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ORIGINAL RESEARCH ARTICLE

Bio-optical trends of seas around Turkey: An assessment of the spatial and temporal variability

Fethi Bengil [a,*], **Sinan Mavruk** [b]

[a] *Marine School — Earth System Science Research Center, Girne American University, Girne, TRNC, Turkey*
[b] *Fisheries Faculty, Department of Marine Biology, Çukurova University, Balcalı, Adana, Turkey*

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Summary Until present, bio-optical characteristics and their variations in the eastern Mediterranean and Black Sea have rarely been studied. In order to characterize the basic features of bio-optical variables found in the seas surrounding Turkey, remotely sensed data sets covering the period between September 1997 and March 2017 were studied for the purpose of this research. Chlorophyll-*a* concentration (CHL), absorption coefficient by colored dissolved organic matter (CDOM) and particulate backscattering coefficient (BBP) were both evaluated to describe their recent linear and non-linear inter-annual patterns in the sub regions of the northern Levantine Sea (LS), the eastern Aegean Sea (AS), the Marmara Sea (MS) and the southern Black Sea (BS). The results determined a highly significant and decreasing trend of CHL in the Black Sea, whilst most other regions from the seas around Turkey displayed non-significant trends. The analysis indicated that the seas around Turkey can be clustered into two regions based on their bio-optical properties; one being the Black Sea and Marmara Sea, and the second cluster being the Aegean Sea and Levantine Sea.

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* Corresponding author at: Girne American University, Marine School-Earth System Science Research Center, University Drive, Karmi Campus, Girne, TRNC, Turkey. Tel.: +90 533 836 08 22; Fax: +90 392 650 20 61.
E-mail address: fethibengil@gau.edu.tr (F. Bengil).

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1. Introduction

Turkey is surrounded by semi-enclosed seas; the Black Sea at the north, the Marmara Sea in the north west, and two important sectors of the eastern basin of the Mediterranean Sea — the Aegean Sea in the west and the Levantine Sea in the south. Each sea has its own distinctive biogeochemical and hydrographic properties as well as ecosystem dynamics.

The Black Sea is commonly known to be one of the world's most distinct seas, with specific regard to its brackish water and anoxic deep water formation. It is surrounded by land, with the exception of its connection to the Marmara Sea through a narrow and shallow strait, the Istanbul Strait (Fig. 1). With considerable precipitation and the inflow of freshwater from local rivers, the water is dominated by brackish characteristics (Berner and Berner, 2012; Oguz et al., 2004). These inflows carry with them various particulate or dissolved matters (Cauwet et al., 2002; Oguz et al., 2004) which significantly influence the biogeochemical dynamics of the Black Sea. During the last century, the Black Sea revealed remarkable regime shifts in climatic conditions and biological communities (Oguz and Gilbert, 2007). Parallel to these developments, there were significant changes to the food-web structure, caused by invasive planktonic predators such as *Mnemiopsis leidyi* and *Beroe ovata* (Oguz et al., 2012). Changes within the structure of the phytoplankton community were also reported during this same period (Agirbas et al., 2017; Kideys, 1994). Mikaelyan et al. (2013) reported a significant biomass increase in phytoplankton and observed a shift from a Dinoflagellate dominated community to a Coccolithophore dominated community over the same period. These shifts also reflected in higher trophic levels, and caused subsequent changes in both spawning and the recruitment dynamics of small pelagic fishes (Gucu et al., 2016).

The Marmara Sea is another semi-closed sea that connects the Black Sea to the Aegean Sea through the Turkish straits, and is characterized by two stratified water layers. The water of the Black Sea is present throughout the upper layer of the Marmara Sea, whilst water from the Mediterranean fills in the lower layers. The mixing of these water types is limited, and salinity gradually increases westward, toward the Dardanelles (see Fig. 1). Detailed investigations about the circulation patterns as well as the physical (Beşiktepe et al., 1994) and biogeochemical properties (Yalçın et al., 2017; Zeri et al., 2014) of the Marmara Sea have previously been conducted. Yalçın et al. (2017) reported on the nutrient dynamics of the Marmara Sea, and observed a high enrichment level of nutrients caused by anthropogenic impacts; which are often responsible for eutrophication issues.

The physical properties and circulation patterns of the Aegean Sea have been outlined in many studies evaluating both coastal (Eronat and Sayin, 2014; Sayin, 2003) and open (Nittis and Perivoliotis, 2002; Roether et al., 1996; Theocharis et al., 1993; Vervatis et al., 2013) regions (see Fig. 1). Results from studies conducted in the Aegean Sea have shown gradual changes in biogeochemical properties ranging from north to south (Ehrmann et al., 2007; Tzortziou et al., 2015). Nutrient-rich surface waters have been detected to the north of the Aegean Sea due to the inflow of water from the Marmara Sea via the Dardanelles (Fig. 1) and inputs from local rivers (Polat and Tugrul, 1995; Souvermezoglou et al., 2014). The biogeochemical properties of these surface waters have an important impact on the ecological status of the Aegean Sea. Although the Aegean Sea is generally thought to be oligotrophic (Ignatiades, 1998; Ignatiades

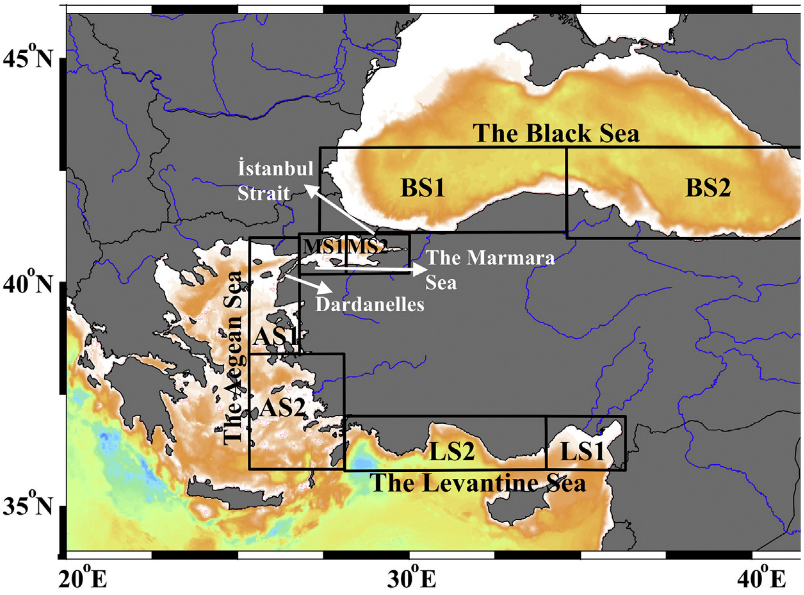

Figure 1 Study area and sub-regions for Seas of Turkey (LS1: the eastern Levantine Sea, LS2: the western Levantine Sea, AS1: the northern Aegean Sea, AS2: the southern Aegean Sea, MS1: the western Marmara Sea, MS2: the eastern Marmara Sea, BS1: the western Black Sea, BS2: the eastern Black Sea).

et al., 2002), a significant decrease in phytoplankton biomass spreading from the northern Aegean Sea toward the southern Aegean Sea, in addition to changes in the food web structure throughout the Aegean Sea, has been formerly presented by Siokou-Frangou et al. (2002).

The Levantine Sea is another important region for water formation in the Mediterranean Sea, and can be divided into two sub-regions based on its bathymetry and habitat characteristics (Fig. 1). The north-western Levantine Sea has a narrow continental shelf, scarce terrestrial inputs and a highly oligotrophic structure. In contrast, the north-eastern Levantine Sea is known to have a wider continental shelf area (Ozsoy et al., 1993) as well as intensive riverine inputs, enriched nutrient concentration and a higher primary production rate (Tuğrul et al., 2016). Driving forces in the areas throughout the southern Turkish coasts also create both permanent and recurrent eddies, gyres and jets. Details on the physical properties of the Levantine Sea are presented by Akpinar et al. (2016) and a hydro-chemical analysis is reviewed by Tuğrul et al. (2016). However, it is important to note that although the bio-optical properties of the northern Levantine Sea have already been described (Orek, 2007), there is currently no information available on the trends of these parameters.

Marine ecosystems are dynamic due to the changes and interactions amongst their living and non-living components over the course of time. Chlorophyll pigments are an important contributor of optically active constituents (OACs) with colored dissolved organic matter (CDOM) and total particulate matter in the seawater column. OACs interact with light based on their inherent optical properties (IOPs) such as absorption or scattering (Garaba et al., 2014). The distribution and composition of OACs in the water column can also contribute to the determination of underwater light fields, which are important for understanding the dynamics of primary production in aquatic environments. From hereinafter OACs and IOPs will be referred to as bio-optical properties due to their optical interactions.

Chlorophyll-*a* concentration (CHL) is a proxy for the estimation of phytoplankton biomass, and is a highly useful indicator in marine studies as it is directly related to primary production in the marine food-web (Kasprzak et al., 2008). Remote sensing enables access to extensive data available in high spatial and temporal resolution. The remotely sensed CHL signal provides a wide range of applications to monitor marine ecosystems, with examples being the Black Sea (Oguz and Gilbert, 2007) and the Mediterranean Sea (Colella et al., 2016).

CDOM represents the colored portion of dissolved organic matter in the sea water and another important bio-optical component to increase understanding of marine ecosystems (Coble et al., 1998; Stedmon and Markager, 2001). Dissolved organic matter (DOM) in marine environments contribute significantly to the organic carbon budget of the earth (Hedges, 1992), and influences the global carbon cycle (Puddu et al., 2000). Although there are many studies on the distribution of dissolved organic carbon, which correlate with CDOM in both the Black Sea and the eastern Mediterranean (Margolin, 2017; Pitta, 2016), CDOM is still an under-researched variable (Margolin, 2017; Pitta, 2016; Tzortziou et al., 2015). Furthermore, the spatial and inter-annual variability of CDOM has not yet been adequately evaluated.

BBP refers to an optical property used for the purpose of estimating different measurements taken from seawater, including suspended particle assemblages, and more specifically, particulate organic carbon (POC) (Loisel et al., 2001; Stramski et al., 2008) and phytoplankton carbon biomass (Siegel et al., 2014). These types of estimations are determined by using either space- or airborne sensors in relation to their refraction properties (Reynolds et al., 2016). Thus, BBP is another important bio-optical property required for understanding the dynamics of primary production. Although previous studies have been conducted via the utilization of optical principles in the Black Sea (Chami et al., 2005; Karageorgis et al., 2014; Orek, 2007), the Aegean Sea (Burenkov et al., 1999; Orek, 2007) and the northern Levantine Sea (Orek, 2007), these efforts focused on either the determination of optical characteristics, the understanding of suspended particulate composition or the circulation patterns of local water masses. To date, no evaluation regarding the temporal trends of BBP in the aforementioned region exists.

Bio-optical properties are responsible for determining the distribution of light in the water column. These properties are also optically relevant components for phytoplankton absorption, which is directly related to primary production. The temporal changes in these properties create a direct impact on biogeochemical cycles, and also influence the dynamics of lower trophic levels. Examples of feedback related to the effects of temporal changes on higher trophic levels observed in Black Sea anchovy have previously been documented by Gucu et al. (2016). Whilst detailed considerations of these properties exist throughout the world (El Hourany et al., 2017; Gregg and Rousseaux, 2014), very few studies describing their trends in the Mediterranean Sea (e.g., Coppini et al., 2013; Colella et al., 2016) are currently available.

The present study investigated a remotely sensed dataset of bio-optical properties, CHL, CDOM and BBP in the seas around Turkey. The study focuses on the northern Levantine Sea, the eastern Aegean Sea, the Marmara Sea and the southern Black Sea, where each region has different climatic and trophic characteristics. The main objective of our study was to characterize the basic features of the bio-optical properties being investigated, and to describe and compare their recent linear and nonlinear inter-annual patterns. These properties are all indicators of ecological conditions within any marine system.

2. Material and methods

Inter-annual changes of bio-optical properties were investigated in the seas surrounding Turkey (the southern Black Sea, the Marmara Sea, the eastern Aegean Sea and the northern Levantine Sea). In order to remove any possible source of bias from the wide spatial coverage and the different sub-regional physical and biological properties, each sea was divided into two sub-regions based on statistical considerations (Fig. 1). Sub-regions were chosen in accordance with the oceanographic properties or dynamics of each sea, as presented in previous studies (Akpinar et al., 2016; Beşiktepe et al., 1994; Nittis and Perivoliotis, 2002; Oguz et al., 2004 for the

Levantine Sea, the Marmara Sea, the Aegean Sea and the Black Sea respectively).

3. Data description

Trends of bio-optical properties were evaluated in terms of CHL, CDOM and BBP. In order to analyze these variables, GlobColour data (http://globcolour.info) was used, which has been developed, validated, and distributed by ACRI-ST, France. GlobColour is a project of the European Space Agency Data User Element (ESA DUE) and provides a continuous dataset from merged outputs of Ocean Color products from different sensors (see the GlobColour Product User Guide document in http://www.globcolour.info/CDR_Docs/GlobCOLOUR_PUG.pdf). The data-sets used in this study were produced at full spatial resolution (1 km^2) under the spatial domain of the extended European area. A total of 235 composite products were generated by using different ocean color products during certain time periods between September 1997 and March 2017. Each composite product was composed by utilizing remotely sensed signals from sensors that were available during the aforementioned time period (see the GlobColour Product User Guide for the detailed information). Composite products by Garver, Siegel, Maritorena Model (GSM) were also used for further analysis. The GSM method, which is a semi-analytical model, uses the normalized reflectances at the original sensor wavelengths without inter calibration (see Maritorena and Siegel (2005) for more details). This method is only available for GlobColour products of CHL, BBP and CDOM (see the GLOBCOLOUR Product User Guide document in http://www.globcolour.info/CDR_Docs/GlobCOLOUR_PUG.pdf). Semi-analytical models are more sensitive than standard algorithms (O'Reilly et al., 1998) and GSM showed a generally excellent level of agreement with in situ measurements (Siegel et al., 2005). A seasonal bias of the variables retrieved from ocean color algorithms showed that there was both underestimation and overestimation apparent within the region (Orek, 2007; Sancak et al., 2005). However, the use of an inter-annual approach in trend analysis is expected to overcome any such systematic errors generated from the algorithms.

Regarding regional analysis, the mean of all pixels belonging to a defined region was calculated for all of the variables used in this study. Monthly mean values were calculated between September 1997 and March 2017 for bio-optical properties, and the maximum, minimum, mean and standard deviation were then calculated to present the descriptive characteristics of each region.

4. Time series analyses

In order to analyze inter-annual changes, a time series of each parameter (Y_t) was firstly decomposed to trend (T_t), seasonal (S_t) and remainder (R_t) components by using a locally reweighted regression (loess) based seasonal trend decomposition (stl) procedure (Cleveland et al., 1990) as follows:

$$Y_t = T_t + S_t + R_t.$$

The trend components (T) from this procedure were used to represent the non-linear trends of parameters. To calculate the linear trends, seasonal signals were first removed ($X_t = Y_t - S_t$). The direction and magnitude of trends were then detected with rank-based non-parametric Mann—Kendall correlation (Hipel and McLeod, 1994) using R library "Kendall" (McLeod, 2011). Letting $X_t = x_1, x_2, \ldots, x_n$; the library uses the following equations to calculate the Mann—Kendall test statistic (S) and Mann—Kendall correlation coefficient (τ);

Table 1 Descriptive statistics of investigated variables in each region of Turkish seas; LS1: the eastern Levantine Sea, LS2: the western Levantine Sea, AS1: the northern Aegean Sea, AS2: the southern Aegean Sea, MS1: the western Marmara Sea, MS2: the eastern Marmara Sea, BS1: the western Black Sea, BS2: the eastern Black Sea; sd: standard deviation.

	LS1	LS2	AS1	AS2	MS1	MS2	BS1	BS2
Chlorophyll concentration (mg m^{-3})								
Max	0.32	0.23	0.92	0.22	6.53	7.01	1.88	1.52
Min	0.07	0.04	0.07	0.04	0.42	0.42	0.18	0.23
Mean	0.16	0.09	0.25	0.10	1.62	1.93	0.62	0.51
sd	0.05	0.04	0.14	0.04	1.13	1.10	0.28	0.20
Colored dissolved organic matter absorption coefficient (m^{-1})								
Max	0.04	0.03	0.08	0.03	0.45	0.36	0.16	0.12
Min	0.01	0.01	0.02	0.01	0.06	0.08	0.04	0.04
Mean	0.02	0.02	0.04	0.02	0.14	0.16	0.08	0.08
sd	0.01	0.01	0.01	0.01	0.06	0.06	0.02	0.02
Particulate backscattering coefficient (m^{-1})								
Max	0.0059	0.0037	0.0053	0.0022	0.0439	0.0488	0.0249	0.0323
Min	0.0013	0.0008	0.0011	0.0008	0.0010	0.0014	0.0020	0.0023
Mean	0.0027	0.0016	0.0020	0.0013	0.0056	0.0071	0.0056	0.0058
sd	0.0009	0.0005	0.0007	0.0002	0.0062	0.0062	0.0031	0.0034

$$S=\sum_{k=1}^{n-1}\sum_{j=k+1}^{n} sgn(x_j-x_k),$$

$$sgn(x)=\begin{cases} +1, & x>0 \\ 0, & x=0 \\ -1, & x<0 \end{cases},$$

$$\tau=\frac{S}{\binom{n}{2}}.$$

The intercept and slope of trend lines were estimated by using Theil-Sen's regression method, which models the variation of medians along a time gradient (Sen, 1968). To compare the slopes of trend lines among regions, 95% confidence intervals were calculated. For these calculations we used R library "zyp" (Bronaugh and Werner, 2013). The library uses the following equation to calculate Theil-Sen's slope (b_{sen});

$$d_k=\frac{x_j-x_i}{j-i},$$

$$b_{\text{sen}}=\text{median}(d_k),$$

where $i<j<n$ and, j and i are indices of the de-seasonalized time series, X_t.

In general terms, the inter-annual changes of ecological properties are non-linear and the trend curves reveal shifts between the stable states (Oguz and Gilbert, 2007). To detect these change-points in non-linear trends, we used Pettitt's single point change detection test (Pettitt, 1979) with R library "trend" (Pohlert, 2016; R Core Team, 2016). This function transforms the original time series to ranks (r) and uses the following equations to calculate change-point (U):

$$U_k=\sum_{i=1}^{k} r_i-(n+1); \quad k=1,2,\ldots,n,$$

$$\hat{U}_k=\max|U_k.$$

Pearson product moment correlations were also calculated between the de-seasonalized time-series (Zuur et al., 2007) of all parameters within each sub-region. For this purpose, we used the cross correlation function in R (R Core Team, 2016).

5. Results

5.1. Descriptives of the variables

The mean CHL were between 0.09 mg m^{-3} (the western Levantine Sea (LS2)) and 1.93 mg m^{-3} (the eastern Marmara Sea (MS2)). The highest maximum was 7.01 mg m^{-3} in MS2, and the lowest minimum was 0.04 mg m^{-3} in LS2 and the southern Aegean Sea (AS2) (Table 1). The seasonality of CHL varied between regions. The summer months were generally identified as having the lowest CHL values for all regions, whilst the highest concentrations were seen in winter and spring.

The mean absorption values of CDOM ranged between 0.02 m^{-1} (LS1, LS2 and AS2) and 0.16 m^{-1} (MS2). The western Marmara Sea (MS1) had the highest maximum value with 0.45 m^{-1}, with the lowest minimum value being 0.01 m^{-1} in LS1, LS2, AS1 and AS2 (Table 1). Seasonal changes generally followed a unimodal pattern, whereby the minimum values were apparent in summer and the maximum values were recorded during the seasons of winter and spring.

Seasonal patterns of BBP varied among regions. Mean values dispersed from 0.0013 m^{-1} in AS2 to 0.0071 m^{-1} in MS2. The highest annual maximum belonged to MS2 (0.0488 m^{-1}), while the lowest annual minimum was 0.0008 m^{-1}in LS2 and AS2 (Table 1).

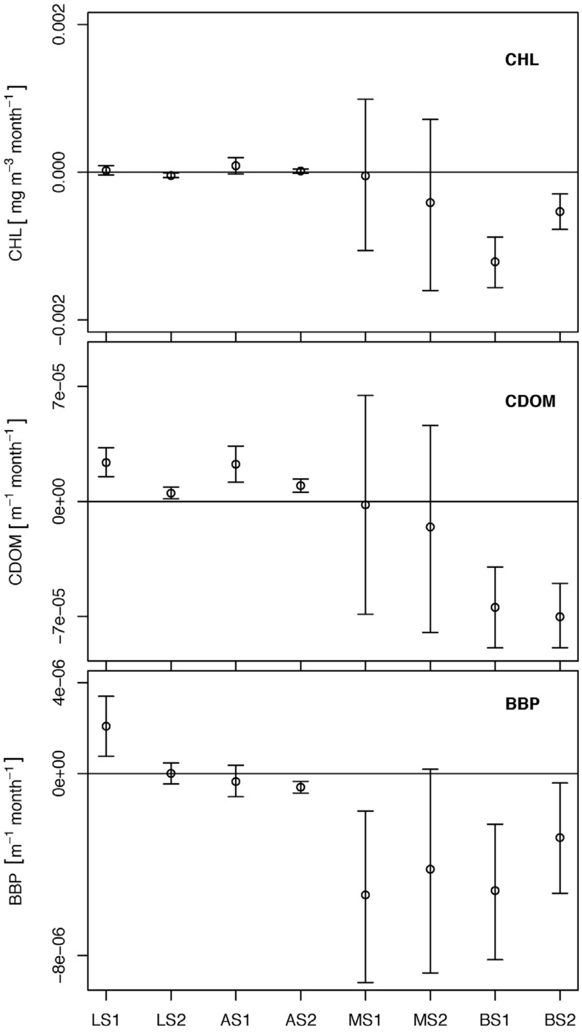

Figure 2 Slope of Theil-Sen regression of time series data (vertical bars indicate 95% confidence intervals). CHL: chlorophyll-*a* concentration, CDOM: colored dissolved organic matter absorption coefficient, BBP: particulate backscattering coefficient.

Table 2 Trends of physical and bio-optical conditions across Turkish Seas. (τ: Mann Kendal Thau, a: intercept, b_{sen}: slope of Theil-Sen's regression, CI: confidence intervals of slope, U: change points derived from Pettitt's test; LS1: the eastern Levantine Sea, LS2: the western Levantine Sea, AS1: the northern Aegean Sea, AS2: the southern Aegean Sea, MS1: the western Marmara Sea, MS2: the eastern Marmara Sea, BS1: the western Black Sea, BS2: the eastern Black Sea).

	LS1	LS2	AS1	AS2	MS1	MS2	BS1	BS2
Chlorophyll concentration								
τ	0.04^{ns}	-0.11^{*}	0.07^{ns}	0.06^{ns}	0.01^{ns}	-0.03^{ns}	-0.29^{***}	-0.19^{***}
a	0.1543	0.0964	0.2292	0.0953	1.5391	1.8937	0.7313	0.5414
b_{sen}	0.00003	-0.00004	0.00009	0.00002	-0.00005	-0.00041	-0.00121	-0.00053
±%95 CI	0.00006	0.00003	0.00011	0.00003	0.00102	0.00116	0.00034	0.00024
U	10/2001	10/2007	9/1999	7/2014	11/2009	6/2006	12/2002	6/2003
Colored dissolved organic matter absorption coefficient								
τ	0.22^{***}	0.12^{**}	0.17^{***}	0.19^{***}	0.00^{ns}	-0.02^{ns}	-0.23^{***}	-0.29^{***}
a	0.0213	0.0161	0.0348	0.0175	0.1318	0.1569	0.0874	0.0852
b_{sen}	0.00002	0.00001	0.00002	0.00001	0.000002	-0.00002	-0.00006	-0.00007
±%95 CI	0.000009	0.000004	0.000011	0.000004	0.000067	0.000063	0.000025	0.000020
U	9/2002	11/2002	2/2003	4/2003	1/2003	8/2014	10/2002	1/2003
Particulate backscattering coefficient								
τ	0.14^{**}	0.00^{ns}	-0.04^{ns}	-0.20^{***}	-0.12^{**}	-0.08^{ns}	-0.15^{***}	-0.10^{*}
a	0.0024	0.0016	0.0020	0.0013	0.0058	0.0070	0.0059	0.0061
b_{sen}	2.1×10^{-6}	1.6×10^{-8}	-3.4×10^{-7}	-5.9×10^{-7}	-5.3×10^{-6}	-4.2×10^{-6}	-5.1×10^{-6}	-2.8×10^{-6}
±%95 CI	1.3×10^{-6}	4.6×10^{-7}	7.0×10^{-7}	2.6×10^{-7}	3.8×10^{-6}	4.5×10^{-6}	3.0×10^{-6}	2.4×10^{-6}
U	6/2002	3/2013	9/2002	1/2008	2/2011	12/2010	2/2003	12/2008

ns: non-significant.
* Significant at 0.05.
** Significant at 0.01.
*** Significant at 0.001.

5.2. Analyses

The trend of CHL was not significant in the LS1, the Aegean Sea or the Marmara Sea, and a slightly decreasing trend was detected in LS2 (Fig. 2). Based on the Pettitt's test, in 2007 the CHL trend in LS2 turned downward. However, there were highly significant and decreasing trends in both the western Black Sea (BS1) and the eastern Black Sea (BS2). The change-points of non-linear trends for the BS1 and BS2 were detected in 2002 and 2003, respectively (Table 2; Fig. 3).

The trends of CDOM were found to be significant in all regions, with the only exception being the Marmara Sea. Generally increasing trends were found in the Levantine Sea and the Aegean Sea. Among these regions, the slopes of LS2 and AS2 were significantly lower than that of the other two regions ($p < 0.05$) (Fig. 2). The Pettitt's test also revealed that for both regions of the Levantine Sea the change point of non-linear trends occurred in 2002, and then in 2003 for both regions of the Aegean Sea. Contrary to the Levantine Sea and the Aegean Sea, CDOM revealed decreasing trends in both regions of the Black Sea, although the slopes were not significantly different to each other. The change-point in the non-linear trend was consistent with the other seas; 2002 for BS1 and then 2003 for BS2 (Table 2; Fig. 4).

The only significant positive trend in BBP was detected in LS1 (Fig. 2). The change point for the non-linear trend was in June 2002. The trends were not found to be significant in the regions of LS2 and AS1, nor were they found to be significant in MS2. In the AS2, MS1 and both regions of the Black Sea, the BBP revealed significantly decreasing trends. The non-linear trend curves showed fluctuating patterns around the linear trend lines, thus Pettitt's method did not detect meaningful change-points in these regions (Table 2; Fig. 5).

However, there were some strong positive correlations between the trends of CHL and BBP values within the regions of study. The strength of correlation was found to be highest in the Levantine Sea (0.65, 0.66 respectively for LS1 and LS2; $p < 0.01$), yet decreasing in both the Aegean Sea (0.65, 0.41 respectively for AS1 and AS1, $p < 0.01$) and the Marmara Sea (0.23, 0.28 respectively for MS1 and MS2, $p < 0.01$), lowest in BS1 (0.11, $p < 0.05$) and was determined as not being significant in BS2 (Table 3).

The trends from CHL and CDOM measurements were significantly correlated within the study domain. The correlations were relatively lower in the Levantine Sea (0.47, 0.28 respectively for LS1 and LS2; $p < 0.01$) and AS2 (0.10; $p < 0.05$) and higher in AS1 (0.67; $p < 0.01$), the Marmara Sea (0.62, 0.58 respectively for M1 and M2; $p < 0.01$) and the Black Sea (0.69, 0.50 respectively for BS1 and BS2; $p < 0.01$) (Table 3).

High positive correlations were observed between the trends of CDOM and BBP in LS1 (0.72; $p < 0.01$), L2 (0.55; $p < 0.01$) and AS1 (0.64; $p < 0.01$). However, the correlation values were found to be lower in the Marmara Sea (0.38, 0.35 respectively for MS1 and MS2; $p < 0.01$) and the western Black Sea (0.21; $p < 0.01$) (Table 3).

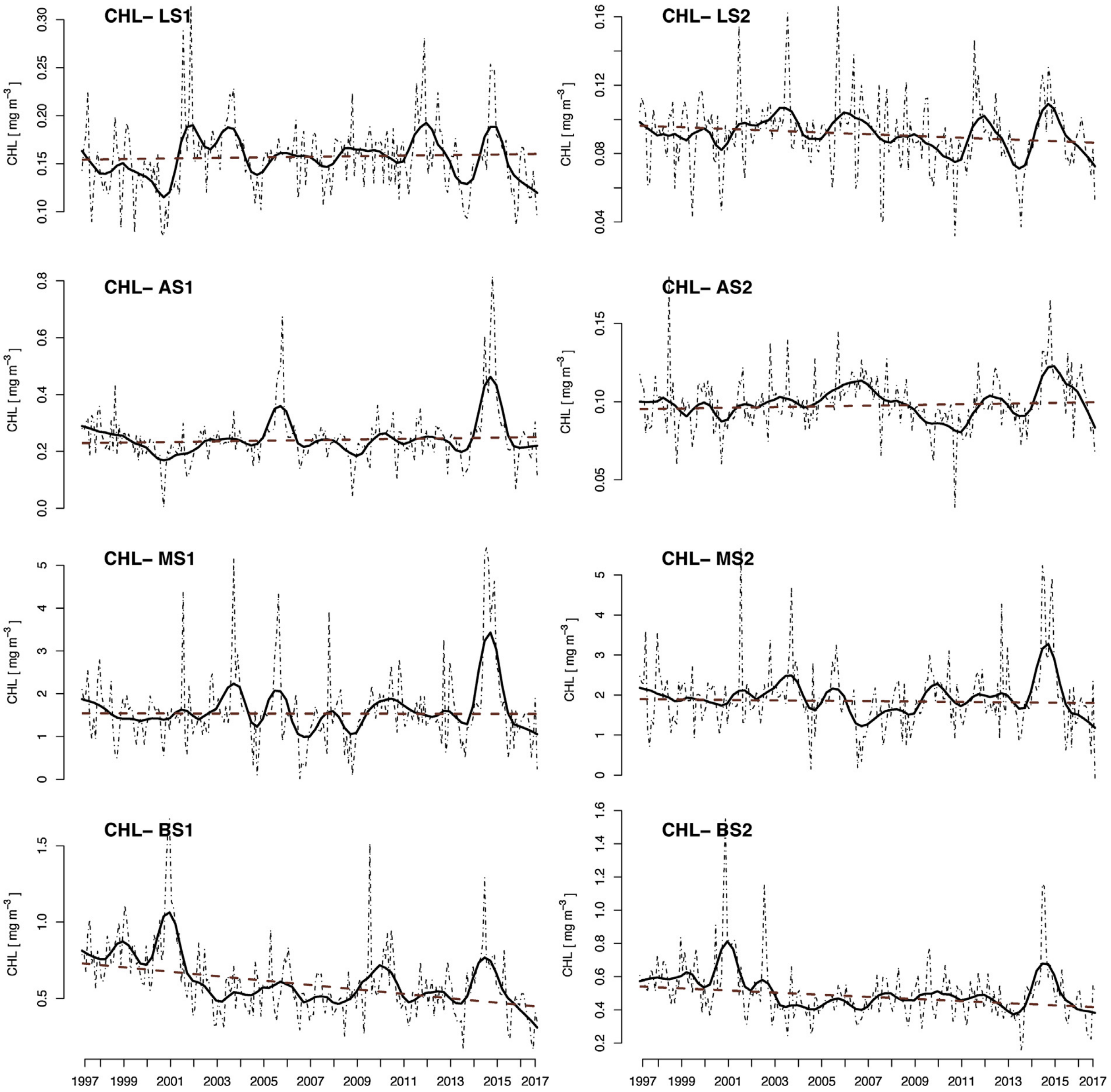

Figure 3 Deseasonalized time series (dash-dot line), non-linear (straight line) and linear (dashed line) trends of chlorophyll in Seas of Turkey (LS1: the eastern Levantine Sea, LS2: the western Levantine Sea, AS1: the northern Aegean Sea, AS2: the southern Aegean Sea, MS1: the western Marmara Sea, MS2: the eastern Marmara Sea, BS1: the western Black Sea, BS2: the eastern Black Sea, CHL: chlorophyll-*a* concentration, CDOM: colored dissolved organic matter absorption coefficient, BBP: particulate backscattering coefficient).

6. Discussion

The phytoplankton community and CHL revealed regime shifts in the Black Sea during the study period (Mikaelyan et al., 2013; Oguz and Gilbert, 2007). From the mid 1970s, the pre-eutrophication regime gradually altered due to the increment of anthropogenic nutrient inputs. The eutrophic phase remained present until the beginning of the 1990s with the contribution of intensified vertical mixings due to the cold SST regime. The Black Sea ecosystem was introduced to the post eutrophication phase after the mid 1990s, and the food web structure was then reorganized after this period. From this point, the phytoplankton biomass turned toward a decreasing trend as a result of several factors, such as diminishing anthropogenic nutrient inputs and the decreasing effect of winter mixing due to increasing SST and changes in the food-web structure (Oguz and Gilbert, 2007). According to our analyses, this decreasing pattern in CHL remained consistent in both parts of the Black Sea during the post-eutrophication phase between the period of 1997 and 2017. Along with other factors, CHL can also be influenced by changes in the phytoplankton community structure (see

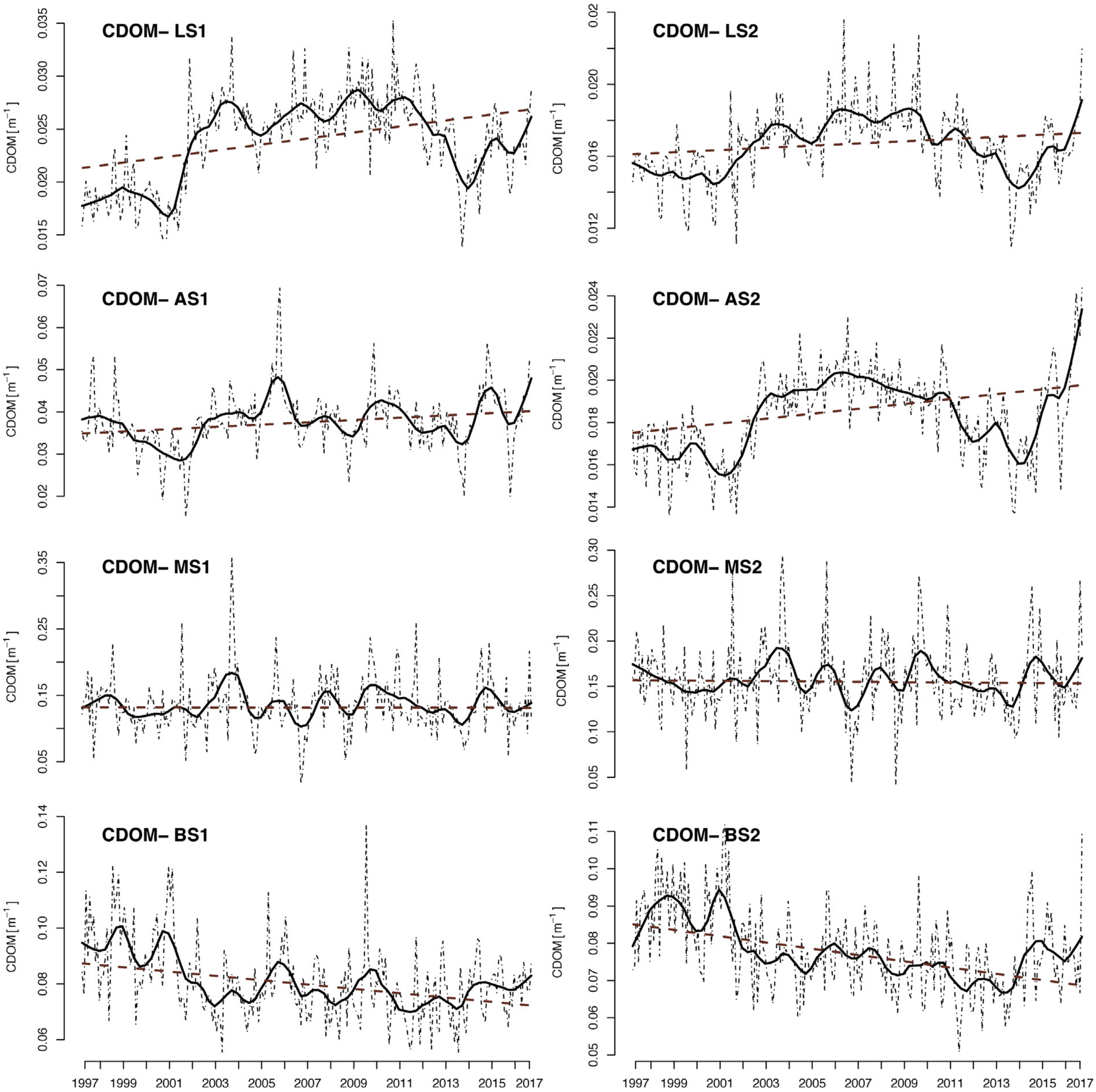

Figure 4 Deseasonalized time series (dash-dot line), non-linear (straight line) and linear (dashed line) trends of CDOM in Seas of Turkey (LS1: the eastern Levantine Sea, LS2: the western Levantine Sea, AS1: the northern Aegean Sea, AS2: the southern Aegean Sea, MS1: the western Marmara Sea, MS2: the eastern Marmara Sea, BS1: the western Black Sea, BS2: the eastern Black Sea, CHL: chlorophyll-*a* concentration, CDOM: colored dissolved organic matter absorption coefficient, BBP: particulate backscattering coefficient).

Orek (2007) for the northeastern Mediterranean), which is a well-documented phenomenon for the Black Sea during the last several decades (Kideys, 1994; Mikaelyan, 1997; Mikaelyan et al., 2013).

Previous studies into CHL throughout the Mediterranean Sea revealed mostly weak and insignificant trends and with the exclusion of some coastal areas the south-western Black Sea showed mostly negative trends (Coppini et al., 2013; Colella et al., 2016). Parallel to previous studies, this study only detected significantly decreasing trends in the Black Sea, with some weak and insignificant fluctuations in other regions (Fig. 3).

The slope of CDOM trends was identified as varying across the different seas of Turkey. These variations may be due to the different compositions of dissolved matter present in the seas as a result of impacts to either terrestrial inputs (Cauwet et al., 2002; Margolin, 2017) or local community differences (Orek, 2007) (Table 2). For example, the CDOM trend was found to be significant in the Black Sea, whereas no significant trend was evident in the Marmara Sea, despite the surface waters originating from the Black Sea (Beşiktepe et al., 1994). This difference may be due to the influences of different terrestrial inputs into the Marmara Sea. Factors such as the chemical structure (humic and fulvic acid ratio) of CDOM together with photo-oxidation properties and salinity levels, may reveal the reason for changes to CDOM in the surface water.

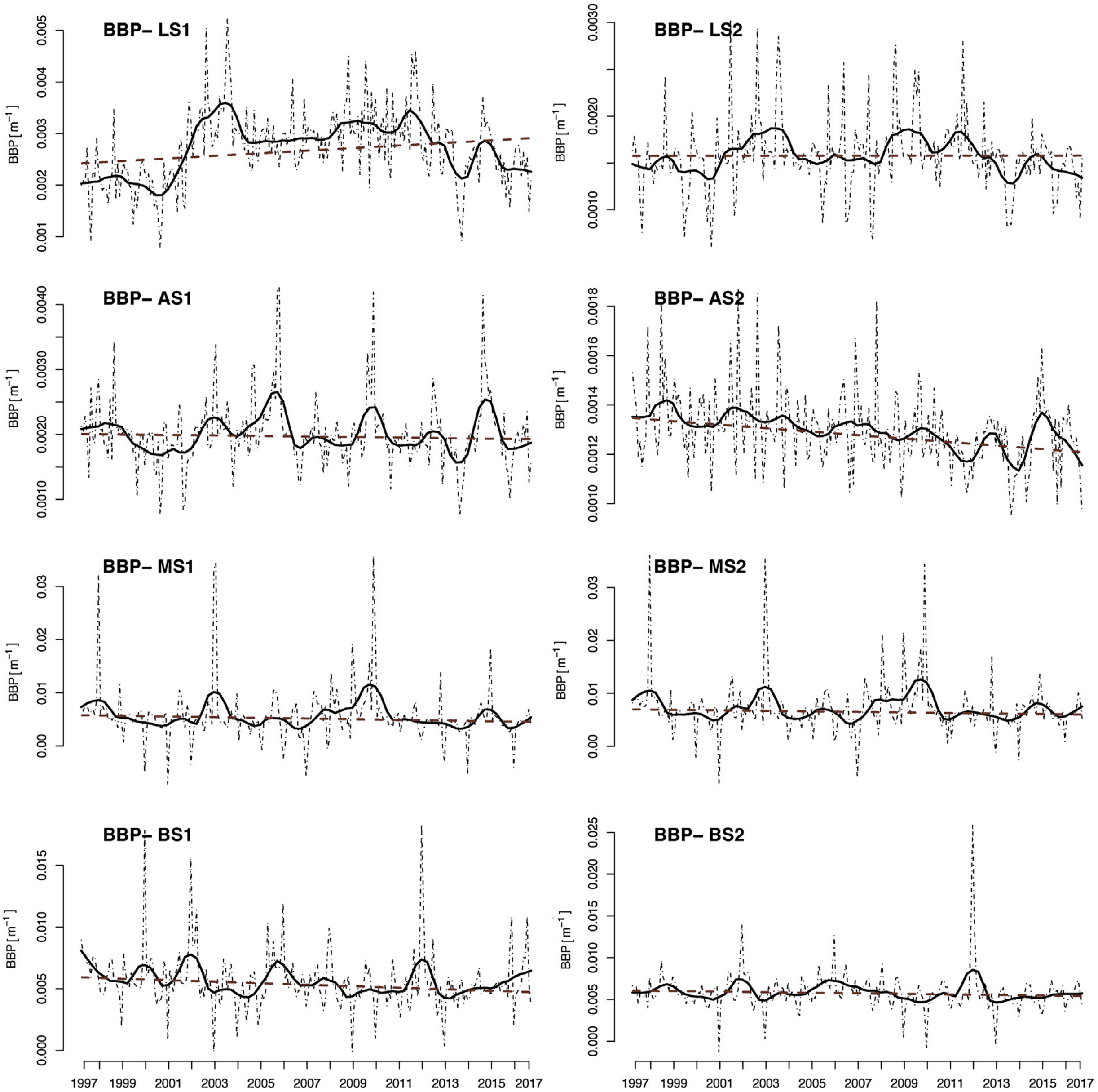

Figure 5 Deseasonalized time series (dash-dot line), non-linear (straight line) and linear (dashed line) trends of BBP in Seas of Turkey (LS1: the eastern Levantine Sea, LS2: the western Levantine Sea, AS1: the northern Aegean Sea, AS2: the southern Aegean Sea, MS1: the western Marmara Sea, MS2: the eastern Marmara Sea, BS1: the western Black Sea, BS2: the eastern Black Sea, CHL: chlorophyll-*a* concentration, CDOM: colored dissolved organic matter absorption coefficient, BBP: particulate backscattering coefficient).

Table 3 Pearson product moment correlation between variables. (CHL: chlorophyll-*a* concentration, CDOM: colored dissolved organic matter absorption coefficient, BBP: particulate backscattering coefficient).

	LS1	LS2	AS1	AS2	MS1	MS2	BS1	BS2
CHL-BBP	0.65**	0.66**	0.65**	0.41**	0.23**	0.28**	0.11*	−0.07
CHL-CDOM	0.47**	0.28**	0.67**	0.10*	0.62**	0.58**	0.69**	0.50**
BBP-CDOM	0.72**	0.55**	0.64**	0.06	0.38**	0.35**	0.21**	0.02

* $p < 0.05$.
** $p < 0.01$; $n = 235$.

Overall, positive CDOM trends were apparent in the waters of both the Levantine and Aegean Seas. Although the increment was lower in the two adjacent regions, LS2 and AS2 in accordance with the results of cross-correlation analyses, the trend dynamics of CDOM did not correlate with CHL. the. The difference in the relationship between these two properties indicates the possible effect that bacterial production can have on the variables. Bacterial production constitutes an important role in the food-web (Siokou-Frangou et al., 2002) and its impact on the dynamics of CHL and CDOM is pointed out by Pitta (2016) in the southern Aegean Sea.

Pitta (2016) highlighted that a lack of correlation between CHL and CDOM is due to the intensity of bacterial production in the summer season being simultaneous to a vertical water column movement in the same region (e.g. Rhodes Gyre).

BBP is calculated by the integration of angular function in the backward direction, thus it is mostly used as an indicator of particle concentration and composition evident in the seawater. Previous studies have discussed the relationship between BBP and different types of particles (Loisel et al., 2001; Stramski et al., 2008) or turbidity (Jafar-Sidik et al., 2017). In this study concept, the trends of BBP did not show any distinctive regional patterns between the seas. LS1 was the region which showed a significantly positive trend, and this region is known to have intensive river inputs (Tuğrul et al., 2016). Changes to the particle load or inflow (Akyurek, 2003) into these rivers from terrestrial sources that contain high humic acids, may be the reason for the increasing trend detected in this study. The Black Sea regions and MS1 both had a significantly negative BBP trend. This negative trend might have been caused by the decreasing terrestrial inputs from rivers, driven by the decreasing trends of precipitation in the region, as stated by Ceribasi and Dogan (2015). Another possible explanation for this trend could be due to changes in the phytoplankton community (Kideys, 1994; Mikaelyan et al., 2013). The relationship between the trends of BBP and CHL are not significant in the Black Sea, and our study also showed a weak correlation in the Marmara Sea. Further biogeochemical, bio-optical and taxonomic investigations will, therefore, be required to fully understand the drivers that determine particle concentration and composition in the regions. Nonetheless, it can be stated that CHL is clearly the main driver in determining the trends of BBP in the Aegean Sea and the Levantine Seas of Turkey.

Our results show that whilst the Black Sea and the Marmara Sea revealed similar patterns, the trends of the Aegean and Levantine Seas were also found to be similar. These spatial differences should, therefore, be further considered and investigated in accordance with the usage of all remotely sensed bio-optical variables involved in monitoring the implications of the seas around Turkey.

7. Conclusion

A descriptive and multi-decadal trend analysis indicated that two main clusters occurred in the seas of Turkey, with regards to bio-optical properties: one cluster being the Black Sea and the Marmara Sea, and the second cluster being the Aegean Sea and the Levantine Sea. The Black Sea and the Marmara Sea both showed different characteristics to the other seas studied, with either higher concentrations of CHL, CDOM or BBP.

This is a descriptive study, aimed at defining recent linear and non-linear inter-annual patterns in bio-optical variables. This study also took an interest in the descriptive features of these variables throughout the different regions of the seas around Turkey. These empirical considerations cannot detect the underlying reasons alone, and should instead be used to develop hypotheses (Daskalov, 1999). Although the results of this study have provided some insight into the dynamical changes found in marine ecosystems, it is not possible to fully comprehend the ecological status of a system unless complementary datasets are utilized. Changes in environmental conditions are usually rather complex and should be investigated with further ecosystem-based approaches (Oguz and Gilbert, 2007). In addition to the purpose and requirement of monitoring, multiyear analyses on datasets that are available for extended time periods provide the baseline required in order to develop key hypotheses for the further understanding of ecosystem dynamics. As pointed out by Zielinski et al. (2009), key aims held by marine scientists include the monitoring and investigation of variables, thus increasing our understanding of all important processes taking place in the oceans. The expansion of spatio-temporal scales of observation, possible through improved satellite technologies, has made possible to proceed toward and reach this aim. However, this technology is limited to surface area observation only, and observations required for calibration or validation purposes.

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