranean Basin (Demirov and Pinardi, 2002).

The Mediterranean Sea is an oligotrophic ecosystem (Azov, 1991) due to the lack of the regions of significant upwelling and limited nutrient input to its surface waters from internal and external sources. It has high evaporation rates and low land run-off, resulting in a deficit in its hydrological balance. Nutrient-depleted Atlantic water flows into the Mediterranean through the narrow (ca 4 km^2) Strait of Gibraltar (Bethoux et al., 1992) which is entering with a surface current that is less salty and less dense, whereas another deeper current flows from the Mediterranean to the Atlantic and, after circulating the basin, exits the same way with nearly 10 % more salt content (Özsoy et al., 1989; Milliman et al., 1992). There is an increasing nutrient

depletion from west to east, with a particularly pronounced gradient for phosphorus (Krom et al., 1991).

One of the most important water masses found in the Eastern Mediterranean is the Levantine Intermediate Water, which affects not only the entire Mediterranean, but the Atlantic Ocean as well. The second important water mass in the Eastern Mediterranean is the Atlantic water which enters through the Gibraltar Strait to balance the mass deficit of the Mediterranean. Both in the summer and the winter, a number of quasi-permanent sub-basin scale gyres seem to be of central importance in controlling the general circulation and its evolution in time (Özsoy et al., 1989; Özsoy et al., 1993; Figure 1.6).

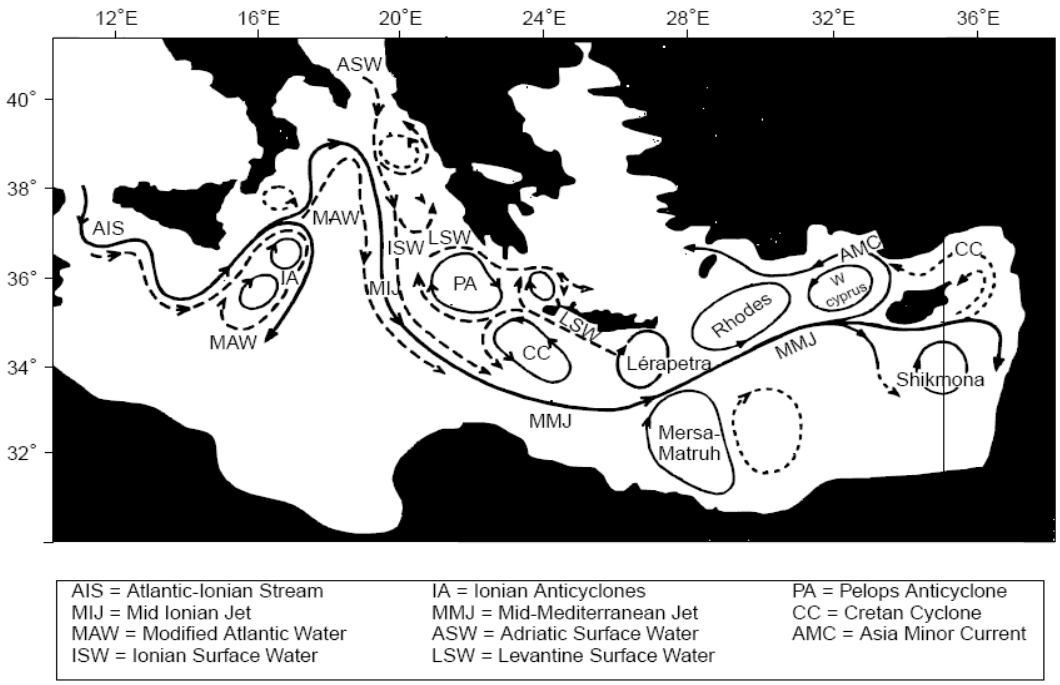

Figure 1.6. Sub-basin scale and mesoscale circulation features in the eastern Mediterranean (Robinson et al., 2001).

Both nitrogen and phosphorous can be limiting nutrients for phytoplankton and bacterial growth in the Mediterranean during summer (Dugdale and Wilkerson, 1988, Bethoux et al., 1992, Krom et al., 1991). Longitude is a surrogate for a number of primary east–west physical, chemical and biological gradients that interact and

may affect species diversity within the Mediterranean Sea environment (Bethoux et al., 1992; 2002). In the northeastern Mediterranean the range of depth of 1% light of the thickness of the euphotic zone was determined as 50-120 m for offshore waters the average being 106 m (Ediger and Yılmaz, 1996).

Both the phosphate-depleted river inflow and spring rains with P-rich Saharan dust highly influence the hydrological and biochemical properties of the shallow zone of the NE Mediterranean shelf. Therefore, the nutrient and particulate contents of the shallow zone drastically exceed the offshore values, especially during the rainy winter-spring period. Through the outer shelf water is always poor in nutrients and biogenic particles, the chemical composition (C/N) ratio of bulk POM displays small local differences on the shelf (Doğan-Sağlamtimur and Tuğrul, 2004). However, it possesses more or less localized eutrophic regions associated with a variety of fertilization mechanisms.

Climatically, the Mediterranean region is generally characterized by warm winters (November-February) dominated by rainfall and dry summers (June-September). The transitional seasons, spring and autumn are of very different lengths. Autumn usually lasts one month (October) and is characterized by an abrupt change from the summer to the unsettled weather of winter. Meteorology of the region displays extreme variability. Westerlies, Etesians and coastal sea-breeze cells are the common wind systems in summer and autumn, while frequent extratropical cyclones and local wind regimes such as Poyraz and Sirocco winds characterize the winter and spring (Özsoy et al., 1993).

Cilician Basin occupies the northeastern part of the eastern Mediterranean Levantine Basin between Cyprus and Turkey (Figure 1.7). Environmental pressure on downstream estuarine and coastal ecosystems has been greatly increased by human development in coastal watersheds (Niemi et al., 2004). This basin has been also significantly altered by natural and anthropogenic changes as a result of increases in population, industrial, agricultural and tourism activities within the last

2-3 decades and also considered one of the most productive regions of the eastern Mediterranean (Uysal et al., 2008).

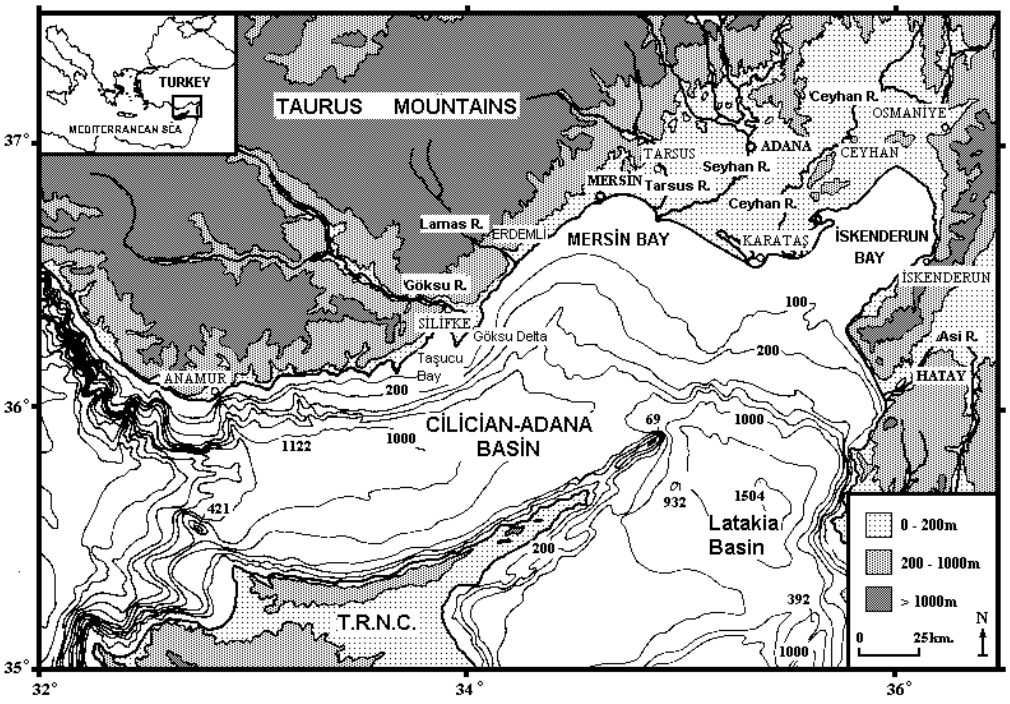

Figure 1.7. Cilician Basin map showing rivers, major towns, land and sea bottom topography (Uysal et al., 2008).

This study was performed in Mersin Bay which covers an area of nearly 1150 km^2 of the continental shelf of the Cilician Basin. The currents in the inner part of the bay are essentially governed by the prevailing winds. The dominant wind direction during the year is northeast and southwest. The water column stratification of the Mersin bay due to its proximity to the coast and shallow depths is effected by local inputs of fresh water, and the intensity of vertical mixing caused by winds and surface cooling. The water column is well mixed during October through April. A sharp seasonal thermal stratification begins in May, becomes well established during August and continues till the end of October (Uysal et al., 2008; Uysal and Köksalan, 2010).

Mersin Bay is a hot spot and sensitive area of the northeastern Mediterranean shelf waters due to the large nutrient and organic matter inputs by untreated anthropogenic and river discharges (at about 10^6-10^7 m^3/year) and limited ventilation of the bay waters with open sea. The transport of nutrients with domestic effluents which are rich in phosphorus, ammonia and organic matter and river inputs into the phosphorus-deficient surface waters of the Mersin Bay causes eutrophication in the region (Tuğrul et al., 2009; Yılmaz et al., 1998).

1.4. The aim and significance of the study

Microorganisms are highly sensitive and profoundly affected by environmental disturbance and they provide sensitive, meaningful and quantifiable indications of ecological changes (Paerl et al., 2006). Marine microbes experience seasonally changing growth conditions that eventually lead to differences in the structuring of community composition over seasonal scales. Changes in environmental factors such as inorganic nutrient availability are of decisive importance for defining ocean primary productivity and for regulating phytoplankton community composition and succession (Smayda and Reynolds, 2001; 2003).

Before this study, Köksalan (2000) studied temporal variability in *Synechococcus* abundances in 1998, Uysal and Uysal et al., (2004, 2006) studied the vertical distributions of the unicellular cyanobacteria *Synechococcus* and heterotrophic bacteria in the NE Mediterranean shelf waters during October 2000 and September 2004 and Bayındırlı (2008) investigated heterotrophic bacteria and *Synechococcus* abundance and biomass distributions between 2005 and 2006. Polat and Uysal (2009) also investigated *Synechococcus* abundance distribution in İskenderun Bay. In all these researches only 2 or 3 stations (shore, median and offshore stations) were sampled. Uysal et al., (2008) and Gazihan-Akoğlu et al., (2010) investigated *Synechococcus* and heterotrophic bacterial abundance and biomass distribution in whole Cilician Basin with 13 stations in the Mersin Bay between 2005 and 2008.

With this study, it is aimed to assess the impacts of physicochemical and biological factors on the surface spatial and vertical distribution patterns of heterotrophic bacteria, *Synechococcus* and flagellates to clarify which conditions promote or decelerate their abundances and biomasses in Mersin Bay ecosystem with a frequent sampling with 50 stations covering the domestic effluent and fresh water input points with open reference offshore stations and compare seasonal and inter-annual abundance and biomass levels of heterotrophic bacteria, *Synechococcus* and flagellates with seasonally changing ambient physical, chemical and biological properties of the bay.

2. MATERIAL AND METHODS

2.1. Sampling

This study was performed in highly eutrophic inner Mersin bay located in the northeastern Mediterranean, which receives substantial amount of freshwater from local rivers as well as urban discharges from the nearby city of Mersin. For this, 8 seasonal cruises were conducted in September 2008, February, April, August, and October 2009, February, April and July 2010 aboard the R/V *Bilim 2* of IMS-METU. A total of 50 stations have been visited during each major cruise carried out in the bay (Figure 2.1). Among these, 18 stations are selected as biology stations for full profiles where standard depths of 0, 10, 20, 30, 50, 75, 100, 125, 150 and 200 m are sampled depending on the total depth of the station. Only surface samplings were performed in the remaining 32 stations. Each cruise took 4 days to cover.

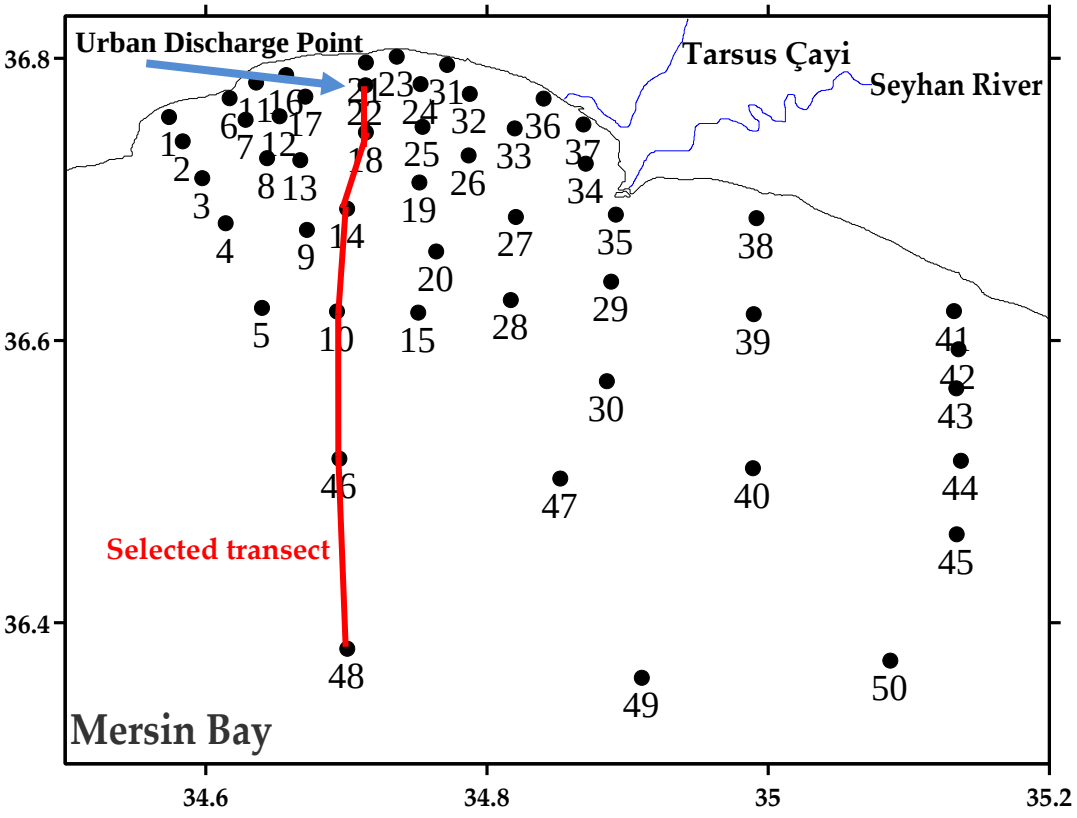

Figure 2.1. Map of the stations.

Surface spatial data are presented as sea surface plots. A transect which consisted of 6 stations from shore to offshore (Station 22 with total 8 m depth, Station 18 with total 18 m depth, Station 14 with total 40 m depth, Station 10 with total 70 m depth, Station 46 with total 125 m depth and Station 48 with total 200 m depth) was created to display cross-shelf changes in the ambient physical, chemical and biological parameters. Additionally, abundance data are evaluated among various depth layers (0-20 m, 20-50 m, 50-100 m and 100-200 m) to express possible changes in the nearshore – offshore extent.

A CTD attached rosette sampler was used in sampling. Direct measurements (pressure, depth, temperature, potential temperature, salinity, sigma-t, sigma-theta, oxygen, oxygen saturation value, PAR/Irradiance, fluorescence, OBS) with high sensitivity were performed via CTD at all 50 stations in the water column, from surface to near bottom. The data recorded during the casts were later processed by the computers in the Institute laboratories. The rosette sampler which has 12 pieces of 5 liters PVC typed Niskin Closing bottles were used to capture seawater from the desired depths for chemical and biological analyses. Secchi disc depths were also measured during day time.

The data will be described below three main headings. These were measurement of biological and chemical data and statistical analysis.

2.2. Measurements of biological parameters

Heterotrophic bacteria, *Synechococcus* and flagellates were counted under epiflourescence microscope, cell volumes and carbon contents were also calculated.

2.2.1. Epiflourescence light microscopy (ELM)

In ecological studies on the natural distribution of bacteria for aquatic environments, epifluorescence counting is known as the method of choice permitting the ready discrimination of bacteria from detritus and not relying on the

adequacy of culture methods to elicit growth of all viable organisms (Francisco et al., 1973).

Fluorescence occurs when a material absorbs light at one wavelength (excitation or absorption spectrum) and then re-emits it at a different wavelength (emission spectrum). The specimen is illuminated with a tungsten-halogen or mercury vapor lamp. In direct fluorescence microscopy, a filter is placed between the light source and the specimen, allowing only light of the desired excitation wavelength to be transmitted, whilst a barrier filter placed between the specimen and the eyepiece transmits the emitted fluorescence and absorbs longer wavelengths. ELM depends on the use of dichroic mirrors as interference filters that transmit one set of wavelengths and reflect the others. ELM can therefore be used for observation and enumeration of all groups of marine microbes including microalgae, ciliates, flagellates, bacteria and viruses. The original ELM stain used in plankton studies is acridine orange (AO, 3, 6- bis [dimethylamino] acridinium chloride), which binds to DNA and RNA (Munn, 2004).

2.2.2. Direct cell counts

Hobbie et al., (1977) describes the basic criteria for a successful direct-counting technique as all the bacteria must be retained by the filter, all the bacteria must be visible at the filter surface, and the staining and optical conditions must produce high contrast between the bacteria and the background. Polycarbonate Nuclepore filters are also mentioned as a good choice for the direct counting of bacteria having a uniform pore size and a flat surface that retains all of the bacteria on top of the filter (Hobbie et al., 1977).

To perform direct counts, 40 ml of seawater samples from Niskin Closing Bottles were drawn into 50 ml dark coloured glass bottles. 1 ml of 25% glutaraldehyde, pre-filtered through 0.2 μm pore sized filter, was added to obtain a final preservative concentration of 0.6% and the bottles were closed tightly. To obtain maximum

homogenous distribution of cells on the filter during filtration, 1.2 μm pore sized backing filters (Whatman® ME 28 Membrane Filters type RA 1.2 μm) were placed under 0.2 μm pore sized nuclepore filters. Depending on the concentration of the organisms in the sample, 5, 10, 15 or 20 ml aliquots from each sample were filtered onto 0.2 μm pore sized nuclepore black membrane filters (MILLIPORE, ISOPORE™, 0.2 μm GTBP) at a vacuum pressure of 125 mm-Hg. 200 μl of acridine orange solution {prepared by mixing 18 mg acridine orange (SIGMA® Acridine Orange A-6014) with 40 ml distilled water which is further filtered through 0.2 μm Acrodisc filter and syringe (MILLIPORE, Millex®-GV) before use} was added to the last 5 ml of the volume to be filtered for staining bacterial DNA as mentioned above (Hobbie, et al., 1977).

The filters were removed and placed between a glass slide and cover slip covering the both sides with a thin film of immersion oil (Resolve® Microscope Immersion Oil, Low Viscosity). Direct cell counts were done using a Nikon EFD3 Epiflourescence Microscope with a filter combination of B-2A (blue excitation-DM 505, EX 450–490, BA 520) and G-1A (green excitation-DM 575, EX 546/10, BA 580) and 100X oil objective (Uysal, 2001).

Enumeration of heterotrophic bacteria, cyanobacteria (*Synechococcus* spp.) and small flagellates were performed on the same slide. Each organism group was counted in 30 randomly chosen microscope fields in each slide.

Bright green appearance of heterotrophic bacteria under blue excitation with relatively smaller size helped distinguish heterotrophic bacteria from other organisms. *Synechococcus* appeared yellowish orange under blue excitation and bright green under green excitation (Caron, 1983). Flagellates attached to an organism were used in identifying small flagellates.

2.2.3. Cell volume & carbon content calculations

The average number of cells per field was converted to organisms per milliliter by knowing the sample volume, the area of the microscope field, and the area of the filter covered by sample, using equation:

Cells per ml = $(X_{ave})(A_{filter}/A_{field})(1/Vol._{fil})(Vol_{sam}+Volume_{glut}/Vol_{sam})$

where

X_{ave} = Average cell number per microscope field

A_{filter} = Area of filter stained with AO after filtration

A_{field} = Area of a single microscope field

Vol_{fil} = Volume filtered

Vol_{sam} = volume sample (40 ml)

$Volume_{glut}$ = Volume glutaraldehyde added (1 ml)

Microscope images are reflected and saved on computer screen using a digital camera (Nikon Digital Camera –DXM 1200F) and the software program (ACT-1 ver. 2.51, Nikon). Depending on the concentration of organisms on filters, adequate number of pictures was taken from each slide for further processing. Image-Pro Plus 5.0, a commercial software program, was used to measure size of cells (Figure 2.2). The *Area*, *Axis major*, *Perimeter* and *Size* (length, feret diameter) of each cell were measured.

2.2.4. Carbon conversion

Using the known morphometric parameters given above volume was determined using a volume formula for an ellipsoid (Sieracki, 1989). For carbon content of heterotrophic bacteria 77 fg C per cubic micron (Carlson et al., 1999) is used. For carbon content of *Synechococcus* 123 fg C per cubic micron (Waterbury et al., 1986) and lastly for carbon content of flagellates 220 fg C per cubic micron was used (Børsheim and Bratbak, 1987).

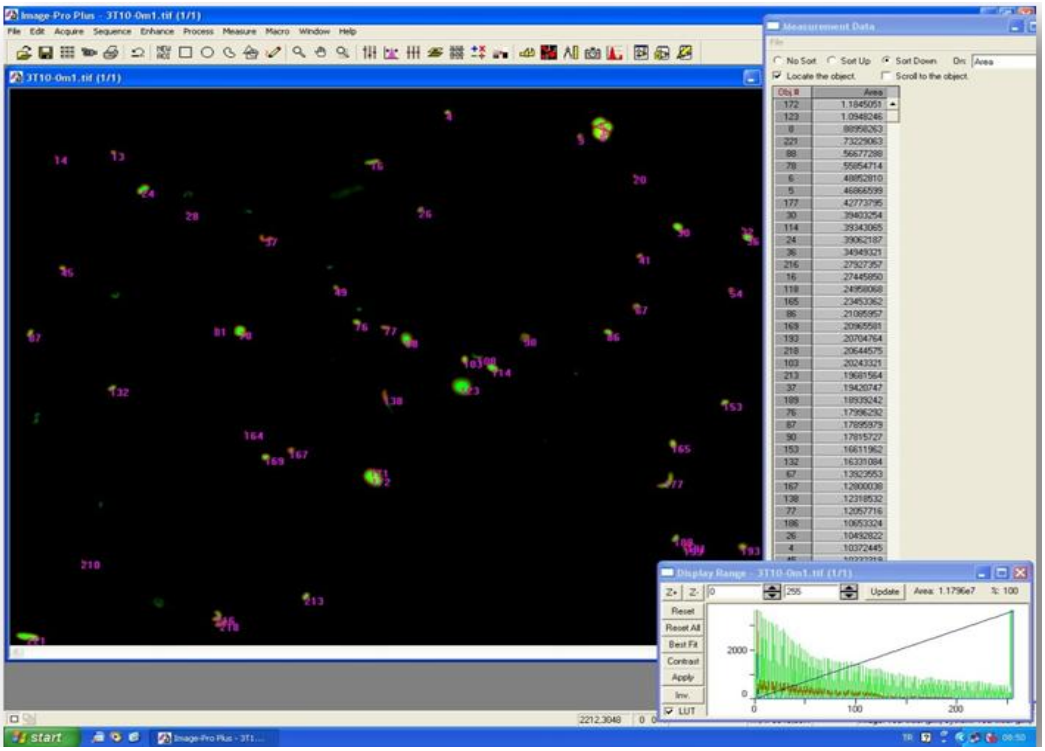

Figure 2.2. Image-Pro Plus 5.0, the commercial software program for image analysis.

2.3. Measurements of chemical parameters

Chemical data were analyzed in the Department of Chemical Oceanography, IMS-METU in the scope of TARAL-SİNHA Project.

Dissolved oxygen (DO)

For DO measurements, prior to any sampling, seawater from Niskin closing bottles were drained into 100 ml glass bottles by means of plastic tubes preventing weatherproof and overfilled for 2 volumes. Manganese(II)chloride ($MnCl_2$) and an alkaline potasium iodide solution (KOH/KI) were added to the samples immediately. Dissolved oxygen measurements were done according to Winkler titration method by using international trade mark Methrohm (Hydro-Bios) 645 Multi-Dosimat Oxygen Auto-Titrator Analyzer and the sensitivity of this method is about ±0.05 ppm.

Nutrient salts

For the analysis of reactive silicate, nitrate, nitrite, ammonia and orto-phosphate, seawater samples were taken into high density polyethylene bottles (HDPE) pre-cleaned with 10% HCl. Bottles for nitrate and phosphate analysis were kept frozen (-20°C), whereas those for silicate were kept cool (+4°C) in the dark until analysis. The nutrient measurements were carried out by using a Technicon model two-channel auto-analyzer; the methods followed were very similar to those described in Strickland and Parsons (1972) and Grasshoff et al., (1983). The detection limits of Autoanalyzer were 0.02, 0.10, 0.02 and 0.04 μM for phosphate, reactive silicate, nitrate and ammonium, respectively.

Chlorophyll-a

Depending upon the concentration of plankton and substrates, an appropriate amount of seawater were taken into dark coloured plastic bottles and filtered over GF/F typed Whatman filters (0,7μm pore size and 47mm diameter) in dim light with low vacuum. The filters were kept in the deep-freezer until the analyses. The chlorophyll-a particles on the filters were extracted with 5ml 90% acetone, The samples are kept in the dark overnight (about 12 hours) at +4 °C (in the refrigerator). Samples were then centrifuged at 3500 rpm for 10 minutes to remove cellular debris. Fluorometric analysis was done by using Hitachi F–3000 type fluorescence spectrophotometer and read in 665 and 440 nm and calculated according to chlorophyll-a standard (Grasshoff et al., 1983) (Sensivity: 0.01 μg/l).

2.4. Statistical analysis

The relationships between heterotrophic bacteria, *Synechococcus* and flagellates and ambient physical, chemical and biological parameters were analyzed to determine their significance for further ecological analyses. Spearman's rank correlation statistics were applied after checking if the data were normally distributed.

3. RESULTS AND DISCUSSIONS

3.1. Spatial and vertical distributions

Coastal regions are highly dynamic and productive areas that have historically attracted human populations. Microorganisms are the most sensitive compartment of the marine food web and respond environmental changes very quickly. In the following, dynamics of heterotrophic bacteria, cyanobacterium *Synechococcus* spp., and various small flagellates in a rapidly changing coastal environment with respect to physical (temperature and salinity) and chemical (PO^{-3}_4-P, NO^{-}_3-N+NO^{-}_2-N, NH_4, Si, chlorophyll-a and DO) parameters will be discussed.

3.1.1. Sea surface distributions in September 2008

Surface spatial distributions of all parameters being studied are shown in the Figure 3.1. The raw data used in both surface and vertical distributions are given in Appendix A. Surface temperature varied in the range 28.97^{0}C - 30.65^{0}C and salinity in the range 38.76 - 39.84 in the area during September 2008. A gradual decrease in surface temperature and an increase in surface salinity from nearshore towards offshore were observed. Lower salinity values (approx. 1.5 psu less than offshore) observed in the inner bay were due to freshwater discharges from the nearby rivers and domestic effluents. River effect was limited in September due to the reduced river flow rates observed during fall in the area.

The main sources of inorganic nutrient input to Mersin Bay are the rivers (Seyhan River and Tarsus Çayı) which are rich in nitrate and silicate; rainfall input rich in nitrate and dissolved ammonia, atmospheric dusts and domestic effluents (Tuğrul et al., 2009). Parallel to this information, the highest concentrations of PO_4 and Si were met at shore stations with peak levels of 0.26 and 6.24 μg/l, respectively, whereas the highest NO_3+NO_2 and NH_4 concentrations were 0.95 μg/l and 2.38 μg/l in the area where freshwater input was most pronounced (Figure 3.1).

The high nutrient concentration in the inner part of the bay stimulated primary productivity and hence increased photosynthetic yield. As a result, the highest chlorophyll-a concentration was 4.19 μg/l and phytoplankton abundances varied in the range $1.8x10^4$ - $4.8x10^6$ cells/l. Dissolved oxygen in the sea water increased in parallel to increasing photosynthetic activity. Parallel to high chlorophyll-a concentration, the highest dissolved oxygen concentration 7.78 mg/l was observed in the inner bay.

Both the abundance and biomass values in all three groups made peaks ($1.3x10^7$ cells/ml and 80.42 μgC/l for heterotrophic bacteria; $1.2x10^6$ cells/ml and 129.69 μgC/l for *Synechococcus* and $1.2x10^4$ cells/ml, 11.15 μgC/l for flagellates) at stations nearby the Tarsus Çayı discharge area. Similar distribution patterns were observed for heterotrophic bacteria, *Synechococcus* and flagellates at surface. In the inner bay, very low nutrient concentrations coupled with marked increases in heterotrophic bacteria, *Synechococcus*, flagellates, phytoplankton and hence chlorophyll-a contents due to rapid utilization of such nutrients by the primary producers.

Highly significant positive correlations were observed between temperature and heterotrophic bacteria, *Synechococcus* and flagellate abundance and inversely a highly significant negative correlation with salinity and heterotrophic bacteria, *Synechococcus* and flagellate abundance. Similarly, significant correlations also existed within the biological groups studied and within physical and chemical properties measured at surface. Detailed results of rank correlations are provided in Appendix B, page 144.

3.1.2. Vertical distributions in September 2008

Vertical distributions of all parameters being studied are shown in Figure 3.2 for the given transect. The coastal region that is shallower than 40 m displayed a uniform water column temperature. Lower salinity values observed in the shallower part

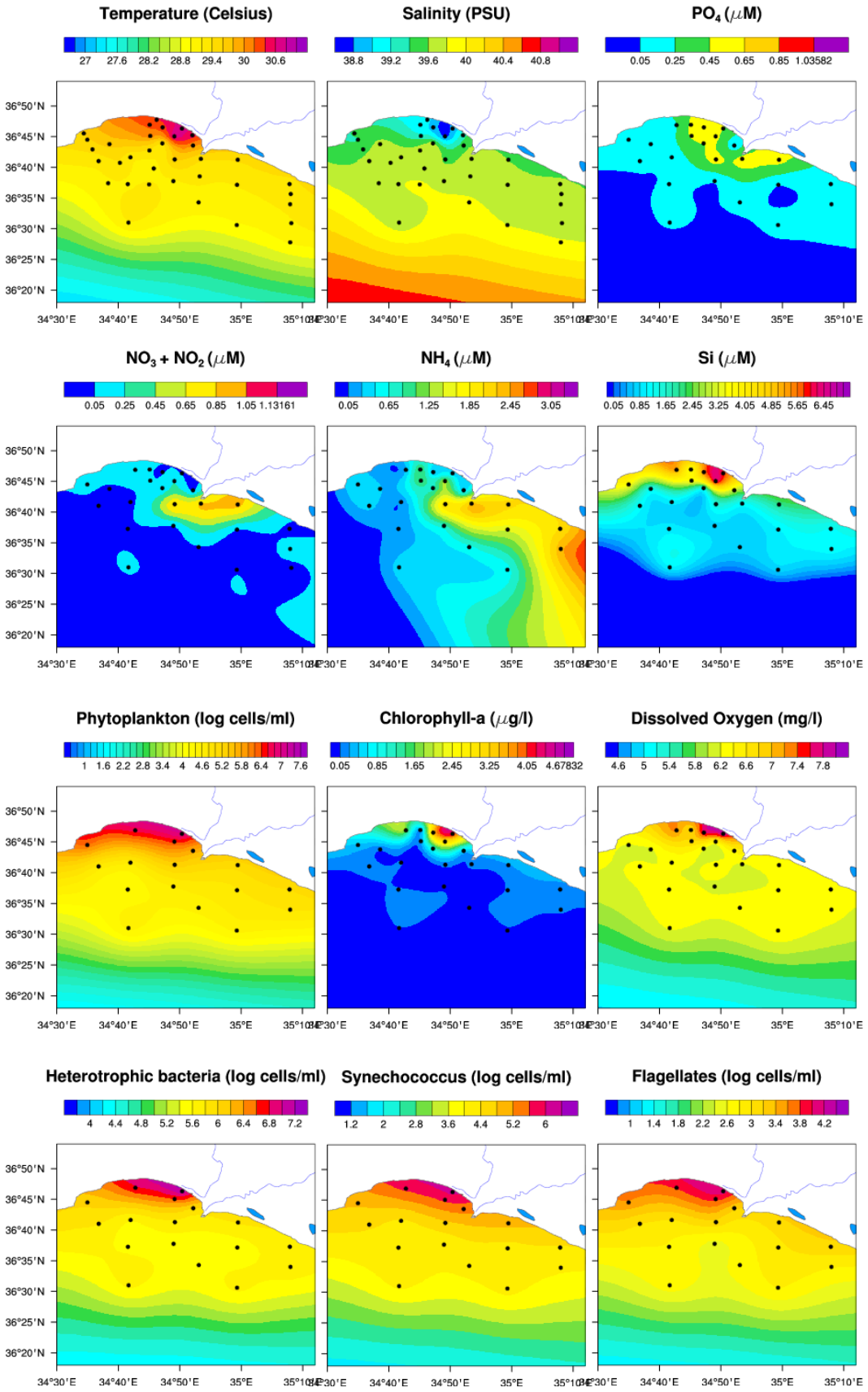

Figure 3.1. Surface distributions of physical, biological and chemical parameters in September 2008.

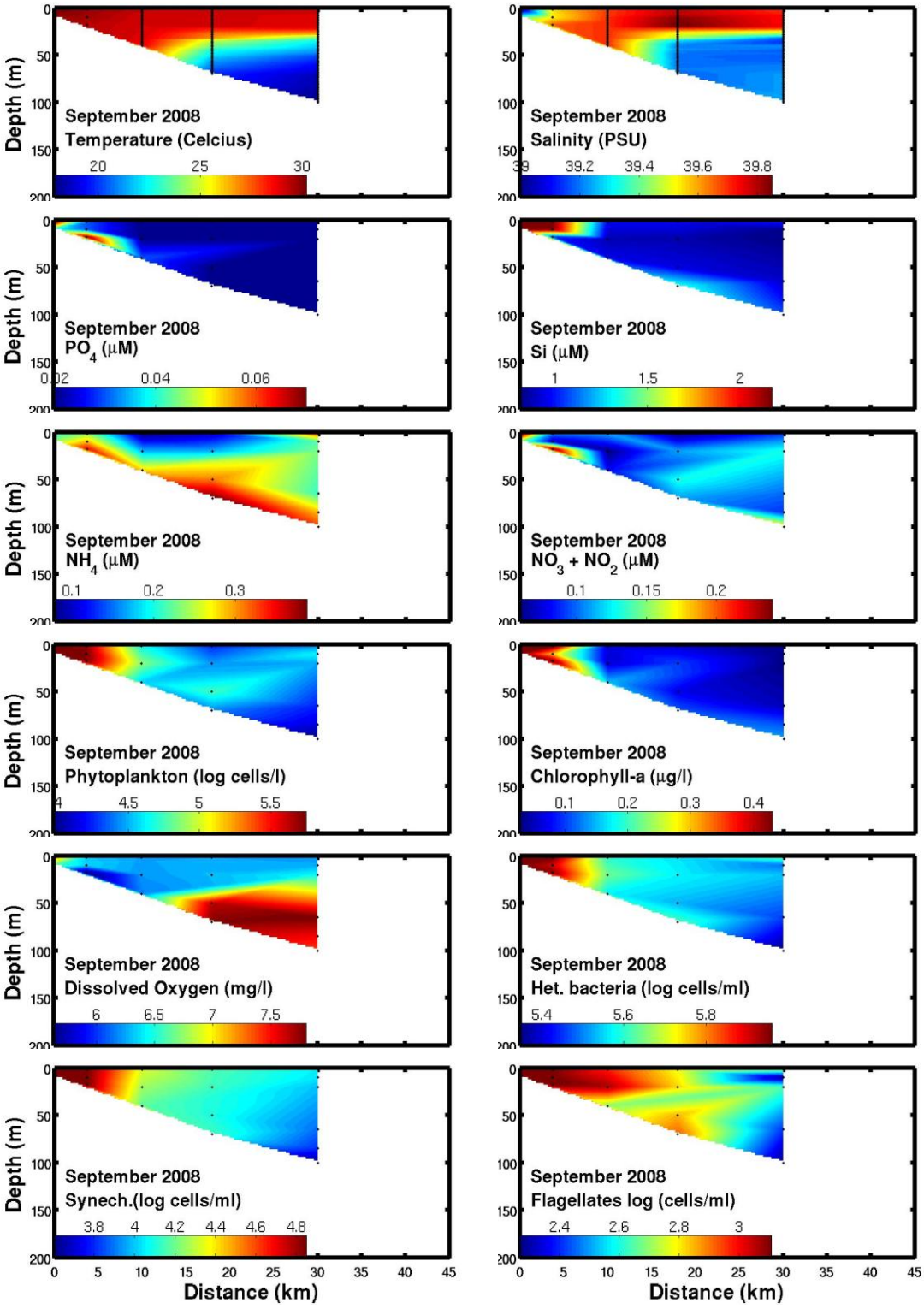

Figure 3.2. Vertical distributions of physical, biological and chemical parameters in September 2008.

were due to the direct injection of freshwater from the nearby rivers. The thermocline was approximately 10 m thick; temperature changed by approximately 8 ^{0}C and halocline appeared at the same depth with 0.5 psu salinity gradient. Changes in salinity below halocline were insignificant and observed stratification in the water column was mainly temperature controlled due to the intense evaporation occurring at surface during this period. The vertical thermal structure showed that the surface mixed layer was warm (29 - 30 ^{0}C) and thin (0-20 m) in September 2008.

Deeper water contained higher NH_4 compared to upper parts and majority remained trapped below the halocline. In the nutrient rich region, both the primary production and photosynthetic yield were high. Dissolved oxygen always increased with increasing depth in all the stations and higher dissolved oxygen concentrations were found below the depth of 40 m, below the thermocline and halocline, since the solubility of oxygen decreases with increasing temperature. The abundance and biomass contents of heterotrophic bacteria, *Synechococcus* and flagellates differed greatly in the near shore and offshore waters.

Changes in abundance of heterotrophic bacteria, *Synechococcus* and flagellates within different depth strata are shown in Figure 3.3. Heterotrophic bacteria, *Synechococcus* and flagellates were most abundant in the 0-20 m depth stratum followed by others in an order, with increasing depth. Based on Spearman rank correlation analysis, highly significant positive correlations between heterotrophic bacteria, *Synechococcus* and flagellate abundances and ambient temperature were observed. Similar correlations were observed among the biological groups including chlorophyll-a and also between the organism groups and nutrient concentrations. Detailed results of rank correlations are provided in Appendix B, page 144.

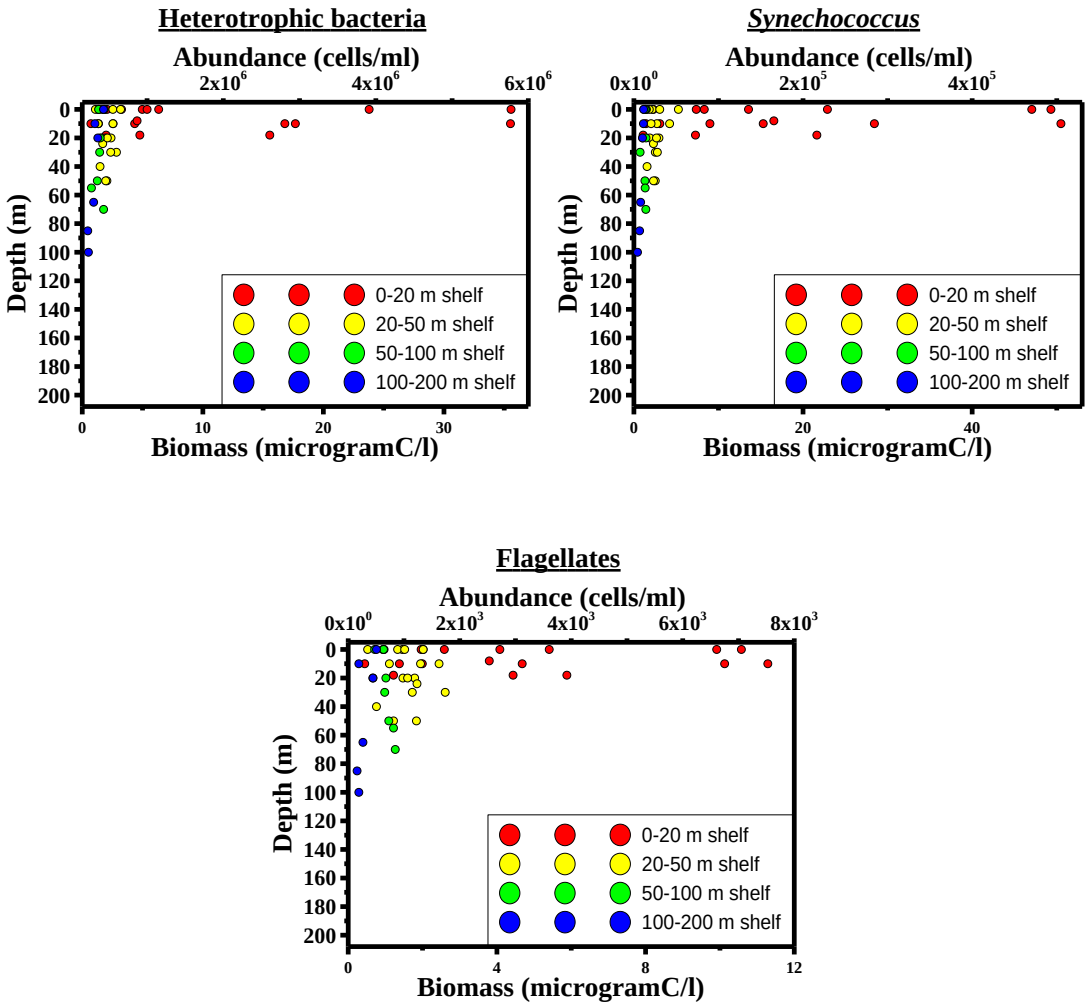

Figure 3.3. Abundance distribution of heterotrophic bacteria, *Synechococcus* and flagellates in different depth strata in Mersin bay in September 2008.

3.1.3. Sea surface distributions in February 2009

Surface spatial distributions of each parameter studied are shown in Figure 3.4. Sea surface temperature varied in the range 14.45^{0}C and 19.12^{0}C and salinity in the range 36.65 psu and 39.43 psu in the area during February 2009. Inner bay was colder and less saline than the outer bay in February. Increased fresh water inputs from local rivers in parallel to increased rainfall have reduced the nearsurface salinity in the area.

PO_4 concentrations were found below the detection limit at offshore stations and at around 0.25 μM in the inner part of the bay. The higher concentrations of NO_3+NO_2, NH_4 and Si were met nearby the river and urban discharge areas with maximal levels of 14.39 μM, 5.93 μM and 0.73 μM, respectively. High nutrient levels observed in the bay is the result of both the nutrient pump from lower depths to upper layers as a result of winter convective mixing and drainage from rivers and city outlets. Enhanced nutrient concentrations have yielded high amounts of chlorophyll-a at peak levels of 6.69 μg/l observed in front of the Tarsus Çayı discharge point. High dissolved oxygen levels are observed in areas with high chlorophyll-a and phytoplankton contents. Dissolved oxygen was found between 7.41 – 9.3 mg/l levels due to the higher solubility of oxygen in colder water. Phytoplankton abundances varied in the range $5.8x10^4$ - $2.1x10^6$ cells/ml in the area (Figure 3.4).

Heterotrophic bacteria and flagellates were found in higher concentrations in the innermost part of the bay with maximum values of $2.1x10^6$ (14.74 μgC/l) and $2.7x10^3$ cells/ml (9.66 μgC/l) respectively and decreased gradually from nearshore towards offshore. *Synechococcus* also peaked nearby the domestic discharge point to a level of $1.0x10^5$ cells/ml (10.31 μgC/l). It is interesting to note here that only after a certain distance to river mouths were achieved higher populations of organism groups. In other words, maximal growth in flora was achieved only after a certain acclimatization period of organisms to elevated nutrient levels. This is also directly related to the retention time of nutrient rich waters in the inner bay and to the rate of exchange of nearshore waters with relatively nutrient poor, oligotrophic offshore waters. Slower the exchange and longer the retention times provide higher biomass yields in the innermost part of the bay (Figure 3.4).

Highly significant positive correlations were observed between heterotrophic bacteria, *Synechococcus* and flagellate abundances and inversely a highly significant negative correlation with salinity and temperature. Similarly, significant correlations also existed within the biological groups studied and within physical

and chemical properties measured at surface. Detailed results of rank correlations are provided in Appendix B, page 144.

3.1.4. Vertical distributions in February 2009

Vertical distributions of all parameters being studied are shown in Figure 3.5 for the given transect. Water column is mixed in February due the winter convectional mixing except the presence of slightly colder and less saline near surface waters in shallow areas. Seeping of nutrient rich colder water in the form of a strip line just above the bottom has also been observed in the area. High abundance of heterotrophic bacteria as well as chlorophyll-a and DO concentrations were also found in this thin layer of water mass near the bottom.

Formation of less saline, colder and nutrient rich water in the shallow coastal area promoted productivity significantly in the water column compared to offshore waters. Much higher chlorophyll-a concentrations as well as higher abundances of heterotrophic bacteria, *Synechococcus*, flagellates and phytoplankton were recorded at stations close to shore (Figure 3.5). Dissolved oxygen was also found in higher concentrations in these regions (Figure 3.5).

Heterotrophic bacteria, *Synechococcus* and flagellates occupied water column more homogenously. A subsurface maximum was observed for each organism groups at about 20 meter depth. A significant decrease in *Synechococcus* abundance was observed below 100 meters.

Changes in abundance of heterotrophic bacteria, *Synechococcus* and flagellates within different depth strata are shown in Figure 3.6. Heterotrophic bacteria in the 0-20 m depth stratum were significantly higher and it is true also for *Synechococcus* with smaller abundance gradient between near shore and offshore. Parallel to surface distributions, highly significant positive correlations were observed between

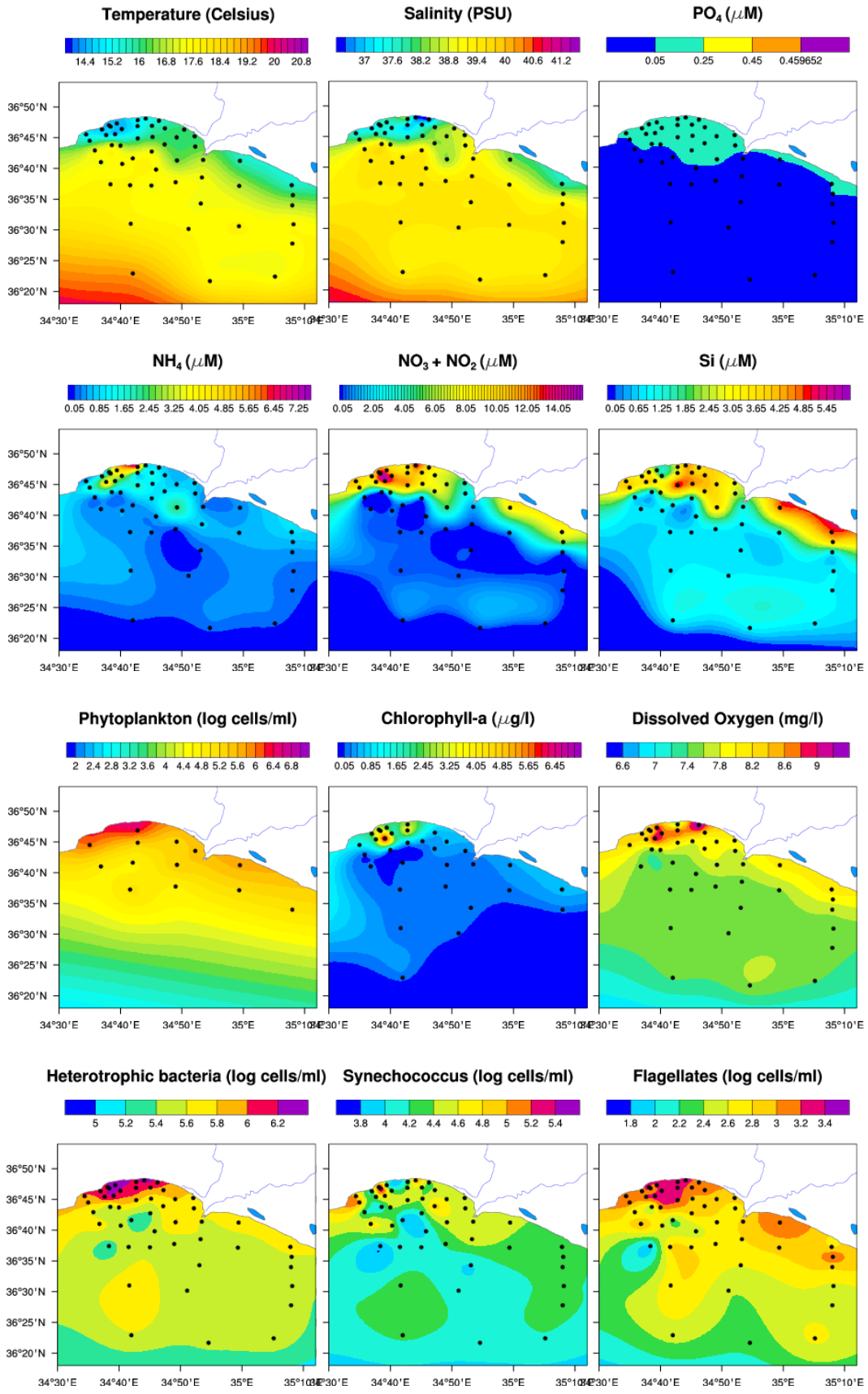

Figure 3.4. Surface distributions of physical, biological and chemical parameters in February 2009.

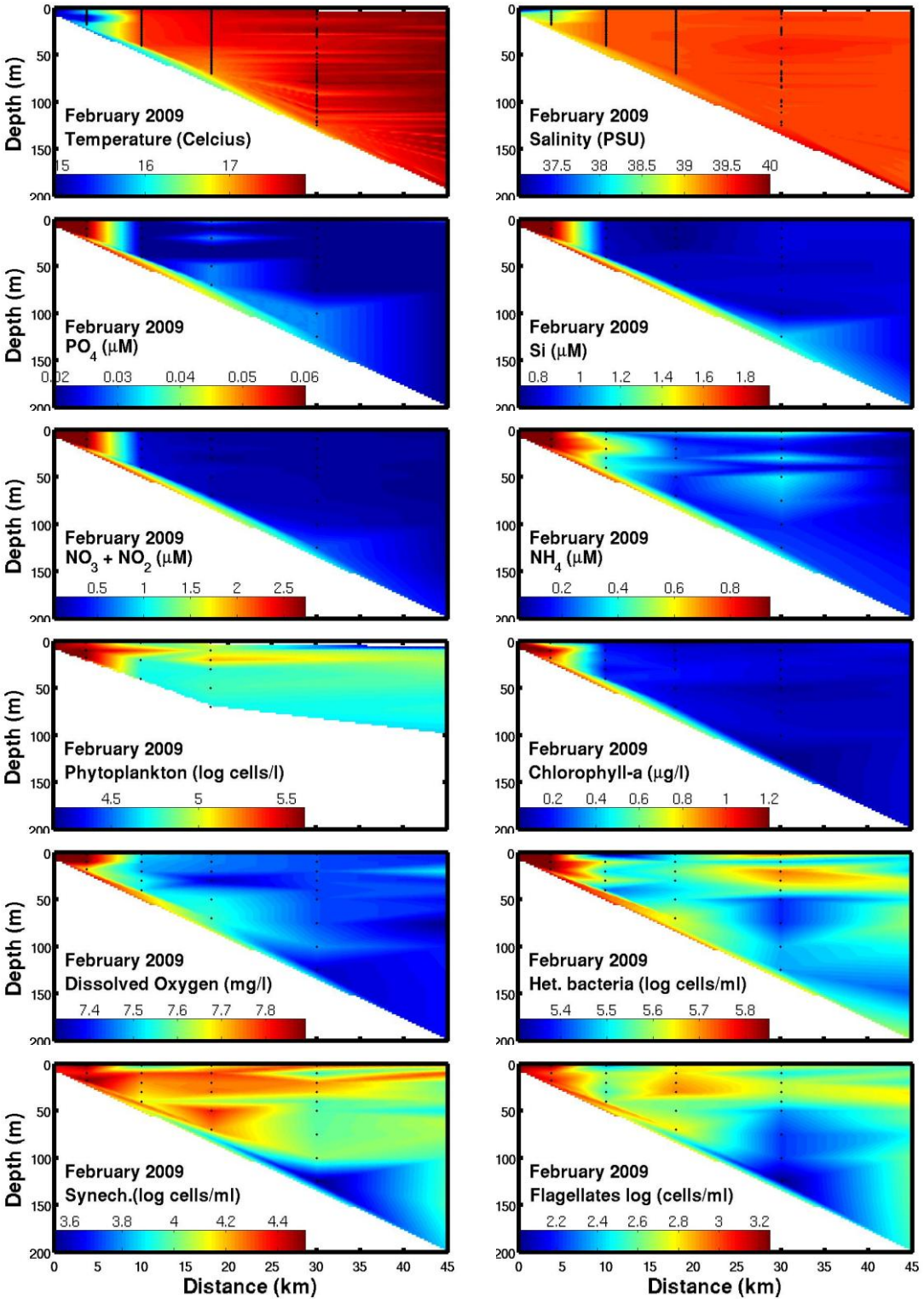

Figure 3.5. Vertical distributions of physical, biological and chemical parameters in February 2009

heterotrophic bacteria, *Synechococcus* and flagellate abundance and inversely a highly significant negative correlation with salinity and temperature. Similarly, significant correlations also existed within the biological groups studied and within physical and chemical properties measured. Detailed results of rank correlations are provided in Appendix B, page 144.

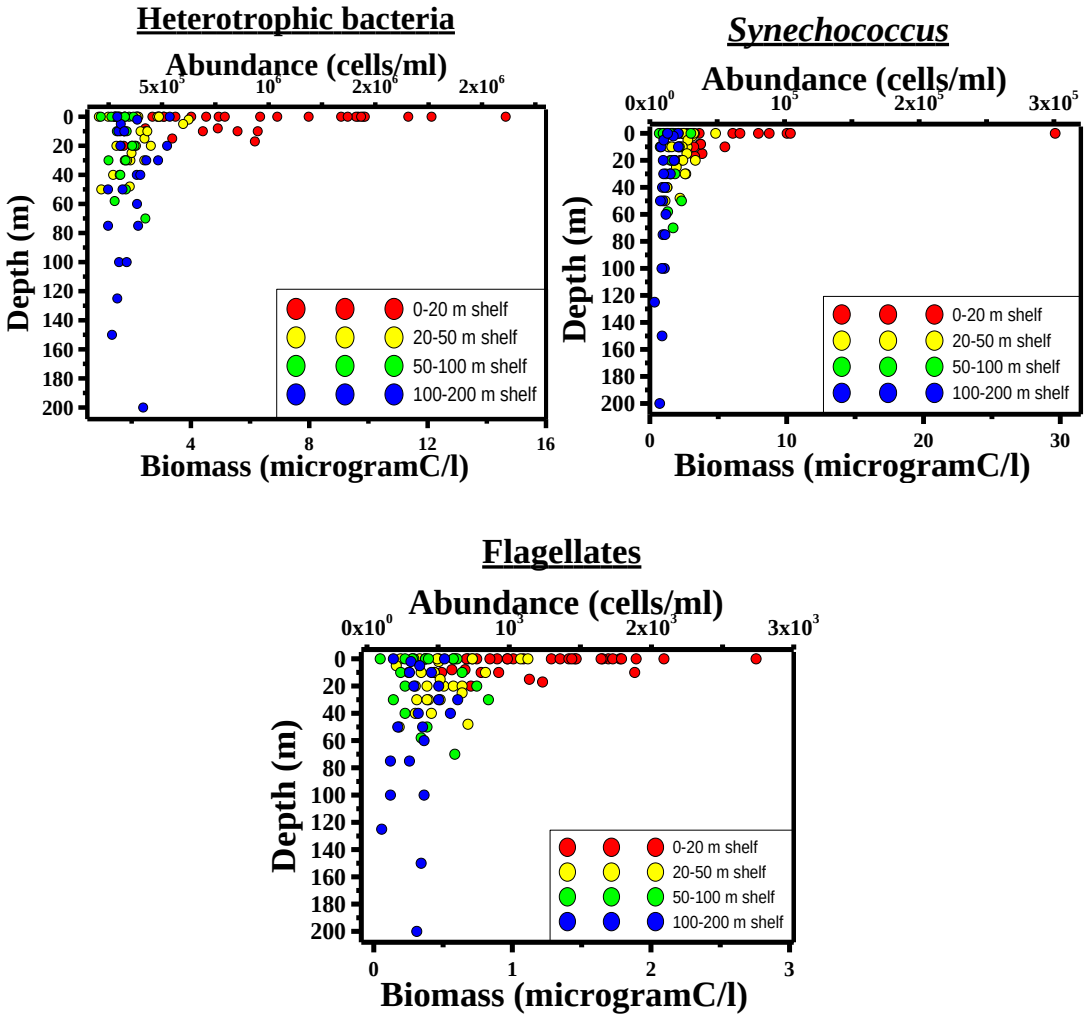

Figure 3.6. Abundance distribution of heterotrophic bacteria, *Synechococcus* and flagellates in different depth strata in Mersin bay in February 2009.

3.1.5. Sea surface distributions in April 2009

Surface spatial distribution of each parameter studied is shown in Figure 3.7. During this time, the surface temperature varied in the range 19.06^{0}C and 21.48^{0}C and salinity in the range 33.10 psu and 39.18 psu in the Bay. With increasing solar heat during spring coastal waters warm up faster compared to offshore waters. The inner part of the bay remained slightly warmer and much less saline (about 6 psu salinity difference) than the outer bay due to increased runoff from rivers in February. Wide distribution of less saline water in the surface water of the bay indicates the magnitude of freshwater input to the basin.

PO_4, NO_3+NO_2, NH_4 and Si concentrations made peak nearby the domestic outlet and river discharge areas with highly elevated levels of 0.31 μM, 5.19 μM, 2.01 μM and 14.78 μM, respectively. PO_4 was found depleted by phytoplankton excessively in the inner bay, even near the discharge area. Parallel to nutrient distributions at surface, phytoplankton abundance and chlorophyll-a concentrations were also found high nearby the discharges reaching maximal levels of 3.5x10^6 cells/l and 1.98 μg/l respectively. Dissolved oxygen was also found at high concentrations in the inner part of the bay as a result of high photosynthetic activity. Offshore areas denuded of nutrients contained much less flora than the inner bay. Surface flora occupied relatively a much wider space and extended eastwards to the river mouths compared to February 2009 case. Highest photosynthetic yield was obtained at stations near the Tarsus Çayı (Figure 3.7).

According to the results, heterotrophic bacteria, *Synechococcus* and flagellates were found in higher concentrations in the inner part of the bay with maximum levels of 1.7x10^6 (9.23 μgC/l), 1x10^4 cells/ml (6.99 μgC/l) and 3.6x10^3 cells/ml (10.60 μgC/l), respectively. Their abundances decreased from shore to offshore gradually. Surface spatial distribution of heterotrophic bacteria, *Synechococcus*, flagellates and phytoplankton mimicked the distribution of both the physical and chemical properties.

Significant positive correlations were observed between heterotrophic bacteria, *Synechococcus* and flagellate abundances and temperature and inversely, highly significant negative correlations are observed with salinity. Similarly, significant correlations also existed within the biological groups studied and within physical and chemical properties measured at surface. Such correlations observed between and within all biological, chemical and physical properties are usual for the entire area as it covers highly distinct extreme environments of oligotrophic to eutrophic nature. Detailed results of rank correlations are provided in Appendix B, page 145.

3.1.6. Vertical distributions in April 2009

Vertical distributions of all parameters being studied are shown in Figure 3.8 for the given transect. As illustrated in Figure 3.8 Less saline coastal waters started to warm up earlier in both horizontal and vertical axes compared to offshore areas. Upper part of the water column which had high photosynthetic yield seemed to have less NH_4, NO_3+NO_2 and NO_2 content compared to deeper parts due to rapid uptake of available nutrients by flora with increasing solar energy during spring. Upper meters contained much higher dissolved oxygen as a result of high photosynthetic activity that occurred in this sunlit layer. Subsurface maxima are observed for all groups studied.

Changes in abundance of heterotrophic bacteria, *Synechococcus* and flagellates within different depth strata are shown in Figure 3.9. Heterotrophic bacteria, *Synechococcus* and flagellates were most abundant in the 0-20 m depth stratum followed by others in an order, with increasing depth. Based on Spearman rank correlation analysis, significant positive correlations between heterotrophic bacteria, *Synechococcus* and flagellate abundances and ambient temperature and negative correlations with salinity were observed. Similar correlations were observed among the biological groups including chlorophyll-a and also between organism groups and nutrient concentrations. Detailed results of rank correlations are provided in Appendix B, page 145.

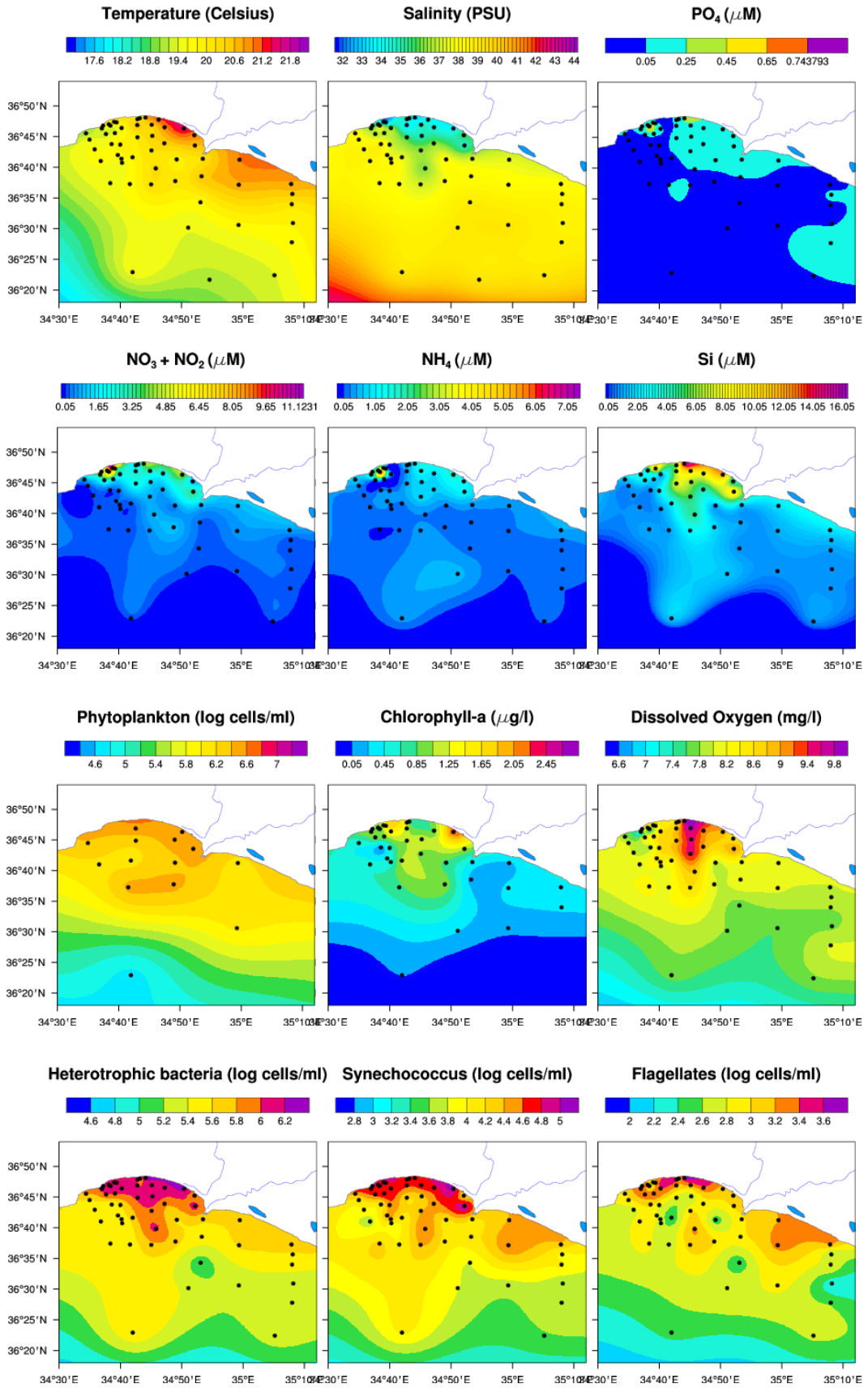

Figure 3.7. Surface distributions of physical, biological and chemical parameters in April 2009

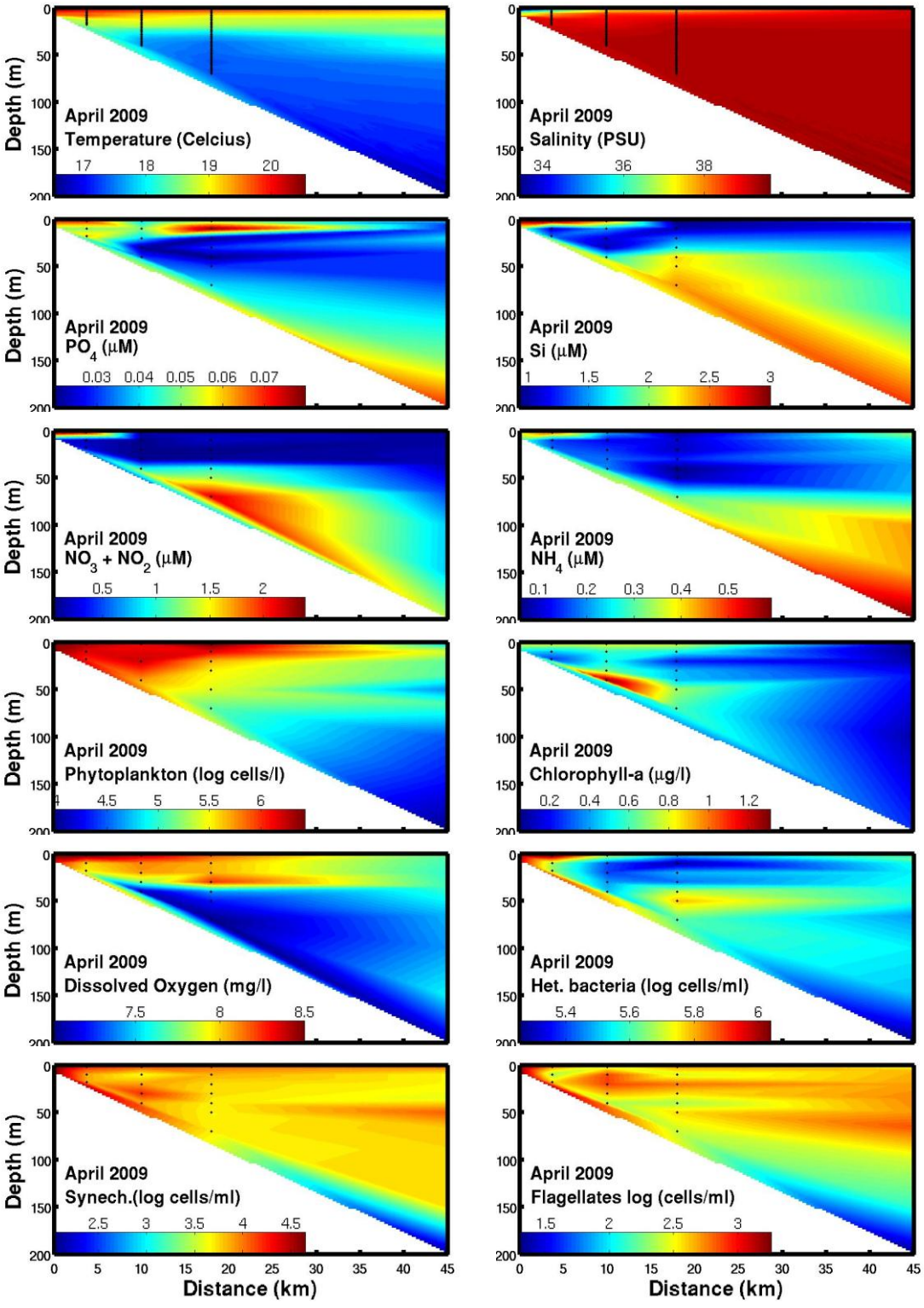

Figure 3.8. Vertical distributions of physical, biological and chemical parameters in April 2009

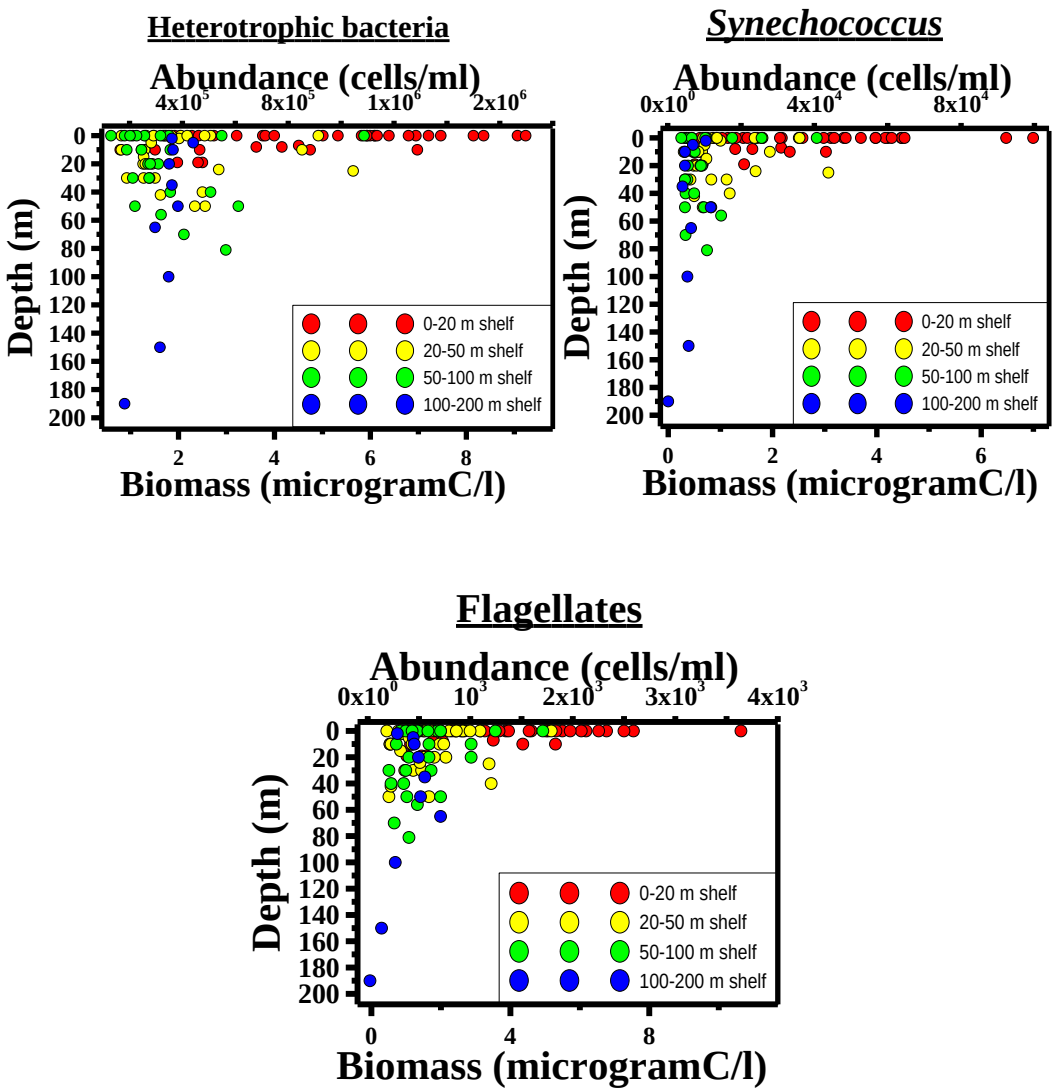

Figure 3.9. Abundance distribution of heterotrophic bacteria, *Synechococcus* and flagellates in different depth strata in Mersin bay in April 2009.

3.1.7. Sea surface distributions in August 2009

Surface spatial distributions of parameters having been studied are shown in Figure 3.10. According to the observations during August 2009 cruise, the surface temperature varied in the range 29.23^{0}C and 31.43^{0}C and salinity in the range 37.77 psu and 39.69 psu in the Bay. There is only 1^{0}C temperature gradient between the shore and the offshore water. Relatively warmer and less saline waters occupied the

inner bay. This low salinity gradient observed in the bay is due to reduced river runoff which is usual for the dry period.

Compared to offshore waters relatively higher PO_4, NH_4 and NO_3+NO_2 concentrations were found in the shallow inner bay eventually fueled with rivers and urban discharges with maximum values of 0.13 μM, 2.32 μM and 4.24 μM, respectively. Si values were high in the riverine discharge area with a maximum of 8.08 μM. Chlorophyll-a concentration was found between 0.02 μg/l and 2.11 μg/l and dissolved oxygen varied in the range 6.16 mg/l – 7.74 mg/l. Higher concentrations of chlorophyll-a and phytoplankton were found in the innermost part of the bay and dissolved oxygen was also recorded at high levels in this area (Figure 3.10).

Higher abundances of heterotrophic bacteria, *Synechococcus* and flagellates were found in the innermost part of the bay. The maximum abundance and biomass values obtained for heterotrophic bacteria, *Synechococcus* and flagellates were $6.4x10^6$ (29.95 μgC/l), $8.5x10^5$ cells/ml and 49.13 μgC/l and $3.2x10^3$ cells/ml and 2.96 μgC/l, respectively. Since nutrient inputs to the bay via river and domestic discharges are very limited during this dry period, existing flora remain nutrient deficient throughout the summer. Only in close proximity to discharge points were flora able to utilize sufficient amount of nutrients. This is why we observe nutrient and flora rich and poor patches within the inner bay during summer. Nutrients remained below the detection levels in the surrounding towards offshore (Figure 3.10).

As can be seen in the Figure 3.10, abundance distribution patterns of heterotrophic bacteria, *Synechococcus* and flagellates were very similar. Parallel to these observations highly significant positive correlations were observed between heterotrophic bacteria, *Synechococcus* and flagellate abundance and temperature based on Spearman rank correlation. Inversely a highly significant negative correlation was found with salinity. Similarly, significant correlations also existed

within the biological groups studied and within physical and chemical properties measured at surface. Detailed results of rank correlations are provided in Appendix B, page 145.

3.1.8. Vertical distributions in August 2009

Vertical distributions of all parameters being studied are shown in Figure 3.11 for the given transect (Figure 2.1). A well pronounced temperature (10 ^{0}C) and a minor salinity (about 0.5 psu) gradient did exist in the water column during August. Picoplankton especially *Synechococcus* seemed to be the most favoured group against the high temperatures during this season. This is also true for other seas and oceans and generally, both heterotrophic bacteria and *Synechococcus* are more abundant in summer than in winter (Li, 1998). Available nutrients seem to be utilized efficiently by existing flora in upper layers during summer leaving only trace amounts towards the lower layer of the euphotic zone. Flagellates distributed homogenously in the water column. Phytoplankton has been found most abundant in the shallow coastal sector with high numbers near bottom as well. There is also a subsurface maximum for phytoplankton between the depths of 35-45 m (Figure 3.11).

Changes in abundance of heterotrophic bacteria, *Synechococcus* and flagellates within different depth strata are shown in Figure 3.12. As can be seen in the figure, all groups were most abundant in the 0-20 m depth stratum followed by others in an order, with increasing depth. Based on Spearman rank correlation analysis, highly significant positive correlations between heterotrophic bacteria, *Synechococcus* and flagellate abundances and ambient temperature and inversely a highly significant negative correlation with salinity were observed. Similar correlations were observed among the biological groups including chlorophyll-a and also between organism groups and nutrient concentrations. Detailed results of rank correlations are provided in Appendix B, page 145.

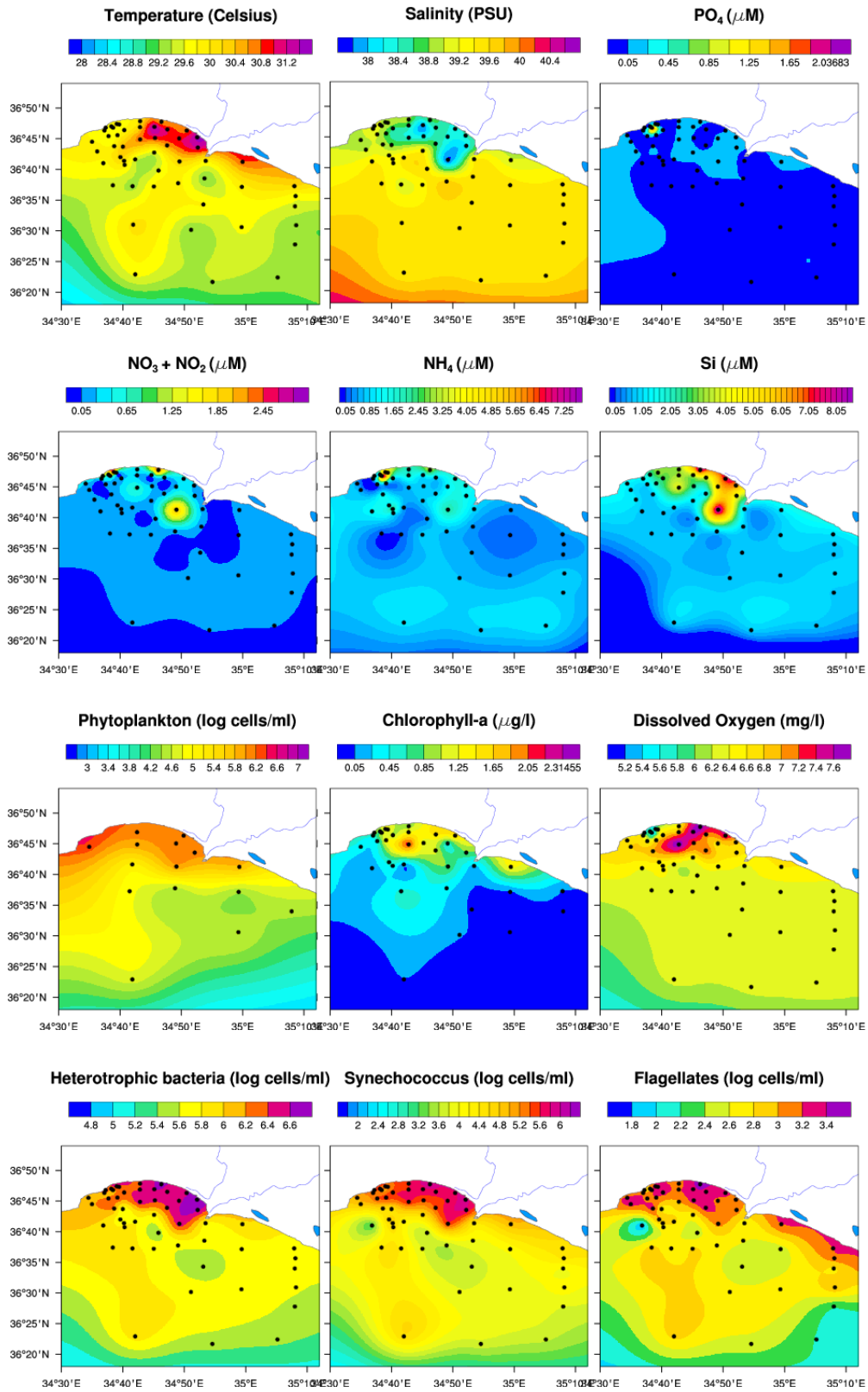

Figure 3.10. Surface distributions of physical, biological and chemical parameters in August 2009.

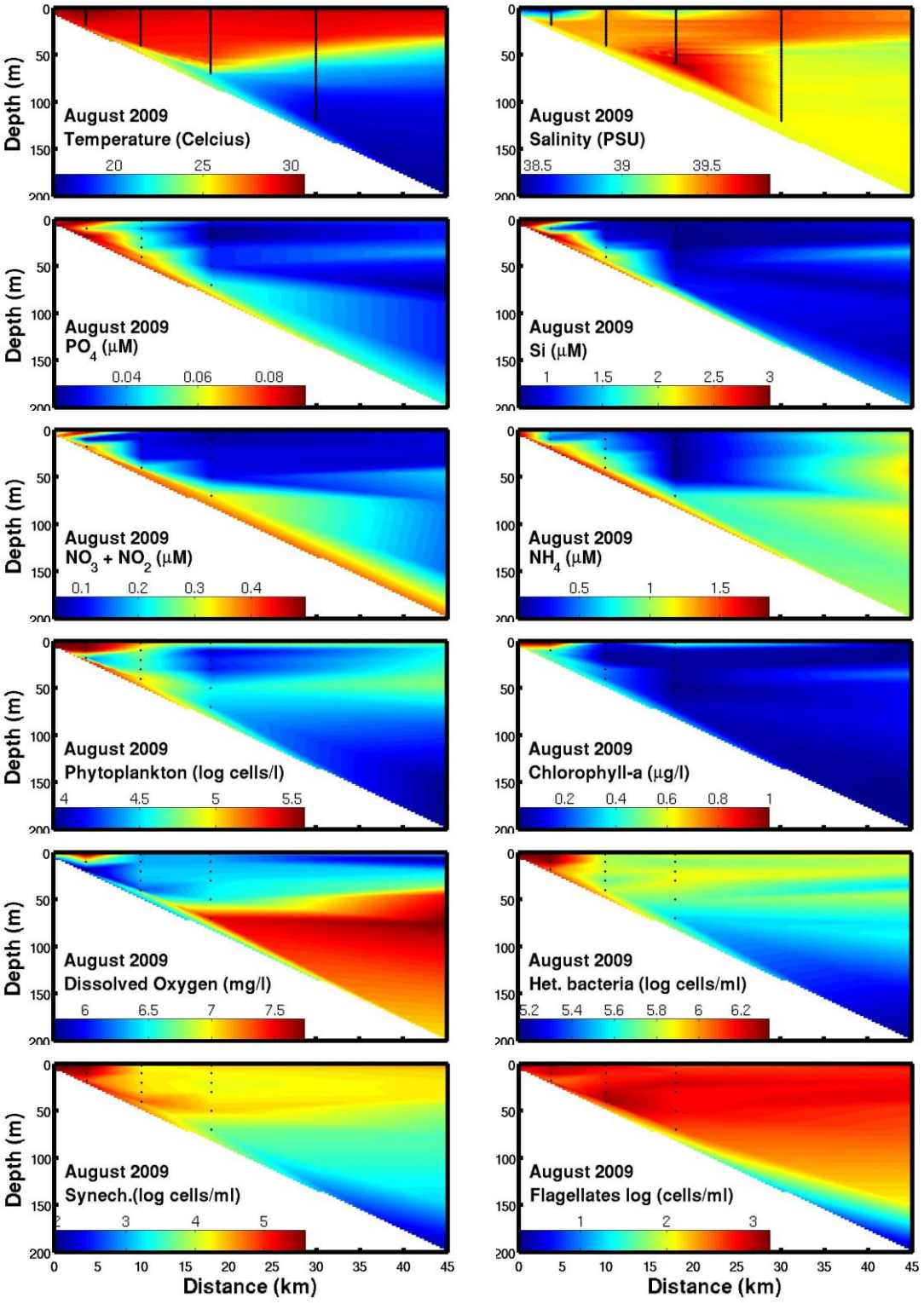

Figure 3.11. Vertical distributions of physical, biological and chemical parameters in August 2009.

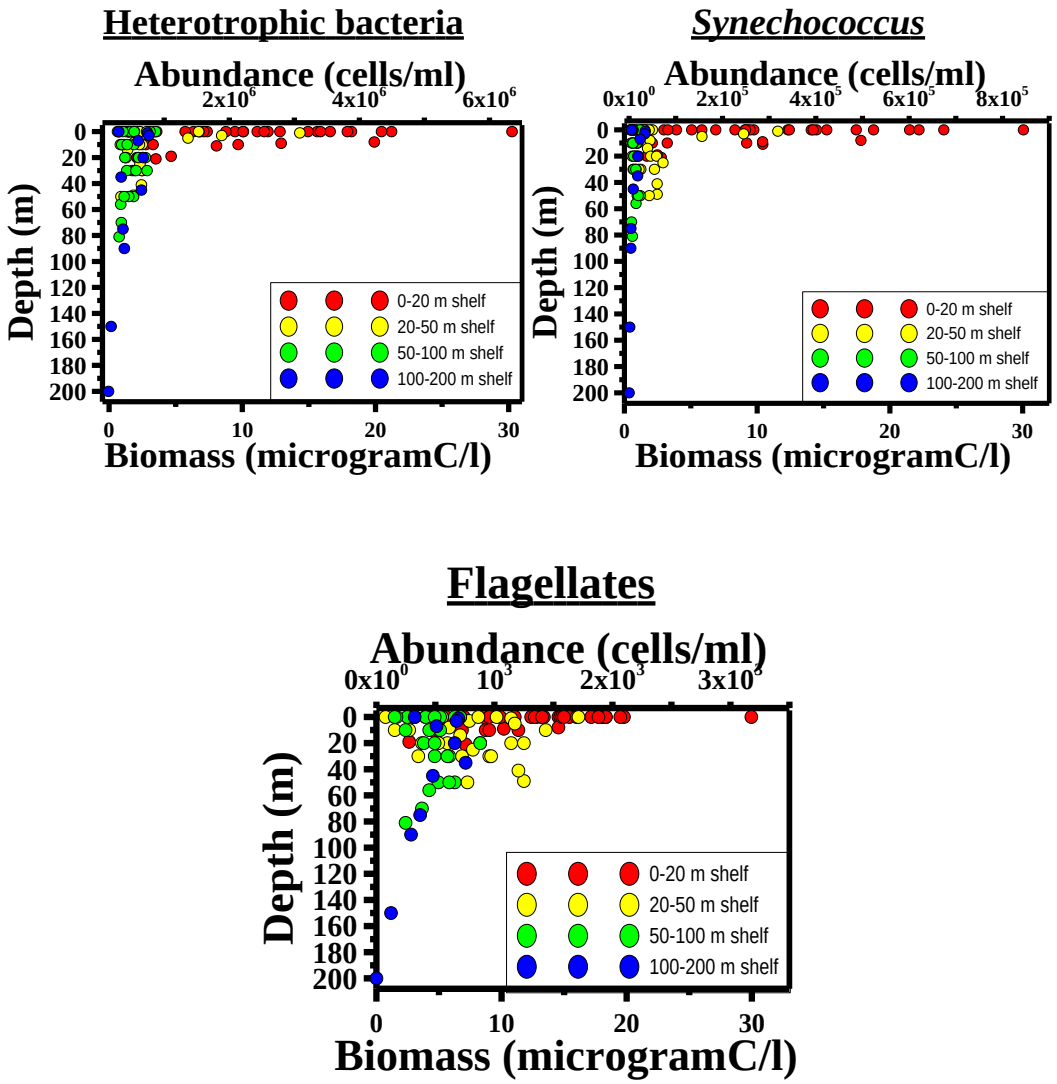

Figure 3.12. Abundance distribution of heterotrophic bacteria, *Synechococcus* and flagellates in different depth strata in Mersin bay in August 2009.

3.1.9. Sea surface distributions in October 2009

Surface spatial distributions of each parameter studied are shown in Figure 3.13. Based on CTD data, the surface temperature varied in range 24.93^{0}C and 26.28^{0}C and salinity in the range 37.80 psu and 39.65 psu in the area. After summer the inner bay started to cool down faster and offshore water remained warmer with a 1.3 ^{0}C temperature gradient and more saline than the inner part of the bay. Lower salinity

values (approx. 1.5 psu less than offshore) observed in the inner bay may due to the freshwater discharge from outlets and rivers to the shallow coastal region.

The highest PO_4, NO_3+NO_2 and NH_4 concentrations which were recorded in the coastal area were 0.21 μM, 8.34 μM and 4.31 μM, respectively. Concentrations remained at supreme low levels in offshore waters. Changes in silicate concentrations is minor as the excess amounts supplied by rivers were possibly consumed by the rich flora in the periphery of the river mouths. In the region which was less saline and contained higher amount of nutrients, chlorophyll-a was also found very high. The chlorophyll-a concentrations varied in the range 0.03 μg/l and 2.34 μg/l and phytoplankton abundance was found at higher values nearby the river mouth with the highest level of $1x10^6$ cells/l. Dissolved oxygen distribution at surface waters was also very similar to phytoplankton abundance distribution. Dissolved oxygen in the inner bay was quite high since the solubility of the oxygen is high in the colder inner bay with increasing photosynthetic activity observed therein (Figure 3.13).

In October 2009, abundance and biomass remained in ranges $3.7x10^5$ cells/ml (2.33 μgC/l) and $2.2x10^6$ (16.42 μgC/l) for the heterotrophic bacteria, $1.1x10^4$ cells/ml (0.69 μgC/l) and $2.4x10^5$ cells/ml (15.35 μgC/l) for the *Synechococcus* and $1.9x10^2$ cells/ml (0.18 μgC/l) and $4.2x10^3$ cells/ml (4.41 μgC/l) for the flagellates at surface. All groups were most abundant in the discharge area nearby Seyhan River and Tarsus Çayı. Their high abundances in less saline innermost part of the bay may indicate the stimulating effect of riverine discharges on planktonic organisms. In this period, no significant correlations were observed between heterotrophic bacteria, *Synechococcus* and flagellate abundance and temperature, salinity and nutrients. However significant correlations existed within the biological groups studied and within physical and chemical properties measured at surface. Detailed results of rank correlations are provided in Appendix B, page 146.

3.1.10. Vertical distributions in October 2009

Vertical distributions of all parameters being studied are shown in Figure 3.14 for the given transect. Surface mixed layer rich in flora terminated with a pronounced thermocline (with a 6 ^{0}C gradient) at around 40 meters. Below the thermocline a decrease in biological parameters with increasing depth and a peak in dissolved oxygen content just below thermocline were observed. Surface mixed layer remained poor in nutrient due to possible uptake by dense flora. Deeper water had higher concentrations of NO_3+NO_2.

Changes in abundances of heterotrophic bacteria, *Synechococcus* and flagellates within different depth strata are shown in Figure 3.15. High abundances of all groups in the 0-20 m depth stratum followed by others in decreasing order, with increasing depth. Thermocline observed at around 40 m set a clear barrier over downward extension of the flora and even a gradual decrease in quantity of flora towards the base of the thermocline is observed within the thick surface mixed layer (Figure 3.14).

Based on Spearman rank correlation analysis, no significant positive correlations between heterotrophic bacteria, *Synechococcus* and flagellate abundances and temperature were observed whereas significant negative correlations were found with salinity. Significant positive correlations were observed among the biological groups including chlorophyll-a and also between organism groups and nutrient concentrations. Detailed results of rank correlations are provided in Appendix B, page 146.

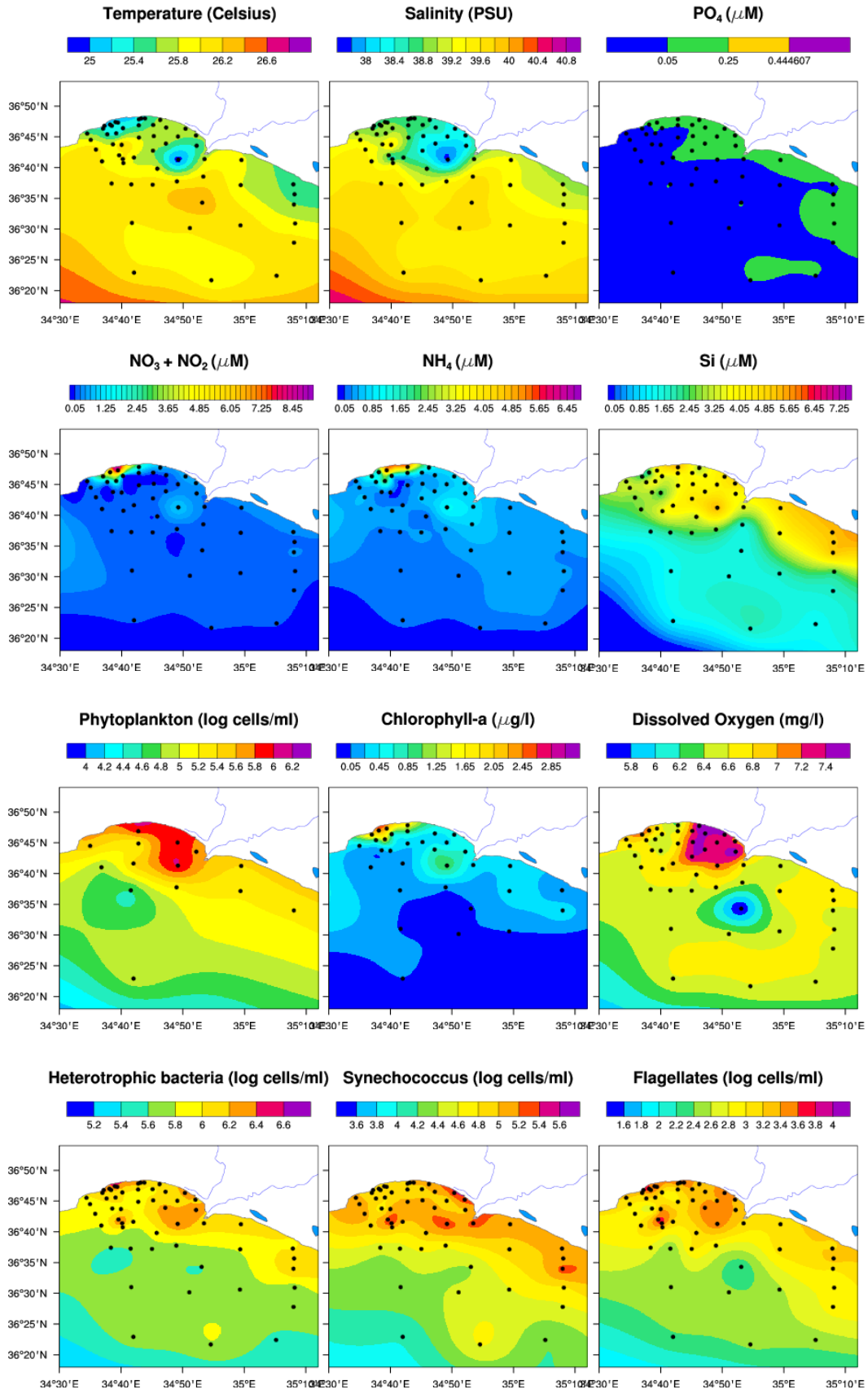

Figure 3.13. Surface distributions of physical, biological and chemical parameters in October 2009.

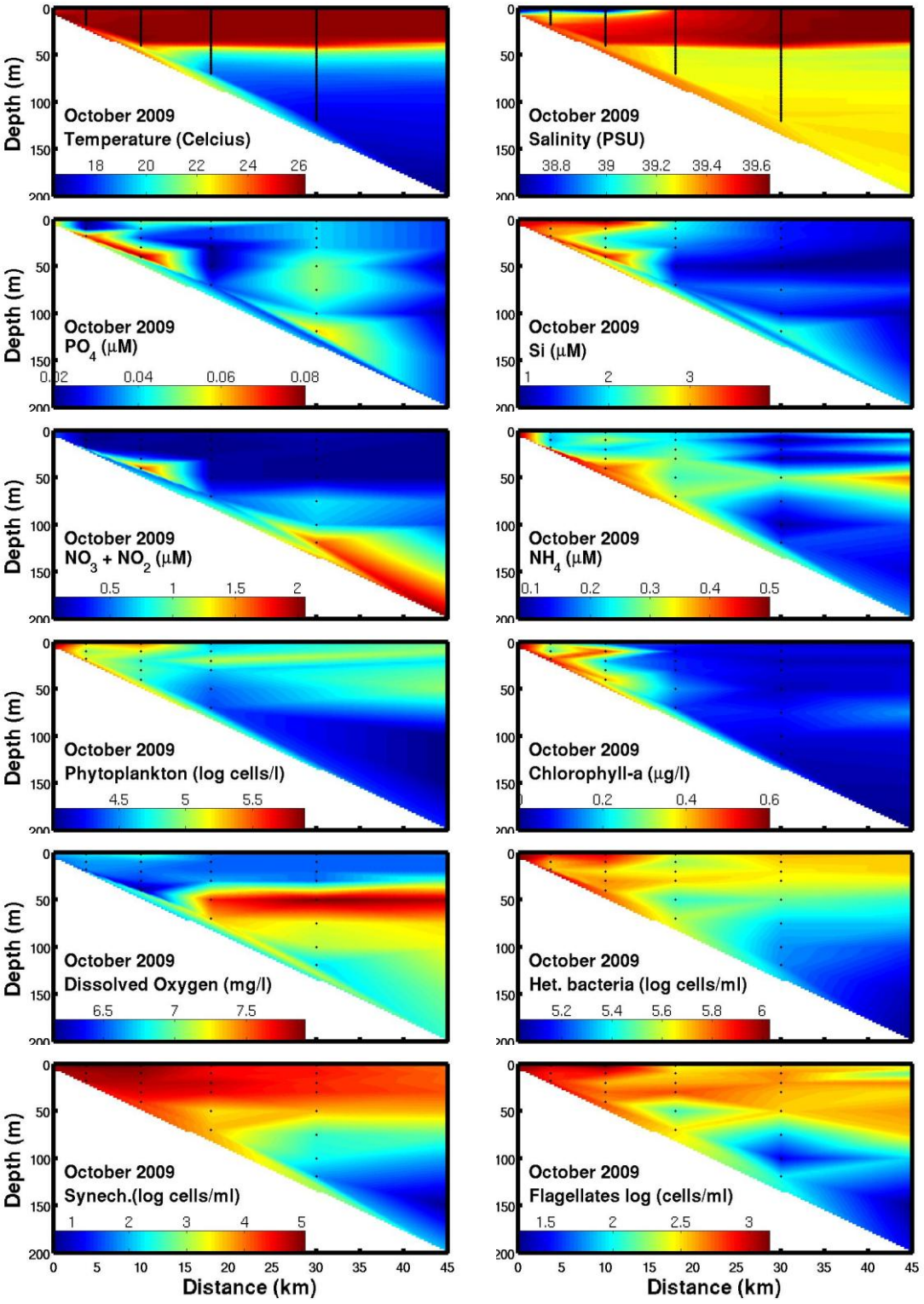

Figure 3.14. Vertical distributions of physical, biological and chemical parameters in October 2009.

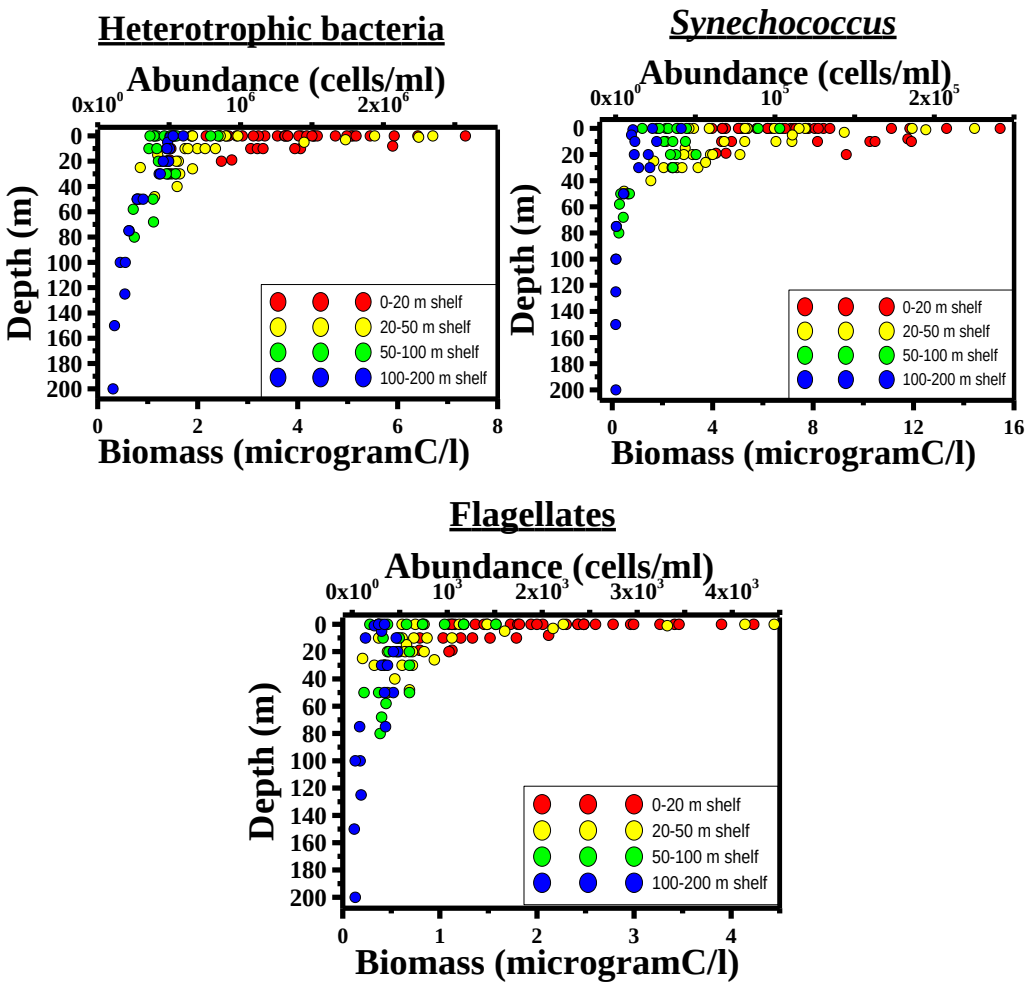

Figure 3.15. Abundance distribution of heterotrophic bacteria, *Synechococcus* and flagellates in different depth strata in Mersin bay in October 2009.

3.1.11. Sea surface distributions in February 2010

Surface spatial distributions of each parameter studied are shown in Figure 3.16. Surface temperature varied in the range 15.05 ^{0}C and 17.84 ^{0}C and salinity in the range 35.45 psu and 39.23 psu in the Bay. Inner bay water was colder and less saline than the outer part in February. Lower salinity values (approx. 4 psu less than offshore) observed in the inner bay is due to the discharge and freshwater inputs to the region. Fresh water input and rainfall decreased salinity at surface appreciably.

In February 2010, relatively much higher nutrient concentrations were found in the coastal zone than offshore waters. PO_4, NO_3+NO_2 and NH_4 concentrations reached

peak levels of 0.21 μM, 8.34 μM and 4.31 μM in the coastal area, respectively. Very low concentrations of PO_4 relative to other nutrients indicate its' rapid and selective uptake by existing flora. Expansion of high chlorophyll-a areas due mainly to excess nutrient pumps from both land and to convectional mixing during winter. Chlorophyll-a varied in the range 0.12 μg/l and 5.63 μg/l in the area. Phytoplankters exhibited similar distribution patterns with chlorophyll-a. As a result of the high photosynthetic activity in the inner part of the bay, dissolved oxygen was also found high within the ranges of 7.49 mg/l – 9.96 mg/l, respectively (Figure 3.16).

Heterotrophic bacteria and flagellates made peaks in the innermost part of the bay reaching maximal abundance and biomass levels of $1.5x10^6$ (6.07 μgC/l) and $3.6x10^3$ cells/ml (3.95 μgC/l). A heterogeneous distribution of *Synechococcus* was also observed at surface. Parallel to these observations, based on Spearman rank correlations, no significant correlations have been observed between *Synechococcus* and temperature, salinity and nutrients except Si. Instead, highly significant positive correlations were observed between heterotrophic bacteria & flagellate abundances and temperature and inversely with salinity. Similarly, significant correlations also existed between heterotrophic bacteria and flagellates and within physical and chemical properties measured at surface. Detailed results of rank correlations are provided in Appendix B, page 146.

3.1.12. Vertical distributions in February 2010

Vertical distributions of all parameters being studied are shown in Figure 3.17 for the given transect. In February, shelf water was colder and a gradual increase in temperature was observed from shore to offshore. Lower temperature and salinity associated with high nutrients resulted in high production in the inner bay. It is to accept that Due to convectional mixing flora distributed evenly in the water column in the inner bay. Against heterotrophic bacteria and flagellates high abundance of *Synechococcus* was observed in the offshore waters.

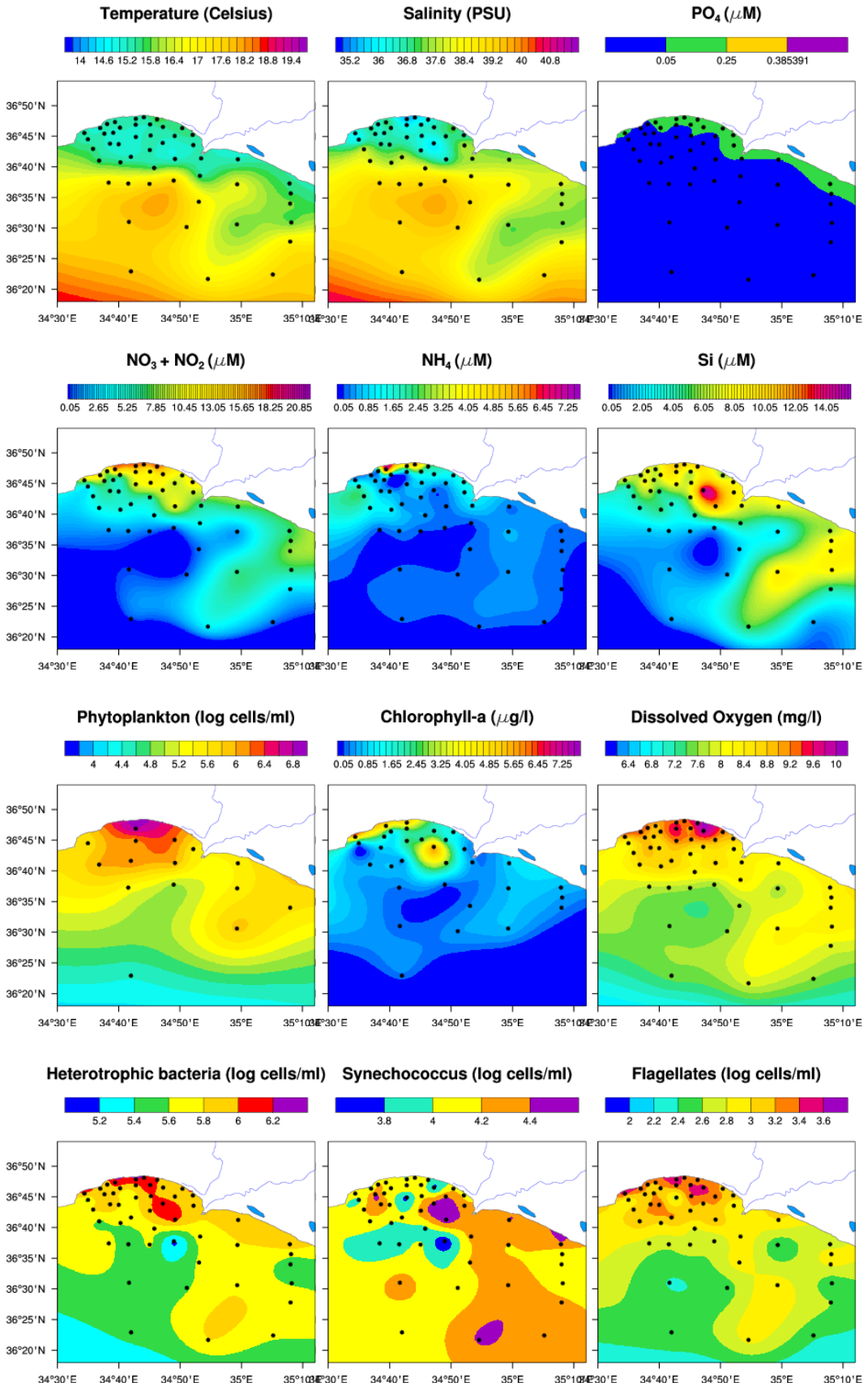

Figure 3.16 . Surface distributions of physical, biological and chemical parameters in February 2010.

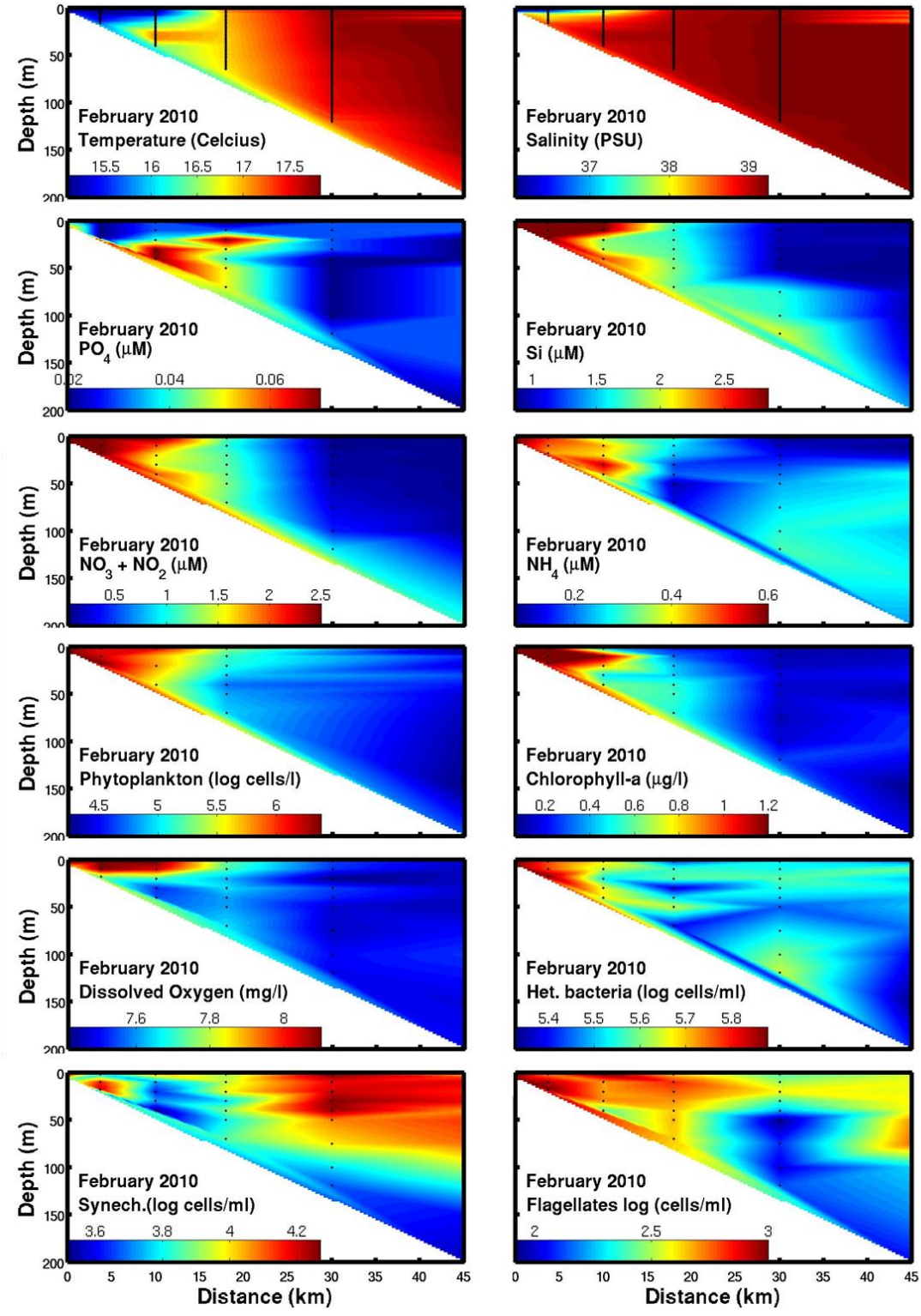

Figure 3.17. Vertical distributions of physical, biological and chemical parameters in February 2010.

Changes in abundance of heterotrophic bacteria, *Synechococcus* and flagellates within different depth strata are shown in Figure 3.18. All groups were most abundant in the 0-20 m depth stratum followed by others in an order, with increasing depth. Despite the observed gradual decrease in numbers of heterotrophic bacteria and flagellates with deepening depth strata no trend was observed for *Synechococcus*.

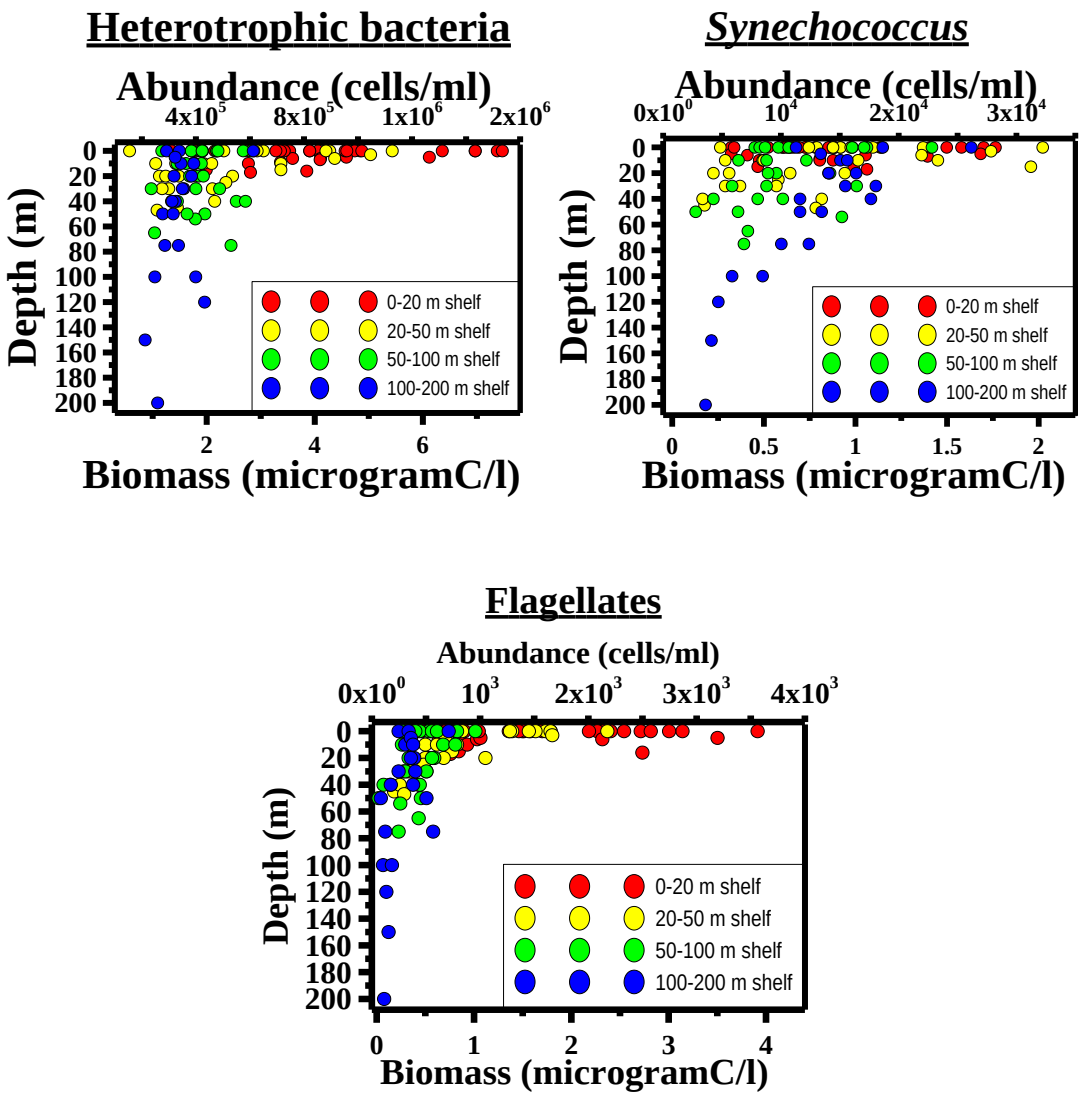

Figure 3.18. Abundance distribution of heterotrophic bacteria, *Synechococcus* and flagellates in different depth strata in Mersin bay in February 2010.

Based on Spearman rank correlation analysis, significant positive correlations between heterotrophic bacteria, *Synechococcus* and flagellate abundances and ambient temperature and negative correlations with salinity were observed. Similar correlations were observed among the biological groups including chlorophyll-a and also between organism groups and nutrient concentrations except the relationships between *Synechococcus* and PO_4 and NH_4. Detailed results of rank correlations are provided in Appendix B, page 146.

3.1.13. Sea surface distributions in April 2010

Surface spatial distributions of each parameter studied are shown in Figure 3.19. In April 2010, surface temperature varied in the range 18.17^0C and 19.81^0C and salinity in the range 34.80 psu and 39.21 psu, in the bay. With the onset of spring surface temperature started to warm up and inner part of the bay was less saline and warmer than the outer part (6.5 psu salinity gradient). Wide distribution of less saline surface water indicates high volume of fresh water input to the bay. Lower temperature values were also recorded at the stations close to river discharges.

With high flow rates of the rivers and increased precipitation during spring, nutrients such as NH_4, NO_3+NO_2 and Si became available and widely distributed at surface. Relatively higher concentrations of NH_4, NO_3+NO_2 and Si reaching peak levels of 1.23 μM, 5.8 μM and 6.94 1.23 μM, respectively, in the innermost part of the bay were recorded. PO_4 concentrations remained in the range 0.02 μM and 0.26 μM. Chlorophyll-a concentrations (in range 0.02 μg/l and 1.76 μg/l) and phytoplankton abundances (in range $6.4x10^4$ cells/l - $1.7x10^6$ cells/l) were distributed similarly at surface. Widely distribution of nutrients as a result of high flow rate of the rivers and rainfall also might increase primary productivity in the region. Distribution patterns of nutrients and chlorophyll-a concentrations showed similarity indicating the effect of nutrient enrichment in the bay. The region which contained high chlorophyll-a concentrations also contained high dissolved oxygen except the river

mouths. To a highest photosynthetic yield was met in front of the Tarsus Çayı (Figure 3.19).

Higher heterotrophic bacteria, *Synechococcus* and flagellates abundance distributions were found in the inner part of the bay parallel to coastline following the isopleths of nutrients. Their concentrations decreased gradually from shore to offshore and varied in the range $1.9x10^5$ cells/ml (0.85 μgC/l) and $1.3x10^6$ (5.91 μgC/l) for heterotrophic bacteria, $1.2x10^3$ cells/ml (0.07 μgC/l) and $3.6x10^4$ cells/ml (5.76 μgC/l) for *Synechococcus* and 0 and $1.3x10^3$ cells/ml (1.95 μgC/l) for flagellates, respectively. The results of Spearman's rank correlation analysis also confirmed these relationships and significant positive correlations were observed between heterotrophic bacteria, *Synechococcus* and flagellate abundance and PO_4, NO_3+NO_2 and Si. Similarly, significant correlations also existed within the biological groups studied and within physical and chemical properties measured at surface. Detailed results of rank correlations are provided in Appendix B, page 147.

3.1.14. Vertical distributions in April 2010

Vertical distributions of all parameters being studied are shown in Figure 3.20 for the given transect. In April 2010, less saline water occupied the water column in the coastal station. Since this less saline water mass was rich in nutrient, a high amount of photosynthetic yield was observed in this region. Especially heterotrophic bacteria followed exactly the same trend. Except NH_4 rest of the nutrients seem to be heavily consumed at nearsurface waters in the area. Dissolved oxygen decreased gradually from surface to bottom.

Changes in abundance of heterotrophic bacteria, *Synechococcus* and flagellates within different depth strata are shown in Figure 3.21. *Synechococcus* abundance did not show significant difference from nearshore to offshore whereas heterotrophic bacteria and flagellates were most abundant in the 0-20 m depth stratum followed

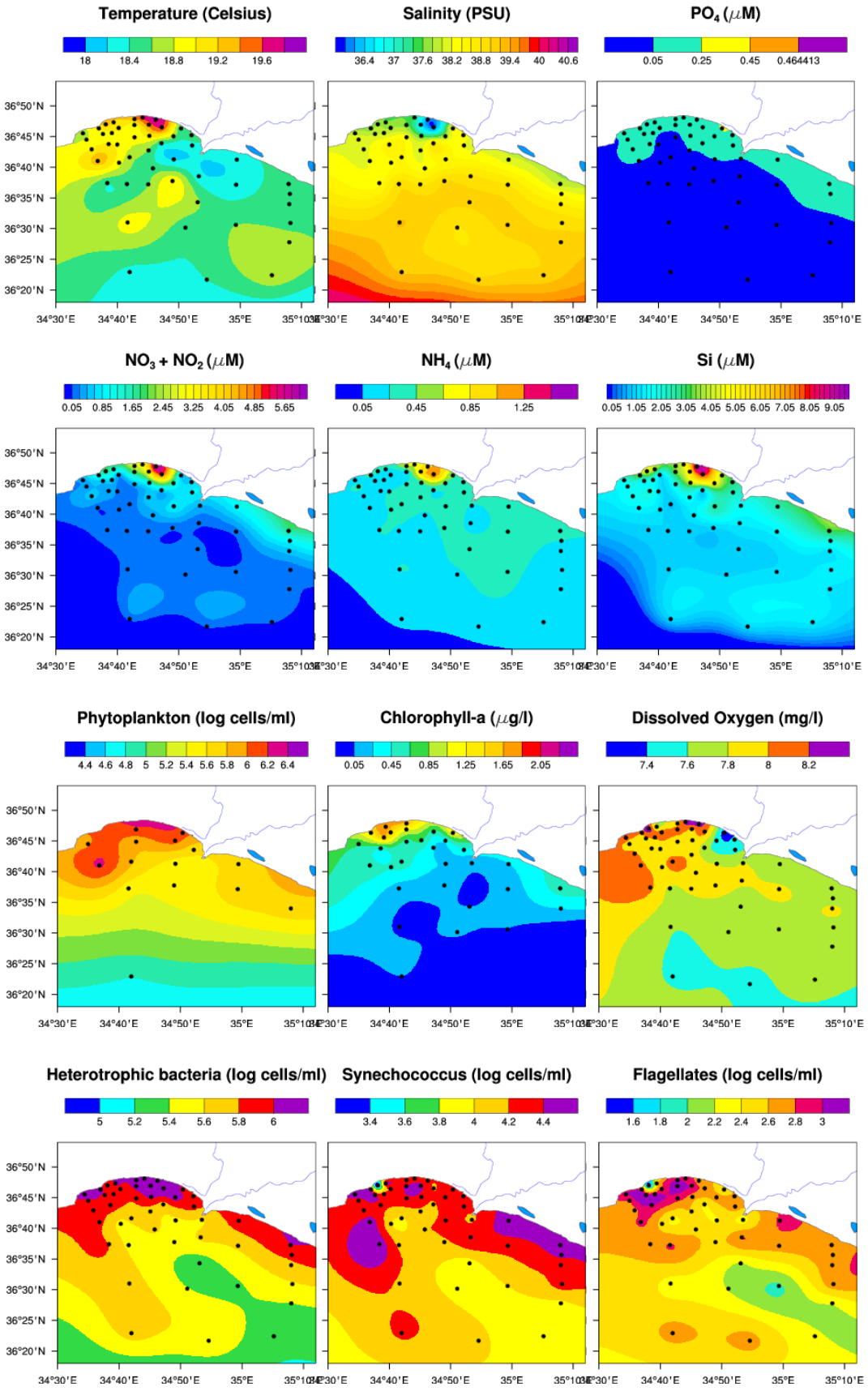

Figure 3.19. Surface distributions of physical, biological and chemical parameters in April 2010.

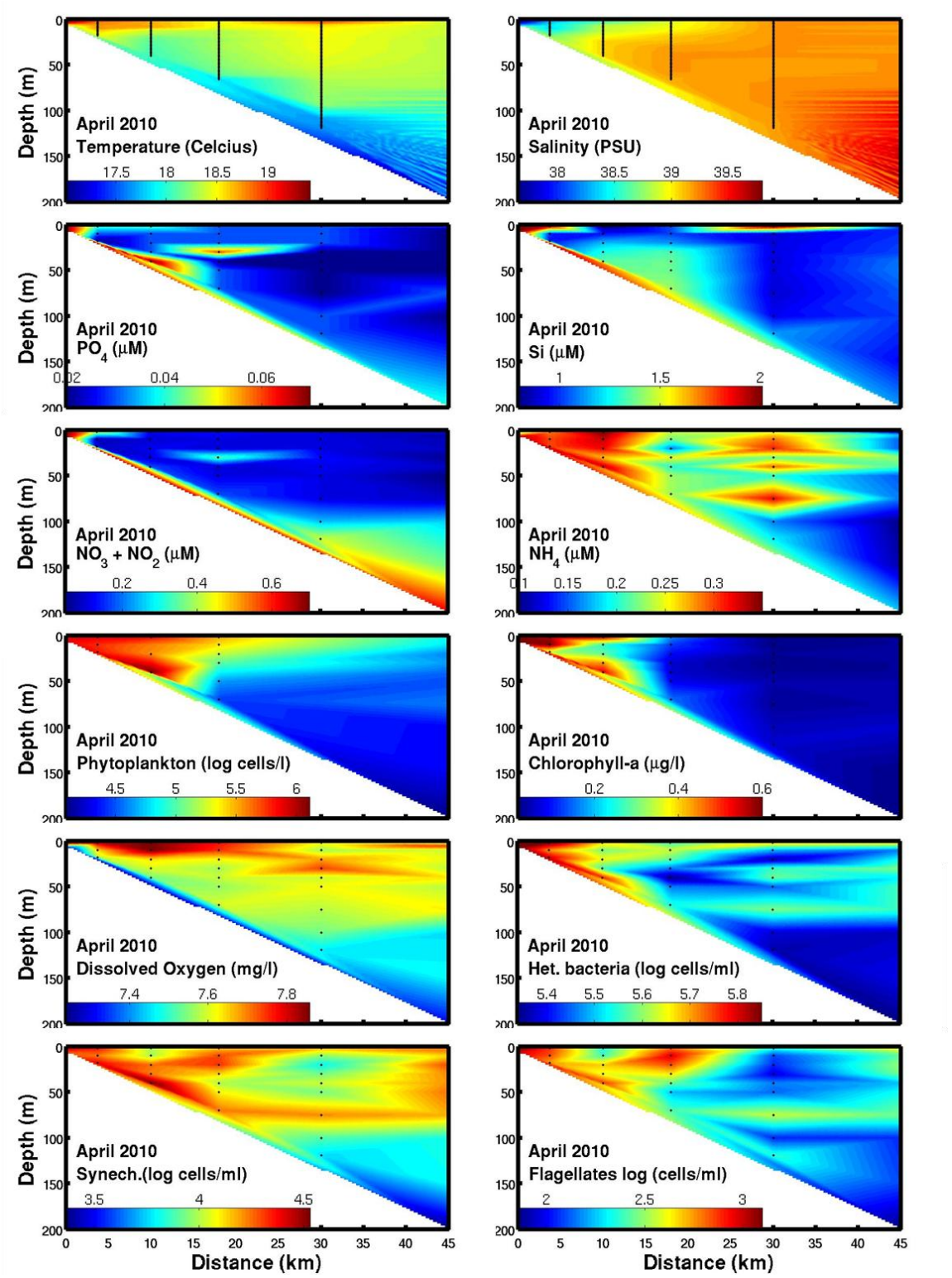

Figure 3.20. Vertical distributions of physical, biological and chemical parameters in April 2010.

by others in an order, with increasing depth. Based on Spearman rank correlation analysis, significant positive correlations between heterotrophic bacteria, *Synechococcus* and flagellate abundances and ambient temperature and inversely significant negative correlation with salinity (except *Synechococcus*) were observed. Similar correlations were observed among the biological groups including chlorophyll-a and also between organism groups and nutrient concentrations. Detailed results of rank correlations are provided in Appendix B, page 147.

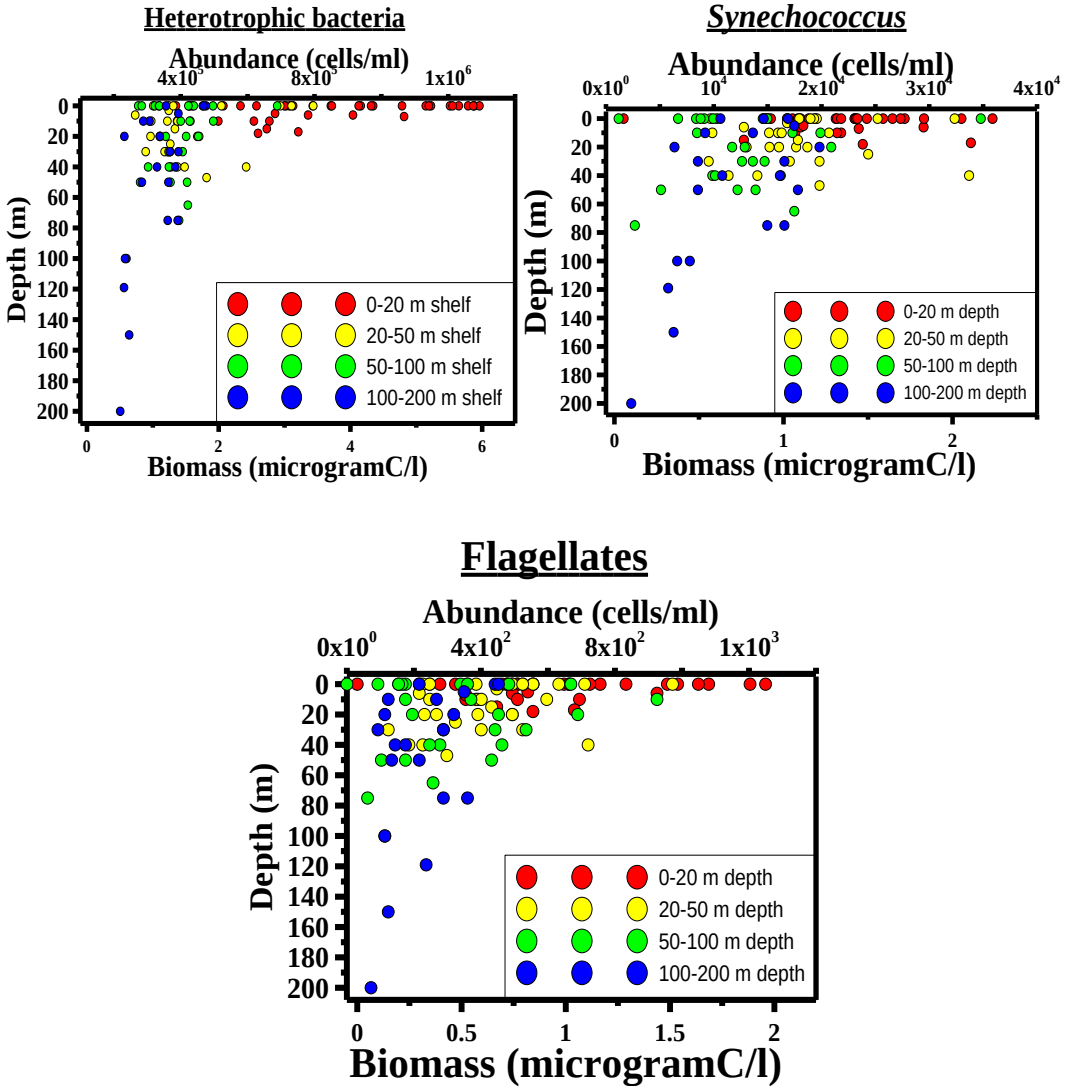

Figure 3.21. Abundance distribution of heterotrophic bacteria, *Synechococcus* and flagellates in different depth strata in Mersin bay in April 2010.

3.1.15. Sea surface distributions in July 2010

Surface spatial distributions of each parameter studied are shown in Figure 3.22. In July 2010, the surface temperature varied in range 26.85^{0}C and 29.87^{0}C and salinity in the range 36.68 psu and 39.40 psu in the Bay. In summer 2010, shelf water was observed significantly warmer and less saline.

Since the river input is limited during summer as a result nutrients were found at lower concentrations in July 2010. The highest concentrations of PO_4 (0.10 μM), NO_3+NO_2 (0.95 μM), NH_4 (4.74 μM) and Si (6.12 μM) were measured in the innermost part of the bay. Lower salinity values observed in this region indicate the direct injection of the nutrient rich freshwater to the inner bay. Chlorophyll-a concentration (in range 0.04 μg/l and 3.01 μg/l) and phytoplankton abundance (in range 2.5x10^4 cells/l and 3x10^7 cells/l) also made peaks in this productive region. Due to the high photosynthetic activity, dissolved oxygen increased up to 10.27 mg/l in July 2010 (Figure 3.22).

Heterotrophic bacteria, *Synechococcus* and flagellates were also found in higher concentrations in the inner bay which is less saline and rich in nutrients with maximum values of 3.2x10^6 (5.91 μgC/l) for heterotrophic bacteria, 4.5x10^3 cells/ml and 0.07 μgC/l for *Synechococcus* and 3.7x10^3 cells/ml for flagellates. Nutrient concentrations were found even below the detection limits due to the rapid uptake by higher amount of primary producers. Significant positive correlations were observed between heterotrophic bacteria, *Synechococcus* and flagellate abundance and temperature and inversely a significant negative correlation with salinity. Similarly, significant correlations also existed within the biological groups studied and within physical and chemical properties measured at surface. Detailed results of rank correlations are provided in Appendix B, page 147.

3.1.16. Vertical distributions in July 2010

Vertical distributions of all parameters being studied are shown in Figure 3.23 for the given transect. A pronounced vertical temperature gradient was observed in July. Prior to thermocline formation, sea water started to warm up and about 8°C temperature gradient was observed from surface to 65 m depth. As can be seen in the Figure 3.23 fresh water input is limited in the inner bay. High abundances of heterotrophic bacteria, *Synechococcus*, flagellates and phytoplankton were observed in this nutrient rich part of the bay. There was a remarkable difference in chlorophyll-a content of the inner bay and the outer bay.

The upper part of the water column was occupied by the organisms effectively but not continuously. Similar to August 2009, in July 2010 higher nutrient concentrations were observed near the bottom, and this nutrient was used by primary producers and a similar high trend was also observed for chlorophyll-a near the bottom. Deep water contained lower dissolved oxygen and there is also an increase just below the temperature gradient (Figure 3.24).

Changes in abundance of heterotrophic bacteria, *Synechococcus* and flagellates within different depth strata are shown in Figure 3.24. Figures clearly indicate that all groups were most abundant in the 0-20 m depth stratum followed by others in an order, with increasing depth. Highly significant positive correlations were observed between heterotrophic bacteria, *Synechococcus* and flagellate abundance and temperature and inversely a highly significant negative correlation with salinity. Similarly, significant correlations also existed within the biological groups studied and within physical and chemical properties measured at surface. Detailed results of rank correlations are provided in Appendix B, page 147.

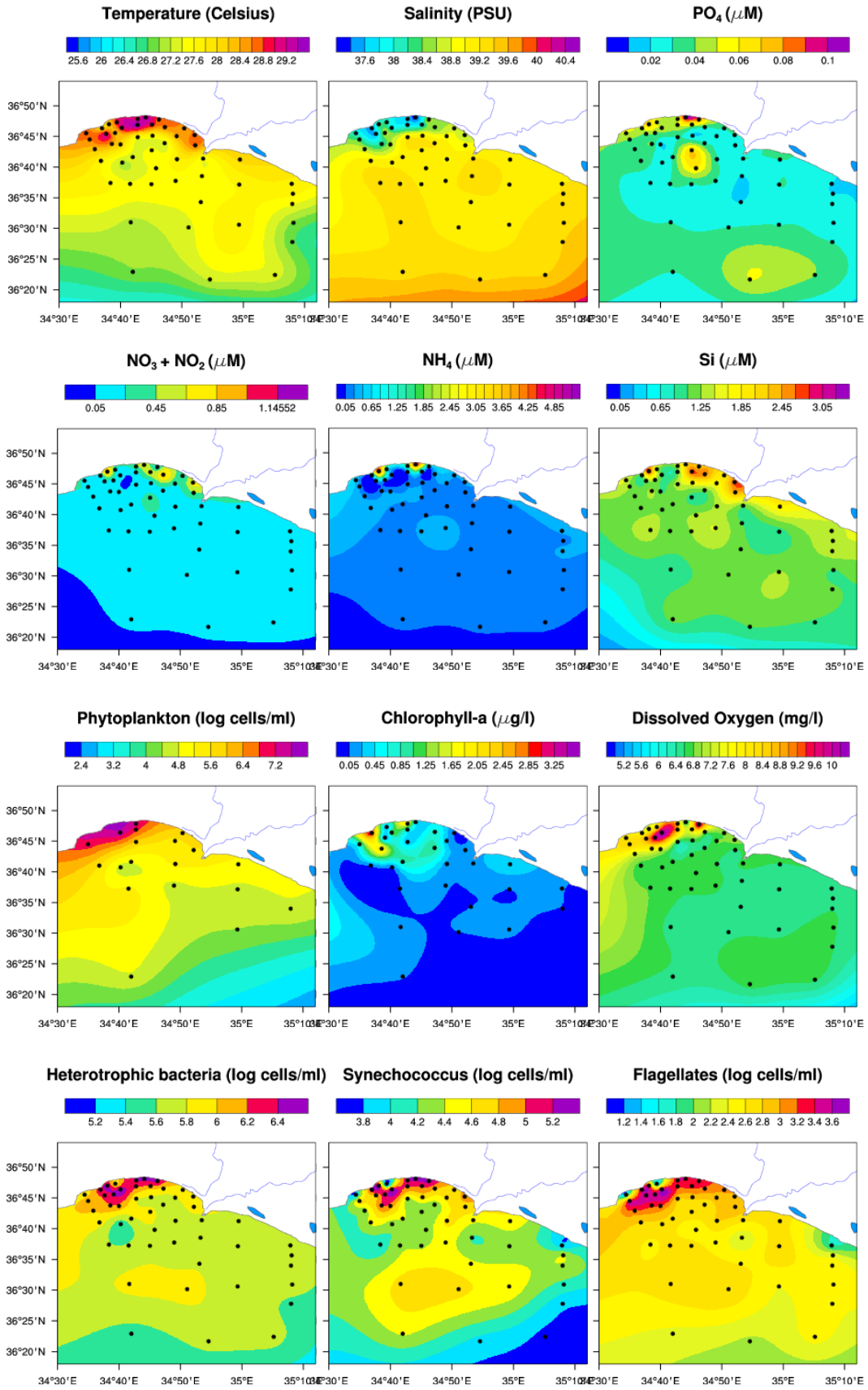

Figure 3.22. Surface distributions of physical, biological and chemical parameters in July 2010.

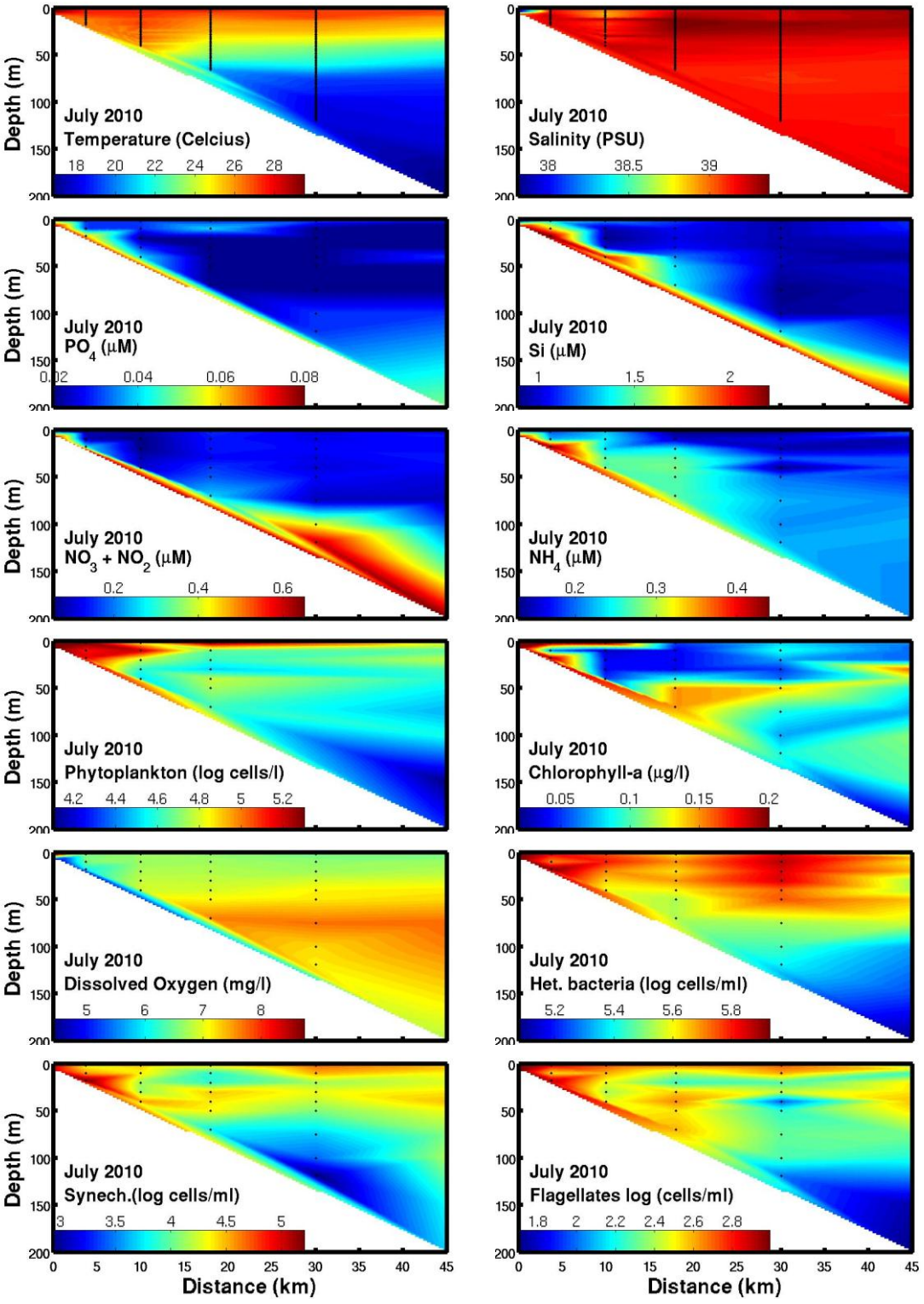

Figure 3.23. Vertical distributions of physical, biological and chemical parameters in July 2010.

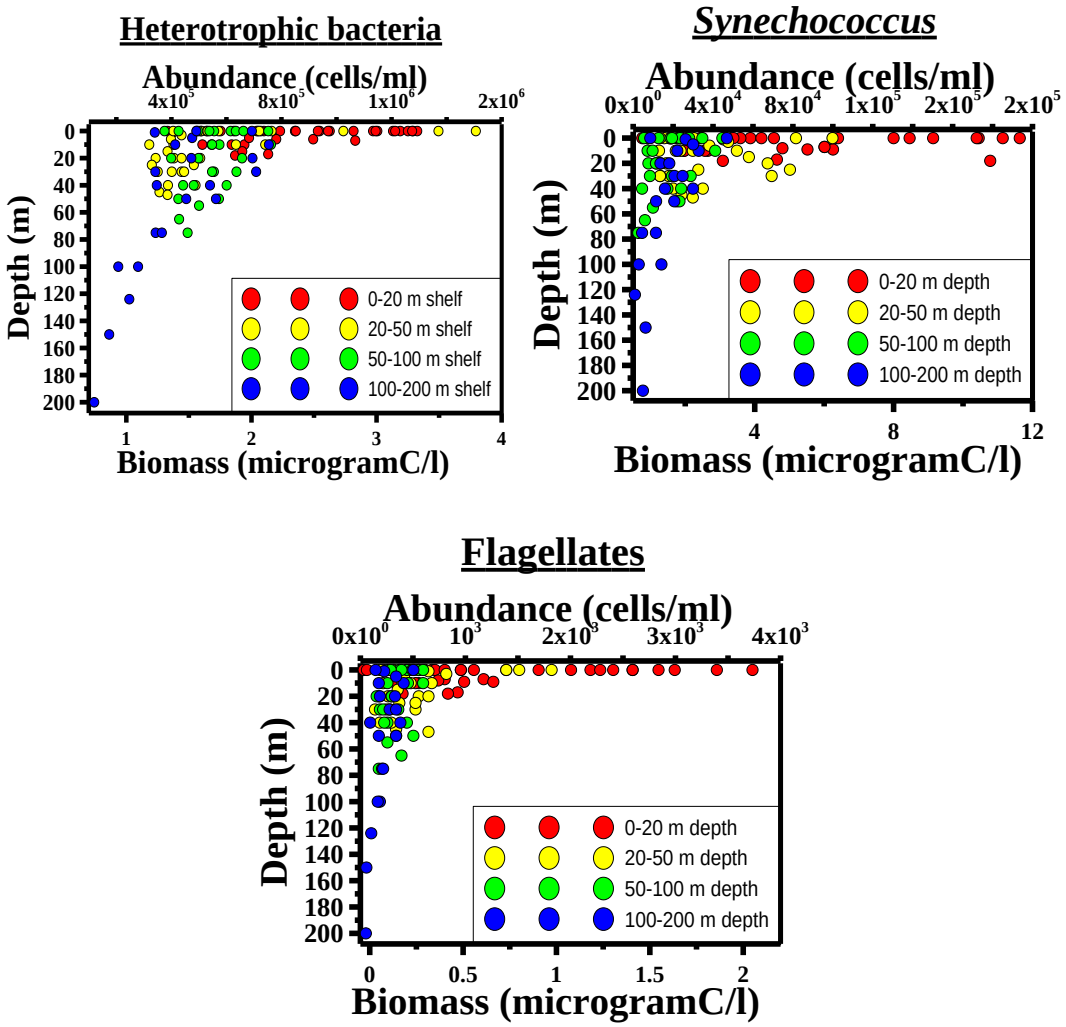

Figure 3.24. Abundance distribution of heterotrophic bacteria, *Synechococcus* and flagellates in different depth strata in Mersin bay in July 2010.

3.2. Seasonal and inter-annual comparisons

3.2.1. Hydrographic variability

3.2.1.1. Temperature

Hydrographic variations in the northeastern Mediterranean are generally driven by the general circulation pattern of the basin (Özsoy et al., 1993). The variations in the turbulent regime, mixed layer depth, temperature and salinity all affect the magnitude and the fate of biological processes. Temperature varied seasonally in Mersin Bay, with lowest temperatures occurring in winter, and highest temperatures during late summer. Seasonal surface temperature distributions

within the same scale in Mersin Bay were shown in Figure 3.25. Sea surface temperature ranged between 28.97^{0}C - 30.65^{0}C in September 2008, 14.45^{0}C - 19.12^{0}C in February 2009, 19.06^{0}C - 21.48^{0}C in April 2009, 29.23^{0}C - 31.43^{0}C in August 2009, 24.93^{0}C - 26.28^{0}C in October 2009, 15.05^{0}C - 17.84^{0}C in February 2010, 18.17^{0}C - 19.81^{0}C in April 2010 and 26.85^{0}C and 29.87^{0}C in July 2010. Almost a 17^{0}C temperature gradient did exist between winter and summer.

In September 2008, the inner bay was slightly warmer (about 2 ^{0}C) than the outer bay. This also implies the rate of exchange of inner bay waters with the offshore ones. Greater the temperature (or salinity) difference means less the exchange of waters. Inversely, invasion of relatively colder waters of the inner bay was observed during February 2009. In general cooling and warming of coastal waters happen in relatively short time scales compared to offshore waters. Only in winter coastal water was colder than offshore. Starting from April surface waters continue to warm up yielding maximal temperature gradient within the sunlit water column towards late summer. Following this period, it starts to cool down from surface towards lower depths forming thermocline below the surface mixed layer during fall. This cycle of warming and cooling events terminate during winter when the water column becomes thoroughly mixed from surface to bottom in the shelf area. The temperature of the river waters also help modify the near surface temperature of the drainage areas (Figure 3.25).

Seasonal vertical distributions of temperature within the same scale were shown in Figure 3.26. In September 2008, a well-defined thermocline formation situated at a depth of 30-40 m was observed in the water column deeper than 60 m and temperature was vertically homogenous in the zone shallower than 40 m. Water column remains thoroughly mixed from December till March in Mersin Bay (Uysal, 2010). Sea water was observed totally mixed in February 2009 and upper layer started to warm up in April 2009. With increasing irradiance the surface water started to warm up and the temperature gradient became much wider with depth during summer. In August 2009 there is a 16 ^{0}C temperature gradient between the

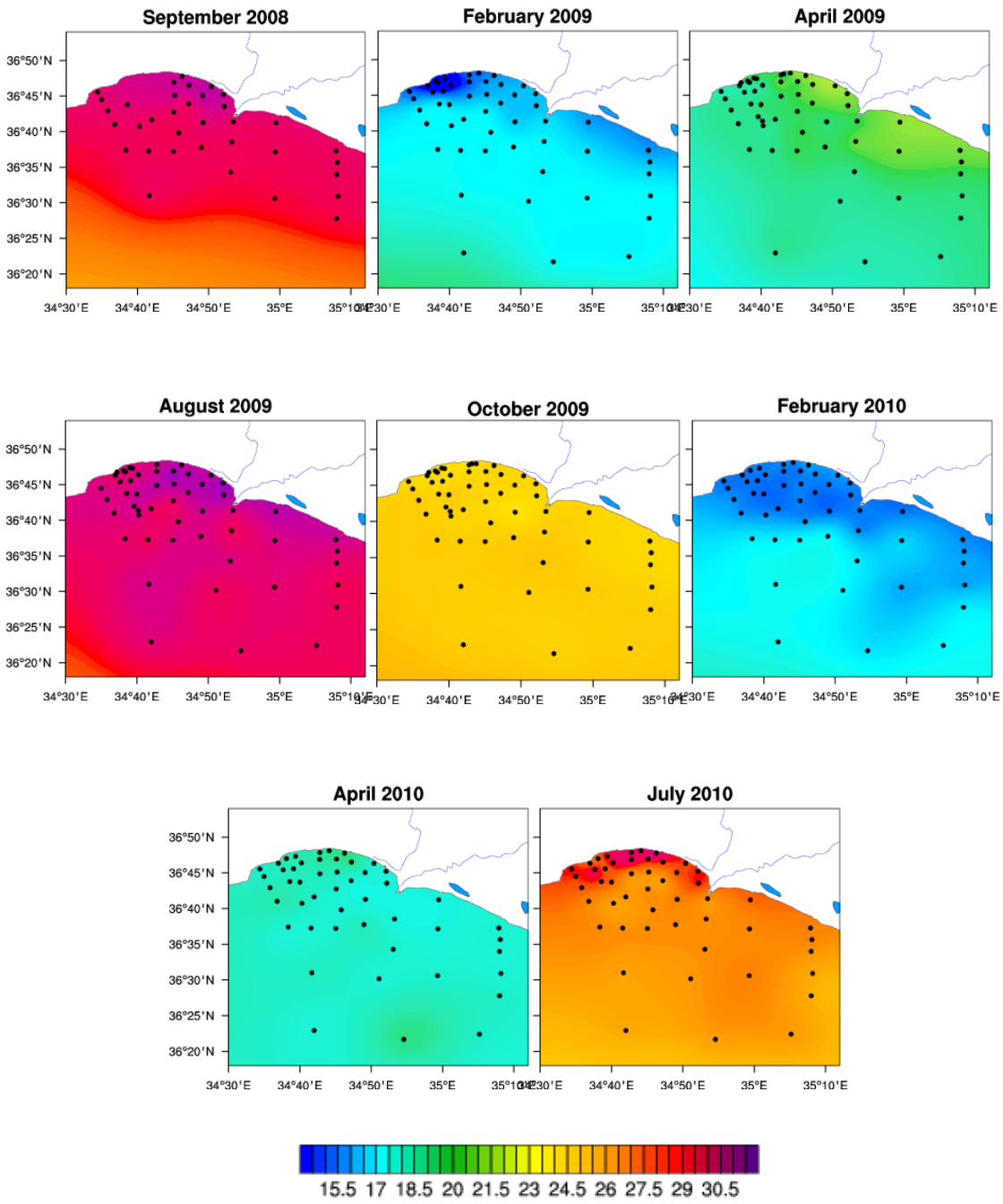

Figure 3.25. Changes in surface temperature (all drawn at a constant scale; 14.75-31.43 ^{0}C) in Mersin Bay.

upper and lower layers. In October 2009, a well defined thermocline was observed between the depths of 40 - 50 m. Similar to February 2010, water column was thoroughly mixed in February 2010 and surface water started to warm up again in Spring 2010. In July 2010, the temperature gradient which was less stronger than as in August 2009 was formed (Figure 3.26).

As can be seen from the Figure 3.27 the highest abundance of heterotrophic bacteria at surface was observed during the summer followed by the fall period. Lower values observed in summer belong to shallower depths with relatively colder waters. The population sizes in winter and spring tend to remain similar both at surface and in the water column in the area.

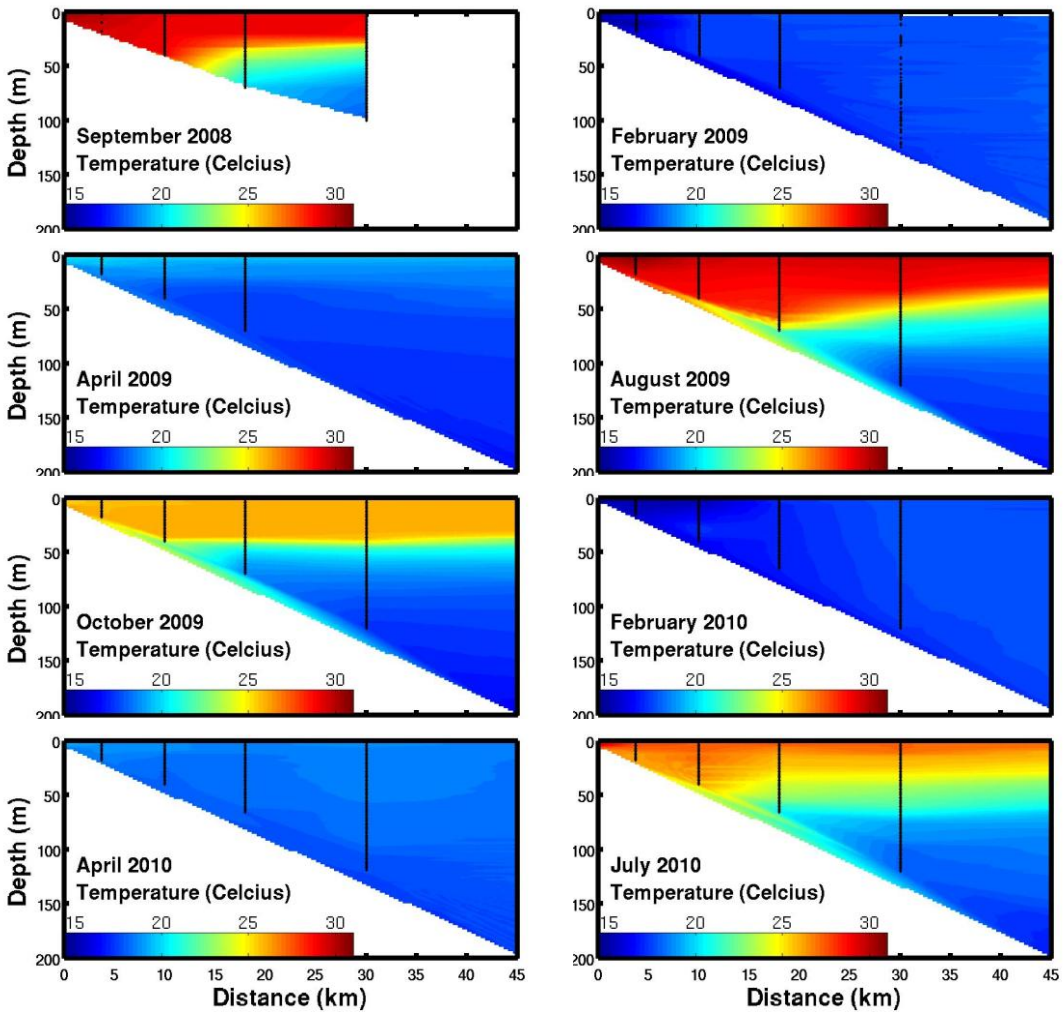

Figure 3.26. Observed temperature profiles (all drawn at a constant scale; 14.5-31 ^{0}C) in Mersin Bay.

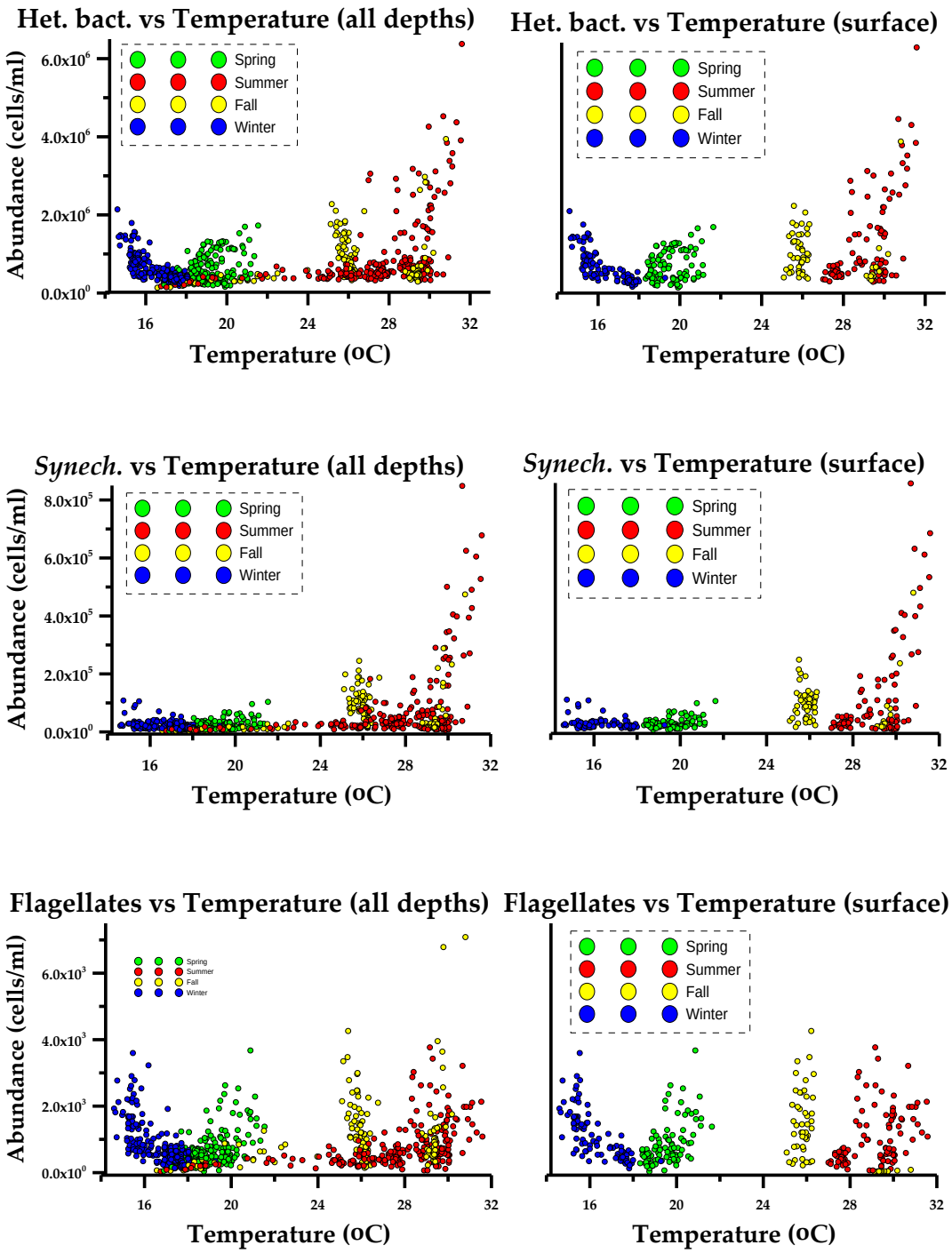

Figure 3.27. Heterotrophic bacteria, *Synechococcus* and flagellates versus temperature

The highest abundance gradient between the shore and the offshore water was observed in summer. This situation was also true for the *Synechococcus* as well as to a lesser extent to flagellates. *Synechococcus* abundances reach peak levels during summer as observed elsewhere (Agawin et al., 2000). The magnitude of change in abundance was greater in summer and in fall compared to winter and spring.

Flagellate abundances fluctuated within similar ranges throughout the year (Figure 3.27).

Based on Spearman's rank correlation analysis, significant positive correlations were found the organism groups studied and temperature in spring, summer and fall seasons whereas significant negative correlations were found in winter since the inner bay is always rich in nutrients. Hence highest abundance values were always recorded in the inner bay which is colder in winter and warmer in spring, summer and fall. Detailed results of rank correlations are provided in Appendix B, page 148.

3.2.1.2. Salinity

Freshwater discharges via major rivers, rainfall, domestic discharges, ground water, evaporation and exchange with more saline offshore waters all take part in regulating salinity budget of the area. Changes in surface salinity in time in the area are illustrated in Figure 3.28. Sea surface salinity varied in ranges 38.76 - 39.84 psu in September 2008, 36.65 - 39.43 psu in February 2009, 32.81 - 39.18 psu in April 2009, 37.77 - 39.69 psu in August 2009, 37.80 - 39.65 psu in October 2009, 35.45 - 39.23 psu in February 2010, 34.8 - 39.21 psu in April 2010 and 36.68 - 39.40 psu in July 2010. Salinity gradient was greater during late winter and spring due to increased freshwater input from major rivers to the basin. River discharges make peaks during late spring early summer as a result of melting snow in Taurus Mountains in the meantime.

In almost all seasons the shallow coastal sector (inner bay) has retained most of the lower salinity waters of river origin compared to offshore waters. Elevated surface salinities observed during dry summer and fall periods in the basin are mainly due to excess evaporation that occurs in the meantime. This situation reverses during winter and spring with increasing river discharges and rainfall (Figure 3.28).

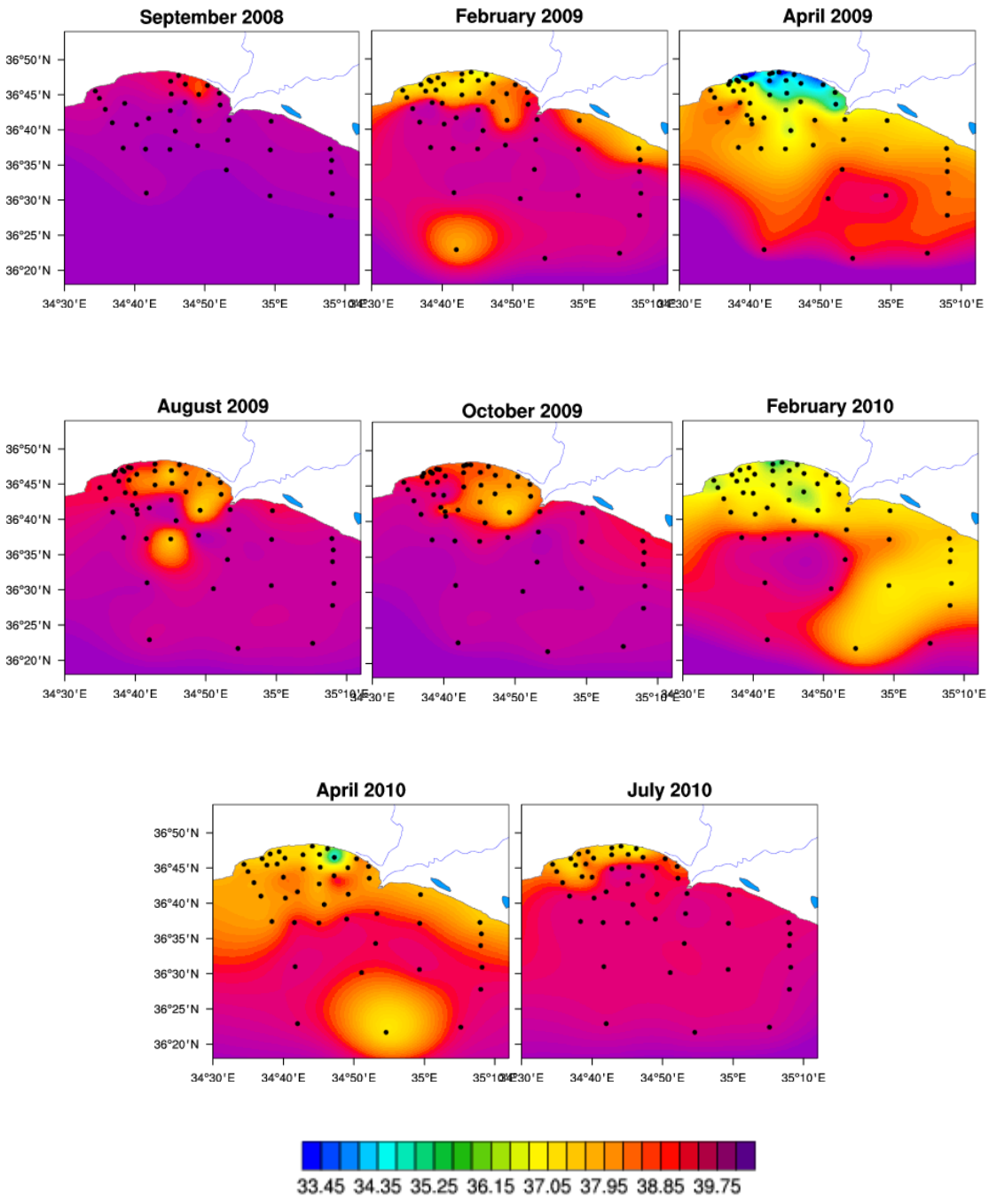

Figure 3.28. Changes in surface salinity (all drawn at a constant scale; 33.45 - 39.84 PSU) in Mersin Bay.

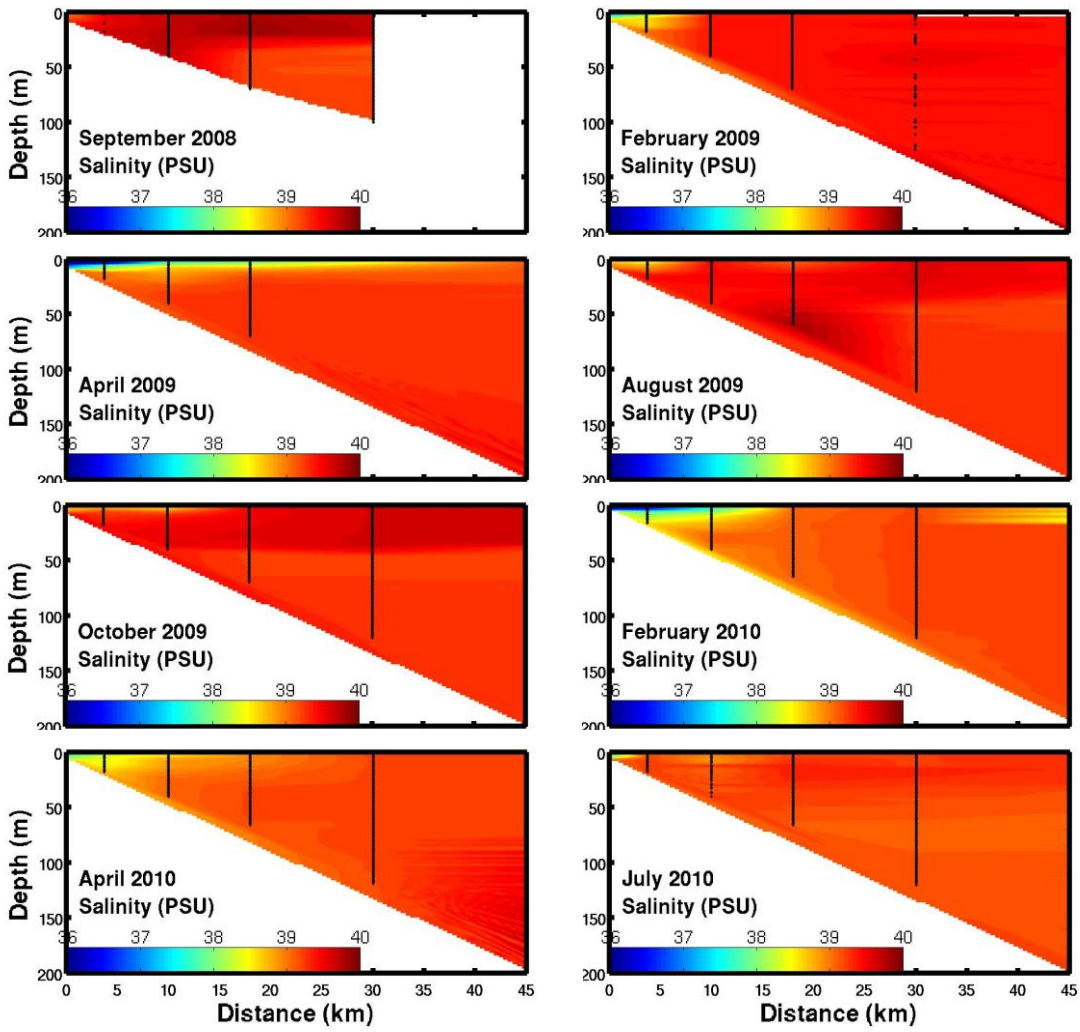

Figure 3.29. Observed salinity profiles (all drawn at a constant scale; 36-40 PSU) in Mersin Bay.

Changes in water column salinity along the given transect are shown in Figure 3.29. Parallel to thermocline formation, a well-defined halocline formation at 30-40 m was observed from the depth profiles of salinity along the selected transect in September 2008. With intensive winter mixing, salinity showed a uniform vertical distribution in February 2009 and with increasing freshwater input in April 2009, lower salinity values were observed only in the upper few meters of the water column.

An increase in abundance of all groups with increasing salinity during summer and fall is observed in the area (Figure 3.30). In contrast to *Synechococcus* a decreasing trend in numbers of heterotrophic bacteria and flagellates with increasing salinity during winter and spring was observed.

Based on rank correlation analysis, significant negative correlations were always found between the organism groups and the salinity. Within the salinity ranges of 37-39 psu both the *Synechococcus* and heterotrophic bacteria seemed to be most promoted. Variations in flagellate abundances were minor against the observed salinity gradient when compared to other groups. Detailed results of rank correlations are provided in Appendix B, page 148.

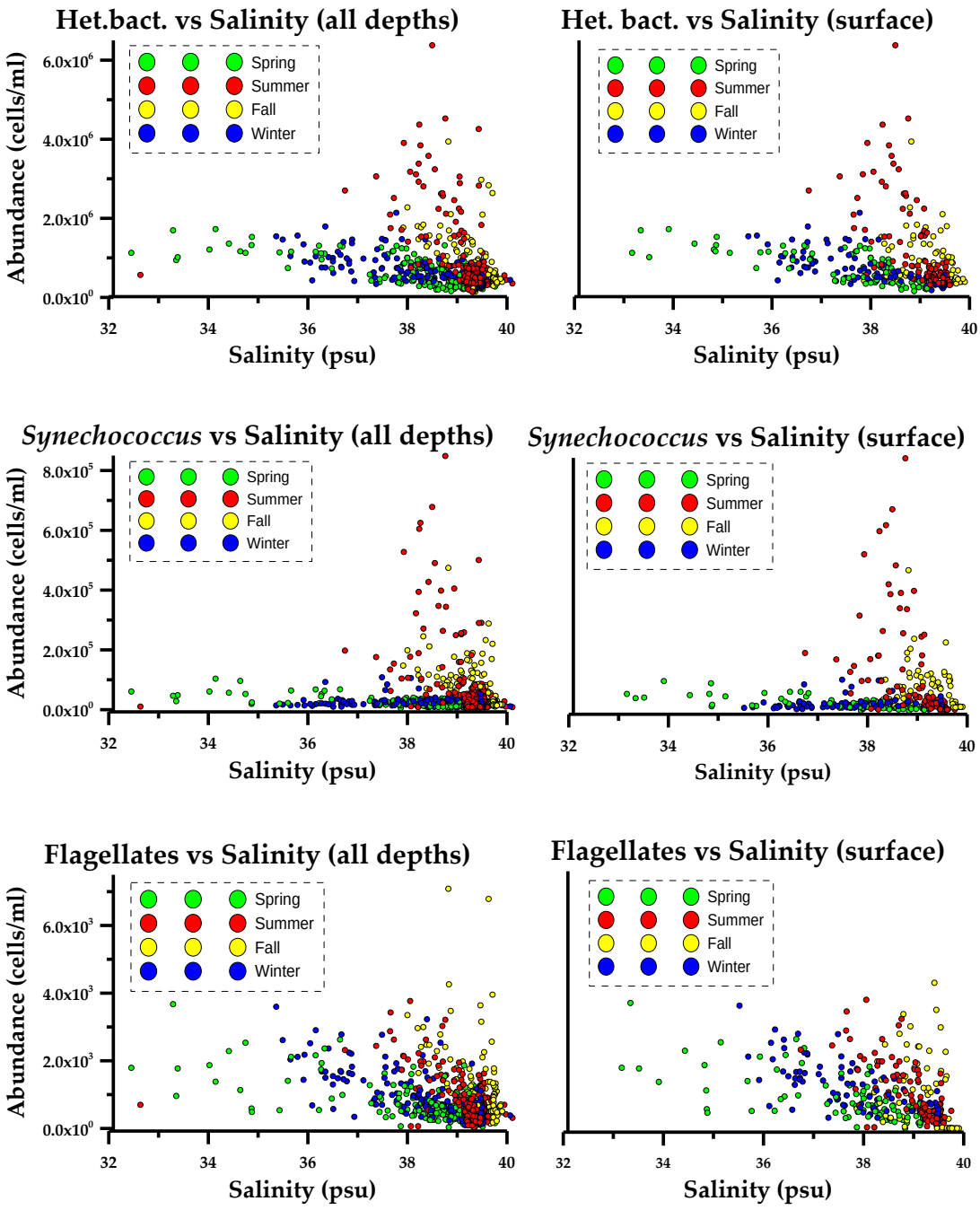

Figure 3.30. Heterotrophic bacteria, *Synechococcus* and flagellates versus salinity.

3.2.2. Nutrients

The three most important nutrients are fixed nitrogen (NO_3^-), phosphorus as phosphate (PO_4^{3-}) and dissolved silica making up the organic matter however supplies of nitrogen, phosphorus and silicon in forms that are biologically utilizable are not always available. They are most heavily utilized in the photic zone, where their availability can limit production, and they can be almost totally depleted in surface waters (James, 2005).

Since the Mediterranean has been known as the most oligotrophic surface waters in the world and it is especially impoverished in primary nutrient elements (Krom et al., 1991; Yılmaz and Tuğrul, 1998), high nutrient inputs which come from domestic effluents which are not treated biologically, Seyhan River and Tarsus Çayı discharges that are polluted by Çukurova Region waste waters and rainfall makes Mersin Bay shelf water one of the most productive region in eastern Mediterranean. Urban discharge point (Figure 2.1) is close to the coast and also shallow and this prevents it to be diluted and transported to the offshore (Tuğrul et al., 2009).

Seasonal thermocline forms in Mersin Bay during autumn. Thermal or salinity differences in the surface layer can produce vertical gradients in density that effectively retard the vertical fluxes of soluble nutrients from depth. Thus, in the surface layers of a stratified water column, nutrients become depleted as the photoautotrophs consume them at rates exceeding their rate of vertical supply (Falkowski and Raven, 2007 and references therein).

According to the results and evaluations in the previous section, it has been found that all the distribution patterns of heterotrophic bacteria, *Synechococcus* and flagellates were closely related to the land based nutrient input and its distribution patterns in Mersin Bay. PO_4, NH_4, NO_3+NO_2 and Si are the nutrients which stimulate primary production or are affected by primary production. Distribution of

the nutrients, at surface and along the selected transect, were evaluated on seasonal and inter-annual base in this section to see the interactions between their availability and picoplankton and flagellates variability for the eight field surveys representing eight seasons surveyed between 2008 and 2010.

Phosphorus is one of the essential elements for all living organisms. In a pelagic plankton food web, dissolved phosphorus is taken up by osmotrophs (e.g., heterotrophic bacteria and phytoplankton) and then transferred through the food web via trophic interactions. Recent studies have suggested phosphorus as the most limiting nutrient also in the Mediterranean Sea (Krom et al., 1991; Zweifel et al., 1993; Thingstad et al., 1998; Zohary and Robarts 1998).

It has been reported before that surface phosphate concentrations in Mersin Bay varied in the range 0.02 – 0.3 μM with annual surface average 0.05 μM for offshore station with 200m depth (Uysal and Köksalan, 2010) and the annual mean concentration for phosphate was 0.06 μM with a maximum level of 0.15 μM for coastal station (Uysal and Köksalan, 2006). Zenginer and Beşiktepe (2010) also found PO_4 concentrations ranging between 0.02 (in June 205) and 0.27 μM (in March 2005) in Mersin Bay.

Seasonal surface distributions of PO_4 concentrations within the same scale were shown in Figure 3.31. Parallel to previous researches PO_4 concentration found at highest levels in shelf waters and declined towards the open sea indicate that PO_4 sources in the Mersin Bay are mainly originated from riverine and urban discharges. Annual mean water discharge for Seyhan River and Tarsus Çayı were found to be 168 and 6 m^3s^{-1}, respectively (Koçak et al., 2010).

Discharges of rivers show similar seasonality with highest values during spring. Concentrations of PO_4 were also widely distributed in higher concentrations during winter and spring seasons, concurrent with periods of increased river flow (Koçak et al., 2010).

During the study period, PO_4 concentrations varied in the range 0.02 and 1.68 μM in Mersin Bay. Higher concentrations of PO_4 were found in this study since the coastal areas which are close to the main sources of PO_4 (urban and riverine discharge points) were sampled. The maximum concentration was recorded in April 2009 when the river discharges were high and minimum values were found at offshore stations in all seasons. PO_4 concentrations at surface varied in ranges 0.02 - 0.26 μM in September 2008, 0.02 - 0.26 μM in February 2009, 0.02 - 1.68 μM in April 2009, 0.02 - 0.13 μM in August 2009, 0.02 - 0.21 μM in October 2009, 0.02 - 0.15 μM in February 2010, 0.02 - 0.26 μM in April 2010 and 0.02 and 0.10 μM in July 2010 (Figure 3.31).

Seasonal vertical distributions of PO_4 within the same scale along the selected transect in Mersin Bay were shown in Figure 3.32. PO_4 concentration was always found at highest levels in coastal stations along the selected transect and decreased gradually from shore to offshore. In summer and spring seasons, its concentrations were higher in the deep water since it was depleted in the photic upper layer. The maximum values recorded in spring were due to the higher riverine input. Since the Mediterranean is impoverished in PO_4, PO_4 was rapidly consumed and even depleted in the discharge area, and decreased to detection levels especially in summer.

Heterotrophic bacteria, *Synechococcus* and flagellates versus PO_4 were shown in Figure 3.33. In all seasons, PO_4 concentration was found significantly positively correlated with heterotrophic bacteria, *Synechococcus* and flagellates according to Spearman's rank correlation. Heterotrophic bacteria and *Synechococcus* showed strong seasonality both at surface and in vertical water column while flagellates did not. Detailed results of rank correlations are provided in Appendix B, page 148.

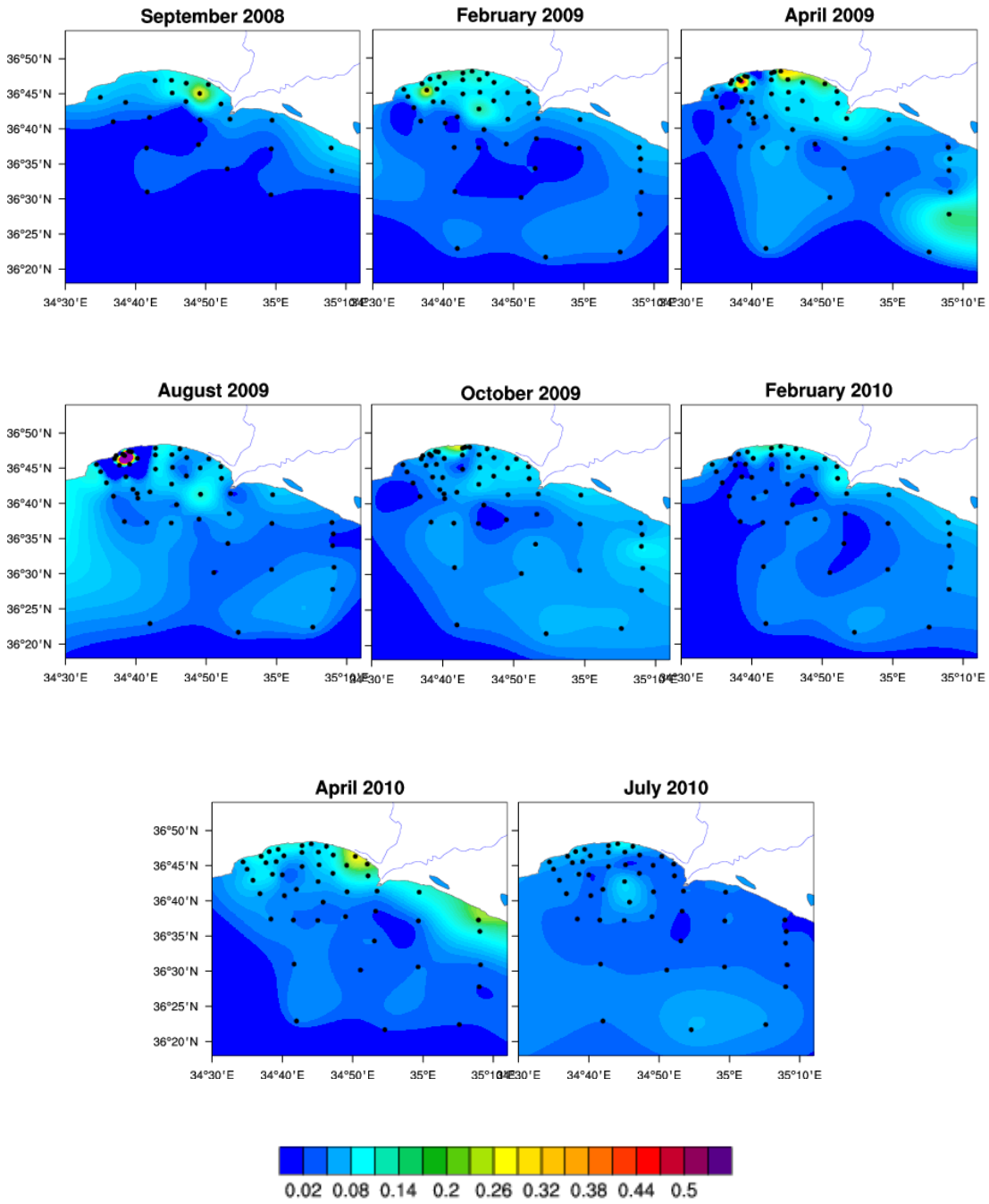

Figure 3.31. Changes in surface PO_4 concentrations (all drawn at a constant scale; 0.02 – 0.51 μM) in Mersin Bay.

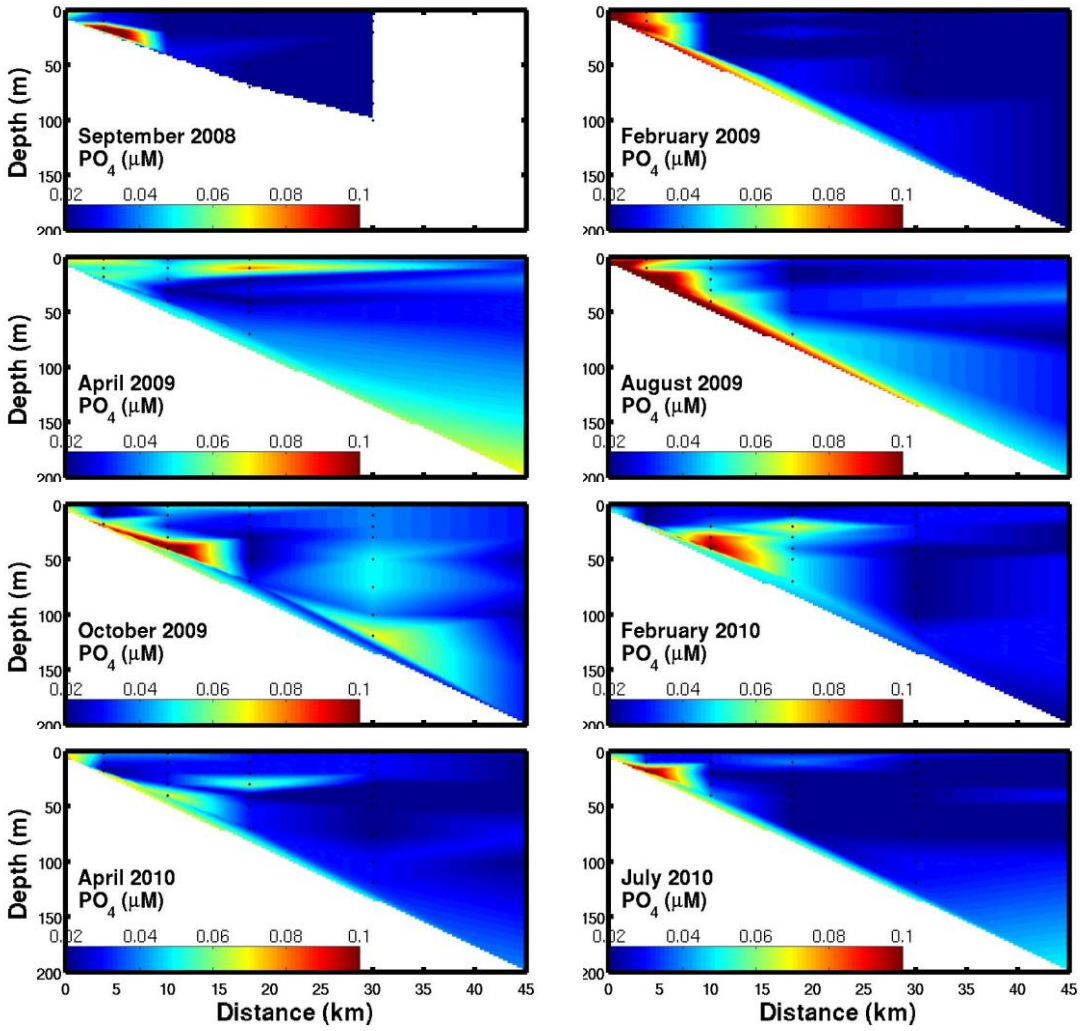

Figure 3.32. Observed PO_4 profiles (all drawn at a constant scale; 0.02 – 0.1 μM) in Mersin Bay.

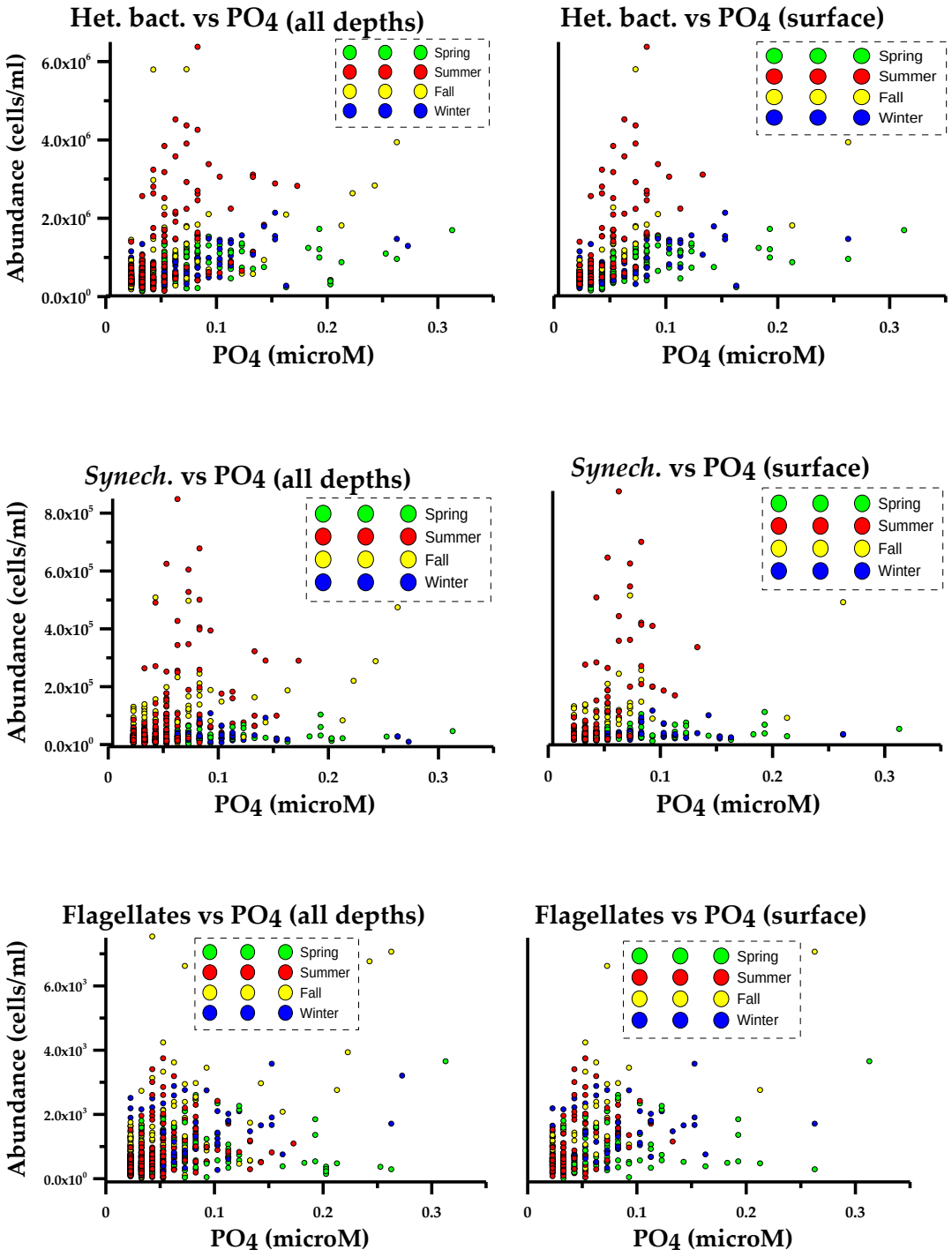

Figure 3.33. Heterotrophic bacteria, *Synechococcus* and flagellates versus PO_4.

N_2 in the atmosphere is converted to NH_4^+, mostly upper part of the water column via the action of prokaryotic nitrogen fixers (primarily cyanobacteria). The NH_4^+ is incorporated into photoautotrophs, which sink into the ocean. The subsequent heterotrophic oxidation of organic nitrogen provides free NH_4^+, which is oxidized through NO_2^- to NO_3^- by nitrifying bacteria. This is an oxygen consuming reaction. The reduction of NO_3^- to NO_2^- and subsequently to N_2O and N_2 completes the nitrogen cycle (James, 2005).

The presence of measurable ammonia in the photic zone while nitrate was close to or below detection limits suggests that grazing is an important process in this system since ammonia are the first products of microbial grazing and a very efficient grazing community is present that recycles bacterial and phytoplankton production rapidly (Thingstad et al., 2005). Relatively higher amount of NH_4 measured at surface water of Mersin Bay in August 2009 may indicate the effect of grazing on microbial community.

Seasonal surface distributions of NH_4 within the same scale were shown in Figure 3.34. During the study period, NH_4 concentrations in sea surface water was recorded between the ranges of 0.08 - 2.38 μM in September 2008, 0.05 - 5.93 μM in February 2009, 0.04 - 29.89 μM in April 2009, 0.05 - 4.24 μM in August 2009, 0.08 - 4.31 μM in October 2009, 0.06 - 6.77 μM in February 2010, 0.10 - 1.23 μM in April 2010 and 0.13 and 4.74 μM in July 2010. Generally, it reached the highest concentrations in shelf water which receives urban and river discharges and declined towards the open sea. In some productive regions NH_4 was found depleted and it may due the uptake of NH_4 by the organisms.

Seasonal vertical distributions of NH_4 within the same scale in Mersin Bay were shown in Figure 3.35. NH_4 was found at higher levels in coastal water and deep waters. It was found in lower concentrations in the upper layer and offshore waters except the higher values recorded at offshore station in August 2009. NH_4 concentrations were always found higher near bottom especially in the water

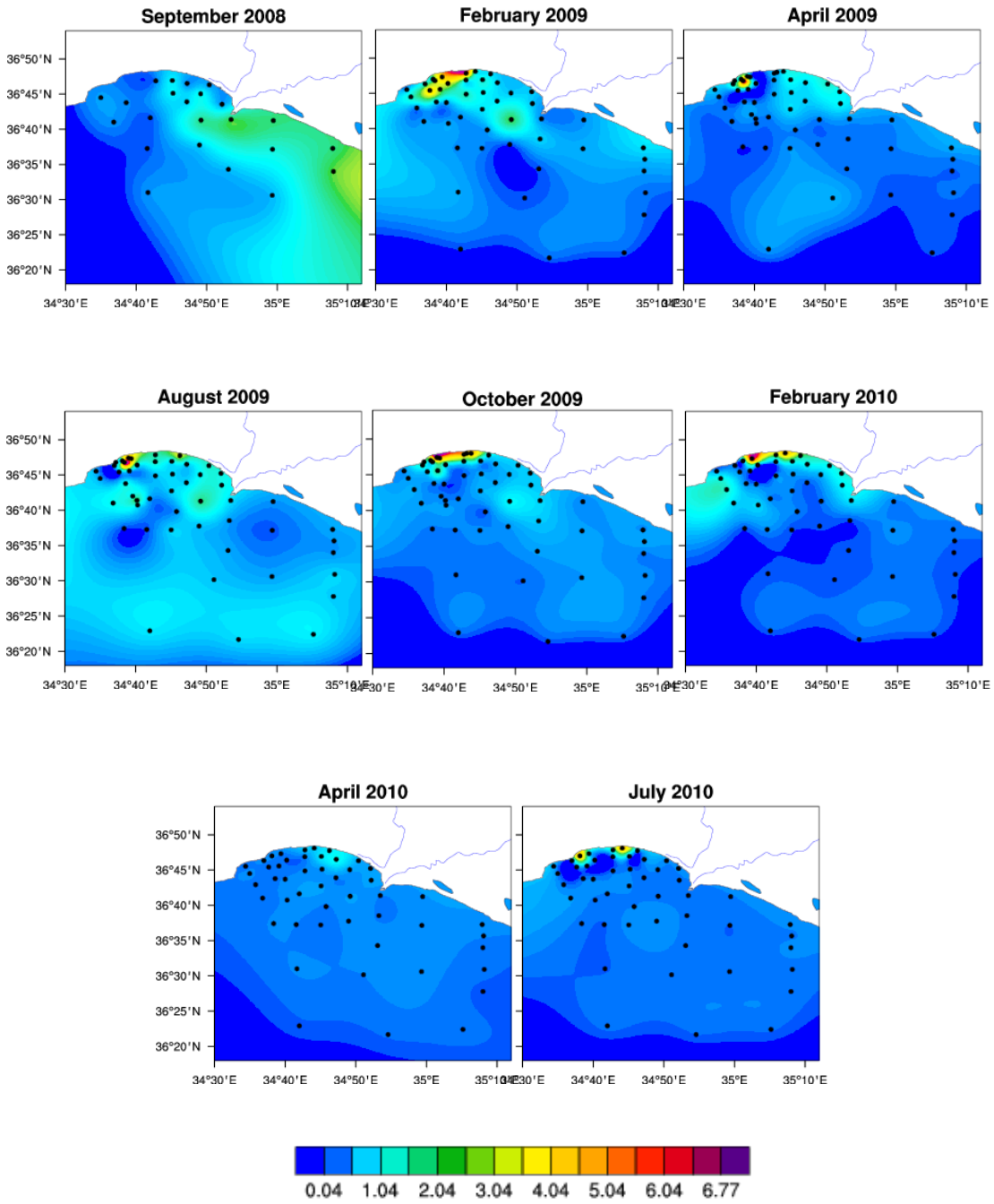

Figure 3.34. Changes in surface NH_4 concentrations (all drawn at a constant scale; 0.04 – 6.77 μM) in Mersin Bay.

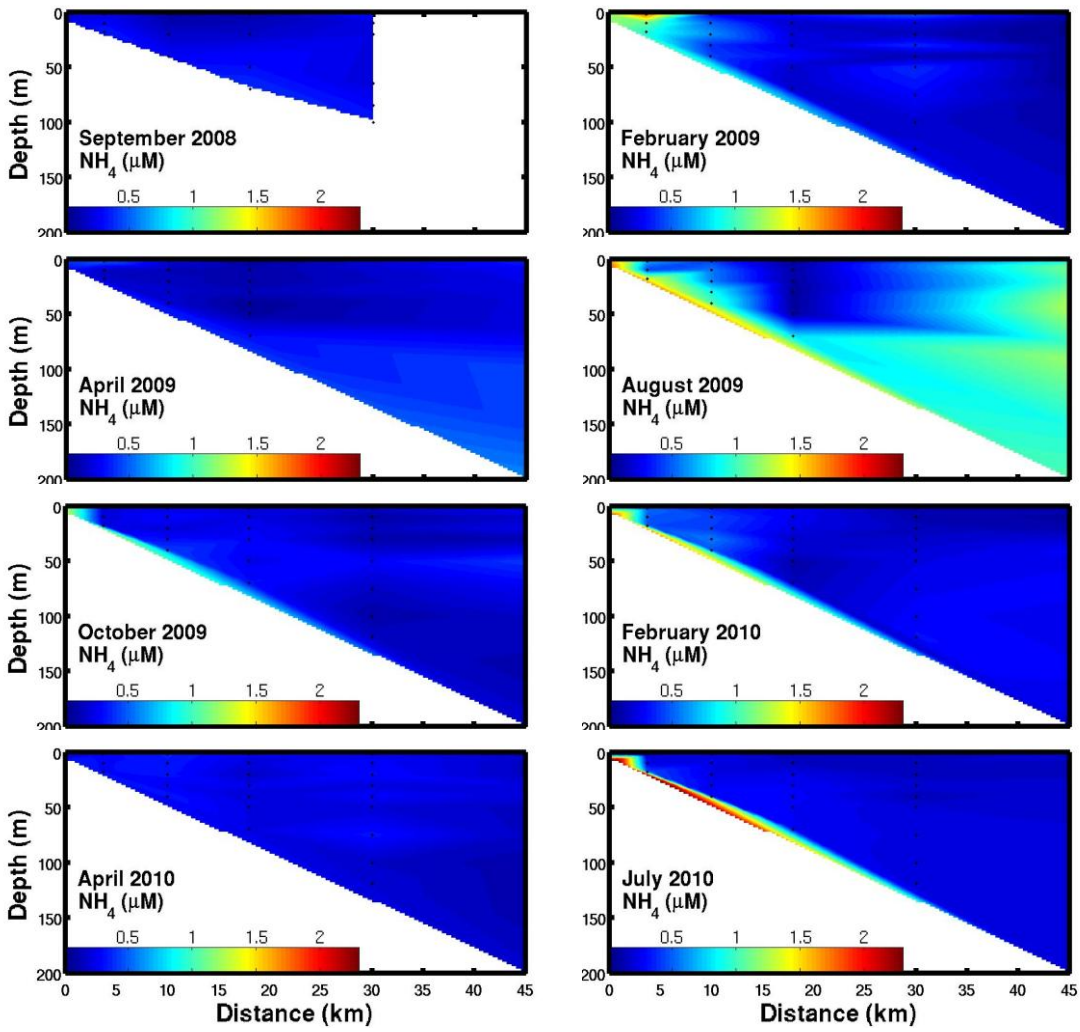

Figure 3.35. Observed NH_4 profiles (all drawn at a constant scale; 0.02 – 2.3 μM) in Mersin Bay.

column shallower than 100 m. In aquatic environments, ammonia is generated by heterotrophic bacteria as a primary end product of the decomposition of organic matter, either directly from proteins or from other nitrogenous organic compounds. Ammonia is also excreted by aquatic animals. However, this process is quantitatively minor in comparison to bacterial deamination. Since water column is well oxygenated, the released ammonia is oxidized to nitrate by heterotrophic bacteria in the water above the bottom (Satoh et al., 2001 and references therein). Significant amount of heterotrophic bacteria and the decrease in dissolved oxygen concentration observed in this region also support this idea. When compared to other seasons, higher amount of NH_4 were found to be accumulated above the

bottom in summer months during the study period. Parallel to these findings, comparatively higher amounts of heterotrophic bacteria and lower dissolved oxygen concentrations were found during the summer cruises.

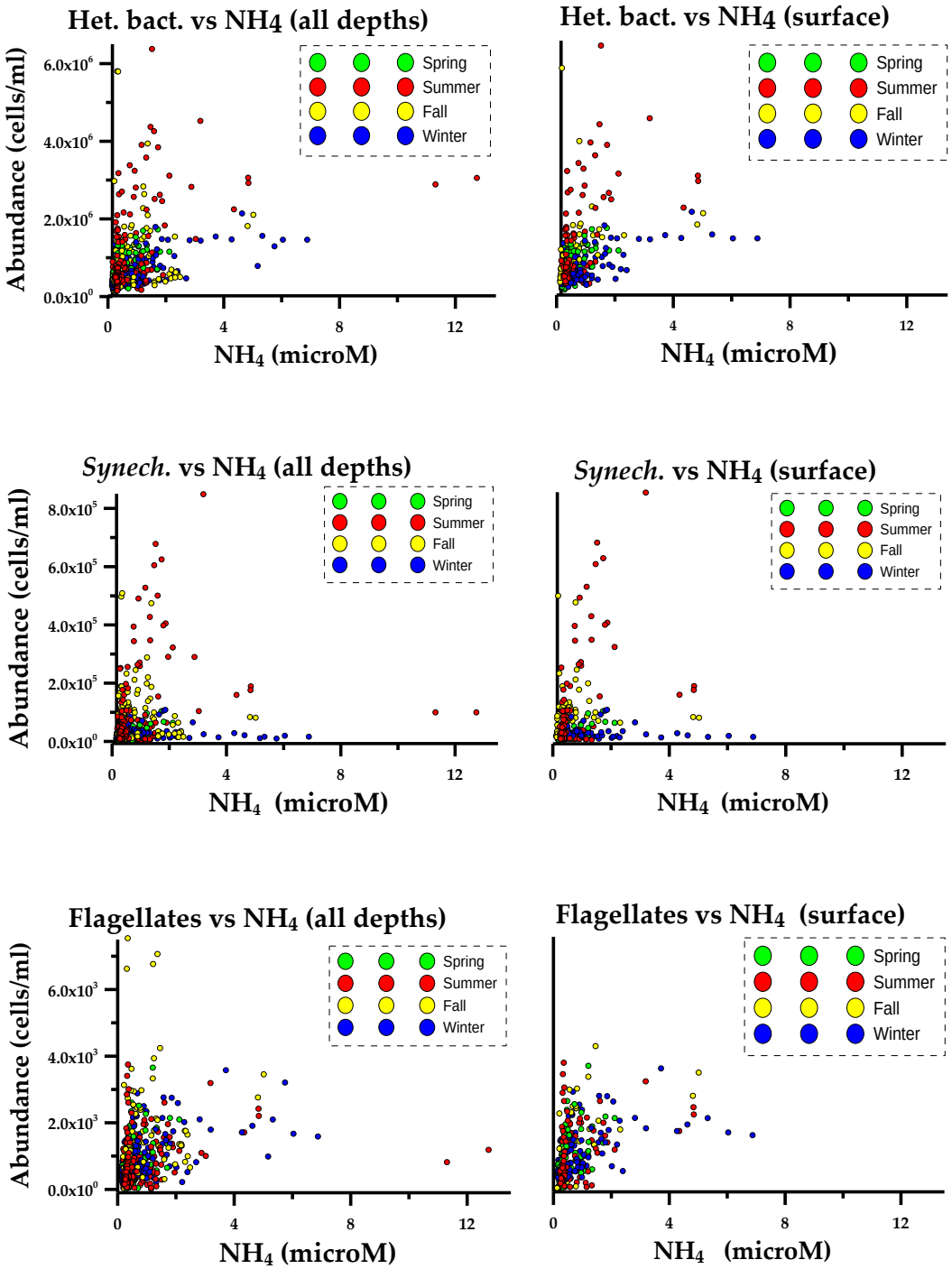

Figure 3.36. Heterotrophic bacteria, *Synechococcus* and flagellates versus NH_4.

It has been found that over a year, surface nitrate concentrations varied in the range 0.02 – 2.85 μM with annual surface averages of 0.6 μM for the offshore station (Uysal and Köksalan, 2010) and coastal stations the annual mean of nitrate was 0.98 μM (Uysal and Köksalan, 2006). Zenginer and Beşiktepe (2010) also found that the concentrations of NO_x varied in the range 0.06 (in July 2005) and 5.69 μM (in March 2005).

Seasonal surface distributions of NO_3+NO_2 concentrations in Mersin Bay were shown in Figure 37. According to the observations during two year cruise series, surface concentration of NO_3+NO_2 varied in the range 0.06 - 0.95 μM in September 2008, 0.06 - 14.39 μM in February 2009, 0.06 - 9.99 μM in April 2009, 0.05 - 2.32 μM in August 2009, 0.05 - 8.34 μM in October 2009, 0.08 - 17.2 μM in February 2010, 0.07 - 5.8 μM in April 2010 and 0.07 and 0.95 μM in July 2010. It reached the highest concentrations in both winter 2009 and winter 2010 cruises and to the lowest values at surface was recorded during the summer and fall.

Vertical distributions of NO_3+NO_2 concentrations along the selected transect in Mersin Bay were shown in Figure 38. Parallel to surface distributions, the highest concentrations were also found in coastal water during winter. NO_3+NO_2 concentrations were also recorded at higher values in deeper water. In spring 2009 and 2010, parallel to the decrease in temperature with depth decrease in abundance of primary producers especially of *Synechococcus* was observed. NO_3+NO_2 were found depleted in this part of the water column due to the uptake by primary producers.

Response of heterotrophic bacteria, *Synechococcus* and flagellates to NO_3+NO_2 are shown in Figure 3.39. According to the figures, in summer abundances of heterotrophic bacteria and *Synechococcus* were found higher at lower concentrations of NO_3+NO_2 and in winter they increased very slowly with increasing NO_3+NO_2 concentrations. Compared to *Synechococcus* and heterotrophic bacteria flagellates responded more efficiently to increase in NO_3+NO_2 concentrations during winter.

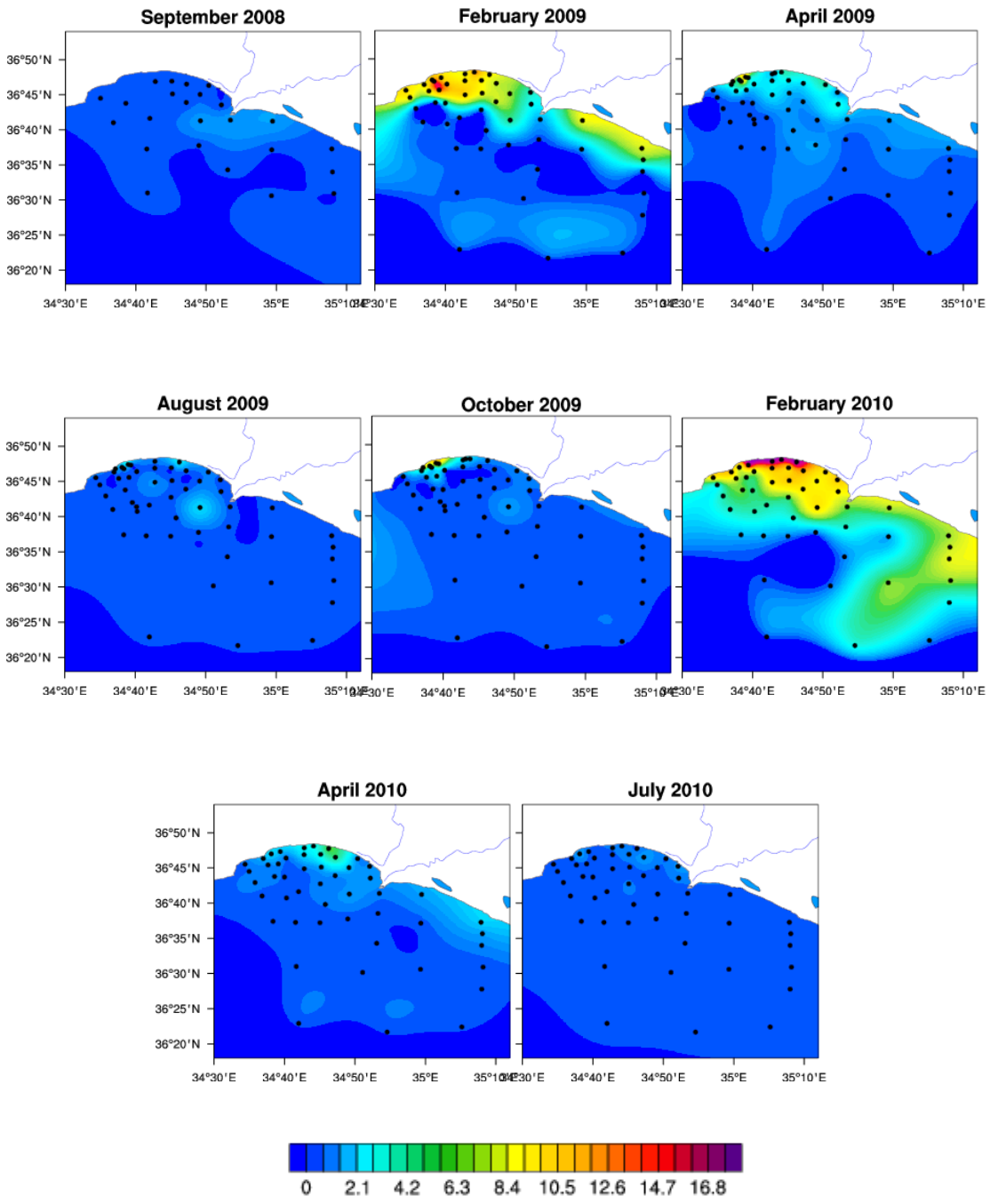

Figure 3.37. Changes in surface NO_3+NO_2 concentrations (all drawn at a constant scale; 0.02 – 17.2 μM) in Mersin Bay.

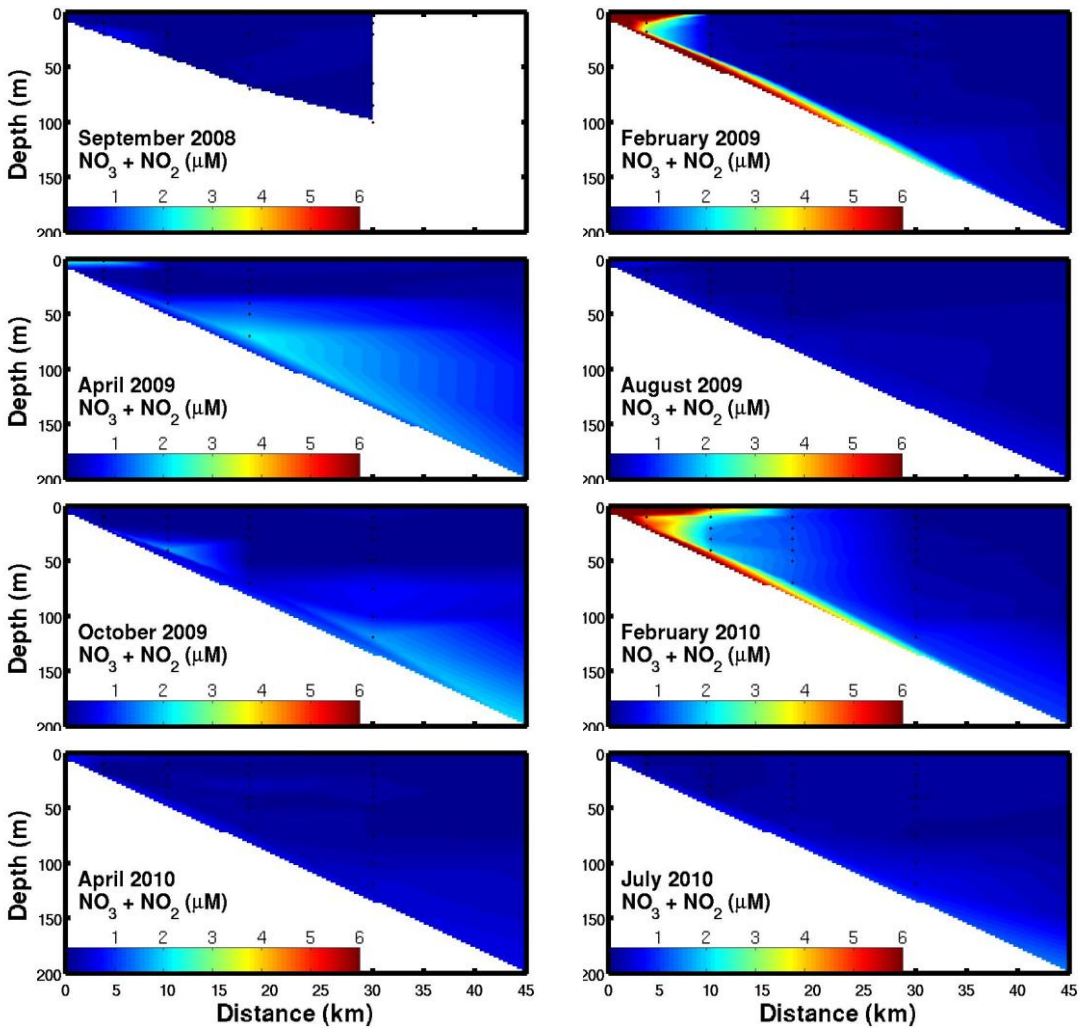

Figure 3.38. Observed NO_3+NO_2 profiles (all drawn at a constant scale; 0.02 – 6 μM) in Mersin Bay.

According to Spearman's rank correlation statistics, NO_3+NO_2 were significantly positively correlated with heterotrophic bacteria and flagellates at surface and in the water column and with *Synechococcus* only in the water column. Detailed results of rank correlations are provided in Appendix B, page 148.

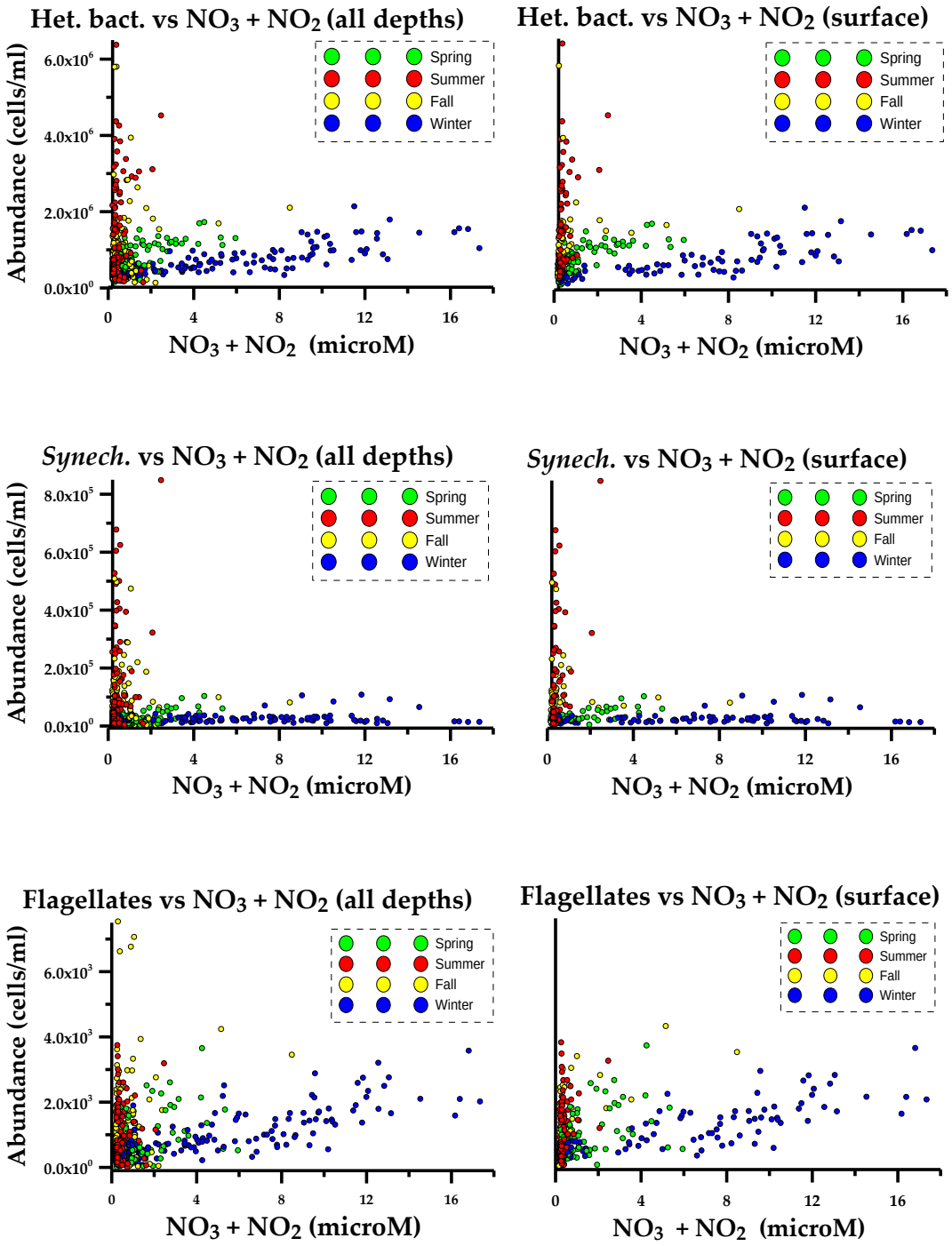

Figure 3.39. Heterotrophic bacteria, *Synechococcus* and flagellates versus NO_3+NO_2.

The biological Si cycle in the marine environment is relatively simple. Diatoms take up silicate, which they mainly incorporate as biogenic silica in their frustules.

Siliceous particles dissolve again to silicate. Thus, reduced inputs from rivers may reduce the primary production or alter the phytoplankton species composition (Kristiansen and Hoel, 2002). The oceanic silicon cycle is being revised following the discovery that colonizing bacteria cause postmortem dissolution of silica from diatom cell walls. These bacteria secrete proteases that denude the silica shell of its protective protein layer and enhance silica dissolution rates (Azam and Worden, 2004).

Seasonal surface distributions of Si in Mersin Bay within the same scale were shown in Figure 3.40. The highest Si concentrations at surface were found in April 2009 and February 2010. According to the observations during two year cruise series, sea surface Si varied in the range 0.73 - 6.24 μM in September 2008, 0.73 - 5.19 μM in February 2009, 0.63 - 14.78 μM in April 2009, 0.69 - 8.08 μM in August 2009, 1.08 - 5.33 μM in October 2009, 0.94 - 14.2 μM in February 2010, 18.17 - 19.81 μM in April 2010 and 0.95 and 6.12 μM in July 2010.

Si distribution was closely followed by phytoplankton abundance and chlorophyll-a distribution in all seasons during the study period. Dissolved oxygen was also found at high concentrations in this region due to the photosynthetic activity. The Si pool was almost exclusively dominated by riverine fluxes (90 %) and only 10 % of the Si was attributed to atmospheric source (Kocak, 2010). In this study the higher concentrations of Si close to the river discharge areas were found. Comparatively higher concentrations were recorded in February 2010 than February 2009 and in April 2010 than April 2009. Higher amount of Si was concentrated in deeper water in all seasons except spring (Figure 3.41).

As can be seen in the Figure 3.42 heterotrophic bacteria and *Synechococcus* were found in higher abundances at the same Si concentration levels. Heterotrophic bacteria, *Synechococcus* and flagellates significantly increased with increasing Si concentrations both at surface and in the water column. Heterotrophic bacteria and

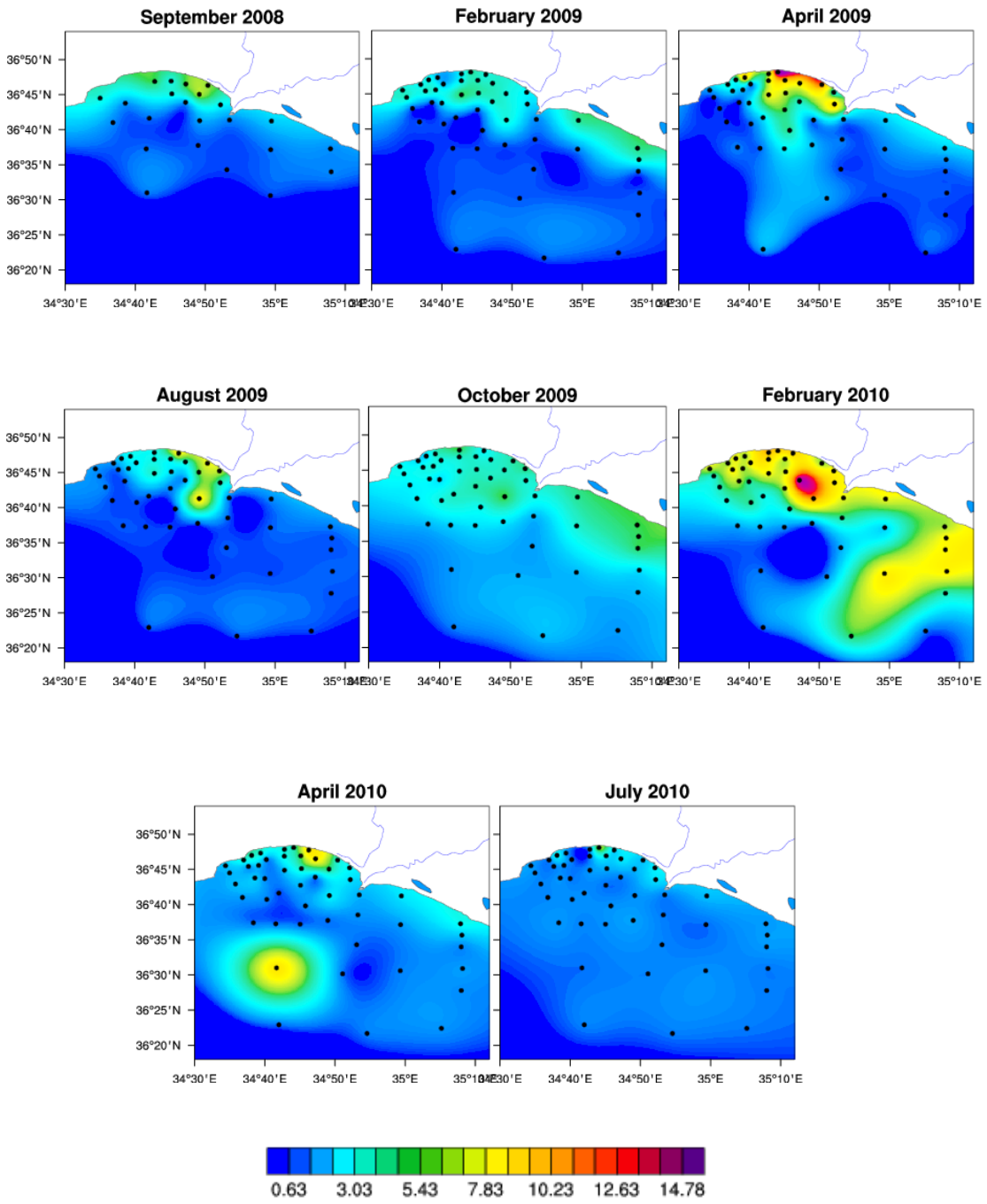

Figure 3.40. Changes in surface Si concentrations (all drawn at a constant scale; 0.63 – 14.78 μM) in Mersin Bay.

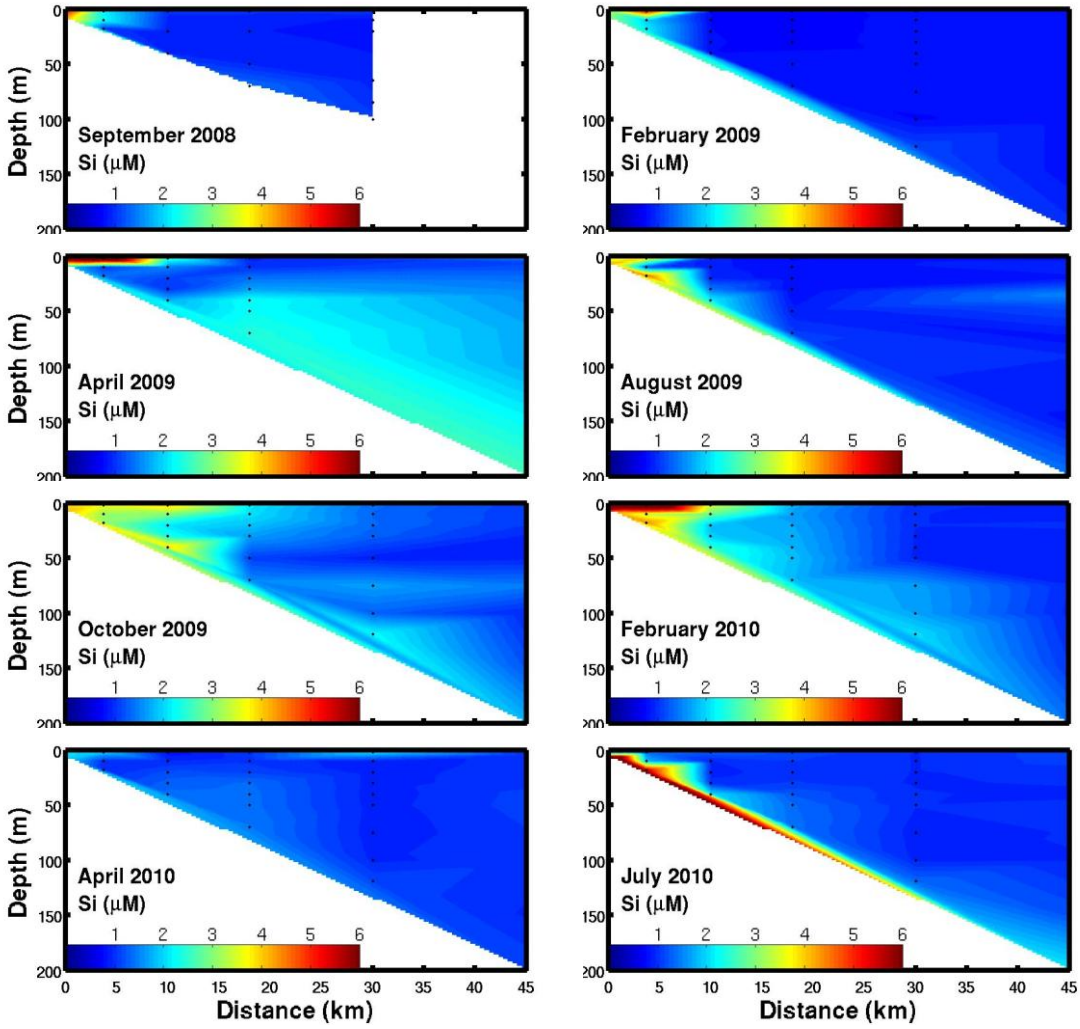

Figure 3.41. Observed Si profiles (all drawn at a constant scale; 0.02 – 6 μM) in Mersin Bay.

Synechococcus showed seasonality and this increase was high in summer and fall seasons and at lower levels in winter and spring. In case of flagellates, they distributed almost homogenously in all seasons. According to Spearman's rank correlation significant positive relationships were found between Si and heterotrophic bacteria, *Synechococcus* and flagellates. Detailed results of rank correlations are provided in Appendix B, page 148.

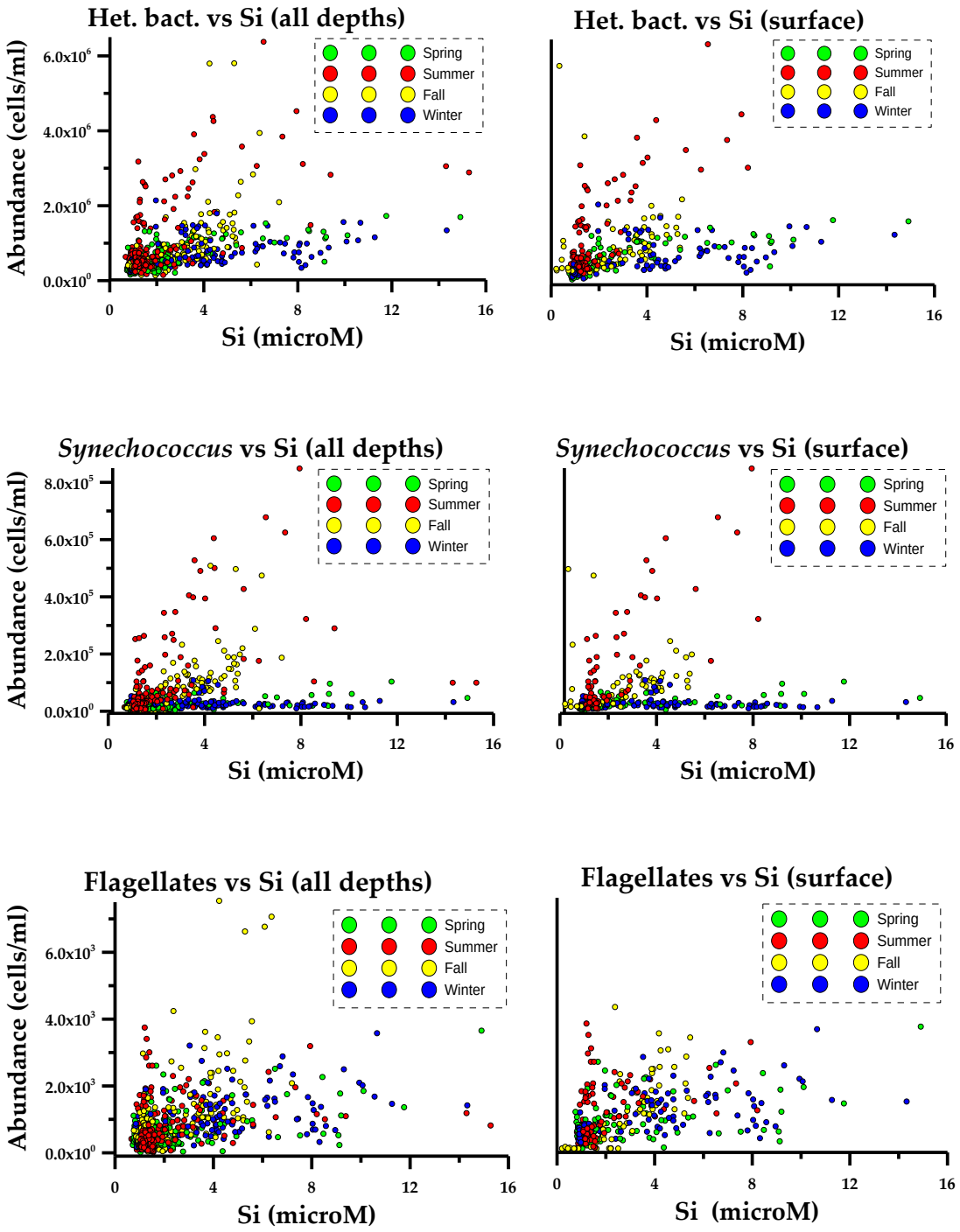

Figure 3.42. Heterotrophic bacteria, *Synechococcus* and flagellates versus Si.

3.2.3. Phytoplankton abundance, chlorophyll-a and dissolved oxygen

Changes in phytoplankton abundance and chlorophyll-a concentrations under varying nutrient regimes will be discussed hereafter. Lastly seasonal variations in dissolved oxygen contents of the water in relation to photosynthetic activity and impact of temperature on all groups will be given.

Variations in phytoplankton have been linked to light, macronutrient availability, temperature, salinity and zooplankton grazing in tropical and subtropical water systems (Fu and Bell, 2003a, b; Chen et al., 2004; Chen, 2005; Ramirez et al., 2005; Li et al., 2006).

According to the observations during two year cruise series, phytoplankton abundances varied in the range $1.8x10^4$ - $4.8x10^6$ cells/l in September 2008, $5.8x10^4$ - $2.1x10^6$ cells/l in February 2009, $5.5\ x10^4$ - $3.5\ x10^6$ cells/l in April 2009, $2.7x10^4$ - $2x10^6$ cells/l in August 2009, $4.1x10^4$ - $1x10^6$ cells/l in October 2009, $2.7x10^4$ - $6.1x10^6$ cells/l in February 2010, $6.4x10^4$ - $1.7x10^6$ cells/l in April 2010 and $2.5x10^4$ - $3x10^7$ cells/l in in July 2010 (Figure 3.43). Since estuarine phytoplankton community composition and biomass are closely tied to eutrophication potentials (Cloern, 2001), phytoplankton abundances reached the higher concentrations in nutrient rich regions.

Phytoplankton was always found in higher concentrations in the inner bay, while it decreased two orders of magnitude from shore to offshore. Enhanced flora occupied substantial space in the bay during the spring (Figure 3.43).

Maximum phytoplankton abundances were recorded in September 2008 and July 2010 in the inner bay where the present high nutrient concentrations were utilized by the phytoplankton communities under optimum light intensities. However, phytoplankton was abundant in inner bay in September 2008 and July 2010. Spatial coverage of flora of surface waters was greater during winter and spring as a result of convectional mixing that occur during winter in the shelf area. They showed

similar distribution patterns with nutrients, especially with Si. High Si concentrations observed in October 2009 did not result in high flora due to lack of other essential nutrients (Figure 3.43).

According to the observations from two year cruise series, sea surface chlorophyll-a concentrations varied in the range 0.01 - 4.19 μg/l in September 2008, 0.07 - 6.69 μg/l in February 2009, 0.05 - 1.98 μg/l in April 2009, 0.02 - 2.11 μg/l in August 2009, 0.03 - 2.34 μg/l in October 2009, 0.12 and 5.63 μg/l in February 2010, 0.02 and 1.76 μg/l in April 2010 and 0.04 and 3.01 μg/l in July 2010 (Figure 3.44).

In Mersin Bay, chlorophyll-a concentrations found in previous studies were varying in the range 0.12 (October) and 2.93 μg (February) for shore station and 0.06 – 3.27 for offshore station (Uysal and Köksalan, 2006; 2010). Zenginer and Beşiktepe found chlorophyll-a concentration ranging 0.1 (June) - 2.4 (March) μg for coastal station and 0.03 (July) - 0.35 (January) μg for offshore station. In this study chlorophyll-a at surface reached the highest values of 6.69 and 5.64 μg/l in February 2009 and February 2010, respectively. These values are much higher than previous researches since highly productive coastal zone was sampled in this study.

As can be seen in the Figure 3.45 heterotrophic bacteria, *Synechococcus* and flagellates increased with increasing chlorophyll-a concentrations. This increase was higher in summer and fall seasons for heterotrophic bacteria and *Synechococcus* and similar for flagellates. Based on Spearman's rank correlation analysis significant positive correlations were found between chlorophyll-a and heterotrophic bacteria, *Synechococcus* and flagellates. Detailed results of rank correlations are provided in Appendix B, page 148.

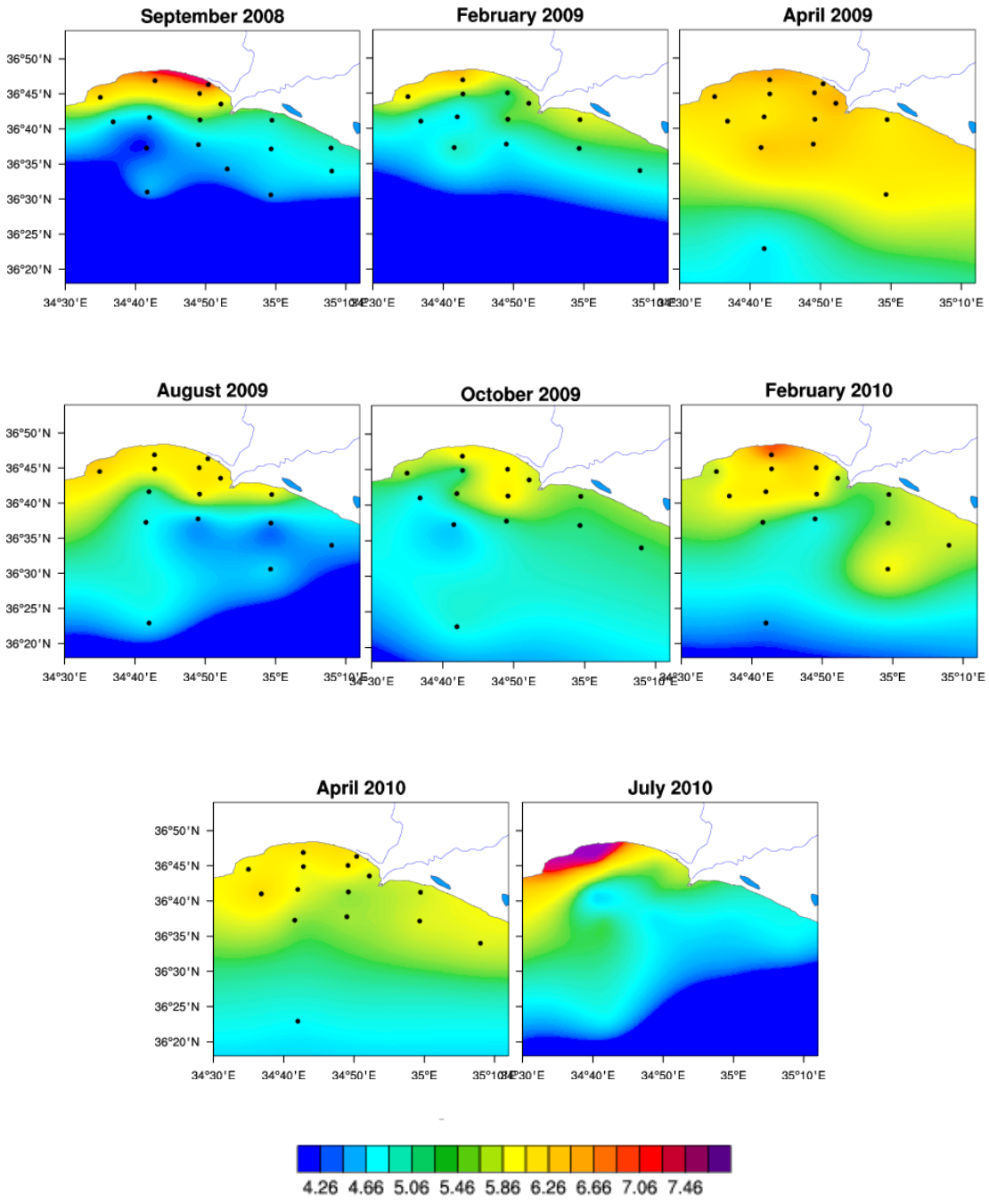

Figure 3.43. Changes in surface phytoplankton abundance distributions (all drawn at a constant scale; 4.26 – 7.48 log of cells/l) in Mersin Bay.

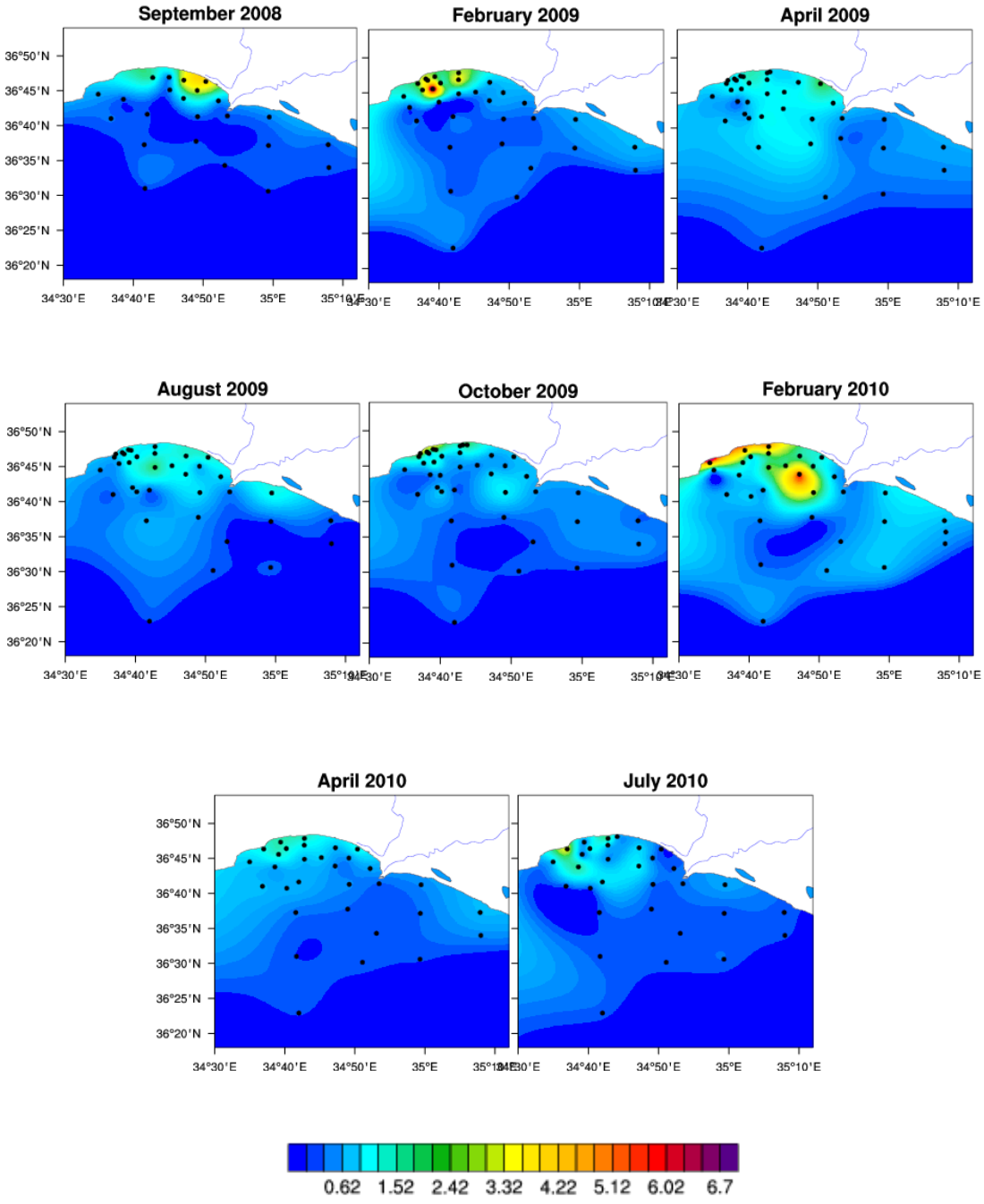

Figure 3.44. Changes in surface chlorophyll-a concentrations (all drawn at a constant scale; 0.02 – 6.8 μg/l) in Mersin Bay.

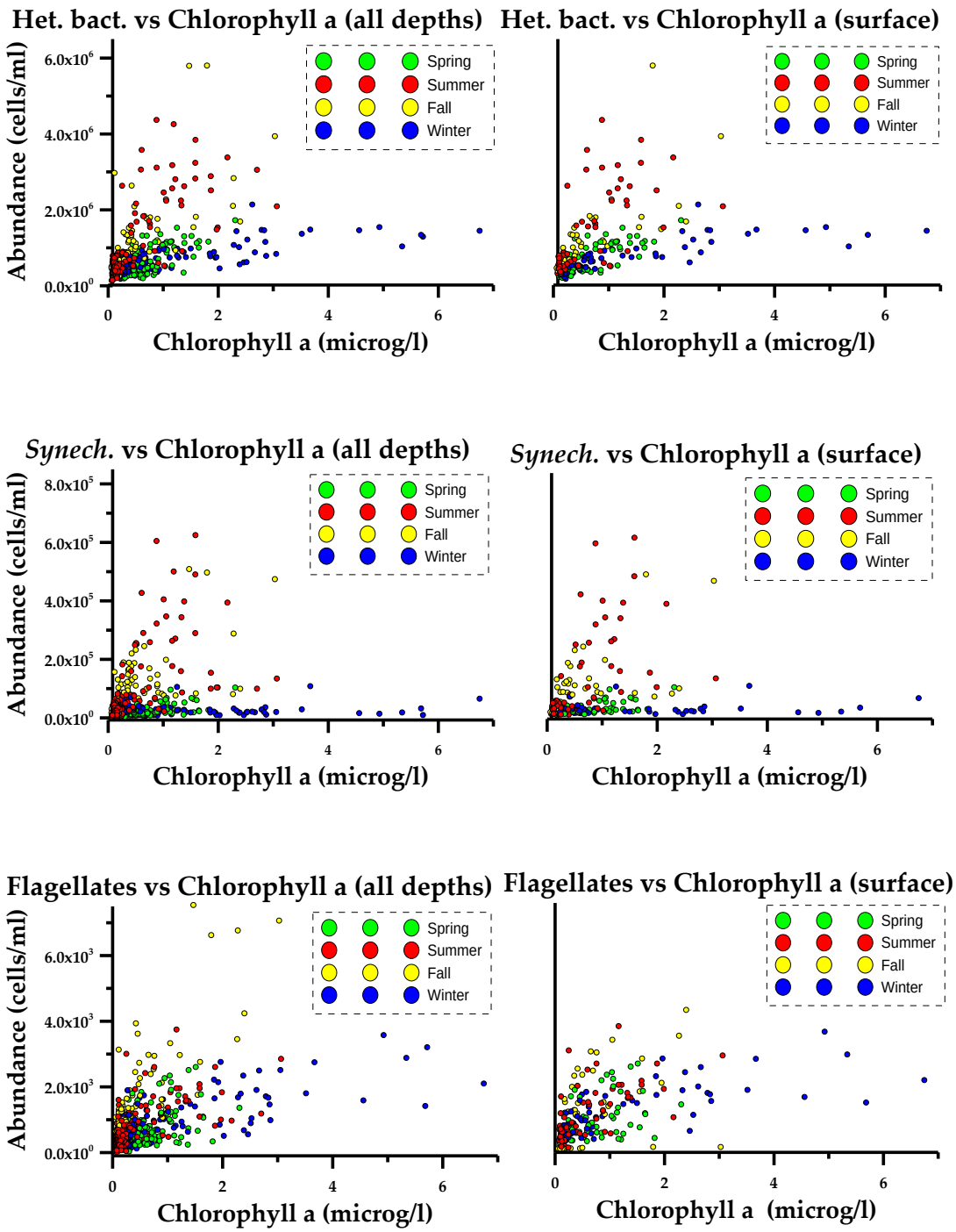

Figure 3.45. Heterotrophic bacteria, *Synechococcus* and flagellates versus chlorophyll-a.

Dissolved oxygen content of the basin waters peaked during winter and spring with increasing phytoplankton abundance and decreasing temperature as the solubility of the oxygen increase with decreasing temperature. The DO concentration in the surface waters decreased with the increase in the water temperature during the summer due to the low solubility of atmospheric oxygen in water at higher temperature. According to the observations during two year cruise series, surface dissolved oxygen content varied in the range 6.18 - 7.78 mg/l in September 2008, 7.41 - 9.3 mg/l in February 2009, 7.38 - 9.73 mg/l in April 2009, 6.16 – 7.74 mg/l in August 2009, 5.66 – 7.52 mg/l in October 2009, 7.49 – 9.96 mg/l in February 2010, 7.34– 8.34 mg/l in April 2010 and 6.46– 10.27 mg/l in July 2010. Seasonal surface distributions of dissolved oxygen in Mersin Bay were shown in Figure 3.46.

In all seasons dissolved oxygen concentrations in the inner bay where the photosynthetic activity is high are always higher than the offshore water showing the increasing effect of photosynthetic activity on dissolved oxygen. In conclusion, we can say that dissolved oxygen concentration in Mersin Bay is mainly regulated by temperature and primary production. During the study period, higher phytoplankton abundances always increased dissolved oxygen concentration in the inner bay for all seasons (Figure 3.46).

Parallel to surface distributions, dissolved oxygen in the water column was higher in winter and spring. In summer and fall seasons, photosynthetically active and warmer upper layer contained low concentrations of dissolved oxygen. Oxygen was depleted in the deep water during summer and fall (Figure 3.47).

Heterotrophic bacteria, *Synechococcus* and flagellates versus dissolved oxygen plots (Figure 3.47) indicate higher heterotrophic bacteria and *Synechococcus* abundances at reduced dissolved oxygen levels especially during summer and fall. Flagellates did not show significant seasonality compared to heterotrophic bacteria and

Synechococcus. The lower levels recorded in summer and fall seasons are because of low solubility of oxygen at higher temperatures. According to Spearman's rank

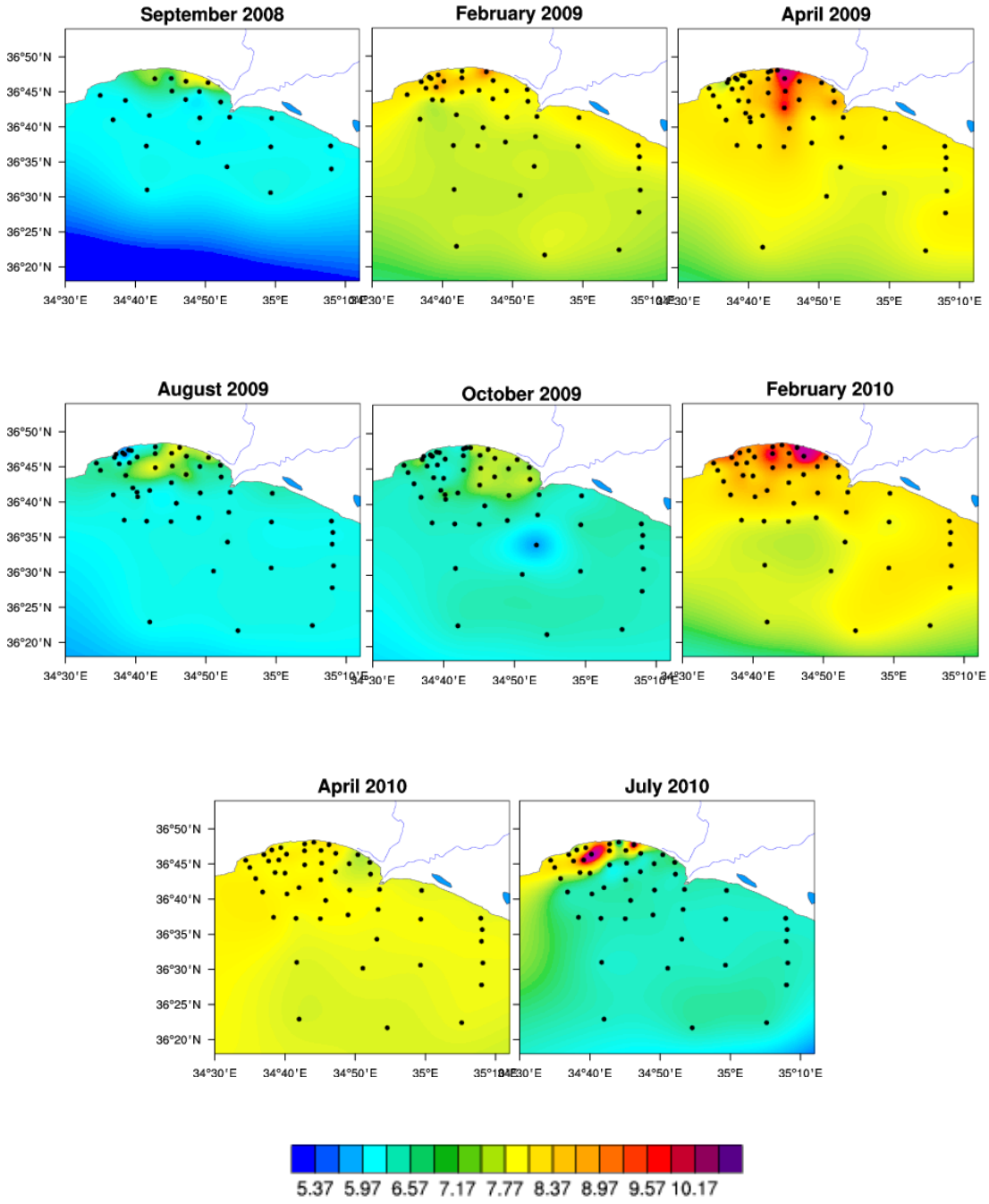

Figure 3.46. Changes in surface dissolved oxygen concentrations (all drawn at a constant scale; 5.37 – 10.27 mg/l) in Mersin Bay.

correlation, negative significant relationships were observed between dissolved oxygen and *Synechococcus* negatively and positive significant relationships were found with flagellates both at surface and in vertical water column. Whereas significant positive relationships observed between heterotrophic bacteria and dissolved oxygen at only surface. Detailed results of rank correlations are provided in Appendix B, page 148.

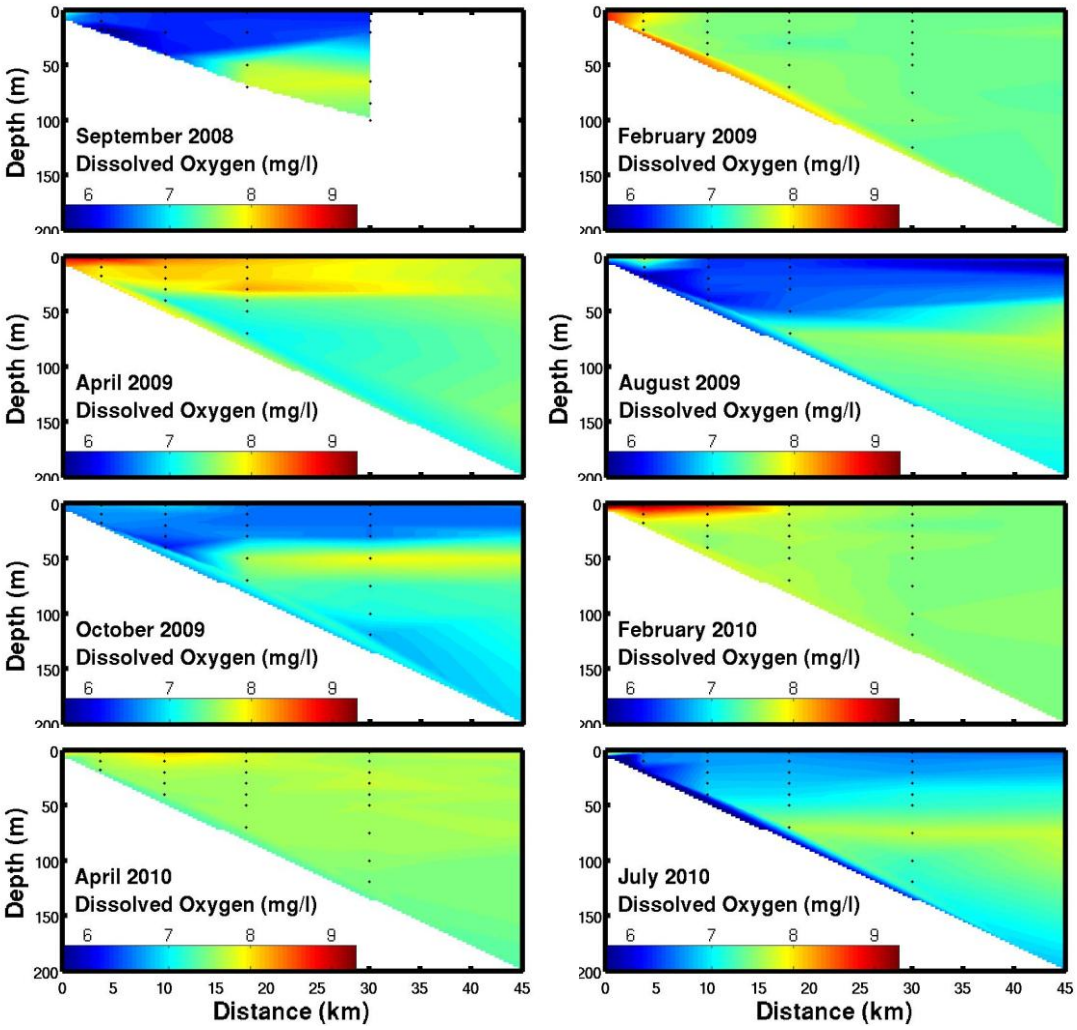

Figure 3.47. Observed dissolved oxygen profiles (all drawn at a constant scale; 5.7 – 9.3 μM) in Mersin Bay.

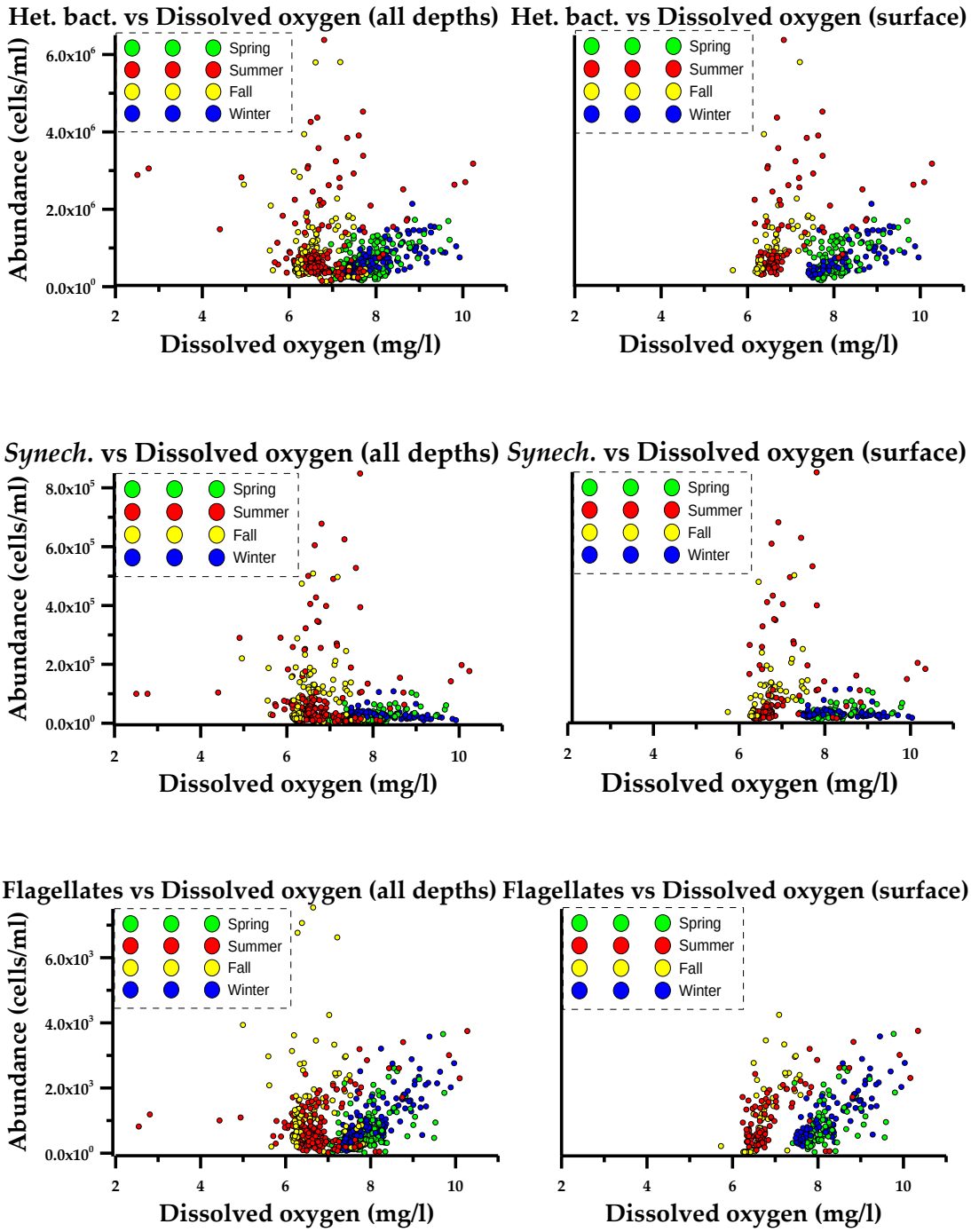

Figure 3.48. Heterotrophic bacteria, *Synechococcus* and flagellates versus dissolved oxygen.

3.2.4. Picoplankton and flagellates

Seasonal surface abundance distributions of heterotrophic bacteria within the same scale in Mersin Bay were shown in Figure 3.49. During the study period their abundance and biomass at surface varied in range $3.2x10^5$ cells/ml (2 μgC/l) - $1.3x10^7$ cells/ml (80.42 μgC/l) in September 2008, $2x10^5$ cells/ml (1.42 μgC/l) and $2.1x10^6$ (14.74 μgC/l) in February 2009, $1.3x10^5$ cells/ml (0.71 μgC/l) - $1.7x10^6$ (9.23 μgC/l) in April 2009, $2.8x10^5$ cells/ml (0.85 μgC/l) and $6.4x10^6$ (29.95 μgC/l) in August 2009, $3.7x10^5$ cells/ml (2.33 μgC/l) and $2.2x10^6$ (16.42 μgC/l) in October 2009, $1.5x10^5$ cells/ml (0.61 μgC/l) and $1.5x10^6$ (6.07 μgC/l) in February 2010, $1.9x10^5$ cells/ml (0.85 μgC/l) and $1.3x10^6$ (5.91 μgC/l) in April 2010 and $2.9x10^5$ cells/ml (0.85 μgC/l) and $3.2x10^6$ (5.91 μgC/l) in July 2010. The abundances remained in ranges given earlier for the Mediterranean (Table 3.1) except some high values recorded in the eutrophic areas. Although, eastern Mediterranean has been known as more oligotrophic than the western part, Mersin bay forms an extraordinary area with high production potential in the northeastern Mediterranean.

Heterotrophic bacteria generally concentrated nearby the riverine and domestic discharge area and found in higher abundance in the innermost part of the bay where nutrient inputs via riverine and domestic discharges promoted primary production. Their abundance decreased from shore to offshore parallel to phytoplankton, *Synechococcus* and flagellates. Heterotrophic bacteria showed seasonality being most abundant in late summer (August) and in early fall (September) at surface. Population abundances were almost 23 and 40 times greater in nearshore waters than offshore waters during August and September, respectively (Figure 3.49).

Seasonal vertical distributions of heterotrophic bacteria within the same scale were shown in Figure 3.50. Parallel to surface distributions, coastal region contained higher amount of bacteria and heterotrophic bacteria showed decreasing pattern

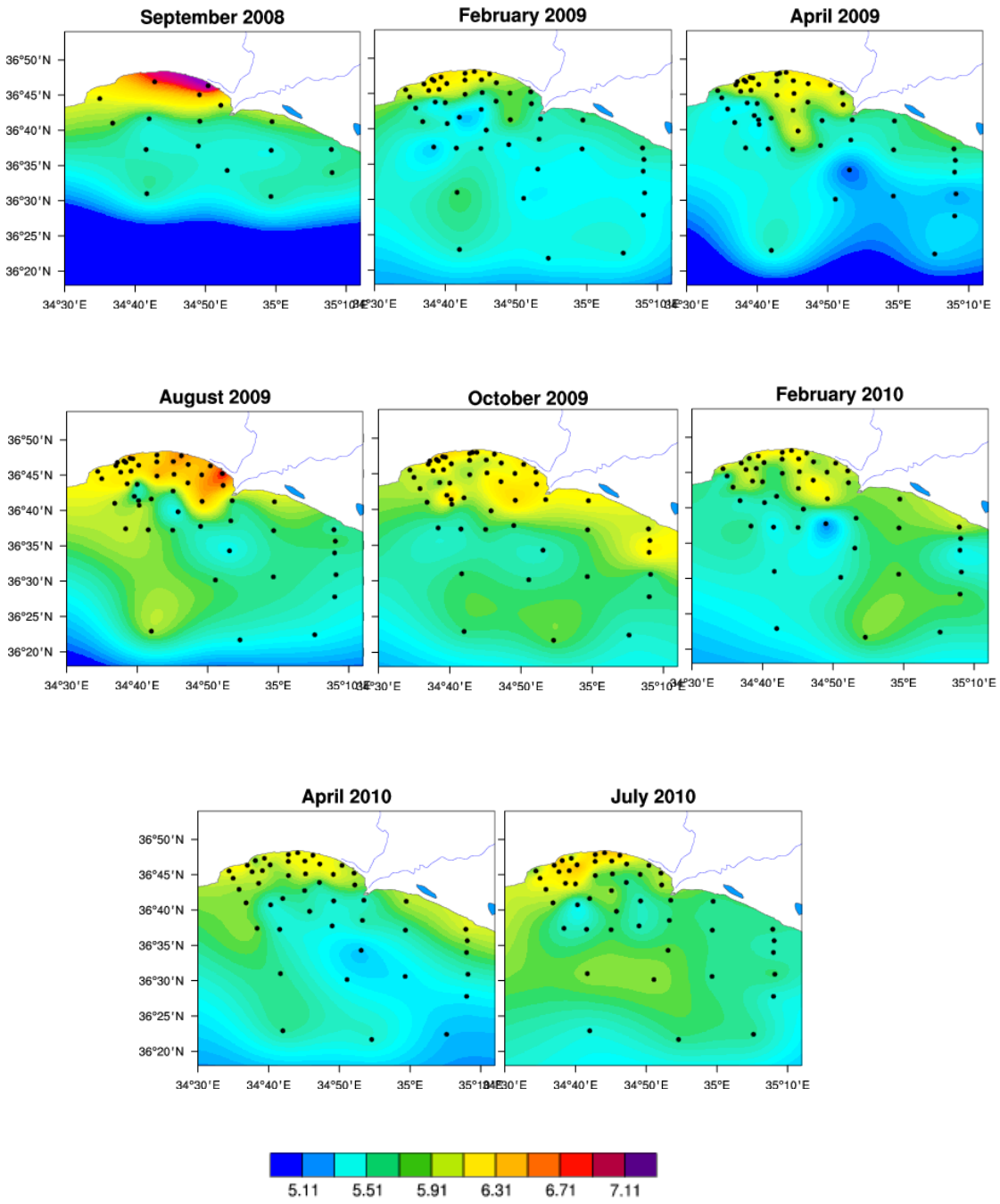

Figure 3.49. Changes in surface distributions of heterotrophic bacteria (all drawn at a constant scale; 5.11 – 7.11 log of cells/ml) in Mersin Bay.

from shore to offshore. In summer and fall, their abundances decreased with decreasing temperature from surface to bottom in the water column. In summer vertical bacterial abundance distributions were very similar to temperature gradient and in fall when stratification occurred in October 2009, heterotrophic bacteria concentrated in the upper mixed layer (Figure 3.50).

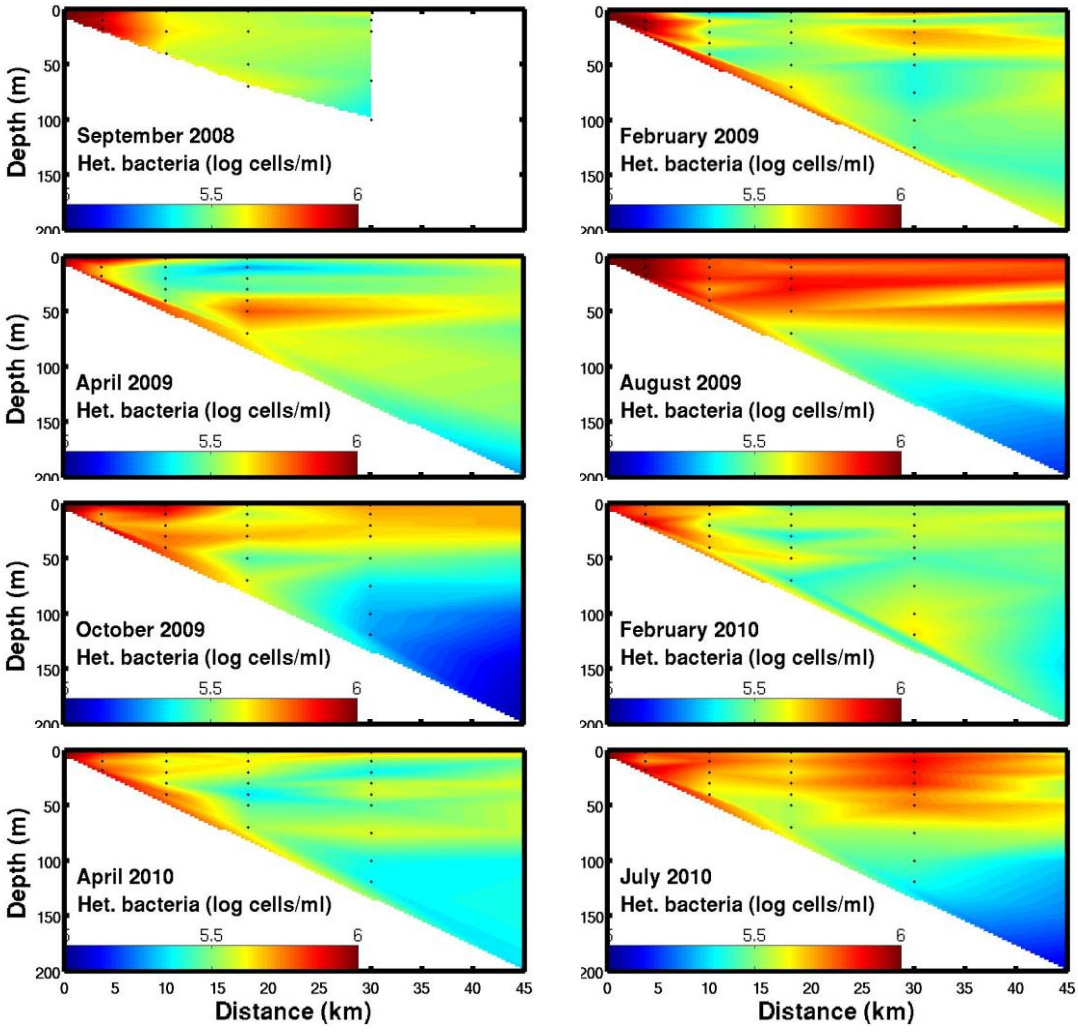

Figure 3.50. Vertical distributions of heterotrophic bacteria (all drawn at a constant scale; 5 – 6 log of cells/ml) in Mersin Bay.

Based on Spearman rank correlation analysis, heterotrophic bacterial abundance showed a positive significant correlation with water temperature (n = 820; r = 0.295;

p<0.0001) and a negative significant correlation with salinity (n = 820; r = - 0.363; p<0.0001) throughout the year. Significant correlations were found between bacterial abundance and the four sampled macronutrients, which included nitrate and nitrite (n = 817; r = 0.347; p<0.0001), ammonium (n = 817; r = 0.434; p < 0.0001), phosphate (n = 817; r = 0.503; p < 0.0001), and silicate (n = 814; r = 0.578; p < 0.0001). Significant correlations also existed between heterotrophic bacteria and *Synechococcus* (n = 820; r = 0.703; p < 0.0001), flagellates (n = 820; r = 0.675; p < 0.0001), phytoplankton (n = 435; r = 0.481; p < 0.0001) and chlorophyll-a (n = 695; r = 0.503; p < 0.0001).

Table 3.1. Bacterial abundance (BA cells/ml), in different Mediterranean Sea areas (revised after Siokou-Frangou et al., 2010).

Eastern Mediterranean				Western Mediterranean			
Location	Period	BA	References	Location	Period	BA	References
Mersin Bay	All seasons	1.3 - 130	This study	Almeria-Oran front front (Alboran Sea)	May	2.3–13.5	Fernandez et al. (1994)
Mersin Bay	All year	2.1 - 96	Bayındırlı, 2007	NW Mediterranean current	May and June	3.6–9.6	Christaki et al. (1996, 1998)
Black Sea	March - September	2.3 – 9.9	Uysal (unpublished)	Barcelona: In-Offshore transect	June	1.5–6.0	Gasol et al. (1998)
Marmara Sea	March - September	0.6 - 26	Uysal (unpublished)	Barcelona Balearic islands	Stratification period (3 yrs.)	3.1–5.4	Pedros-Alio et al. (1999)
Cilician Basin	March - September	0.4 - 20	Uysal (unpublished)	Algerian current	October	6.6–9.0	Moran et al. (2001)
Levantine Basin	March - September	0.4 - 5	Uysal (unpublished)	NW: transects off-shore	March	1.5–8.9	Vaquez et al. (2001)
Levantine Basin, Cyprus eddy	September	2.8-4.9	Zohary and Robarts (1992)	NW Mediterranean: station off-Nice	Monthly (one year)	1.4–11.0	Lemee et al. (2002)
Levantine basin	October - November	0.4 – 3.9	Robarts et al. (1996)	Almeria-Oran front (Alboran Sea)	November, January	5.0–15.0	Van Wambeke et al. (2004)
Cyprus eddy	March	2.5-3.5	Zohary et al. (1998)	East-west transect	June-July	2.9 – 5.0	Christaki et al. (2001)
S. Aegean Sea (Transect off-shore	September March	3.0-5.0	Van Wambeke et al. (2000)				
North and South Aegean	March	2.3 – 15.2	Christaki et al. (2003)				

Since bacteria take up a significant fraction of dissolved organic carbon (DOC) produced by phytoplankton and remineralize up to 50% of primary production (Azam et al., 1983), similar distribution patterns of heterotrophic bacteria and phytoplankton and chlorophyll-a may indicate the importance of heterotrophic bacteria in efficiently using phytoplankton end products and nutrient cycling within the system especially in summer and fall when the nutrients are limited due to stratification and dry season. However higher nutrient concentrations exist in spring and winter, higher abundance and biomass values of heterotrophic bacteria in summer and fall seasons may indicate the stimulating effect of temperature on their activity and also indicate that they are not affected by nutrient limitation due to their high surface to volume ratio. It is well known that physiological processes, individual cell-specific bacterial production and respiration are strongly affected by temperature (White et al., 1991, Pomeroy and Wiebe, 2001, Kirchman et al., 2005).

Synechococcus

Abundance distributions of *Synechococcus* at surface during the study period within the same scale were given in Figure 3.51 and their biomass followed the same seasonal pattern described for their abundance. Abundance and biomass of *Synechococcus* at surface varied in the range $1.1x10^4$ cells/ml (1.2 μgC/l) - $1.2x10^6$ cells/ml (129.69 μgC/l) in September 2008, $6.9x10^3$ cells/ml (0.69 μgC/l) and $1.0x10^5$ cells/ml (10.31 μgC/l) in February 2009, $3.7x10^3$ cells/ml (0.26 μgC/l) - $1x10^4$ cells/ml (6.99 μgC/l) in April 2009, $1.9x10^3$ cells/ml (0.11 μgC/l) and $8.5x10^5$ cells/ml (49.13 μgC/l) in August 2009, $1.1x10^4$ cells/ml (0.69 μgC/l) and $2.4x10^5$ cells/ml (15.35 μgC/l) in October 2009, $4.9x10^3$ cells/ml (0.30 μgC/l) and $3.2x10^4$ cells/ml (2.01 μgC/l) in February 2010, $1.2x10^3$ cells/ml (0.07 μgC/l) and $3.6x10^4$ cells/ml (5.76 μgC/l) in April 2010 and $4.5x10^3$ cells/ml (0.07 μgC/l) and $1.9x10^5$ cells/ml (5.76 μgC/l) in July 2010. They were least abundant in April 2010 ($1.2x10^3$ cells/ml (0.07 μgC/l)) and most in September 2008 ($1.2x10^6$ cells/ml (129.69 μgC/l)). Their abundance was generally in the same range with those previously cited for the Mediterranean (Table 3.2).

Synechococcus in Mersin Bay shelf water exhibited a clear seasonal abundance pattern at especially innermost part of the bay during late summer and early fall. Cell abundances were generally high in summer and fall which were concomitant with high temperature. Similar to heterotrophic bacteria, *Synechococcus* was also found in higher concentrations nearby the riverine and domestic discharges at surface and their abundances decreased from shore towards offshore in all seasons. High abundances observed during low nutrient conditions indicate the importance of temperature on their physiology. The interactions between *Synechococcus* and temperature were well studied elsewhere (Agawin et al., 2000).

Seasonal vertical distributions of *Synechococcus* within the same scale were shown in Figure 3.52. The summer thermocline did affect *Synechococcus* abundance and values decreased from top to bottom parallel to temperature gradient throughout the water column. In winter and spring seasons, *Synechococcus* distribution in water column was more homogenous due to the winter convectional mixing. Parallel to surface abundance values, their vertical abundance distributions also reached the highest values in summer and fall seasons. Their isopleths were very similar with temperature. *Synechococcus* abundance decreased suddenly below the thermocline in fall and gradually with decreasing temperature in summer.

Synechococcus abundance showed a positive significant correlation with water temperature ($n = 820$; $r= 0.407$; $p<0.0001$) and a negative significant correlation with salinity ($n = 820$; $r =-0.098$; $p=0.005$) throughout the year. Significant correlations were found between *Synechococcus* abundance and the four sampled macronutrients, which included nitrate and nitrite ($n = 817$; $r = 0.08$; $p=0.019$), ammonium ($n = 817$; $r = 0.295$; $p < 0.0001$), phosphate ($n = 817$; $r = 0.355$; $p < 0.0001$), and silicate ($n = 814$; $r = 0.431$; $p < 0.0001$). Significant correlations also existed between *Synechococcus* and heterotrophic bacteria ($n = 820$; $r = 0.703$; $p < 0.0001$), flagellates ($n = 820$; $r = 0.635$; $p < 0.0001$), phytoplankton ($n = 435$; $r = 0.297$; $p < 0.0001$) and chlorophyll-a ($n = 695$; $r = 0.301$; $p < 0.0001$).

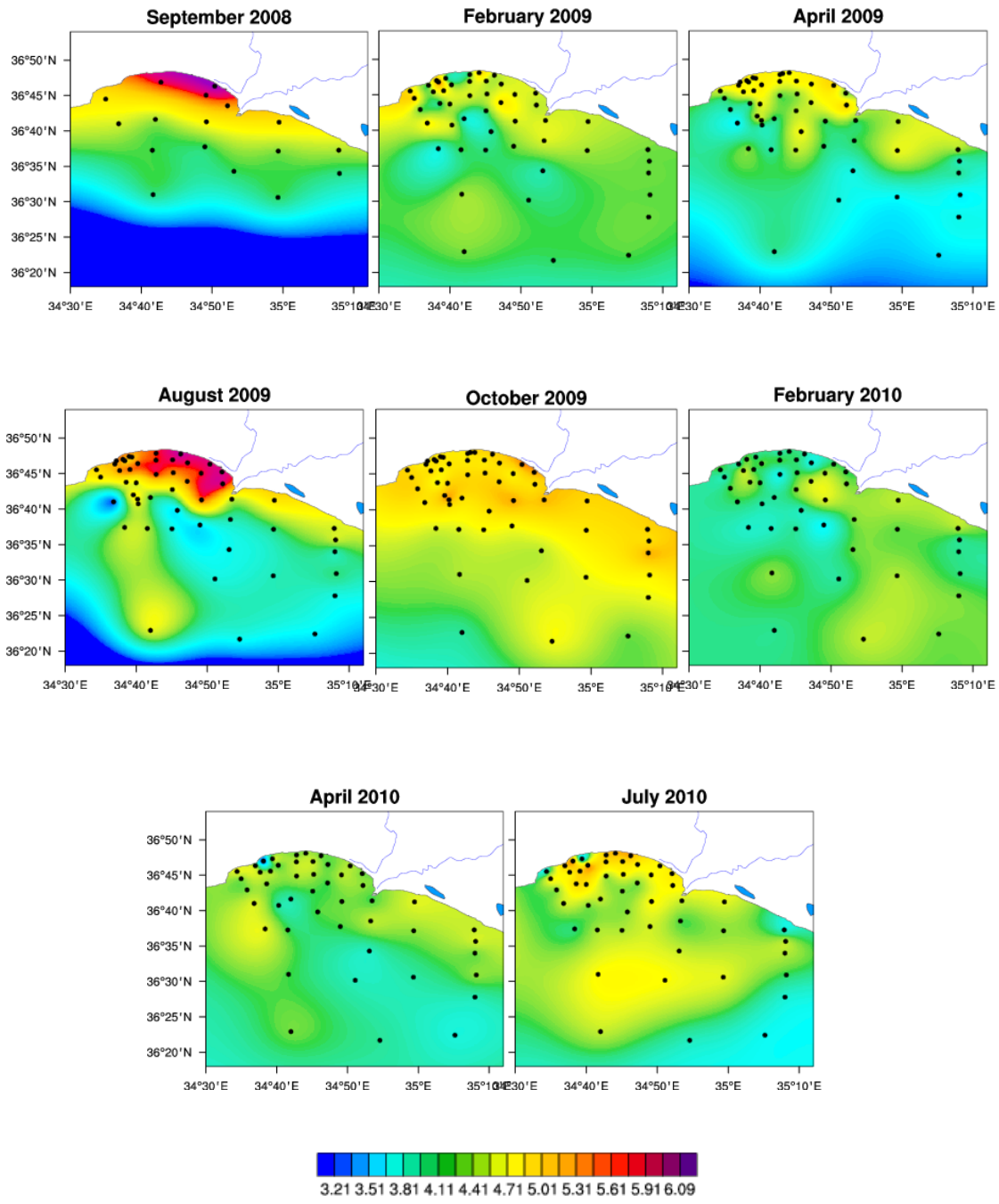

Figure 3.51. Changes in surface distributions of *Synechococcus* (all drawn at a constant scale; 3.21– 6.09 log of cells/ml) in Mersin Bay.

The significant positive correlations found between water temperatures and *Synechococcus* abundance in this study suggest that temperature is an important

factor on *Synechococcus* abundance. A similar pattern of seasonality and abundance was observed in the Mediterranean (Agawin, 1997; Uysal and Köksalan, 2006; 2010). It has been suggested that nutrient concentration is one of the important factor regulating *Synechococcus* abundance, biomass, and growth rate (Lantoine and Neveux, 1997). However significant correlations were found between *Synechococcus* and macronutrients, their isopleths were not always similar. Since the system is poor in nutrient especially in summer and fall, nutrients were consumed very rapidly and decreased to below the detection limits even in the areas nearby the discharge points (Figure 3.51).

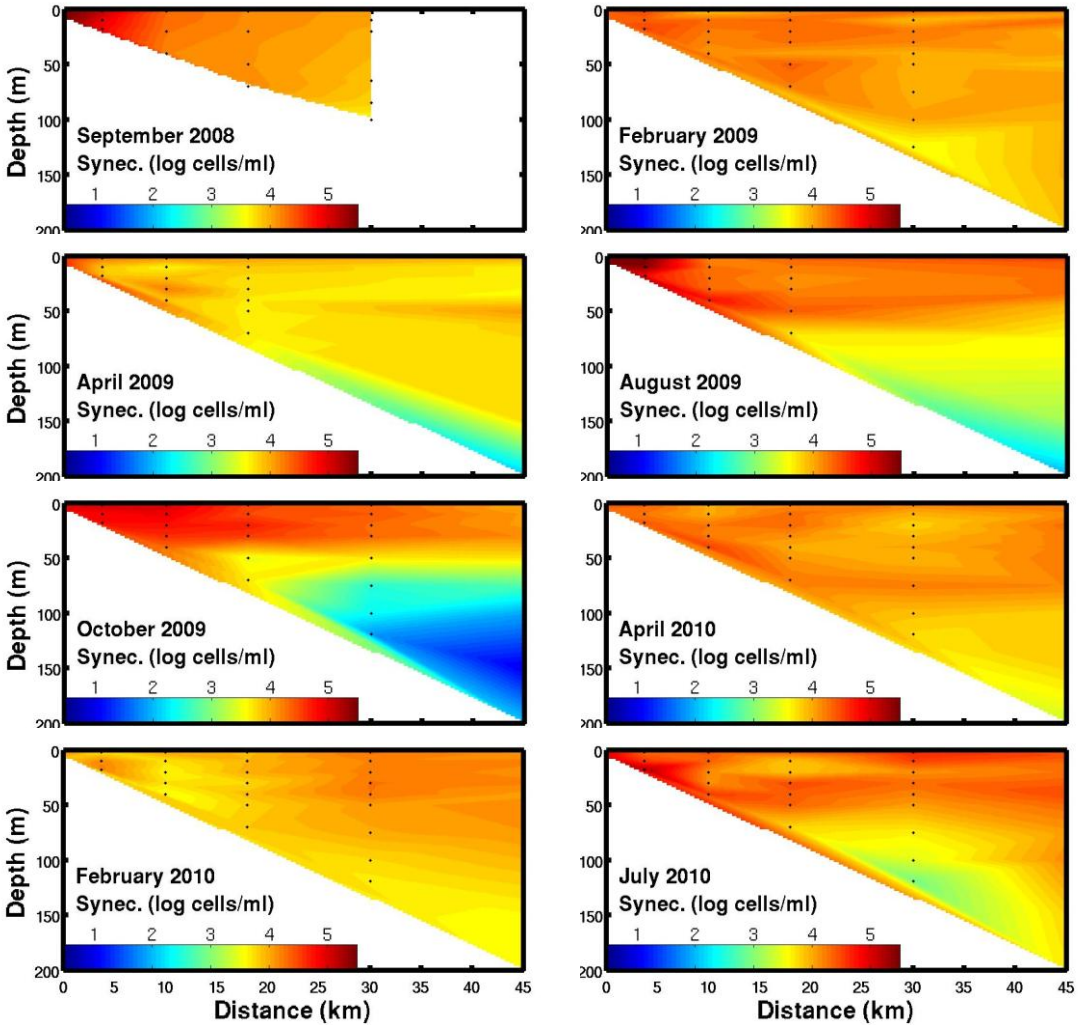

Figure 3.52. Vertical distributions of *Synechococcus* (all drawn at a constant scale; 0.5 – 5.5 log of cells/ml) in Mersin Bay.

Synechococcus abundance made peaks in late summer and early fall when waters were stratified and nutrients concentrations were at their lowest. However nutrients are important and necessary for *Synechococcus* growth, *Synechococcus* were able to thrive under lower nutrient concentrations when larger phytoplankton was nutrient-limited due to their high surface-to-volume ratio (Raven, 1986). *Synechococcus* has a more competitive advantage over other phytoplankters in oligotrophic conditions (Donald et al., 1997). In terms of nutrient acquisition, *Synechococcus* are able to utilize nitrate, nitrite, ammonium, urea, and some amino acids (Moore et al., 2002). Under nitrogen deprivation, *Synechococcus* will degrade the major light-harvesting pigment protein phycoerythrin as an internal nitrogen source (Wyman et al., 1985). Phosphorus utilization is via the uptake of phosphate and numerous organic P sources (Scanlan et al., 1997) as well as of novel organic sources of N and P, such as cyanates and phosphonates (Palenik et al., 2003). Phosphorus stress on this group during the summer months was demonstrated from the Red Sea (Fuller et al., 2005).

Table 3.2. *Synechococcus* abundance (SA cells 10^5/ml) at surface in different Mediterranean Sea areas.

Eastern Mediterranean				Western Mediterranean			
Location	Period	SA	References	Location	Period	SA	References
Mersin Bay	All seasons	0.01 -12	This study	Bay of Blanes	All year	5-600	Agawin et al., 1998
Mersin Bay	All year	4 (average)	Bayındırlı, 2007	transect Barcelona - Balearic Islands	June	17-130	Agawin and Agusti, 1997
Mersin Bay	All year	0.006- 1.5	Köksalan and Uysal, 2006; 2010	Villefranche Bay	July	0.43	Jacquet et al., 98
Black Sea Marmara Sea Aegean Sea NE Medit. Levantine basin	April-June-October Sept.-October October October October	0.009 – 2.11 0.56-1.61 0.15-0.19 0.09-0.22 0.05-0.73	Uysal, 2001	Alboran Sea	December-January	0.16	Jacquet et al., 2002
Black Sea Marmara Sea Cilician Basin Levantine Basin	March-September	0.002 – 0.68 0.003 – 2.1 0.0003-2.1 0.002 – 0.34	Uysal (unpublished)	West-East Transect	September	0.11-0.62	Moutin et al., 2002
Aegan Sea	March September	0.2 (average)	Christaki et al., 1999				

Flagellates

Abundance distributions of flagellates at surface during the study period within the same scale were given in Figure 3.53 and their biomass followed the same seasonal pattern described for their abundance. Similar to heterotrophic bacteria and *Synechococcus*, flagellates were also found at higher levels in the inner bay for all seasons since the nutrient concentration is always high in the inner bay. Their abundances and biomasses were gradually decreased from shore to offshore. Except the highest abundances observed in September 2008 and lower values recorded in April 2010 in the inner part of the bay, they were found at similar concentrations in almost all seasons.

Abundance and biomass of flagellates at surface varied in range $3.5x10^2$ cells/ml (0.32 μgC/l) - $1.2x10^4$ cells/ml (11.15 μgC/l) in September 2008, 9.2x10 cells/ml (0.33 μgC/l) and $2.7x10^3$ cells/ml (9.66 μgC/l) in February 2009, $1.9x10^2$ cells/ml (0.54 μgC/l) - $3.6x10^3$ cells/ml (10.60 μgC/l) in April 2009, 7.7x10 cells/ml and (0.07 μgC/l) and $3.2x10^3$ cells/ml (2.96 μgC/l) in August 2009, $1.9x10^2$ cells/ml (0.18 μgC/l) and $4.2x10^3$ cells/ml (4.41 μgC/l) in October 2009, $2.5x10^2$ cells/ml (0.27 μgC/l) and $3.6x10^3$ cells/ml (3.95 μgC/l) in February 2010, 0 cells/ml (0 μgC/l) and $1.3x10^3$ cells/ml (1.95 μgC/l) in April 2010 and 3.1x10 cells/ml (0 μgC/l) and $3.7x10^3$ cells/ml (1.95 μgC/l) in July 2010 at surface (Figure 3.53). Their abundance was generally in the same range with those provided for other regions in the Mediterranean (Table 3.3).

Seasonal vertical distributions of flagellates within the same scale were shown in Figure 3.54. Similar to the surface distributions, flagellates were always found at higher concentrations in coastal stations during the study period. Their distributions were gradually decreased from shore to offshore. Different from heterotrophic bacteria and *Synechococcus*, they distributed more homogenously along the selected transect.

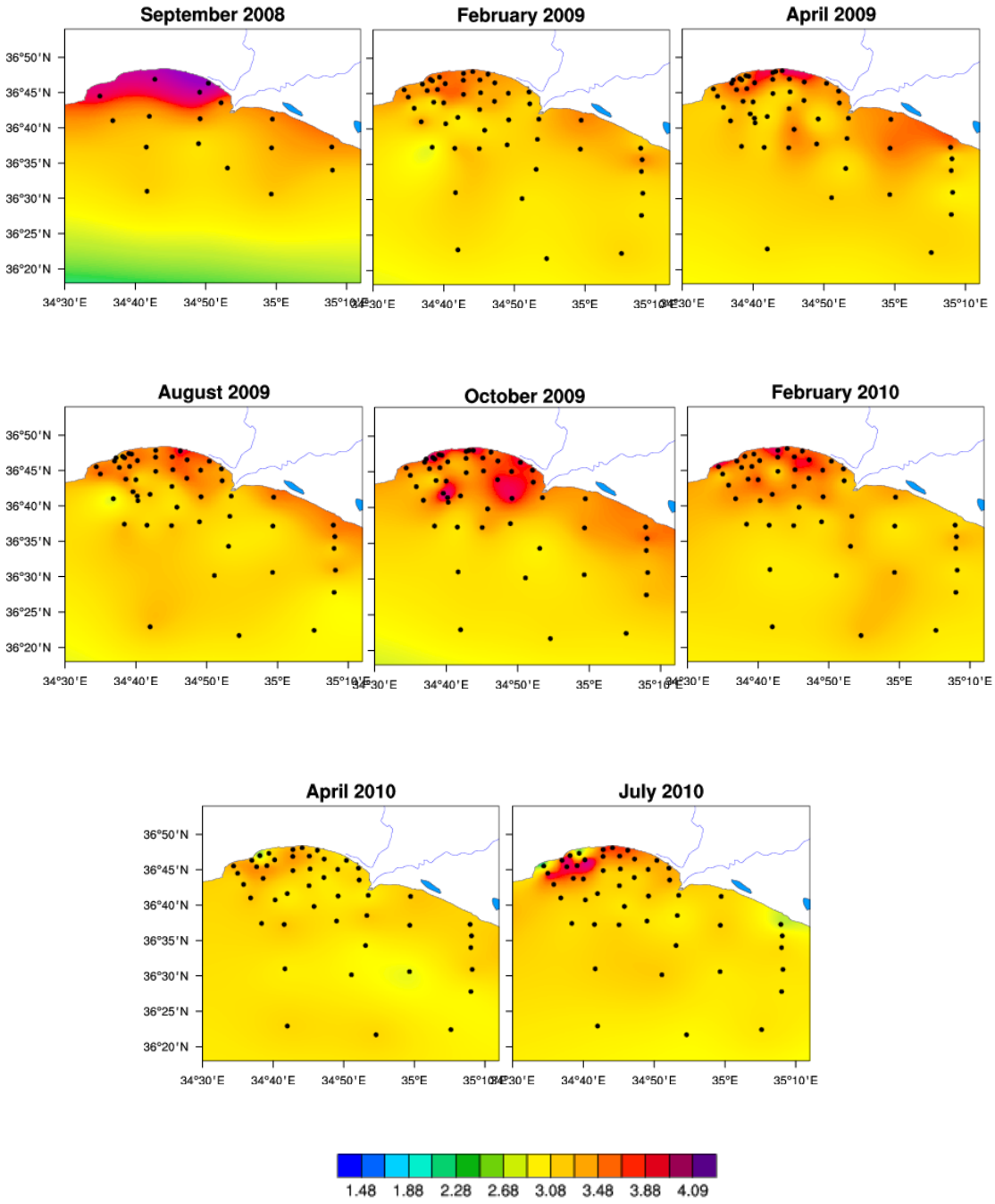

Figure 3.53. Changes in surface distributions of flagellates (all drawn at a constant scale; 1.4 – 4.09 log of cells/ml) in Mersin Bay.

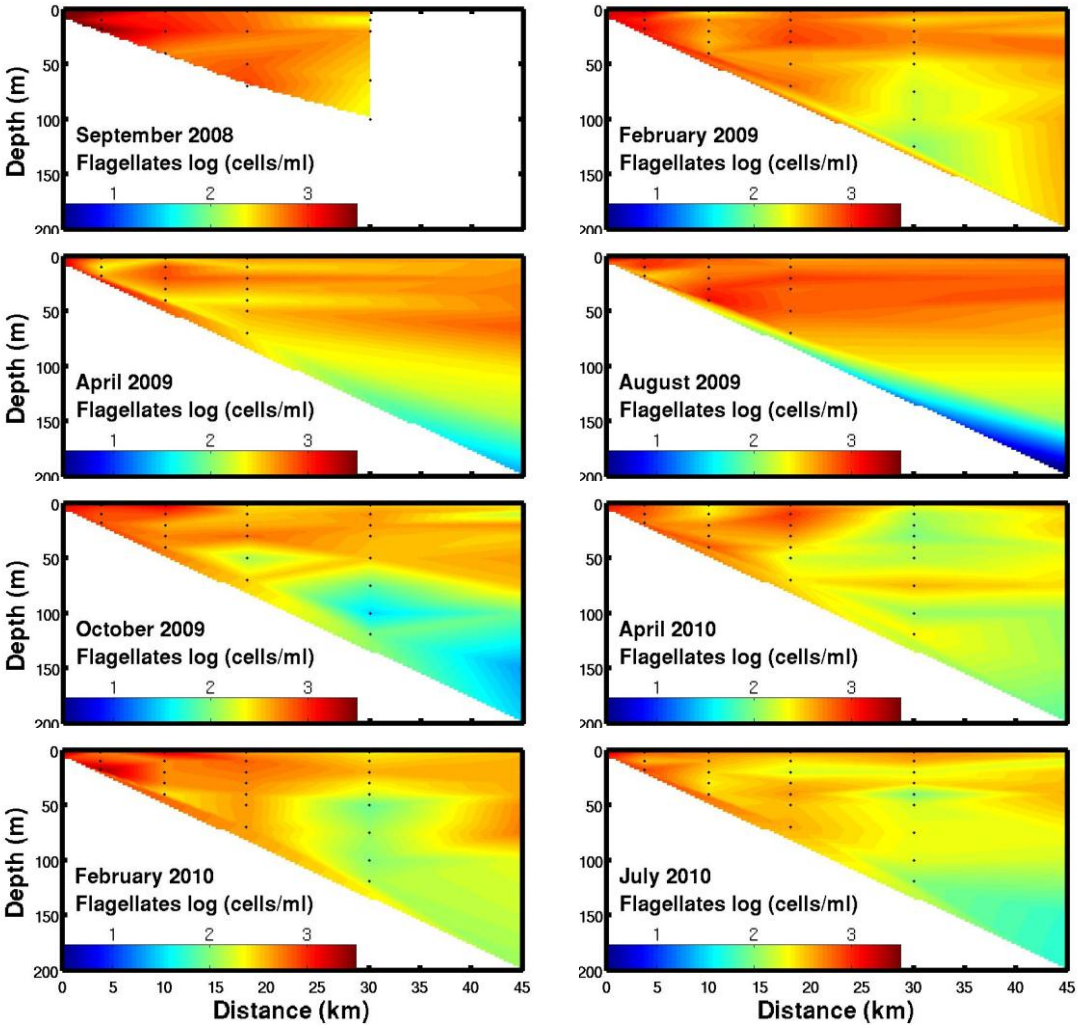

Figure 3.54. Vertical distributions of flagellates (all drawn at a constant scale; 0.5 – 3.5 log of cells/ml) in Mersin Bay.

Based on Spearman rank correlation analysis, flagellate abundances showed a positive significant correlation with water temperature ($n = 820$; $r = 0.138$; $p<0.0001$) and a negative significant correlation with salinity ($n = 820$; $r = -0.358$; $p < 0.0001$) throughout the year. Significant correlations were found between flagellates abundance and the four sampled macronutrients, which included nitrate and nitrite ($n = 817$; $r = 0.318$; $p < 0.0001$), ammonium ($n = 817$; $r = 0.439$; $p < 0.0001$), phosphate ($n = 817$; $r = 0.395$; $p < 0.0001$), and silicate ($n = 814$; $r = 0.481$; $p < 0.0001$). Significant correlations also existed between flagellates and heterotrophic bacteria ($n = 820$; $r =$

0.675; $p < 0.0001$), *Synechococcus* ($n = 820$; $r = 0.635$; $p < 0.0001$), phytoplankton ($n = 483$; $r = 0.297$; $p < 0.0001$) and chlorophyll-a ($n = 695$; $r = 0.556$; $p < 0.0001$).

Since flagellates can be phototrophic, heterotrophic and mixotrophic (Throndsen, 1997), they have the advantage to either acquire carbon under low light conditions or to acquire nutrients in short supply (Nygaard and Tobiesen, 1993) and the ability of motility also enhances their nutrient uptake (Throndsen, 1997). In this study, different from heterotrophic bacteria and *Synechococcus*, flagellates did not show seasonality and their abundances remained almost at similar levels versus temperature, nutrient concentrations and chlorophyll-a.

Table 3.3. Flagellate abundance (FA cells 103/ml) in different Mediterranean Sea areas (HA; Heterotrophic flagellates, AF; Autotrophic flagellates; MF; Mixotrophic flagellates).

Eastern Mediterranean				Western Mediterranean			
Location	Period	FA	References	Location	Period	FA	References
Mersin Bay	All seasons	0- 12 TF	This study	West to east transect	June-July	0.07-7.07 PF 0.11-3.24 HF	Christaki et al., 2001
Aegean Sea Eastern Mediterranean	Spring Summer	0.07 MF 0.34 HF 0.64 AF	Christaki et al., 1999	The Gulf of Naples	Winter Non-winter	721±884 TF 5,758±6,027 TF	Zingone et al., 2010
Creten Sea Eastern	September	40–119 TF	Danovaro et al., 1998	Algerian Sea	September	1.5-5.2 HF	Bonilla-Findji et al., 2009

4. CONCLUSION

Mersin Bay shelf waters showed elevated nutrient concentrations relative to the open waters where summer dissolved inorganic nutrient concentrations are typically below detection limits. The elevated nutrient concentrations in Mersin Bay likely derive from inputs from the land, through the combined discharges of the Seyhan River and Tarsus Çayı and urban discharges of Mersin. These high nutrient inputs to the bay promoted productivity and higher abundances of heterotrophic bacteria, *Synechococcus* and flagellates were found in the innermost part of the bay nearby the discharges. Chlorophyll-a and phytoplankton also accompanied with higher concentrations in this region. Dissolved oxygen concentrations increased with higher photosynthetic activity at surface and always found higher in the inner bay. Since the system is poor in nutrient especially in summer and fall, available nutrients were consumed very rapidly and decreased to levels below the detection limits even in the areas nearby the discharge points.

Heterotrophic bacteria varied in range $1.3x10^5$ cells/ml (0.71 μgC/l) and $1.3x10^7$ cells/ml (80.42 μgC/l) at surface showing seasonality being most abundant in late summer (August) and in early fall (September) at surface. Average abundance of heterotrophic bacteria in 0-20 m depth stratum was 2.3, 3 and 3.2 times higher than those calculated for the 20-50, 50-100 and 100-200m depth strata. Their vertical abundance distributions followed the similar trend with temperature gradient in summer and concentrated in the upper mixed layer during fall. They took the advantage of their small size (having high surface to volume ratio) to utilise scarce nutrients and with the stimulating effect of temperature they reached higher concentrations in summer and fall.

Similar to heterotrophic bacteria, *Synechococcus* varied in the range $1.2x10^3$ cells/ml (0.07 μgC/l) and $1.2x10^6$ cells/ml (129.69 μgC/l) and found in higher concentrations nearby the riverine and domestic discharges at surface and their abundances decreased from shore towards offshore in all seasons. Average abundance of

Synechococcus in 0-20 m depth stratum was 2.8, 5.5 and 6.2 times higher than those calculated for 20-50, 50-100 and 100-200m depth strata. *Synechococcus* in Mersin Bay shelf water exhibited a clear seasonal abundance pattern at especially innermost part of the bay during late summer and early fall. High abundances observed during low nutrient conditions indicate the importance of temperature on their physiology. The summer thermocline did affect *Synechococcus* abundance and values decreased from surface to bottom parallel to temperature gradient in the water column. In winter and spring seasons, *Synechococcus* distribution in water column was more homogenous due to the winter convectional mixing. However nutrients are important and necessary for *Synechococcus* growth, *Synechococcus* were able to thrive under low nutrient concentrations when larger phytoplankton was nutrient-limited due to their high surface-to-volume ratio. *Synechococcus* has a more competitive advantage over other phytoplankters in oligotrophic conditions.

Similar to heterotrophic bacteria and *Synechococcus*, flagellates were also found at high levels in the inner bay for all seasons since the nutrient concentration is always high in the inner bay. Their abundance and biomas have reached peak levels of 1.2 x 10^4 cells/ml and 11.15 μgC/l, respectively. Average abundance of flagellates in 0-20 m depth stratum was 2.4, 3.3 and 5 times higher than the averages calculated for 20-50, 50-100 and 100-200m depth strata. Apart from heterotrophic bacteria and *Synechococcus*, they distributed more homogenously in the water column. In contrast to heterotrophic bacteria and *Synechococcus*, flagellates did not show seasonality and their abundances remained almost at similar levels against highly variable parameters, such as the temperature, nutrient concentrations and chlorophyll-a. Since flagellates can be phototrophic, heterotrophic and mixotrophic, they have the advantage to either acquire carbon under low light conditions or to acquire nutrients in short supply and the ability of motility also enhances their nutrient uptake.

Abundance and biomasses of heterotrophic bacteria in winter and spring tend to remain similar both at surface and in the water column in the area. The highest

abundance gradient between the shore and the offshore water was observed in summer. This situation was also true for the *Synechococcus* as well as to a lesser extent to flagellates. Since the average cell volume and carbon contents of heterotrophic bacteria, *Synechococcus* and flagellates were different, the average abundances of heterotrophic bacteria, *Synechococcus* and flagellates were $6.9x10^5$, $4.2x10^4$ and $8x10^2$ cells/ml, respectively whereas their average biomassess were 3.45, 2.76 and 1.16 μgC/l. Bacteria were found as the dominant group both in terms of abundance and biomass.

In this study highly significant relationships were observed within the organism goups studied (heterotrophic bacteria and *Synechococcus* $n = 820$; $r = 0.703$; $p < 0.0001$; heterotrophic bacteria and flagellates $n = 820$; $r = 0.675$; $p < 0.0001$; *Synechococcus* and flagellates $n = 820$; $r = 0.635$; $p < 0.0001$). These significant relationships indicated the collective responses of heterotrophic bacteria, *Synechococcus* and flagellates to changing environmental conditions. When the water temperature is high in summer and fall, picoplankton used available nutrients more efficiently and reached the higher abundance values. Significant relationships observed between temperature and all groups also supported this idea. In this work promoting effects of nutrient were also observed concurrent with significant correlations obtained between biological groups and nutrient levels.

This study established a comprehensive frame work for understanding the interactions among heterotrophic bacteria, *Synechococcus* and flagellates and some physico-chemical variables. In order to understand the dynamics of heterotrophic bacteria, *Synechococcus* and flagellates in detail, additional investigations such as measurement of growth rates against varying nutrient levels and mixtures, as well as, losses from individual groups due to grazing should be carried out. Since the growth of bacteria depends excessively on the amount and availability of dissolved organic carbon in seawater it is strongly advised to include this parameter in future studies.

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APPENDICES

APPENDIX A: Abundance and biomass values of heterotrophic bacteria, *Synechococcus* and flagellates.

September 2008

Station	Depth	HB abundance	HB biomass	CB abundance	CB biomass	FLG abundance	FLG biomass
TRL 2	0	1151510	7.17	73689	7.72	3604	3.30
TRL 2	10	2944153	16.78	152861	8.95	3120	4.90
TRL 2	18	2608823	7.93	216267	9.71	3920	1.64
TRL 4	0	651679	4.06	30504	3.20	1012	0.93
TRL 4	10	551501	3.14	42157	2.47	1296	2.04
TRL 4	20	478741	2.06	26648	1.19	1064	0.44
TRL 4	30	521976	2.93	27676	1.33	1149	1.55
TRL 4	50	456597	1.73	23135	1.16	1223	1.75
TRL 10	0	368019	2.29	14738	1.54	622	0.57
TRL 10	20	384891	1.65	14224	0.64	674	0.28
TRL 10	50	346929	1.31	13024	0.65	727	1.04
TRL 10	70	429180	1.25	14052	0.25	843	0.70
TRL 14	0	412308	2.57	21849	2.29	970	0.89
TRL 14	20	452379	1.94	18851	0.84	1191	0.50
TRL 14	40	382782	1.32	15509	0.40	506	1.16
TRL 18	0	936392	5.83	135467	14.19	2719	2.49
TRL 18	10	836743	4.77	89840	5.26	1328	2.09
TRL 18	18	904758	2.75	72746	3.27	2956	1.23
TRL 22	0	5772575	35.92	493027	51.66	6608	6.05
TRL 22	10	5765457	32.86	504852	29.56	7525	11.82
TRL 27	0	550447	3.43	52567	5.51	1344	1.23
TRL 27	10	553610	3.16	27119	1.59	1628	2.56
TRL 27	20	526721	2.26	29561	1.32	980	0.41
TRL 27	30	597899	3.36	25320	1.22	1739	2.35
TRL 28	0	359583	2.24	13367	1.40	348	0.32
TRL 28	20	407035	1.75	10453	0.47	443	0.18
TRL 28	50	472414	1.79	25191	1.26	811	1.16
TRL 30	0	363801	2.26	13624	1.43	474	0.43
TRL 33	0	3911653	24.34	470407	49.29	7051	6.46
TRL 33	10	2806014	15.99	284301	16.65	6750	10.60
TRL 34	0	999662	6.22	228777	23.97	1723	1.58
TRL 34	8	868377	4.95	165414	9.69	2529	3.97
TRL 36	0	12300153	76.54	1178070	123.44	11586	10.61
TRL 38	0	664332	4.13	83157	8.71	1344	1.23
TRL 38	10	362219	2.06	30589	1.79	917	1.44
TRL 39	0	321621	2.00	18165	1.90	885	0.81
TRL 39	10	358529	2.04	20221	1.18	738	1.16
TRL 39	24	417580	2.72	23049	1.52	1233	0.51
TRL 40	0	438670	2.73	13281	1.39	632	0.58
TRL 40	30	377510	2.12	7283	0.35	653	0.88
TRL 40	55	269951	0.98	13281	0.84	811	1.16
TRL 41	0	439725	2.74	23049	2.42	1307	1.20
TRL 43	0	474523	2.95	11824	1.24	643	0.59
TRL 43	10	262569	1.50	14138	0.83	295	0.46
TRL 43	18	461869	1.40	10882	0.49	811	0.34
TRL 46	0	428125	2.66	11482	1.20	506	0.46
TRL 46	10	315294	1.80	11225	0.66	190	0.30
TRL 46	20	353256	1.52	10111	0.45	443	0.18
TRL 46	65	298422	1.46	7883	0.19	263	0.44
TRL 46	85	221444	0.77	6683	0.12	158	0.21
TRL 46	100	229880	1.07	4199	0.10	190	0.34

APPENDIX A continued.

February 2009							
Station	Depth	HB abundance	HB biomass	CB abundance	CB biomass	FLG abundance	FLG biomass
TRL 1	0	959848.5	6.70	80585.04	7.96	1295.6	4.58
TRL 2	0	765409.8	5.35	101818	10.06	1357.203	4.79
TRL 2	10	691337.8	4.11	55673.9	4.83	1881.577	5.57
TRL 2	15	547823.5	3.11	38746.03	3.36	1141.285	3.75
TRL 3	0	388877.5	2.72	15966.54	1.58	411.2737	1.45
TRL 4	0	478381.1	3.34	48777.36	4.82	1079.594	3.81
TRL 4	10	320978.3	1.91	27711.56	2.40	293.0325	0.87
TRL 4	20	447517.8	2.54	33730.36	3.05	539.7968	1.77
TRL 4	30	351841.6	2.10	26708.43	2.65	431.8374	1.18
TRL 4	48	348755.3	2.11	22319.72	1.38	709.4472	1.81
TRL 5	0	212956.7	1.49	6938.339	0.69	92.53659	0.33
TRL 6	0	1187208	8.29	16802.48	1.66	1028.184	3.63
TRL 7	0	1442345	10.07	24576.77	2.43	1696.504	5.99
TRL 8	0	292172.5	2.04	12288.38	1.21	318.7371	1.13
TRL 9	0	345668.9	2.41	30428.38	3.01	411.2737	1.45
TRL 10	0	324064.6	2.26	13458.71	1.33	632.3334	2.23
TRL 10	10	334352.4	1.99	21901.74	1.90	668.3198	1.98
TRL 10	20	371388.3	2.11	18307.18	1.65	771.1383	2.53
TRL 10	30	329208.5	1.96	18641.56	1.85	853.393	2.33
TRL 10	50	330237.3	2.00	23490.04	1.45	421.5556	1.08
TRL 10	70	421798.4	1.94	17220.46	1.13	616.9106	1.78
TRL 11	0	1450575	10.13	104325.9	10.31	2734.97	9.66
TRL 12	0	1419712	9.92	61525.51	6.08	2087.214	7.37
TRL 13	0	485582.5	3.39	24911.14	2.46	1131.003	3.99
TRL 14	0	203697.8	1.42	7690.689	0.76	236.4824	0.84
TRL 14	10	422827.2	2.51	21065.8	1.83	472.9648	1.40
TRL 14	20	305546.6	1.74	17053.27	1.54	421.5556	1.38
TRL 14	30	416654.5	2.48	15047	1.49	349.5827	0.95
TRL 14	40	270568.2	1.51	12789.95	1.03	452.4011	1.20
TRL 15	0	366244.5	2.56	11954.01	1.18	606.6288	2.14
TRL 16-	0	2111049	14.74	17304.05	1.71	1891.859	6.68
TRL 17	0	1409424	9.84	20815.02	2.06	1778.759	6.28
TRL 18	0	706769.5	4.94	31431.51	3.11	1727.35	6.10
TRL 18	10	948532	5.64	22821.28	1.98	925.3659	2.74
TRL 18	17	935157.9	5.31	33270.59	3.01	1233.821	4.05
TRL 19	0	247935.1	1.73	13876.68	1.37	740.2927	2.61
TRL 20	0	325093.4	2.27	10114.93	1.00	329.019	1.16
TRL 21	0	1433086	10.01	15632.16	1.54	1655.377	5.85
TRL 22	0	1339467	9.36	25161.93	2.49	1789.041	6.32
TRL 23	0	1763323	12.32	88610.11	8.75	1645.095	5.81
TRL 24	0	1040093	7.26	28087.73	2.77	1460.022	5.16
TRL 25	0	488668.9	3.41	25579.9	2.53	915.0841	3.23
TRL 26	0	507186.8	3.54	66875.56	6.61	987.057	3.49
TRL 27	2	624467.4	4.36	31598.7	3.12	503.8103	1.78
TRL 27	5	598748	4.18	28171.33	2.78	205.6369	0.73
TRL 27	10	399165.3	2.37	24075.2	2.09	472.9648	1.40
TRL 27	15	417683.3	2.37	27418.98	2.38	514.0922	1.69
TRL 27	20	377561	2.14	24493.17	2.21	606.6288	1.99
TRL 27	30	325093.4	1.94	26081.47	2.59	514.0922	1.40
TRL 28	0	281884.8	1.97	17053.27	1.68	493.5285	1.74
TRL 28	10	431057.4	2.56	13709.49	1.19	380.4282	1.13
TRL 28	20	285999.9	1.62	15214.19	1.37	339.3008	1.11
TRL 28	30	336409.9	2.01	15882.94	1.58	421.5556	1.15
TRL 28	40	301431.5	1.68	12622.76	0.78	339.3008	0.90
TRL 28	50	215014.3	1.30	11285.25	0.81	226.2006	0.58
TRL 29	0	380647.3	2.66	32518.24	3.21	616.9106	2.18
TRL 30	0	283942.3	1.98	9780.55	0.97	411.2737	1.45
TRL 31	0	1370330	9.57	23740.82	2.35	1418.894	5.01
TRL 32	0	794215.5	5.55	28923.68	2.86	1100.157	3.88

APPENDIX A continued.

February 2009

Station	Depth	HB abundance	HB biomass	CB abundance	CB biomass	FLG abundance	FLG biomass
TRL 33	0	636812.7	4.45	36614.37	3.62	863.6748	3.05
TRL 33	8	761294.7	4.53	37199.53	3.23	596.3469	1.76
TRL 34	0	509244.4	3.56	25496.31	2.52	503.8103	1.78
TRL 34	8	421798.4	2.51	37701.09	3.27	688.8835	2.04
TRL 35	0	385791.2	2.69	33103.4	3.27	709.4472	2.51
TRL 37	0	562740.8	3.93	31933.08	3.15	771.1383	2.72
TRL 38	0	482496.2	3.37	27418.98	2.71	1470.304	5.19
TRL 38	10	853884.5	5.08	32601.83	2.83	801.9838	2.37
TRL 39	0	297316.4	2.08	21149.39	2.09	740.2927	2.61
TRL 39	10	324064.6	1.93	16217.32	1.41	832.8293	2.46
TRL 39	20	359043	2.04	18139.99	1.64	668.3198	2.20
TRL 39	25	356985.5	2.13	19644.69	1.95	668.3198	1.82
TRL 41	0	454719.2	3.18	17387.64	1.72	606.6288	2.14
TRL 42	0	379618.5	2.65	16050.13	1.59	1439.458	5.08
TRL 43	0	301431.5	2.11	17136.86	1.69	699.1653	2.47
TRL 43	10	304517.9	1.81	14461.84	1.25	524.374	1.55
TRL 43	20	319949.5	1.82	22654.09	2.05	730.0109	2.40
TRL 44	0	276740.9	1.93	15799.35	1.56	370.1464	1.31
TRL 45	0	278798.4	1.95	16468.11	1.63	318.7371	1.13
TRL 46	0	535992.6	3.74	20982.21	2.07	544.9377	1.92
TRL 46	10	295258.9	1.76	8275.85	0.72	298.1735	0.88
TRL 46	20	523647.3	2.97	17972.81	1.62	503.8103	1.66
TRL 46	30	481467.4	2.87	15214.19	1.51	503.8103	1.37
TRL 46	40	381676.1	2.13	9278.983	0.75	359.8645	0.96
TRL 46	50	246906.4	1.49	9613.361	0.59	215.9187	0.55
TRL 46	75	246906.4	1.14	9696.956	0.64	164.5095	0.47
TRL 46	100	298345.2	2.07	10783.68	0.84	164.5095	0.45
TRL 46	125	290115	1.52	3427.372	0.31	102.8184	0.17
TRL 47	0	262338	1.83	12957.14	1.28	267.3279	0.94
TRL 47	10	288057.4	1.71	7607.094	0.66	236.4824	0.70
TRL 47	20	360071.8	2.05	16300.92	1.47	267.3279	0.88
TRL 47	30	248963.9	1.48	11870.41	1.18	185.0732	0.50
TRL 47	40	304517.9	1.70	10783.68	0.87	267.3279	0.71
TRL 47	58	277769.7	1.71	13207.92	0.95	380.4282	0.94
TRL 48	2	383733.7	2.68	17387.64	1.72	308.4553	1.09
TRL 48	5	306575.4	2.14	10282.12	1.02	370.1464	1.31
TRL 48	10	323035.8	1.92	21149.39	1.83	452.4011	1.34
TRL 48	20	304517.9	1.73	9864.144	0.89	329.019	1.08
TRL 48	30	425913.5	2.54	10198.52	1.01	637.4743	1.74
TRL 48	40	398136.5	2.22	11034.47	0.89	586.0651	1.56
TRL 48	50	314805.6	1.90	7774.283	0.48	390.71	1.00
TRL 48	60	382704.9	2.36	11870.41	0.85	400.9919	0.99
TRL 48	75	387848.8	1.78	11201.66	0.74	298.1735	0.86
TRL 48	100	334352.4	2.32	8861.011	0.69	400.9919	1.09
TRL 48	150	265424.4	1.75	9028.2	0.62	380.4282	0.82
TRL 48	200	411510.6	2.48	7272.717	0.74	349.5827	0.83
TRL 49	0	290115	2.03	13124.33	1.30	185.0732	0.65
TRL 50	0	326122.2	2.28	15214.19	1.50	431.8374	1.52

APPENDIX A continued.

April 2009							
Station	Depth	HB abundance	HB biomass	CB abundance	CB biomass	FLG abundance	FLG biomass
TRL 1	0	604921	3.29	31097	2.18	864	2.52
TRL 2	0	391964	2.13	13292	0.93	941	2.74
TRL 2	10	296288	1.82	8777	0.55	432	0.87
TRL 2	19	475295	2.73	9530	0.69	524	0.82
TRL 3	0	262338	1.43	9655	0.68	540	1.57
TRL 4	0	333324	1.81	5183	0.36	792	2.31
TRL 4	10	251021	1.54	9363	0.58	699	1.42
TRL 4	20	286000	1.64	7022	0.51	545	0.85
TRL 4	30	253079	1.29	6186	0.33	360	0.61
TRL 4	50	485583	2.01	9530	0.65	206	0.28
TRL 5	0	348755	1.90	17555	1.23	679	1.98
TRL 6	0	1126510	6.13	63699	4.47	2128	6.20
TRL 6	8	678993	4.17	23072	1.44	632	1.28
TRL 7	0	930528	5.06	48025	3.37	1897	5.53
TRL 8	0	291658	1.59	12288	0.86	1095	3.19
TRL 9	0	256165	1.39	10533	0.74	494	1.44
TRL 10	0	316863	1.72	10199	0.72	483	1.41
TRL 10	10	189295	1.16	7022	0.44	278	0.56
TRL 10	20	308633	1.77	5517	0.40	596	0.93
TRL 10	30	275712	1.40	5350	0.29	370	0.63
TRL 10	40	506158	1.98	4848	0.30	226	0.39
TRL 10	50	611093	2.52	4681	0.32	380	0.52
TRL 10	70	405338	1.56	4848	0.48	257	0.51
TRL 11	0	1126510	6.13	60063	4.21	2082	6.06
TRL 12	0	1077129	5.86	59310	4.16	2329	6.78
TRL 13	0	393507	2.14	35737	2.51	709	2.07
TRL 14	0	506158	2.75	12372	0.87	298	0.87
TRL 14	10	257194	1.58	4347	0.27	740	1.50
TRL 14	20	251021	1.44	7858	0.57	761	1.19
TRL 14	30	296288	1.51	16050	0.86	442	0.75
TRL 14	42	316863	1.24	7189	0.44	226	0.39
TRL 15	0	548338	2.98	25580	1.79	1244	3.62
TRL 16	0	1097190	5.97	56677	3.98	1758	5.12
TRL 16	7	839482	5.15	30930	1.93	1224	2.48
TRL 17	0	1282370	6.97	63824	4.48	2591	7.55
TRL 18	0	1109021	6.03	16385	1.15	504	1.47
TRL 18	10	465007	2.86	7189	0.45	216	0.44
TRL 18	19	458834	2.63	7356	0.53	380	0.59
TRL 19	0	913554	4.97	24410	1.71	925	2.70
TRL 20	0	1086388	5.91	40627	2.85	1707	4.97
TRL 21	0	1097190	5.97	48527	3.40	2498	7.28
TRL 22	0	987625	5.37	44472	3.12	1738	5.06
TRL 22	10	882690	5.42	43135	2.69	1830	3.71
TRL 23	0	1666618	9.06	42508	2.98	3640	10.60
TRL 24	0	1180521	6.42	56677	3.98	1835	5.35
TRL 25	0	1499956	8.16	20564	1.44	452	1.32
TRL 26	0	703683	3.83	30596	2.15	848	2.47
TRL 27	2	386820	2.10	14378	1.01	339	0.99
TRL 27	5	281885	1.53	10031	0.70	401	1.17
TRL 27	10	244849	1.50	8359	0.52	216	0.44
TRL 27	15	253079	1.45	10533	0.66	319	0.50
TRL 27	25	1045237	5.32	43803	3.15	1182	2.01
TRL 28	0	483525	2.63	13208	0.93	997	2.90
TRL 28	10	168719	1.04	6855	0.43	226	0.46
TRL 28	20	259252	1.49	8861	0.64	648	1.01
TRL 28	30	189295	0.96	11870	0.64	524	0.89
TRL 28	40	475295	1.86	16886	1.04	1203	2.07
TRL 28	50	446489	1.84	11870	0.81	596	0.81
TRL 29	0	339496	1.85	13417	0.94	864	2.52

APPENDIX A continued.

April 2009							
Station	Depth	HB abundance	HB biomass	CB abundance	CB biomass	FLG abundance	FLG biomass
TRL 30	0	129626	0.70	6520	0.46	319	0.93
TRL 32	0	1330208	7.23	52665	3.70	2252	6.56
TRL 34	0	1135769	6.18	92288	6.48	1100	3.20
TRL 34	8	775698	4.76	18391	1.15	730	1.48
TRL 35	0	435172	2.37	14796	1.04	910	2.65
TRL 36	0	1697481	9.23	99645	6.99	1347	3.92
TRL 37	0	712942	3.88	18558	1.30	1373	4.00
TRL 38	0	460892	2.51	25747	1.81	1594	4.64
TRL 38	10	1288028	7.91	33271	2.07	1511	3.06
TRL 39	0	417683	2.27	35946	2.52	1789	5.21
TRL 39	10	851827	5.23	27837	1.73	432	0.87
TRL 39	24	537021	3.08	23950	1.72	509	0.79
TRL 40	0	181065	0.98	5016	0.35	709	2.07
TRL 40	10	244849	1.50	4681	0.29	596	1.21
TRL 40	20	269539	1.55	9363	0.67	401	0.63
TRL 40	30	211928	1.08	4681	0.25	206	0.35
TRL 40	40	353899	1.38	7189	0.44	350	0.60
TRL 40	56	318921	1.32	14545	1.00	483	0.66
TRL 41	0	518503	2.82	21735	1.52	1573	4.58
TRL 42	0	370360	2.01	8777	0.62	386	1.12
TRL 43	0	327151	1.78	10784	0.76	648	1.89
TRL 43	10	164604	1.01	8025	0.50	416	0.84
TRL 43	19	380647	2.18	20815	1.50	571	0.89
TRL 44	0	168719	0.92	4514	0.32	185	0.54
TRL 45	0	211928	1.15	5852	0.41	370	1.08
TRL 47	0	226331	1.23	6520	0.46	586	1.71
TRL 47	10	353899	2.17	7356	0.46	1008	2.04
TRL 47	20	277770	1.59	9028	0.65	1008	1.57
TRL 47	30	273655	1.39	4681	0.25	617	1.05
TRL 47	50	220158	0.91	9864	0.68	709	0.96
TRL 47	81	563770	2.17	10700	1.05	401	0.85
TRL 48	2	360072	1.96	10366	0.73	288	0.84
TRL 48	5	440316	2.39	6855	0.48	442	1.29
TRL 48	10	364187	2.24	4681	0.29	452	0.92
TRL 48	20	349784	2.01	4681	0.34	494	0.77
TRL 48	35	360072	1.41	4013	0.22	555	0.94
TRL 48	50	382705	1.58	11703	0.80	514	0.70
TRL 48	65	296288	1.14	6353	0.62	709	1.40
TRL 48	100	347726	2.06	5350	0.38	267	0.36
TRL 48	150	314806	0.98	5684	0.25	134	0.10
TRL 48	190	181065	0.92	113	0.01	21	0.03
TRL 50	0	201640	1.10	3678	0.26	432	1.26

APPENDIX A continued.

August 2009							
Station	Depth	HB abundance	HB biomass	CB abundance	CB biomass	FLG abundance	FLG biomass
TRL 1	0	1447489	6.83	101441.9	5.90	1634.813	1.52
TRL 2	0	1558596	7.36	74482.65	4.33	1912.423	1.78
TRL 2	10	719114.8	2.18	81629.98	4.91	1202.976	0.75
TRL 2	21	870345	3.84	68840.03	6.51	755.7155	0.29
TRL 4	0	839481.7	3.96	1880.875	0.11	77.11383	0.07
TRL 4	10	660474.5	2.00	18181.79	1.09	1434.317	0.90
TRL 4	20	660474.5	2.91	15924.74	1.51	1249.244	0.48
TRL 4	30	660474.5	2.53	25078.33	1.91	724.87	0.49
TRL 4	49	524676	3.07	60188	3.07	1249.244	0.70
TRL 5	0	864172.3	4.08	24325.98	1.41	709.4472	0.66
TRL 7	0	1657359	7.82	248275.5	14.44	1403.472	1.31
TRL 8	0	1527733	7.21	47774.23	2.78	1711.927	1.60
TRL 9	0	780841.4	3.69	32978.01	1.92	493.5285	0.46
TRL 10	0	728373.8	3.44	23072.07	1.34	416.4147	0.39
TRL 10	10	533935	1.62	16426.31	0.99	539.7968	0.34
TRL 10	20	709855.8	3.13	13416.91	1.27	879.0976	0.34
TRL 10	30	734546.5	2.81	14670.83	1.12	616.9106	0.42
TRL 10	50	527762.4	3.08	23824.42	1.22	663.1789	0.37
TRL 10	70	339496.3	1.36	5141.058	0.30	385.5691	0.62
TRL 11	0	1604891	7.57	254795.9	14.82	909.9431	0.85
TRL 12	0	2086359	9.85	340062.2	19.78	1542.277	1.44
TRL 13	0	444431.5	2.10	33855.75	1.97	555.2195	0.52
TRL 14	0	620352.3	2.93	15548.57	0.90	694.0244	0.65
TRL 14	10	617265.9	1.87	18307.18	1.10	524.374	0.33
TRL 14	20	669733.5	2.95	19937.28	1.89	601.4878	0.23
TRL 14	30	506158.1	1.94	21316.58	1.62	956.2114	0.65
TRL 14	41	648129.2	3.79	60062.61	3.06	1202.976	0.68
TRL 15	0	540107.7	2.55	6394.975	0.37	663.1789	0.62
TRL 16	0	2215985	10.46	155736.5	9.06	1696.504	1.58
TRL 17	0	2209812	10.43	343071.6	19.95	1819.886	1.70
TRL 18	0	3351754	15.82	390218.9	22.70	956.2114	0.89
TRL 18	10	2135740	6.48	251786.5	15.14	925.3659	0.58
TRL 18	19	1104906	4.87	60438.78	5.72	277.6098	0.11
TRL 19	0	620352.3	2.93	37366.72	2.17	524.374	0.49
TRL 20	0	314805.6	1.49	4514.1	0.26	308.4553	0.29
TRL 21	0	2428941	11.46	401253.3	23.34	1357.203	1.27
TRL 22	0	2592517	12.24	394231.4	22.93	1557.699	1.45
TRL 22	11	1802417	5.47	286394.6	17.22	493.5285	0.31
TRL 24	0	3876430	18.29	523635.6	30.46	2097.496	1.96
TRL 25	0	2777697	13.11	267084.3	15.53	1943.268	1.81
TRL 26	0	2536963	11.97	259560.8	15.10	1943.268	1.81
TRL 27	1	3083243	14.55	318494.8	18.52	1141.285	1.06
TRL 27	3	1882661	8.89	245266.1	14.27	786.561	0.73
TRL 27	5	1364158	4.14	155987.2	9.38	1172.13	0.73
TRL 27	8	546280.4	1.66	44764.83	2.69	616.9106	0.39
TRL 27	14	435172.5	1.32	39372.98	2.37	709.4472	0.44
TRL 27	20	401222.9	1.77	46144.13	4.36	1141.285	0.44
TRL 27	30	543194	2.08	54294.59	4.14	971.6342	0.66
TRL 28	0	447517.8	2.11	4263.317	0.25	508.9512	0.47
TRL 28	10	324064.6	0.98	4639.492	0.28	277.6098	0.17
TRL 28	20	413568.2	1.82	6394.975	0.60	385.5691	0.15
TRL 28	30	657388.2	2.52	8401.242	0.64	354.7236	0.24
TRL 28	50	333323.6	1.95	43134.73	2.20	771.1383	0.43
TRL 29	0	499985.4	2.36	9655.158	0.56	416.4147	0.39

APPENDIX A continued.

August 2009							
Station	Depth	HB abundance	HB biomass	CB abundance	CB biomass	FLG abundance	FLG biomass
TRL 30	0	299374	1.41	5768.017	0.34	262.187	0.24
TRL 31	0	4493696	21.21	844638.3	49.13	3177.09	2.96
TRL 32	0	3209783	15.15	486519.7	28.30	2066.651	1.93
TRL 33	0	3549279	16.75	423322.3	24.62	1418.894	1.32
TRL 33	9	2796215	8.48	285893	17.19	1079.594	0.67
TRL 34	0	4339380	20.48	600876.9	34.95	1172.13	1.09
TRL 34	8	4228272	12.82	496551	29.86	1542.277	0.96
TRL 35	0	586402.6	2.77	28087.73	1.63	493.5285	0.46
TRL 36	0	3814703	18.00	620939.5	36.11	1943.268	1.81
TRL 37	0	6345494	29.95	674105.6	39.21	1048.748	0.98
TRL 38	0	882690.3	4.17	83009.28	4.83	1573.122	1.47
TRL 38	10	827136.4	2.51	49655.1	2.99	956.2114	0.60
TRL 39	0	530848.7	2.51	12037.6	0.70	323.8781	0.30
TRL 39	10	376532.2	1.14	7272.717	0.44	154.2277	0.10
TRL 39	20	598748	2.64	58683.3	5.55	524.374	0.20
TRL 39	25	626524.9	2.40	72601.78	5.53	817.4065	0.55
TRL 40	0	484553.8	2.29	8777.417	0.51	539.7968	0.50
TRL 40	10	345668.9	1.05	9278.983	0.56	246.7642	0.15
TRL 40	20	604920.6	2.67	10282.12	0.97	400.9919	0.15
TRL 40	30	422827.2	1.62	9780.55	0.75	493.5285	0.33
TRL 40	50	453690.5	2.65	17304.05	0.88	524.374	0.29
TRL 40	56	330237.3	1.93	14796.22	0.75	447.2602	0.72
TRL 41	0	450604.1	2.13	29315.71	1.71	1588.545	1.48
TRL 42	0	583316.3	2.75	28463.91	1.66	1310.935	1.22
TRL 43	0	453690.5	2.14	9655.158	0.56	586.0651	0.55
TRL 43	10	478381.1	1.45	17178.66	1.03	724.87	0.45
TRL 43	20	577143.6	2.54	37742.89	3.57	879.0976	0.34
TRL 44	0	413568.2	1.95	12288.38	0.71	863.6748	0.81
TRL 45	0	364186.9	1.72	6269.583	0.36	169.6504	0.16
TRL 47	0	537021.4	2.53	6771.15	0.39	493.5285	0.46
TRL 47	10	428999.8	1.30	8025.067	0.48	447.2602	0.28
TRL 47	20	395050.2	1.74	9905.942	0.94	493.5285	0.19
TRL 47	30	564798.3	2.16	14294.65	1.09	601.4878	0.41
TRL 47	50	382704.9	2.24	19561.1	1.00	616.9106	0.35
TRL 47	81	305546.6	1.22	7021.933	0.50	246.7642	0.40
TRL 48	1	740719.1	3.50	34482.71	2.01	694.0244	0.65
TRL 48	3	762323.4	3.60	33604.97	1.95	678.6017	0.63
TRL 48	7	598748	1.82	23573.63	1.42	508.9512	0.32
TRL 48	20	675906.2	2.98	18432.58	1.74	663.1789	0.26
TRL 48	35	336409.9	1.29	18307.18	1.39	755.7155	0.51
TRL 48	45	648129.2	3.79	8777.417	0.45	478.1057	0.27
TRL 48	75	364186.9	1.46	3887.142	0.28	370.1464	0.60
TRL 48	90	385791.2	1.93	3636.358	0.11	293.0325	0.12
TRL 48	150	182093.5	0.57	1379.308	0.11	123.3821	0.21
TRL 48	200	141971.2	1.04	92.53659	0.01	0	0.00
TRL 49	0	299374	0.91	5266.45	0.31	323.8781	0.30
TRL 50	0	280856	0.85	4263.317	0.25	154.2277	0.14

APPENDIX A continued.

October 2009							
Station:	Depth:	HB abundance	HB biomass	CB abundance	CB biomass	FLG abundance	FLG biomass
TRL 1	0	915097	5.84	120878	7.69	1666	1.65
TRL 2	0	851827	5.43	124890	7.95	1080	1.07
TRL 2	10	1419712	7.63	126646	5.68	1450	1.25
TRL 2	19	938244	3.78	69216	3.36	1049	0.84
TRL 3	0	896579	5.72	118871	7.56	756	0.75
TRL 4	0	660475	4.21	82550	5.25	1126	1.12
TRL 4	10	611093	3.28	110595	4.96	648	0.56
TRL 4	20	435172	1.75	77994	3.78	756	0.61
TRL 4	30	547824	2.21	38370	1.81	632	0.41
TRL 4	48	398137	2.24	5266	0.32	601	0.52
TRL 5	0	395050	2.52	31724	2.02	571	0.57
TRL 6	0	1462920	9.33	66959	4.26	2005	1.99
TRL 7	0	1169719	7.46	104577	6.65	1419	1.41
TRL 8	0	654302	4.17	48903	3.11	524	0.52
TRL 9	0	842568	5.38	102947	6.55	1511	1.50
TRL 10	0	412025	2.63	32978	2.10	278	0.28
TRL 10	10	358014	1.92	30345	1.36	324	0.28
TRL 10	20	424370	1.71	50407	2.44	386	0.31
TRL 10	30	489183	1.98	35360	1.66	601	0.39
TRL 10	50	276227	1.55	3135	0.19	123	0.11
TRL 10	68	390421	1.47	4765	0.54	308	0.20
TRL 11	0	1663532	10.61	95548	6.08	4226	4.19
TRL 12	0	1513845	9.66	60439	3.85	1743	1.73
TRL 13	0	981453	6.26	115110	7.32	2221	2.20
TRL 14	0	858000	5.47	99561	6.34	1419	1.41
TRL 14	10	697511	3.75	81003	3.63	787	0.68
TRL 14	20	455234	1.83	59436	2.88	370	0.30
TRL 14	30	574057	2.32	41630	1.96	524	0.34
TRL 14	40	555539	3.12	22069	1.33	447	0.67
TRL 15	0	538565	3.44	44514	2.83	972	0.96
TRL 16	0	2075557	13.24	77367	4.92	3439	3.41
TRL 17	0	1124967	7.18	82884	5.27	1049	1.04
TRL 18	0	759237	4.84	111849	7.12	1018	1.01
TRL 18	10	512331	2.75	66458	2.98	709	0.61
TRL 18	19	503072	2.03	62947	3.05	709	0.57
TRL 20	0	790207	5.04	89404	5.69	1172	1.16
TRL 21	0	1786985	11.40	79749	5.07	2745	2.72
TRL 22	0	1012316	6.46	78244	4.98	1296	1.29
TRL 22	10	1070956	5.75	72727	3.26	1141	0.98
TRL 24	0	898122	5.73	76990	4.90	2375	2.36
TRL 25	0	1327122	8.47	113103	7.20	1882	1.87
TRL 26	0	1771553	11.30	130407	8.30	2930	2.91
TRL 27	1	2246848	14.34	194608	12.38	3316	3.29
TRL 27	3	1734517	11.07	143448	9.13	2113	2.10
TRL 27	5	1444402	7.76	110846	4.97	1604	1.38
TRL 27	10	751521	4.04	68088	3.05	524	0.45
TRL 27	15	419741	1.69	43636	2.12	571	0.46
TRL 27	20	481467	1.94	48276	2.34	494	0.40
TRL 27	25	297831	1.20	23950	1.13	108	0.07
TRL 27	30	518503	2.09	51661	2.43	339	0.22
TRL 28	0	532392	3.40	46019	2.93	663	0.66
TRL 28	10	631154	3.39	31599	1.42	278	0.24
TRL 28	20	564798	2.27	42759	2.07	632	0.51
TRL 28	30	498442	2.01	30094	1.42	231	0.15
TRL 28	50	293201	1.65	7900	0.48	370	0.32

APPENDIX A continued.

October 2009							
Station	Depth	HB abundance	HB biomass	CB abundance	CB biomass	FLG abundance	FLG biomass
TRL 30	0	395050	2.52	25831	1.64	185	0.18
TRL 31	0	1512302	9.65	134420	8.55	1758	1.74
TRL 32	0	1089474	6.95	106332	6.77	2252	2.23
TRL 33	0	1257945	8.03	66959	4.26	2437	2.42
TRL 33	10	1117251	6.00	159498	7.15	1727	1.49
TRL 34	0	1743776	11.13	95298	6.06	2375	2.36
TRL 34	8	2064755	11.09	183323	8.22	2067	1.78
TRL 35	0	1308604	8.35	173041	11.01	1388	1.38
TRL 36	0	1808589	11.54	241254	15.35	2961	2.94
TRL 37	0	1536992	9.81	207649	13.21	2437	2.42
TRL 38	0	1311690	8.37	119373	7.60	1172	1.16
TRL 38	10	1379589	7.41	185580	8.32	1265	1.09
TRL 39	0	663561	4.23	81254	5.17	1172	1.16
TRL 39	10	824050	4.43	100564	4.51	1049	0.90
TRL 39	20	549367	2.21	60815	2.95	555	0.41
TRL 39	26	663561	2.68	56426	2.66	864	0.52
TRL 40	0	552453	3.52	38997	2.48	370	0.37
TRL 40	10	484554	2.60	43762	1.96	478	0.41
TRL 40	20	493813	1.99	37743	1.83	601	0.44
TRL 40	30	544737	2.20	35987	1.69	339	0.20
TRL 40	50	277770	1.56	7398	0.45	601	0.52
TRL 40	58	248450	1.40	2382	0.14	355	0.31
TRL 41	0	972194	6.20	127147	8.09	1511	1.50
TRL 42	0	1330208	8.49	102570	6.53	1943	1.93
TRL 43	0	1499956	9.57	184577	11.74	1049	1.04
TRL 43	10	1157374	6.22	162758	7.29	956	0.82
TRL 43	20	865715	3.49	144702	7.02	1018	0.82
TRL 44	0	518503	3.31	58683	3.73	740	0.73
TRL 45	0	506158	3.23	38370	2.44	740	0.73
TRL 46	0	527762	3.37	23072	1.47	339	0.34
TRL 46	10	484554	2.60	25705	1.15	463	0.40
TRL 46	20	458320	1.85	20439	0.99	432	0.35
TRL 46	30	438259	1.77	21442	1.01	370	0.24
TRL 46	50	317892	1.79	4890	0.29	339	0.30
TRL 46	75	217586	0.82	339	0.04	77	0.05
TRL 46	100	192896	0.90	224	0.03	31	0.02
TRL 46	125	189809	1.12	69	0.00	93	0.09
TRL 47	0	466036	2.97	27335	1.74	278	0.28
TRL 47	10	413568	2.22	35862	1.61	494	0.43
TRL 47	20	478381	1.93	34357	1.67	463	0.37
TRL 47	30	479924	1.94	35862	1.69	339	0.22
TRL 47	50	387334	2.18	8652	0.52	278	0.24
TRL 47	80	256165	0.97	2006	0.11	293	0.11
TRL 48	1	506158	3.23	10784	0.69	231	0.23
TRL 48	5	489183	2.63	9906	0.44	308	0.27
TRL 48	10	503072	2.70	12038	0.54	139	0.12
TRL 48	20	496899	2.00	11661	0.57	478	0.38
TRL 48	30	429426	1.73	14420	0.68	308	0.20
TRL 48	50	276227	1.55	5266	0.32	432	0.38
TRL 48	75	220158	0.83	509	0.06	350	0.23
TRL 48	100	157403	0.73	82	0.01	82	0.05
TRL 48	150	117281	0.33	5	0.00	21	0.02
TRL 48	200	106993	0.60	118	0.01	31	0.01
TRL 49	0	598748	3.82	41128	2.62	278	0.28
TRL 50	0	365730	2.33	16677	1.06	308	0.31

APPENDIX A continued.

February 2010							
Station	Depth	HB abundance	HB biomass	CB abundance	CB biomass	FLG abundance	FLG biomass
TRL 1	0	1007687	3.99	14545	0.91	2869	3.18
TRL 2	0	401223	1.59	8903	0.56	648	0.72
TRL 2	10	391964	2.32	8150	0.48	679	0.71
TRL 2	15	438259	1.69	8025	0.50	802	0.98
TRL 3	0	649672	2.57	15047	0.94	1296	1.44
TRL 4	0	383734	1.52	13041	0.81	1275	1.42
TRL 4	10	325093	1.93	8443	0.50	689	0.72
TRL 4	20	264910	1.02	5601	0.35	524	0.64
TRL 4	30	299374	1.42	6520	0.37	329	0.26
TRL 4	45	331266	1.56	3511	0.18	206	0.22
TRL 5	0	476838	1.89	7774	0.49	524	0.58
TRL 6	0	876518	3.47	10157	0.63	2144	2.38
TRL 7	0	966021	3.82	27210	1.70	1265	1.40
TRL 8	0	895036	3.54	22069	1.38	1604	1.78
TRL 9	0	415111	1.64	9781	0.61	956	1.06
TRL 10	0	273655	1.08	8192	0.51	442	0.49
TRL 10	10	363158	2.15	8777	0.52	658	0.69
TRL 10	20	376532	1.45	9613	0.60	576	0.70
TRL 10	30	234561	1.12	5852	0.33	504	0.40
TRL 10	40	331266	1.45	8025	0.42	442	0.44
TRL 10	50	433115	2.04	6353	0.33	452	0.48
TRL 10	65	246906	1.16	7189	0.37	432	0.46
TRL 11	0	726831	2.88	17304	1.08	1650	1.83
TRL 12	0	746892	2.96	14169	0.89	1635	1.81
TRL 13	0	626525	2.48	14420	0.90	2175	2.41
TRL 14	0	476838	1.89	10658	0.67	1650	1.83
TRL 14	10	427457	2.53	5266	0.31	494	0.51
TRL 14	20	336410	1.29	4263	0.26	494	0.60
TRL 14	30	460892	2.19	5266	0.30	504	0.40
TRL 14	40	469335	2.05	3344	0.17	257	0.25
TRL 15	0	424370	1.68	10784	0.67	555	0.62
TRL 16	0	1433600	5.67	12163	0.76	1573	1.75
TRL 17	0	725287	2.87	16050	1.00	1465	1.63
TRL 17	9	712942	4.22	13292	0.79	833	0.92
TRL 18	0	586403	2.32	5768	0.36	540	0.60
TRL 18	10	594118	3.52	14420	0.85	879	0.92
TRL 18	16	810162	3.12	16176	1.00	2498	3.04
TRL 19	0	881147	3.49	18558	1.16	1511	1.68
TRL 20	0	481467	1.91	8652	0.54	601	0.67
TRL 21	0	1515388	6.00	10157	0.63	3563	3.95
TRL 21	5	1263852	7.49	5768	0.34	3193	3.33
TRL 22	0	851827	3.37	15047	0.94	2483	2.76
TRL 22	6	757694	4.49	7147	0.42	972	1.01
TRL 23	0	1533906	6.07	12038	0.75	2082	2.31
TRL 24	0	1433600	5.67	12915	0.81	2576	2.86
TRL 25	0	987625	3.91	14044	0.88	2329	2.58
TRL 26	0	1311690	5.19	28213	1.76	1403	1.56
TRL 27	0	1126510	4.46	32226	2.01	1450	1.61
TRL 27	3	1046266	4.14	27837	1.74	1666	1.85
TRL 27	6	913554	5.41	21944	1.30	679	0.71
TRL 27	10	714485	4.23	23323	1.38	787	0.82
TRL 27	15	714485	2.75	31223	1.94	740	0.90
TRL 27	20	535478	2.06	14044	0.87	663	0.81
TRL 27	25	510788	2.43	9781	0.56	478	0.38
TRL 28	0	154316	0.61	4848	0.30	422	0.47
TRL 28	10	251021	1.49	8527	0.50	360	0.38
TRL 28	20	288057	1.11	10784	0.67	566	0.69

APPENDIX A continued.

February 2010							
Station	Depth	HB abundance	HB biomass	CB abundance	CB biomass	FLG abundance	FLG biomass
TRL 28	30	274683	1.31	9613	0.55	360	0.28
TRL 28	40	309662	1.35	13459	0.70	432	0.43
TRL 28	47	256165	1.21	12957	0.67	298	0.32
TRL 29	0	503072	1.99	17806	1.11	833	0.92
TRL 30	0	422827	1.67	16050	1.00	771	0.86
TRL 31	0	1013859	4.01	10408	0.65	2005	2.23
TRL 32	0	726831	2.88	6019	0.38	2745	3.05
TRL 33	0	820964	3.25	24075	1.50	2205	2.45
TRL 33	6	861086	5.10	17179	1.02	2128	2.22
TRL 34	0	712942	2.82	18433	1.15	663	0.74
TRL 34	5	956762	5.67	26959	1.59	1002	1.05
TRL 36	0	952133	3.77	14420	0.90	1388	1.54
TRL 37	0	958305	3.79	14545	0.91	1357	1.51
TRL 38	0	695967	2.75	25329	1.58	987	1.10
TRL 38	7	859543	5.09	22445	1.33	617	0.64
TRL 39	0	614180	2.43	15925	0.99	293	0.33
TRL 39	10	458320	2.72	16552	0.98	601	0.63
TRL 39	20	399680	1.54	15423	0.96	1049	1.28
TRL 40	0	603377	2.39	22821	1.43	787	0.87
TRL 40	10	330237	1.96	12163	0.72	771	0.80
TRL 40	20	410482	1.58	14169	0.88	555	0.68
TRL 40	30	399680	1.90	16426	0.93	293	0.23
TRL 40	40	549367	2.40	10157	0.53	170	0.17
TRL 40	54	397794	1.88	15172	0.78	262	0.28
TRL 41	0	820964	3.25	22654	1.41	463	0.51
TRL 42	0	470151	1.86	11034	0.69	853	0.95
TRL 43	0	310176	1.23	11536	0.72	679	0.75
TRL 43	10	395050	2.34	13292	0.79	709	0.74
TRL 43	17	601834	2.31	17304	1.08	725	0.88
TRL 44	0	383734	1.52	12372	0.77	308	0.34
TRL 45	0	575086	2.28	17304	1.08	401	0.45
TRL 46	0	338467	1.34	18642	1.16	247	0.27
TRL 46	10	344640	2.04	15047	0.89	308	0.32
TRL 46	20	383734	1.48	16385	1.02	391	0.48
TRL 46	30	354928	1.69	18056	1.03	247	0.19
TRL 46	40	324065	1.42	17638	0.91	175	0.17
TRL 46	50	276741	1.31	11620	0.60	82	0.09
TRL 46	75	335381	1.16	10031	0.51	123	0.11
TRL 46	100	399165	1.36	5852	0.50	103	0.07
TRL 46	120	432086	2.22	4681	0.36	134	0.10
TRL 47	0	382705	1.51	10658	0.67	324	0.36
TRL 47	10	419741	2.49	6395	0.38	278	0.29
TRL 47	20	427457	1.64	8903	0.55	339	0.41
TRL 47	30	487640	2.32	8777	0.50	308	0.24
TRL 47	40	583316	2.55	4263	0.22	108	0.11
TRL 47	50	367273	1.73	2759	0.14	62	0.07
TRL 47	75	529820	1.83	6855	0.35	247	0.21
TRL 48	0	291144	1.15	11285	0.70	339	0.38
TRL 48	5	323036	1.91	13375	0.79	360	0.38
TRL 48	10	391964	2.32	15632	0.92	380	0.40
TRL 48	20	318921	1.23	14044	0.87	360	0.44
TRL 48	30	349784	1.66	15465	0.88	401	0.32
TRL 48	40	311719	1.36	11620	0.60	380	0.38
TRL 48	50	315834	1.49	13459	0.69	504	0.53
TRL 48	75	284971	0.98	12372	0.63	566	0.49
TRL 48	100	247935	0.85	8443	0.72	185	0.13
TRL 48	150	211928	0.97	4096	0.30	154	0.13
TRL 48	200	258223	1.18	3595	0.25	113	0.11
TRL 49	0	612122	2.42	26165	1.63	709	0.79
TRL 50	0	422827	1.67	17053	1.07	278	0.31

APPENDIX A continued.

April 2010							
Station	Depth	HB abundance	HB biomass	CB abundance	CB biomass	FLG abundance	FLG biomass
TRL 1	0	1205212	5.51	35862	1.99	987	1.54
TRL 2	0	938244	4.29	18056	1.00	663	1.03
TRL 2	10	665104	2.59	21818	1.72	355	0.37
TRL 2	15	657388	2.79	12790	1.02	447	0.71
TRL 3	0	731460	3.34	17931	1.00	555	0.87
TRL 4	0	697511	3.19	32351	1.80	709	1.11
TRL 4	10	429000	1.67	15967	1.26	596	0.62
TRL 4	20	309662	1.32	13041	1.04	267	0.42
TRL 4	30	295259	1.57	9530	0.82	123	0.17
TRL 4	40	411511	2.06	11369	0.83	226	0.27
TRL 5	0	633726	2.90	34775	1.93	483	0.75
TRL 6	0	1274654	5.83	23323	1.30	725	1.13
TRL 7	0	851827	3.89	25705	1.43	1203	1.87
TRL 8	0	796273	3.64	19561	1.09	972	1.51
TRL 9	0	350298	1.60	10282	0.57	339	0.53
TRL 10	0	365216	1.67	14545	0.81	668	1.04
TRL 10	10	427971	1.67	19895	1.57	925	0.96
TRL 10	20	379619	1.61	20899	1.67	689	1.09
TRL 10	30	289086	1.53	13626	1.17	442	0.59
TRL 10	40	218101	1.09	9864	0.72	278	0.33
TRL 10	50	290115	1.24	12205	0.98	175	0.21
TRL 10	65	345882	1.32	17471	1.15	257	0.38
TRL 11	0	626525	2.86	1630	0.09	31	0.05
TRL 12	0	975280	3.80	21317	1.19	1080	1.68
TRL 14	0	466036	2.13	9697	0.54	226	0.35
TRL 14	10	388878	1.52	9864	0.78	247	0.26
TRL 14	20	449575	1.91	17638	1.41	494	0.78
TRL 14	30	360072	1.91	17053	1.46	401	0.54
TRL 14	40	595662	2.98	33689	2.47	720	0.86
TRL 15	0	347726	1.59	1170	0.07	0	0.00
TRL 16	0	1132683	5.18	23072	1.28	324	0.50
TRL 17	0	736090	3.37	15047	0.84	648	1.01
TRL 18	0	714485	3.27	23072	1.28	756	1.18
TRL 18	10	512331	2.00	17555	1.38	694	0.72
TRL 18	18	631154	2.68	23824	1.91	555	0.88
TRL 19	0	521590	2.38	14922	0.83	386	0.60
TRL 20	0	426942	1.95	14963	0.83	360	0.56
TRL 21	0	1148115	5.25	18809	1.05	1049	1.63
TRL 22	0	1141942	5.22	26583	1.48	1249	1.95
TRL 22	6	915097	4.18	18056	1.42	925	0.96
TRL 23	0	1231446	5.63	21442	1.19	833	1.30
TRL 24	0	1259223	5.76	27712	1.54	956	1.49
TRL 25	0	1061697	4.85	21818	1.21	494	0.77
TRL 26	0	527432	2.41	14671	0.82	247	0.38
TRL 27	0	364187	1.67	16802	0.93	247	0.38
TRL 27	3	364187	1.67	16802	0.93	447	0.70
TRL 27	6	263881	1.03	12790	1.01	216	0.22
TRL 27	10	311719	1.22	20690	1.63	386	0.40
TRL 27	15	382705	1.63	17806	1.43	432	0.69
TRL 27	20	337953	1.44	15172	1.21	231	0.37
TRL 27	25	368816	1.96	24326	2.09	324	0.43
TRL 28	0	317892	1.45	14713	0.82	360	0.56
TRL 28	10	360072	1.40	15131	1.19	391	0.41
TRL 28	20	338467	1.44	16050	1.28	391	0.62
TRL 28	30	351842	1.87	19812	1.70	524	0.70
TRL 28	40	389906	1.95	14044	1.03	185	0.22

APPENDIX A continued.

April 2010							
Station	Depth	HB abundance	HB biomass	CB abundance	CB biomass	FLG abundance	FLG biomass
TRL 28	47	477352	2.04	19812	1.59	298	0.36
TRL 29	0	427457	1.95	25204	1.40	632	0.99
TRL 30	0	197525	0.90	8359	0.46	154	0.24
TRL 31	0	1277740	5.84	17304	0.96	509	0.79
TRL 32	0	1293172	5.91	15298	0.85	555	0.87
TRL 33	0	1212928	5.55	24201	1.35	478	0.74
TRL 33	7	1067870	4.16	23448	1.85	355	0.37
TRL 34	0	725287	3.32	19436	1.08	509	0.79
TRL 34	5	682079	2.66	18307	1.44	540	0.56
TRL 35	0	385791	1.76	14796	0.82	216	0.34
TRL 36	0	932072	4.26	23197	1.29	278	0.43
TRL 37	0	848741	3.88	17806	0.99	463	0.72
TRL 38	0	794730	3.63	32978	1.83	663	1.03
TRL 38	6	780841	3.05	29467	2.32	494	0.51
TRL 39	0	435172	1.99	19310	1.07	494	0.77
TRL 39	10	390421	1.52	16301	1.28	401	0.42
TRL 39	20	455234	1.94	18683	1.50	494	0.78
TRL 40	0	239457	1.09	9948	0.55	93	0.14
TRL 40	10	323036	1.26	8443	0.67	175	0.18
TRL 40	20	340525	1.45	11703	0.94	195	0.31
TRL 40	30	329208	1.75	12623	1.08	535	0.72
TRL 40	40	291144	1.45	16217	1.19	463	0.56
TRL 40	50	343611	1.47	13877	1.12	432	0.52
TRL 41	0	969108	4.43	27335	1.52	524	0.82
TRL 42	0	709856	3.25	29509	1.64	555	0.87
TRL 43	0	578687	2.65	16802	0.93	478	0.74
TRL 43	10	618809	2.41	21442	1.69	509	0.53
TRL 43	17	751521	3.19	33856	2.71	679	1.08
TRL 44	0	377561	1.73	18976	1.06	524	0.82
TRL 45	0	253079	1.16	9112	0.51	165	0.26
TRL 46	0	475295	2.17	14629	0.81	216	0.34
TRL 46	10	306575	1.20	9195	0.72	123	0.13
TRL 46	20	231475	0.98	6353	0.51	113	0.18
TRL 46	30	367273	1.95	8527	0.73	93	0.12
TRL 46	40	383734	1.92	10784	0.79	144	0.17
TRL 46	50	283942	1.21	8527	0.69	134	0.16
TRL 46	75	390935	1.49	16552	1.09	360	0.53
TRL 46	100	237647	1.07	7774	0.53	113	0.17
TRL 46	119	230446	0.99	5768	0.41	236	0.26
TRL 47	0	254108	1.16	8777	0.49	154	0.24
TRL 47	10	351842	1.37	17304	1.36	370	0.38
TRL 47	20	274683	1.17	12874	1.03	452	0.72
TRL 47	30	283942	1.51	14713	1.26	288	0.39
TRL 47	40	284971	1.42	10115	0.74	247	0.30
TRL 47	50	192381	0.82	5099	0.41	103	0.12
TRL 47	75	317892	1.21	2675	0.18	62	0.09
TRL 48	0	468093	2.14	16886	0.94	442	0.69
TRL 48	5	392993	1.53	17471	1.38	350	0.36
TRL 48	10	288057	1.12	13626	1.07	267	0.28
TRL 48	20	337439	1.43	19812	1.59	319	0.51
TRL 48	30	392993	2.09	16552	1.42	288	0.39
TRL 48	40	329208	1.64	16134	1.18	175	0.21
TRL 48	50	363158	1.55	17806	1.43	216	0.26
TRL 48	75	361101	1.38	14963	0.98	288	0.42
TRL 48	100	233532	1.05	6604	0.45	113	0.17
TRL 48	150	245878	0.98	6270	0.47	123	0.16
TRL 48	200	219129	0.99	2341	0.15	72	0.12
TRL 49	0	355957	1.63	10616	0.59	452	0.70
TRL 50	0	186209	0.85	6688	0.37	175	0.27

APPENDIX A continued.

July 2010							
Station	Depth	HB abundance	HB biomass	CB abundance	CB biomass	FLG abundance	FLG biomass
TRL 1	0	722201	3.41	7273	0.42	31	0.03
TRL 2	0	1515388	7.15	45893	2.67	2591	2.36
TRL 2	10	456777	1.39	37367	2.25	370	0.23
TRL 2	17	700597	3.09	71975	6.81	925	0.35
TRL 3	0	1024661	4.84	19060	1.11	1388	1.26
TRL 4	0	763867	3.61	27962	1.63	617	0.56
TRL 4	10	407396	1.24	21317	1.28	401	0.24
TRL 4	20	408939	1.80	16552	1.57	262	0.10
TRL 4	30	350298	1.34	17806	1.36	278	0.18
TRL 4	45	356471	2.08	24201	1.23	339	0.19
TRL 5	0	417683	1.97	12706	0.74	370	0.34
TRL 6	0	2064755	9.74	130407	7.58	2838	2.58
TRL 7	0	1722172	8.13	58683	3.41	3393	3.09
TRL 8	0	1506129	7.11	99812	5.81	1820	1.66
TRL 9	0	293201	1.38	18683	1.09	555	0.51
TRL 10	0	423856	2.00	22236	1.29	442	0.40
TRL 10	10	506158	1.54	7189	0.43	257	0.16
TRL 10	20	424885	1.87	7607	0.72	175	0.07
TRL 10	30	484554	1.85	28756	2.19	360	0.24
TRL 10	40	406367	1.56	23992	1.83	442	0.24
TRL 10	50	346698	2.03	21818	1.11	339	0.19
TRL 10	65	349784	2.04	5852	0.41	391	0.62
TRL 11	0	2894977	13.66	185078	10.76	2190	1.99
TRL 12	0	2604862	12.29	138432	8.05	2992	2.72
TRL 13	0	1370330	6.47	81505	4.74	1511	1.38
TRL 14	0	570971	2.69	26708	1.55	509	0.46
TRL 14	10	634241	1.92	23699	1.43	401	0.24
TRL 14	20	504615	2.22	13041	1.23	293	0.11
TRL 14	30	436716	1.67	13542	1.03	247	0.16
TRL 14	40	387334	1.48	34859	2.66	293	0.16
TRL 15	0	549367	2.59	23490	1.37	494	0.45
TRL 16	0	808618	3.82	4514	0.26	31	0.03
TRL 17	0	3148056	14.86	173041	10.06	3732	3.40
TRL 18	0	657388	3.10	22320	1.30	679	0.62
TRL 18	10	506158	1.54	35862	2.16	339	0.21
TRL 18	18	842568	3.71	178809	16.91	833	0.31
TRL 19	0	719115	3.39	18056	1.05	555	0.51
TRL 20	0	569428	2.69	19436	1.13	278	0.25
TRL 21	0	2484495	11.73	150219	8.74	2591	2.36
TRL 21	7	3024603	9.17	95799	5.76	1172	0.71
TRL 22	0	1678963	7.92	100063	5.82	1697	1.54
TRL 22	9	1453661	6.86	100063	6.02	987	0.60
TRL 23	0	3030776	14.30	172037	10.01	2406	2.19
TRL 23	7	2857941	8.67	95799	5.76	802	0.49
TRL 24	0	1379589	6.51	102570	5.97	2005	1.82
TRL 25	0	601834	2.84	49154	2.86	709	0.65
TRL 26	0	499985	2.36	18307	1.06	463	0.42
TRL 27	1	405852	1.92	45141	2.63	648	0.59
TRL 27	3	436716	2.06	47523	2.76	817	0.74
TRL 27	6	398137	1.21	38119	2.29	416	0.25
TRL 27	10	319435	0.97	51912	3.12	478	0.29
TRL 27	15	385791	1.70	57931	5.48	355	0.22
TRL 27	20	342583	1.51	67335	6.37	555	0.21
TRL 27	25	328694	1.26	32602	2.48	370	0.14
TRL 27	30	401223	1.54	69342	5.28	524	0.35
TRL 28	0	406367	1.92	30345	1.76	319	0.29
TRL 28	10	546280	1.66	12915	0.78	216	0.13
TRL 28	20	436716	1.92	13668	1.29	648	0.24

APPENDIX A continued.

July 2010							
Station	Depth	HB abundance	HB biomass	CB abundance	CB biomass	FLG abundance	FLG biomass
TRL 28	30	445975	1.71	13417	1.02	139	0.09
TRL 28	40	487640	1.87	19937	1.52	185	0.10
TRL 28	47	385791	2.25	29843	1.52	648	0.35
TRL 29	0	509244	2.40	15549	0.90	185	0.17
TRL 30	0	598748	2.83	28004	1.63	391	0.36
TRL 31	0	2672761	12.61	193605	11.26	2283	2.08
TRL 32	0	885777	4.18	64201	3.73	1388	1.26
TRL 33	0	611093	2.88	45893	2.67	802	0.73
TRL 33	9	1021575	3.10	87273	5.25	1265	0.77
TRL 34	0	774669	3.66	53668	3.12	956	0.87
TRL 34	8	793187	2.41	74733	4.49	740	0.45
TRL 35	0	549367	2.59	28088	1.63	432	0.39
TRL 36	0	768496	3.63	50157	2.92	1080	0.98
TRL 37	0	811705	3.83	70470	4.10	956	0.87
TRL 38	0	499985	2.36	33605	1.95	463	0.42
TRL 38	10	459863	1.39	25329	1.52	555	0.34
TRL 39	0	506158	2.39	19310	1.12	555	0.51
TRL 39	10	740719	2.25	29843	1.79	679	0.41
TRL 39	25	481467	2.12	78495	7.42	524	0.20
TRL 40	0	485583	2.29	34608	2.01	257	0.23
TRL 40	10	477352	1.45	9697	0.58	452	0.28
TRL 40	20	318921	1.41	11536	1.09	298	0.11
TRL 40	30	477352	1.83	8359	0.64	185	0.12
TRL 40	40	365216	1.40	4431	0.34	257	0.17
TRL 40	55	426942	2.49	9864	0.50	257	0.14
TRL 41	0	472208	2.23	7273	0.42	62	0.06
TRL 42	0	432086	2.04	25078	1.46	216	0.20
TRL 43	0	413568	1.95	23574	1.37	370	0.34
TRL 43	10	432086	1.31	25580	1.54	524	0.32
TRL 43	18	469122	2.07	44890	4.25	401	0.15
TRL 44	0	530849	2.51	13375	0.78	308	0.28
TRL 45	0	347726	1.64	7273	0.42	267	0.24
TRL 46	0	692367	3.27	46896	2.73	504	0.46
TRL 46	10	754093	2.29	32769	1.97	411	0.25
TRL 46	20	694424	3.06	13626	1.29	185	0.07
TRL 46	30	707798	2.71	20648	1.57	278	0.18
TRL 46	40	540108	2.07	15883	1.21	93	0.05
TRL 46	50	561712	3.28	11452	0.58	175	0.10
TRL 46	75	342583	1.37	4431	0.31	206	0.32
TRL 46	100	278798	1.40	2759	0.08	185	0.07
TRL 46	124	246906	0.77	823	0.02	103	0.04
TRL 47	0	695453	3.28	44639	2.60	596	0.54
TRL 47	10	705741	2.14	41045	2.47	596	0.36
TRL 47	20	593604	2.62	11369	1.08	154	0.06
TRL 47	30	572000	2.19	19394	1.48	216	0.14
TRL 47	40	533935	2.04	17137	1.31	226	0.12
TRL 47	50	504101	2.95	23156	1.18	504	0.28
TRL 47	75	382705	1.53	2508	0.18	175	0.28
TRL 48	1	339496	1.60	26249	1.53	226	0.21
TRL 48	5	475295	1.44	30010	1.80	339	0.31
TRL 48	10	413568	1.25	22069	1.33	175	0.11
TRL 48	20	472208	2.08	18056	1.71	329	0.12
TRL 48	30	341554	1.31	24744	1.89	339	0.22
TRL 48	40	346698	1.33	29927	2.28	380	0.21
TRL 48	50	453690	2.65	20564	1.05	339	0.19
TRL 48	75	365216	1.46	11369	0.81	216	0.34
TRL 48	100	206784	1.04	14127	0.43	165	0.06
TRL 48	150	173863	0.54	6186	0.48	57	0.09
TRL 48	200	119338	0.87	4848	0.30	51	0.07
TRL 49	0	490726	2.32	8527	0.50	144	0.13
TRL 50	0	467065	2.20	5434	0.32	288	0.26

APPENDIX B. Results of Spearman's rank correlation analyses (values in bold are different from 0 with a significance level alpha=0.05).

September 2008 Surface							
		R values			p values		
Variables	n	HB Ab.	CB Ab.	FLG Ab.	HB Ab.	CB Ab.	FLG Ab.
HB Ab.	16	**1**	**0.771**	**0.880**	**0**	**0.001**	**< 0.0001**
CB Ab.	16	**0.771**	**1**	**0.915**	**0.001**	**0**	**< 0.0001**
FLG Ab.	16	**0.880**	**0.915**	**1**	**< 0.0001**	**< 0.0001**	**0**
Phyto	16	**0.815**	**0.850**	**0.920**	**0.000**	**< 0.0001**	**< 0.0001**
PO_4	16	**0.764**	**0.663**	**0.768**	**0.001**	**0.006**	**0.001**
NO_3+NO_2	16	**0.704**	**0.550**	**0.619**	**0.003**	**0.029**	**0.012**
NH_4	16	0.000	-0.056	0.050	1.000	0.839	0.852
Si	16	**0.879**	**0.851**	**0.937**	**< 0.0001**	**< 0.0001**	**< 0.0001**
DO	16	**0.524**	0.494	0.452	**0.039**	0.053	0.080
Total chl-a	16	**0.871**	**0.891**	**0.930**	**< 0.0001**	**< 0.0001**	**< 0.0001**
Temperature	15	**0.800**	**0.868**	**0.937**	**0.001**	**< 0.0001**	**< 0.0001**
Salinity	15	**-0.782**	**-0.786**	**-0.920**	**0.001**	**0.001**	**< 0.0001**
September 2008 All depths							
		R values			p values		
Variables	n	HB Ab.	CB Ab.	FLG Ab.	HB Ab.	CB Ab.	FLG Ab.
HB Ab.	50	**1**	**0.864**	**0.898**	**0**	**< 0.0001**	**< 0.0001**
CB Ab.	50	**0.864**	**1**	**0.915**	**< 0.0001**	**0**	**< 0.0001**
FLG Ab.	50	**0.898**	**0.915**	**1**	**< 0.0001**	**< 0.0001**	**0**
Phyto	50	**0.824**	**0.857**	**0.870**	**< 0.0001**	**< 0.0001**	**< 0.0001**
PO_4	51	**0.705**	**0.632**	**0.675**	**< 0.0001**	**< 0.0001**	**< 0.0001**
NO_3+NO_2	51	**0.400**	**0.393**	**0.459**	**0.004**	**0.005**	**0.001**
NH_4	51	0.062	0.063	0.121	0.669	0.661	0.402
Si	51	**0.715**	**0.784**	**0.765**	**< 0.0001**	**< 0.0001**	**< 0.0001**
DO	51	-0.157	-0.114	-0.101	0.276	0.428	0.482
Total chl-a	50	**0.573**	**0.683**	**0.663**	**< 0.0001**	**< 0.0001**	**< 0.0001**
Temperature	46	**0.653**	**0.691**	**0.641**	**< 0.0001**	**< 0.0001**	**< 0.0001**
Salinity	46	-0.117	-0.161	-0.293	0.444	0.290	0.051
February 2009 Surface							
		R values			p values		
Variables	n	HB Ab.	CB Ab.	FLG Ab.	HB Ab.	CB Ab.	FLG Ab.
HB Ab.	48	**1**	**0.647**	**0.834**	**0**	**< 0.0001**	**< 0.0001**
CB Ab.	48	**0.647**	**1**	**0.599**	**< 0.0001**	**0**	**< 0.0001**
FLG Ab.	48	**0.834**	**0.599**	**1**	**< 0.0001**	**< 0.0001**	**0**
Phyto	13	**0.852**	0.516	**0.682**	**0.000**	0.072	**0.012**
PO_4	47	**0.735**	**0.364**	**0.756**	**< 0.0001**	**0.012**	**< 0.0001**
NO_3+NO_2	47	**0.852**	**0.563**	**0.871**	**< 0.0001**	**< 0.0001**	**< 0.0001**
NH_4	47	**0.785**	**0.461**	**0.755**	**< 0.0001**	**0.001**	**< 0.0001**
Si	47	**0.632**	**0.598**	**0.674**	**< 0.0001**	**< 0.0001**	**< 0.0001**
DO	41	**0.793**	**0.533**	**0.806**	**< 0.0001**	**0.000**	**< 0.0001**
Total chl-a	31	**0.822**	**0.364**	**0.832**	**< 0.0001**	**0.045**	**< 0.0001**
Temperature	48	**-0.851**	**-0.532**	**-0.869**	**< 0.0001**	**0.000**	**< 0.0001**
Salinity	48	**-0.822**	**-0.519**	**-0.785**	**< 0.0001**	**0.000**	**< 0.0001**
February 2009 All depths							
		R values			p values		
Variables	n	HB Ab.	CB Ab.	FLG Ab.	HB Ab.	CB Ab.	FLG Ab.
HB Ab.	107	**1**	**0.679**	**0.733**	**0**	**< 0.0001**	**< 0.0001**
CB Ab.	107	**0.679**	**1**	**0.690**	**< 0.0001**	**0**	**< 0.0001**
FLG Ab.	107	**0.733**	**0.690**	**1**	**< 0.0001**	**< 0.0001**	**0**
Phyto	49	**0.654**	**0.667**	**0.570**	**< 0.0001**	**< 0.0001**	**< 0.0001**
PO_4	106	**0.548**	**0.464**	**0.546**	**< 0.0001**	**< 0.0001**	**< 0.0001**
NO_3+NO_2	106	**0.645**	**0.598**	**0.657**	**< 0.0001**	**< 0.0001**	**< 0.0001**
NH_4	106	**0.608**	**0.582**	**0.630**	**< 0.0001**	**< 0.0001**	**< 0.0001**
Si	106	**0.558**	**0.567**	**0.562**	**< 0.0001**	**< 0.0001**	**< 0.0001**
DO	100	**0.614**	**0.701**	**0.691**	**< 0.0001**	**< 0.0001**	**< 0.0001**
Total chl-a	89	**0.635**	**0.634**	**0.706**	**< 0.0001**	**< 0.0001**	**< 0.0001**
Temperature	102	**-0.692**	**-0.601**	**-0.710**	**< 0.0001**	**< 0.0001**	**< 0.0001**
Salinity	100	**-0.681**	**-0.657**	**-0.721**	**< 0.0001**	**< 0.0001**	**< 0.0001**

APPENDIX B continued.

April 2009 Surface							
		R values			p values		
Variables	n	HB Ab.	CB Ab.	FLG Ab.	HB Ab.	CB Ab.	FLG Ab.
HB Ab.	46	**1**	**0.887**	**0.703**	**0**	**< 0.0001**	**< 0.0001**
CB Ab.	46	**0.887**	**1**	**0.818**	**< 0.0001**	**0**	**< 0.0001**
FLG Ab.	46	**0.703**	**0.818**	**1**	**< 0.0001**	**< 0.0001**	**0**
Phyto	13	0.549	**0.610**	**0.610**	0.054	**0.029**	**0.029**
PO_4	46	**0.695**	**0.600**	**0.420**	**< 0.0001**	**< 0.0001**	**0.004**
NO_3+NO_2	46	**0.899**	**0.882**	**0.735**	**< 0.0001**	**< 0.0001**	**< 0.0001**
NH_4	46	**0.834**	**0.759**	**0.611**	**< 0.0001**	**< 0.0001**	**< 0.0001**
Si	46	**0.886**	**0.767**	**0.538**	**< 0.0001**	**< 0.0001**	**0.000**
DO	46	**0.716**	**0.598**	**0.436**	**< 0.0001**	**< 0.0001**	**0.003**
Total chl-a	31	**0.792**	**0.630**	0.326	**< 0.0001**	**0.000**	0.074
Temperature	46	**0.416**	**0.331**	0.284	**0.004**	**0.025**	0.056
Salinity	46	**-0.909**	**-0.829**	**-0.661**	**< 0.0001**	**< 0.0001**	**< 0.0001**
April 2009 All depths							
		R values			p values		
Variables	n	HB Ab.	CB Ab.	FLG Ab.	HB Ab.	CB Ab.	FLG Ab.
HB Ab.	101	**1**	**0.754**	**0.568**	**0**	**< 0.0001**	**< 0.0001**
CB Ab.	101	**0.754**	**1**	**0.707**	**< 0.0001**	**0**	**< 0.0001**
FLG Ab.	101	**0.568**	**0.707**	**1**	**< 0.0001**	**< 0.0001**	**0**
Phyto	48	0.253	**0.614**	**0.418**	0.083	**< 0.0001**	**0.003**
PO_4	99	**0.532**	**0.555**	**0.368**	**< 0.0001**	**< 0.0001**	**0.000**
NO_3+NO_2	99	**0.725**	**0.611**	**0.365**	**< 0.0001**	**< 0.0001**	**0.000**
NH_4	99	**0.639**	**0.601**	**0.509**	**< 0.0001**	**< 0.0001**	**< 0.0001**
Si	99	**0.651**	**0.448**	**0.388**	**< 0.0001**	**< 0.0001**	**< 0.0001**
DO	99	**0.363**	**0.514**	**0.456**	**0.000**	**< 0.0001**	**< 0.0001**
Total chl-a	84	**0.609**	**0.587**	**0.321**	**< 0.0001**	**< 0.0001**	**0.003**
Temperature	101	**0.329**	**0.506**	**0.481**	**0.001**	**< 0.0001**	**< 0.0001**
Salinity	101	**-0.532**	**-0.679**	**-0.580**	**< 0.0001**	**< 0.0001**	**< 0.0001**
August 2009 Surface							
		R values			p values		
Variables	n	HB Ab.	CB Ab.	FLG Ab.	HB Ab.	CB Ab.	FLG Ab.
HB Ab.	47	**1**	**0.923**	**0.749**	**0**	**< 0.0001**	**< 0.0001**
CB Ab.	47	**0.923**	**1**	**0.809**	**< 0.0001**	**0**	**< 0.0001**
FLG Ab.	47	**0.749**	**0.809**	**1**	**< 0.0001**	**< 0.0001**	**0**
Phyto	15	**0.861**	**0.836**	**0.851**	**< 0.0001**	**0.000**	**< 0.0001**
PO_4	46	**0.653**	**0.664**	**0.478**	**< 0.0001**	**< 0.0001**	**0.001**
NO_3+NO_2	46	**0.766**	**0.749**	**0.580**	**< 0.0001**	**< 0.0001**	**< 0.0001**
NH_4	46	**0.558**	**0.514**	**0.333**	**< 0.0001**	**0.000**	**0.024**
Si	46	**0.847**	**0.911**	**0.716**	**< 0.0001**	**< 0.0001**	**< 0.0001**
DO	46	**0.712**	**0.698**	**0.615**	**< 0.0001**	**< 0.0001**	**< 0.0001**
Total chl-a	30	**0.812**	**0.795**	**0.700**	**< 0.0001**	**< 0.0001**	**< 0.0001**
Temperature	47	**0.692**	**0.707**	**0.603**	**< 0.0001**	**< 0.0001**	**< 0.0001**
Salinity	46	**-0.851**	**-0.814**	**-0.679**	**< 0.0001**	**< 0.0001**	**< 0.0001**
August 2009 All depths							
		R values			p values		
Variables	n	HB Ab.	CB Ab.	FLG Ab.	HB Ab.	CB Ab.	FLG Ab.
HB Ab.	101	**1**	**0.827**	**0.700**	**0**	**< 0.0001**	**< 0.0001**
CB Ab.	101	**0.827**	**1**	**0.816**	**< 0.0001**	**0**	**< 0.0001**
FLG Ab.	101	**0.700**	**0.816**	**1**	**< 0.0001**	**< 0.0001**	**0**
Phyto	57	**0.698**	**0.800**	**0.687**	**< 0.0001**	**< 0.0001**	**< 0.0001**
PO_4	100	**0.549**	**0.665**	**0.437**	**< 0.0001**	**< 0.0001**	**< 0.0001**
NO_3+NO_2	100	**0.404**	**0.447**	**0.317**	**< 0.0001**	**< 0.0001**	**0.001**
NH_4	100	**0.298**	**0.250**	**0.204**	**0.003**	**0.012**	**0.041**
Si	100	**0.575**	**0.797**	**0.590**	**< 0.0001**	**< 0.0001**	**< 0.0001**
DO	100	**0.240**	0.124	0.182	**0.016**	0.218	0.069
Total chl-a	83	**0.633**	**0.724**	**0.600**	**< 0.0001**	**< 0.0001**	**< 0.0001**
Temperature	100	**0.650**	**0.582**	**0.551**	**< 0.0001**	**< 0.0001**	**< 0.0001**
Salinity	99	**-0.573**	**-0.551**	**-0.492**	**< 0.0001**	**< 0.0001**	**< 0.0001**

APPENDIX B continued.

October 2009 Surface							
		R values			p values		
Variables	n	HB Ab.	CB Ab.	FLG Ab.	HB Ab.	CB Ab.	FLG Ab.
HB Ab.	47	**1**	**0.707**	**0.885**	**0**	**< 0.0001**	**< 0.0001**
CB Ab.	47	**0.707**	**1**	**0.630**	**< 0.0001**	**0**	**< 0.0001**
FLG Ab.	47	**0.885**	**0.630**	**1**	**< 0.0001**	**< 0.0001**	**0**
Phyto	14	**0.842**	0.481	**0.832**	**0.000**	0.082	**0.000**
PO_4	46	-0.171	-0.175	-0.248	0.255	0.244	0.097
NO_3+NO_2	46	-0.016	0.092	-0.147	0.917	0.541	0.328
NH_4	46	-0.072	-0.023	-0.136	0.634	0.877	0.366
Si	46	-0.119	-0.255	-0.247	0.428	0.088	0.098
DO	46	-0.070	-0.031	-0.097	0.643	0.836	0.520
Total chl-a	35	-0.165	-0.023	-0.290	0.343	0.895	0.091
Temperature	46	0.064	0.004	0.160	0.669	0.978	0.286
Salinity	46	0.224	0.245	**0.316**	0.135	0.101	**0.033**
October 2009 All depths							
		R values			p values		
Variables	n	HB Ab.	CB Ab.	FLG Ab.	HB Ab.	CB Ab.	FLG Ab.
HB Ab.	110	**1**	**0.887**	**0.880**	**0**	**< 0.0001**	**< 0.0001**
CB Ab.	110	**0.887**	**1**	**0.857**	**< 0.0001**	**0**	**< 0.0001**
FLG Ab.	110	**0.880**	**0.857**	**1**	**< 0.0001**	**< 0.0001**	**0**
Phyto	52	**0.832**	**0.775**	**0.811**	**< 0.0001**	**< 0.0001**	**< 0.0001**
PO_4	108	**0.493**	**0.401**	**0.433**	**< 0.0001**	**< 0.0001**	**< 0.0001**
NO_3+NO_2	108	**0.285**	0.172	**0.285**	**0.003**	0.075	**0.003**
NH_4	108	**0.560**	**0.471**	**0.610**	**< 0.0001**	**< 0.0001**	**< 0.0001**
Si	108	**0.795**	**0.815**	**0.810**	**< 0.0001**	**< 0.0001**	**< 0.0001**
DO	108	-0.012	-0.006	0.153	0.901	0.948	0.113
Total chl-a	94	**0.781**	**0.744**	**0.823**	**< 0.0001**	**< 0.0001**	**< 0.0001**
Temperature	110	-0.012	0.066	-0.102	0.903	0.495	0.289
Salinity	110	**-0.568**	**-0.535**	**-0.678**	**< 0.0001**	**< 0.0001**	**< 0.0001**
February 2010 Surface							
		R values			p values		
Variables	n	HB Ab.	CB Ab.	FLG Ab.	HB Ab.	CB Ab.	FLG Ab.
HB Ab.	49	**1**	**0.322**	**0.746**	**0**	**0.025**	**< 0.0001**
CB Ab.	49	**0.322**	**1**	0.037	**0.025**	**0**	0.798
FLG Ab.	49	**0.746**	0.037	**1**	**< 0.0001**	0.798	**0**
Phyto	15	**0.557**	0.232	**0.804**	**0.033**	0.400	**0.000**
PO_4	49	**0.430**	-0.024	**0.322**	**0.002**	0.868	**0.025**
NO_3+NO_2	49	**0.812**	0.022	**0.757**	**< 0.0001**	0.880	**< 0.0001**
NH_4	49	**0.601**	-0.136	**0.661**	**< 0.0001**	0.351	**< 0.0001**
Si	47	**0.676**	**0.289**	**0.555**	**< 0.0001**	**0.049**	**< 0.0001**
DO	49	**0.738**	-0.090	**0.844**	**< 0.0001**	0.539	**< 0.0001**
Total chl-a	31	**0.899**	0.238	**0.739**	**< 0.0001**	0.197	**< 0.0001**
Temperature	49	**-0.629**	-0.212	**-0.664**	**< 0.0001**	0.143	**< 0.0001**
Salinity	49	**-0.761**	-0.086	**-0.762**	**< 0.0001**	0.555	**< 0.0001**
February 2010 All depths							
		R values			p values		
Variables	n	HB Ab.	CB Ab.	FLG Ab.	HB Ab.	CB Ab.	FLG Ab.
HB Ab.	117	**1**	**0.444**	**0.703**	**0**	**< 0.0001**	**< 0.0001**
CB Ab.	117	**0.444**	**1**	**0.372**	**< 0.0001**	**0**	**< 0.0001**
FLG Ab.	117	**0.703**	**0.372**	**1**	**< 0.0001**	**< 0.0001**	**0**
Phyto	58	**0.666**	0.247	**0.750**	**< 0.0001**	0.062	**< 0.0001**
PO_4	117	**0.341**	0.044	**0.331**	**0.000**	0.637	**0.000**
NO_3+NO_2	117	**0.818**	**0.234**	**0.805**	**< 0.0001**	**0.011**	**< 0.0001**
NH_4	117	**0.419**	-0.111	**0.496**	**< 0.0001**	0.233	**< 0.0001**
Si	114	**0.796**	**0.359**	**0.744**	**< 0.0001**	**< 0.0001**	**< 0.0001**
DO	117	**0.719**	**0.313**	**0.848**	**< 0.0001**	**0.001**	**< 0.0001**
Total chl-a	99	**0.790**	**0.213**	**0.781**	**< 0.0001**	**0.034**	**< 0.0001**
Temperature	117	**-0.785**	**-0.325**	**-0.779**	**< 0.0001**	**0.000**	**< 0.0001**
Salinity	117	**-0.794**	**-0.320**	**-0.799**	**< 0.0001**	**0.000**	**< 0.0001**

APPENDIX B continued.

April 2010 Surface							
		R values			p values		
Variables	n	HB Ab.	CB Ab.	FLG Ab.	HB Ab.	CB Ab.	FLG Ab.
HB Ab.	49	**1**	**0.680**	**0.674**	**0**	**< 0.0001**	**< 0.0001**
CB Ab.	49	**0.680**	**1**	**0.735**	**< 0.0001**	**0**	**< 0.0001**
FLG Ab.	49	**0.674**	**0.735**	**1**	**< 0.0001**	**< 0.0001**	**0**
Phyto	15	**0.671**	**0.590**	0.335	**0.007**	**0.023**	0.220
PO_4	48	**0.803**	**0.544**	**0.395**	**< 0.0001**	**< 0.0001**	**0.006**
NO_3+NO_2	49	**0.815**	**0.450**	**0.400**	**< 0.0001**	**0.001**	**0.005**
NH_4	49	**0.399**	0.133	0.018	**0.005**	0.361	0.899
Si	49	**0.765**	**0.459**	**0.357**	**< 0.0001**	**0.001**	**0.012**
DO	49	**0.370**	0.131	**0.399**	**0.009**	0.367	**0.005**
Total chl-a	31	**0.770**	**0.536**	**0.613**	**< 0.0001**	**0.002**	**0.000**
Temperature	48	**0.450**	-0.003	**0.304**	**0.001**	0.982	**0.036**
Salinity	46	**-0.810**	**-0.436**	**-0.521**	**< 0.0001**	**0.003**	**0.000**
April 2010 All depths							
		R values			p values		
Variables	n	HB Ab.	CB Ab.	FLG Ab.	HB Ab.	CB Ab.	FLG Ab.
HB Ab.	115	**1**	**0.743**	**0.704**	**0**	**< 0.0001**	**< 0.0001**
CB Ab.	115	**0.743**	**1**	**0.777**	**< 0.0001**	**0**	**< 0.0001**
FLG Ab.	115	**0.704**	**0.777**	**1**	**< 0.0001**	**< 0.0001**	**0**
Phyto	55	**0.762**	**0.538**	**0.629**	**< 0.0001**	**< 0.0001**	**< 0.0001**
PO_4	117	**0.623**	**0.395**	**0.364**	**< 0.0001**	**< 0.0001**	**< 0.0001**
NO_3+NO_2	118	**0.547**	**0.298**	**0.270**	**< 0.0001**	**0.001**	**0.004**
NH_4	118	**0.397**	**0.224**	0.144	**< 0.0001**	**0.016**	0.124
Si	118	**0.612**	**0.424**	**0.407**	**< 0.0001**	**< 0.0001**	**< 0.0001**
DO	118	**0.345**	**0.242**	**0.376**	**0.000**	**0.009**	**< 0.0001**
Total chl-a	99	**0.745**	**0.574**	**0.633**	**< 0.0001**	**< 0.0001**	**< 0.0001**
Temperature	117	**0.493**	0.181	**0.332**	**< 0.0001**	0.054	**0.000**
Salinity	115	**-0.757**	**-0.559**	**-0.624**	**< 0.0001**	**< 0.0001**	**< 0.0001**
July 2010 Surface							
		R values			p values		
Variables	n	HB Ab.	CB Ab.	FLG Ab.	HB Ab.	CB Ab.	FLG Ab.
HB Ab.	50	**1**	**0.711**	**0.788**	**0**	**< 0.0001**	**< 0.0001**
CB Ab.	50	**0.711**	**1**	**0.836**	**< 0.0001**	**0**	**< 0.0001**
FLG Ab.	50	**0.788**	**0.836**	**1**	**< 0.0001**	**< 0.0001**	**0**
Phyto	19	**0.854**	**0.697**	**0.879**	**< 0.0001**	**0.001**	**< 0.0001**
PO_4	50	**0.573**	**0.319**	**0.363**	**< 0.0001**	**0.024**	**0.010**
NO_3+NO_2	50	**0.449**	**0.291**	0.259	**0.001**	**0.040**	0.069
NH_4	50	**0.497**	**0.379**	**0.301**	**0.000**	**0.007**	**0.034**
Si	50	0.244	**0.383**	0.224	0.087	**0.006**	0.117
DO	50	**0.648**	**0.417**	**0.569**	**< 0.0001**	**0.003**	**< 0.0001**
Total chl-a	31	**0.553**	**0.487**	**0.563**	**0.001**	**0.006**	**0.001**
Temperature	50	**0.757**	**0.618**	**0.618**	**< 0.0001**	**< 0.0001**	**< 0.0001**
Salinity	50	**-0.838**	**-0.703**	**-0.751**	**< 0.0001**	**< 0.0001**	**< 0.0001**
July 2010 All depths							
		R values			p values		
Variables	n	HB Ab.	CB Ab.	FLG Ab.	HB Ab.	CB Ab.	FLG Ab.
HB Ab.	119	**1**	**0.535**	**0.585**	**0**	**< 0.0001**	**< 0.0001**
CB Ab.	119	**0.535**	**1**	**0.817**	**< 0.0001**	**0**	**< 0.0001**
FLG Ab.	119	**0.585**	**0.817**	**1**	**< 0.0001**	**< 0.0001**	**0**
Phyto	66	**0.643**	**0.600**	**0.706**	**< 0.0001**	**< 0.0001**	**< 0.0001**
PO_4	119	**0.295**	**0.364**	**0.340**	**0.001**	**< 0.0001**	**0.000**
NO_3+NO_2	119	**0.241**	0.168	**0.215**	**0.008**	0.068	**0.019**
NH_4	119	**0.228**	**0.346**	**0.289**	**0.013**	**0.000**	**0.001**
Si	119	**0.230**	**0.511**	**0.421**	**0.012**	**< 0.0001**	**< 0.0001**
DO	119	0.004	**-0.187**	-0.088	0.966	**0.042**	0.340
Total chl-a	98	**0.345**	**0.511**	**0.497**	**0.001**	**< 0.0001**	**< 0.0001**
Temperature	119	**0.663**	**0.551**	**0.614**	**< 0.0001**	**< 0.0001**	**< 0.0001**
Salinity	119	**-0.512**	**-0.451**	**-0.570**	**< 0.0001**	**< 0.0001**	**< 0.0001**

APPENDIX B continued.

All data at surface							
		R values			p values		
Variables	n	HB Ab.	CB Ab.	FLG Ab.	HB Ab.	CB Ab.	FLG Ab.
HB Ab.	352	**1**	**0.707**	**0.682**	**0**	**< 0.0001**	**< 0.0001**
CB Ab.	352	**0.707**	**1**	**0.544**	**< 0.0001**	**0**	**< 0.0001**
FLG Ab.	352	**0.682**	**0.544**	**1**	**< 0.0001**	**< 0.0001**	**0**
Phyto	120	**0.427**	0.163	**0.713**	**< 0.0001**	0.076	**< 0.0001**
PO_4	348	**0.439**	**0.279**	**0.137**	**< 0.0001**	**< 0.0001**	**0.011**
NO_3+NO_2	349	**0.364**	0.085	**0.462**	**< 0.0001**	0.113	**< 0.0001**
NH_4	349	**0.450**	**0.277**	**0.359**	**< 0.0001**	**< 0.0001**	**< 0.0001**
Si	347	**0.563**	**0.370**	**0.462**	**< 0.0001**	**< 0.0001**	**< 0.0001**
DO	343	**0.121**	**-0.181**	**0.360**	**0.026**	**0.001**	**< 0.0001**
Total chl-a	236	**0.608**	**0.298**	**0.524**	**< 0.0001**	**< 0.0001**	**< 0.0001**
Temperature	349	**0.212**	**0.378**	-0.075	**< 0.0001**	**< 0.0001**	0.164
Salinity	346	**-0.424**	-0.086	**-0.494**	**< 0.0001**	0.110	**< 0.0001**
All data in all depths							
		R values			p values		
Variables	n	HB Ab.	CB Ab.	FLG Ab.	HB Ab.	CB Ab.	FLG Ab.
HB Ab.	820	**1**	**0.703**	**0.675**	**0**	**< 0.0001**	**< 0.0001**
CB Ab.	820	**0.703**	**1**	**0.635**	**< 0.0001**	**0**	**< 0.0001**
FLG Ab.	820	**0.675**	**0.635**	**1**	**< 0.0001**	**< 0.0001**	**0**
Phyto	435	**0.481**	**0.297**	**0.483**	**< 0.0001**	**< 0.0001**	**< 0.0001**
PO_4	816	**0.503**	**0.355**	**0.395**	**< 0.0001**	**< 0.0001**	**< 0.0001**
NO_3+NO_2	817	**0.347**	**0.082**	**0.318**	**< 0.0001**	**0.019**	**< 0.0001**
NH_4	817	**0.434**	**0.295**	**0.439**	**< 0.0001**	**< 0.0001**	**< 0.0001**
Si	814	**0.578**	**0.431**	**0.481**	**< 0.0001**	**< 0.0001**	**< 0.0001**
DO	811	-0.062	**-0.254**	**0.084**	0.076	**< 0.0001**	**0.017**
Total chl-a	695	**0.503**	**0.301**	**0.556**	**< 0.0001**	**< 0.0001**	**< 0.0001**
Temperature	811	**0.295**	**0.407**	**0.138**	**< 0.0001**	**< 0.0001**	**< 0.0001**
Salinity	805	**-0.363**	**-0.098**	**-0.358**	**< 0.0001**	**0.006**	**< 0.0001**