What are Marine Ecological Time Series telling us about the ocean? A status report

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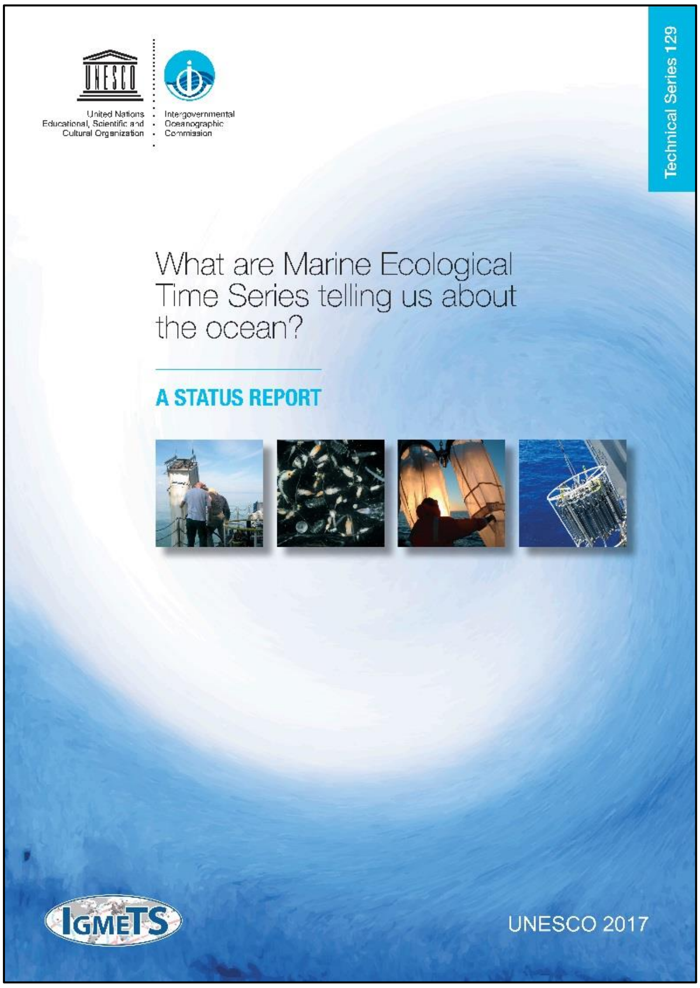

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2 Methods and Visualizations

Todd D. O'Brien

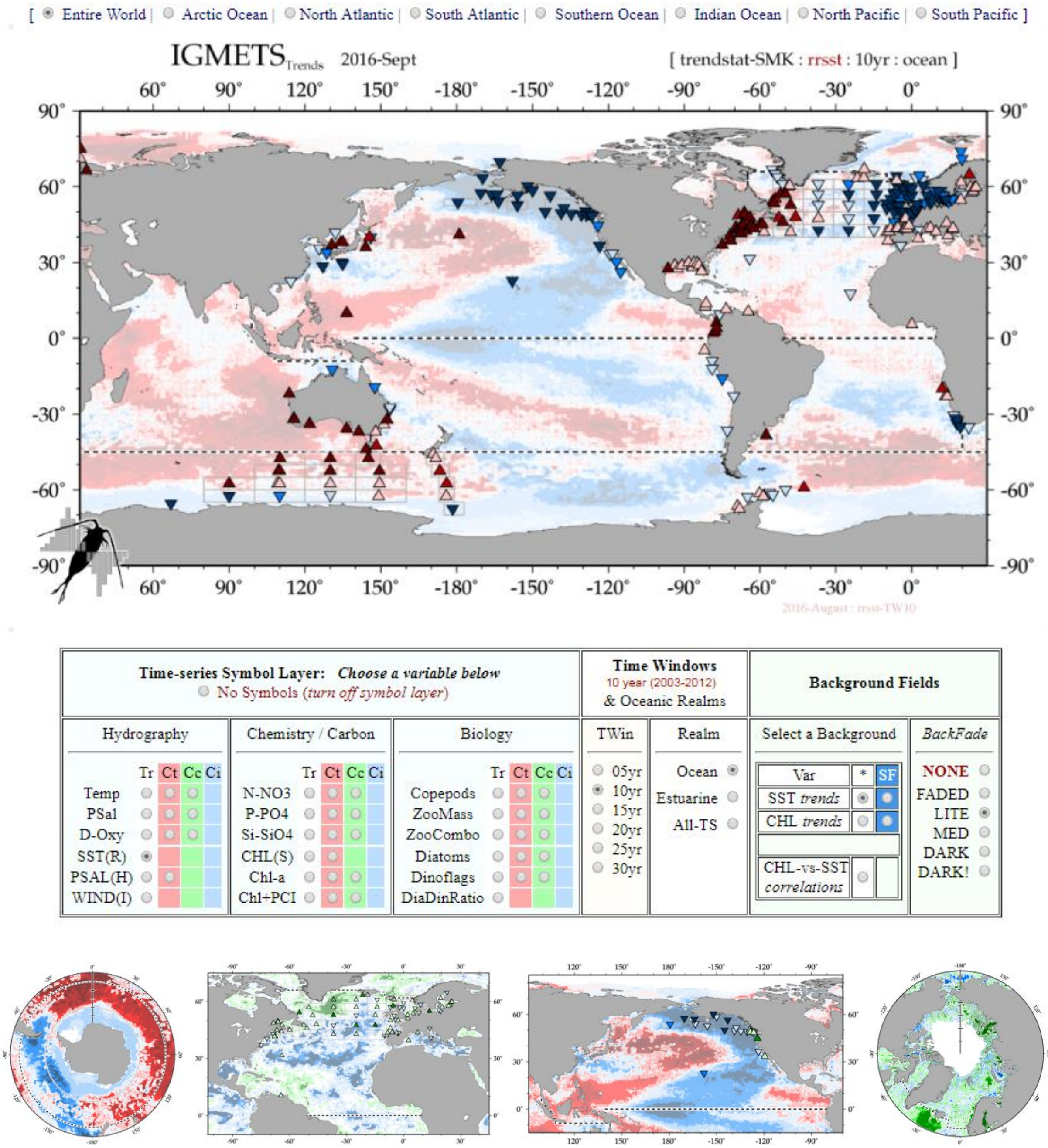

Figure 2.1. An example screenshot from the IGMETS time series Explorer available online at http://igmets.net/explorer and a selection of additional spatio-temporal visualizations available via the Explorer and used throughout this report.

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2.1 Introduction

With a collection of over 340 marine ecological time series, the data-assembling effort behind IGMETS was considerable (Figure 2.1). As these time series also varied in their available variables, methodologies, months of coverage, and years in length (Figures 2.2 and 2.3), a flexible yet robust analytical method was required to synthesize and compare the information. For over 12 years, the Coastal & Oceanic Plankton Ecology, Production, & Observation Database (COPEPOD) been working with marine ecological time-series data assembly, analysis, and visualization when it provided the data backbone for the SCOR Global Comparisons of Zooplankton Time Series working group (WG125). COPEPOD continued its support with other time-series groups, such as the ICES Working Group on Zooplankton Ecology (WGZE), the ICES Working Group on Phytoplankton and Microbial Ecology (WGPME), and the SCOR Global Patterns of Phytoplankton Dynamics in Coastal Ecosystems working group (WG137).

During these years of collaboration, a suite of analytical and visualization tools has been created, modified, and expanded to support the specific needs of each of these groups (Mackas *et al.*, 2012; O'Brien *et al.*, 2012, 2013; Paerl *et al.*, 2015). These tools were again adapted and expanded to fit the requirements of IGMETS, creating the first-of-its-kind interactive time series visual explorer (http://igmets.net/explorer) as well as the spatio-temporal trend fields seen throughout the following chapters of the report.

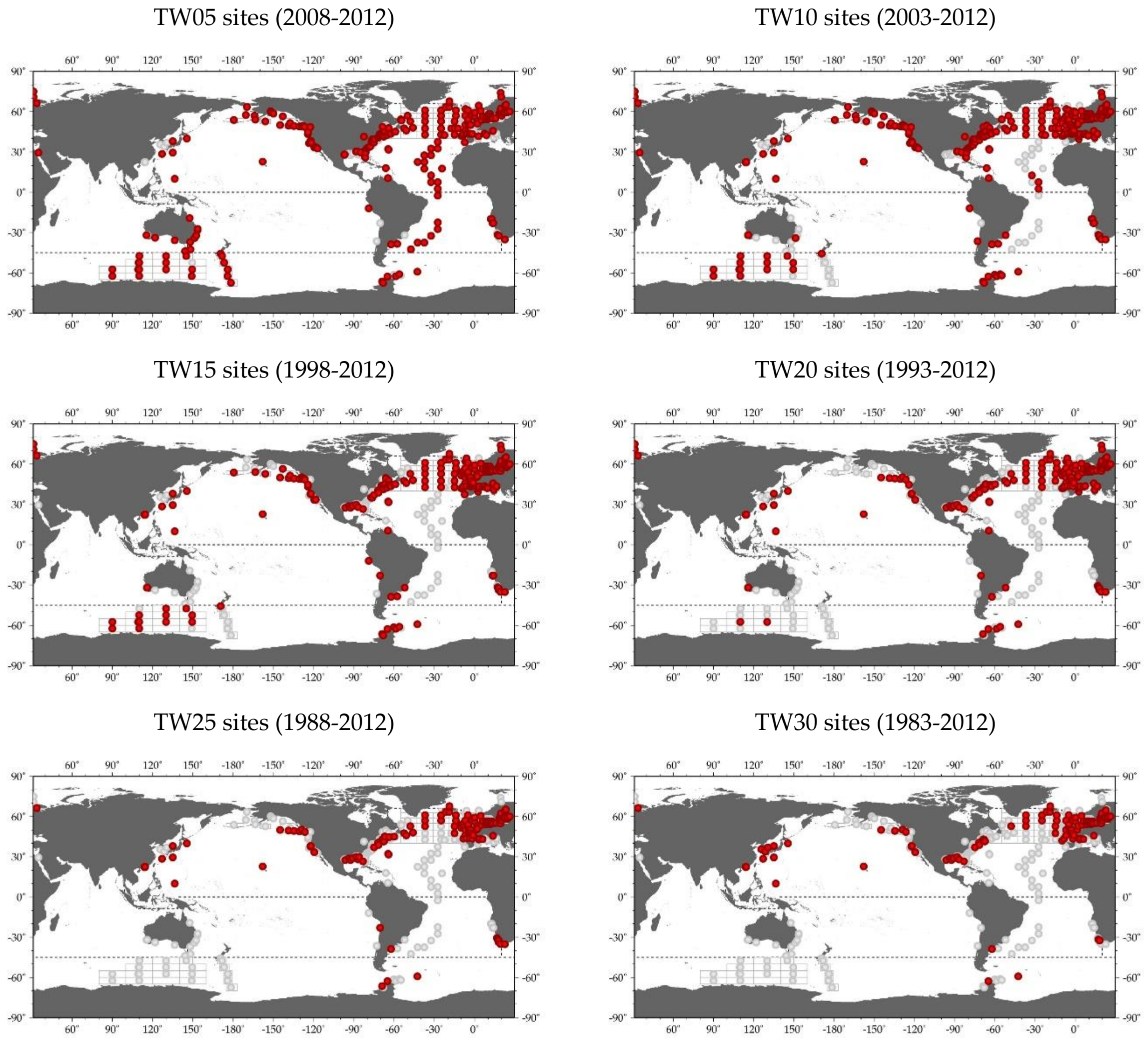


Figure 2.2. Panel of maps showing locations of IGMETS-participating time series based on time-window qualification. Red symbols indicate time-series sites with at least one biological or biogeochemical variable (i.e. excluding temperature- and salinity-only time series) that qualified for that time-window (e.g. TW05, TW20). The time-window concept and method are described in Section 2.3.2. Light gray symbols indicate sites that did not have enough data from the given time-window to be included in that analysis.

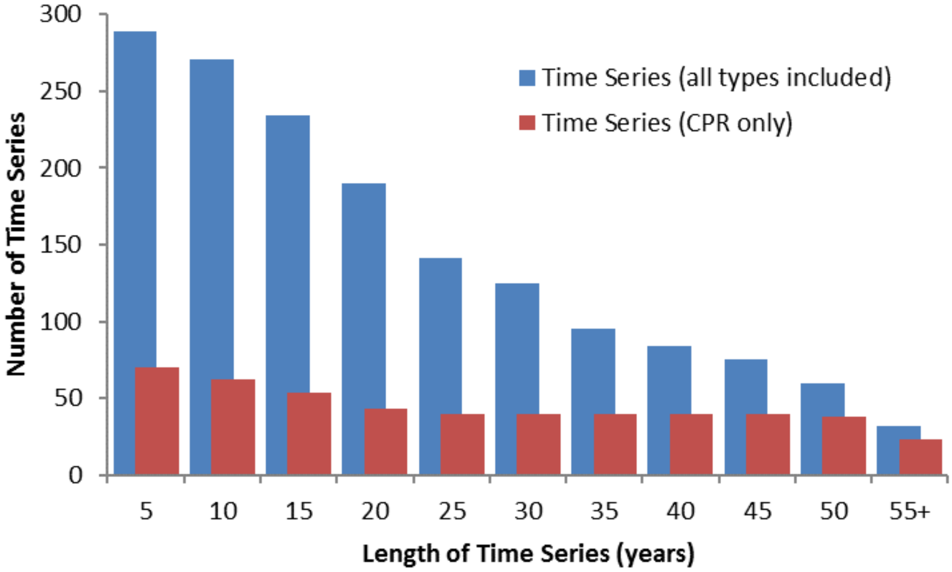


Figure 2.3. Histogram of all IGMETS-participating time series sorted by their length in years. The Continuous Plankton Recorder (CPR) time series is also plotted separately, highlighting its significant contributions to the longer time-spans.

2.2 *In situ* data sources

The International Group for Marine Ecological Time Series effort focused on ship-based, *in situ* time series with chemical and/or biological data elements. IGMETS did not pursue data from buoys, floats, pier-mounted sensors, or automated underwater vehicles (AUV). With an interest in ecological time series, IGMETS most heavily pursued datasets that had chemical or biological variables (e.g. nutrients, pigments, or plankton data).

At the time of preparation of this report, more than 340 time series were participating in IGMETS. These sites are listed at the end of each chapter in the "Regional listing of participating time series" tables and are presented in more detail in the Annex of this report. The IGMETS online metabase (http://igmets.net/metabase) also includes this information and offers additional content and search tools (e.g. search by variable, length in years, programme, investigator, or country). Finally, the metabase also contains any additional time series identified and added after this initial report was published.

The term "participating time series" was used to identify time series that provided data for the IGMETS numerical analysis. Time series acknowledged in the report, but not classified as "participating", implies that their data were not available for the analysis. Reasons for this unavailability included receiving no response after repeated attempts to contact the data holders or, in some rare cases, non-public proprietary data.

The chapters of the IGMETS report are divided into larger ocean-based regions (e.g. North Atlantic, South Pacific, Arctic Ocean), separated by land masses, or, in the case of an in-water division, indicated with black dashed lines (Figure 2.4). Each regional chapter only discusses time series and trends found within that specific region. For the purpose of this report, most of the analyses and visualizations also only focused on trends within oceanic, non-estuarine sites.

2.3 Analytical methods

The IGMETS time series vary greatly in their available variables, methodologies, months of coverage, and years in length (Figures 2.2 and 2.3). A flexible yet robust analytical method was required to conduct the analyses and compare them in a meaningful way. The following sections describe the methods used and the challenges addressed by the IGMETS analysis. Many of these methods are refinements and expansions of earlier work developed by COPEPOD to support other time-series working groups.

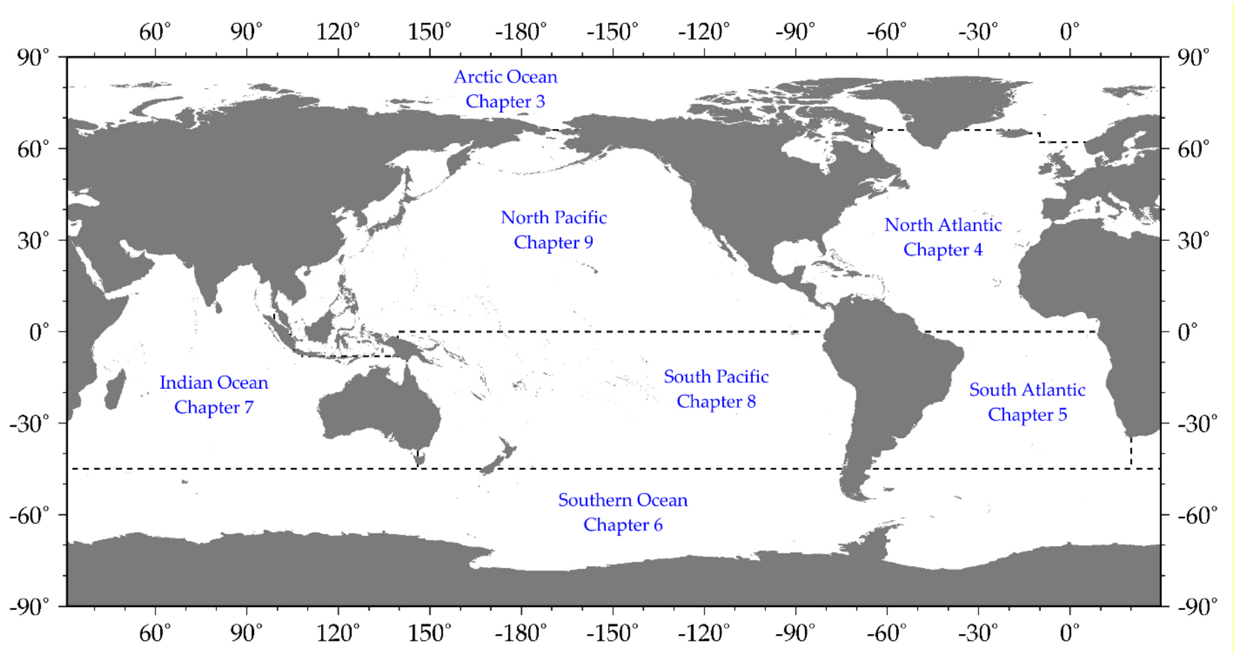


Figure 2.4. Global map illustrating the geographical boundaries of each chapter. The geographical separation of the ocean-basin chapters is set by land masses or, in the case of an in-water division, indicated with black dashed lines.

The IGMETS analysis addressed the following questions:

- How to compare time series with different methods or measuring units (Section 2.3.1),
- How to address time series with different seasonal influences (Section 2.3.1),
- How to compare time series with different time spans (Section 2.3.2),
- How to get a spatially-coherent overview from sparse data (Section 2.3.3).

2.3.1 The IGMETS statistical methodology

The comparison of variables sampled using different methods requires a careful yet flexible analysis. These differences not only include the measurement technique itself (e.g. instrumentation used, chemical method, counting method), but also sampling protocols and depth at which such measurements were collected (e.g. "surface" vs. a bottle triggered at 10 m vs. an average of the top 10 m vs. an integration of values over the top 10 m). Quantitatively, these values are not easily intercomparable, if at all. In terms of a time-series study, however, the focus is on how these variables are changing over time relative to themselves and to each other. Using data from different methods, one cannot necessarily intercompare how much they are changing, but it is possible to detect if these variables are similarly increasing or decreasing over time. As long as the method used within each individual time series is consistent over the duration of that individual time series, a comparison of relative trends among multiple time series, even with different methodologies, is possible.

2.3.1.1 Calculation of trends over time

A monotonic upward (or downward) trend means that the variable consistently increases (or decreases) over time, even though that trend may or may not be linear. Previous time-series studies by SCOR WG125 (Mackas *et al*., 2012) and ICES WGZE/WGPME (O'Brien *et al*., 2012, 2013) looked at trends by calculating the linear regression (slope) of annual anomalies within a time series. These annual anomalies were, in turn, calculated using "the Mackas method" (Mackas *et al*., 2001; O'Brien *et al*., 2013), which removed the seasonal cycle during the calculations. The Mackas method is also very tolerant of sparse data or time series with missing years or months (Mackas *et al*., 2001).

While the Mackas method itself was robust, ICES WGPME/WGZE found that the (parametric) linear regressions used to estimate trends were limited (e.g. yielded weak p values) when accounting for the statistical complexity in some shorter ecological time series, especially those less than ten years in length. Following the suggestion of these working groups, the IGMETS time-series analysis used the non-parametric seasonal Mann-Kendall (SMK) test to test for monotonic trend in time series with seasonal variation (Hirsch *et al*., 1982). The SMK works by calculating the Mann-Kendall score (Mann, 1945; Kendall, 1975; Gilbert, 1987) separately for each month; the sum of these values gives the final test statistic. The variance of the test statistic is likewise obtained by summing the variances of each month, and a normal approximation is then used to evaluate the significance level. IGMETS found results from the SMK to be equivalent to the Mackas method for time series longer than ten years and that it also frequently helped near-but-not-quite-significant shorter time series cross the "$p < 0.05$" borderline.

2.3.1.2 Statistical significance

The IGMETS analyses provide tables and visualization figures that differentiate between statistically significant ($p < 0.05$) and non-significant trends within the *in situ* variables and satellite-based background fields. In terms of estimating the statistical significance of a monotonic trend, the calculations behind the p value depend on the:

a) number of observations (e.g. the number of years in the time series),
b) strength of the trend (e.g. the magnitude of change over time), and
c) error/variance/noise of the variable.

In terms of time series, this means:

a) A shorter time series may require a stronger trend to be considered statistically significant, while a less pronounced trend may require more years in length before being considered statistically significant.
b) A variable with a large, but natural, variance (e.g. biological or biologically influenced variables) may require more years in length and/or a stronger trend (to be considered statistically significant) than a variable with a relatively lower variance (e.g. temperature).

These patterns are easily seen in the "Spatial frequency" tables (Section 2.4.4), where the ratio of significant to non-significant trends greatly increases with length of time. Statistically significant or not, spatially coherent patterns of "increasing" and "decreasing" were evident in both temperature and chlorophyll spatio-temporal fields (Section 2.4.4 and Figures 2.8, 2.9, and 2.10).

2.3.1.3 Combined variables

Within the IGMETS variables set, a handful of related, but slightly different, variables were present. For example, some time series had chlorophyll *a* measurements, others had total chlorophyll, or fluorescence, and the Continuous Plankton Recorder (CPR) time series had data from its Phytoplankton Colour Index (PCI). As stated in the beginning of this section (Section 2.3.1), as long as the method used in each individual time series was consistent over the duration of that individual time series, one can compare general trends among time series, even if they used different methodologies to measure the same variable. By grouping the trends from these three methods into a loose "combined chlorophyll" category, it is possible to obtain a larger and more coherent spatial picture than if only considering one method-specific variable at a time. For example, in the North Atlantic, the combined chlorophyll included the CPR PCI trends that fill the entire central transbasin North Atlantic region, an area where no chlorophyll *a* time series were otherwise available.

Similar combinations were done for the "combined zooplankton" grouping, which included trends from the "total copepods" abundance time series and trends from various total zooplankton biomass methods (e.g. total wet weights, total dry weights, or total sample volumes). This approach has been used by SCOR WG125 as well as the ICES WGZE and WGPME plankton time-series groups (Mackas *et al*., 2012; O'Brien *et al*., 2012, 2013).

For those who wish to not combine similar variables, the IGMETS Explorer (http://igmets.net/explorer) can display the distributions and trends of time-series variables both individually and in their combined grouping forms.

Table 2.1. Year-span and minimum year requirements for the IGMETS time-windows.

IGMETS time-window	Year-span	Minimum year requirement
"TW05" (5 years)	2008–2012	4 of 5
"TW10" (10 years)	2003–2012	8 of 10
"TW15" (15 years)	1998–2012	12 of 15
"TW20" (20 years)	1993–2012	16 of 20
"TW25" (25 years)	1988–2012	20 of 25
"TW30" (30 years)	1983–2012	24 of 30

2.3.2 IGMETS time-windows

While it is not really meaningful to compare long-term trends from a 31-year time series with a 12-year time series, it is possible to compare the 10-year trends created from the overlapping 10-year periods shared by these two time series. By splitting each time series into multiple "time-windows" with common starting and ending dates, the IGMETS analysis looked at patterns of change over time (trends) at a variety of shared time-intervals (e.g. 5 years, 10 years, 30 years).

O'Brien *et al.* (2012) used a similar approach to look at 10-year and 30-year trends in major North Atlantic phytoplankton taxonomic groups. IGMETS expanded upon this approach to include 5-, 10-, 15-, 20-, 25-, and 30-year time-windows. For this study, an analysis ending date of December 2012 was selected to allow the time-series researchers sufficient time to process complex biological samples (e.g. complete microscope identification and enumeration of plankton samples) and to conduct any necessary quality control on their data. The IGMETS time-windows were then calculated by counting backwards from 2012 (Table 2.1).

Table 2.1 summarizes the year span and minimum number-of-years-present requirements for the six IGMETS time-windows used in this report. Using this criteria, a time series with data for 2007–2012 would be eligible for the 5-year (TW05) time-window, but none of the longer windows. A time series encompassing 1981–2012, with no missing years, would be eligible for all six time-windows.

To ensure that a minimum number of years of data were available for statistical-trend calculations within each time-window, it was required that 80% of the years within the time-window must have data present to qualify for that window. For example, a time series with ten years of data from 2001 to 2010 could qualify for the 10-year (TW10) time-window, but would not qualify for the 5-year time-window as it only had data for three of the required four TW05 years (e.g. 2008, 2009, and 2010 are present, but 2011 and 2012 are both missing). In this example, if data for 2011 or 2012 could also be added, the time series would then qualify for the 5-year (TW05) window. Adding values for both 2011 and 2012 together would also allow this time series to participate in the 15-year time-window, as it would now have the 12 years minimum required by TW15. Under this criterium, a "60-year" time series from 1950 to 2010, but missing data every other year, would fail to qualify for any of the IGMETS time-windows.

2.3.3 Calculation of spatio-temporal trend fields

Within some oceanic regions, participating time series were sparse or simply did not exist (e.g. upper Indian Ocean and South Atlantic, central South Pacific). Even within data-rich regions like the North Atlantic, the available sites still often had vast areas with no information (Figure 2.2). While IGMETS is focused on *in situ*, ship-based measurements, satellite data were used to create globally covered, spatially complete fields that could shed light on the general physical (e.g. sea surface temperature) and biological (e.g. surface chlorophyll) changes that occurred during the different IGMETS time-windows.

The IGMETS spatio-temporal analysis used temperature data from the NOAA Optimum Interpolation Sea Surface Temperature dataset (OISST version 2.0, https://www.ncdc.noaa.gov/oisst) and chlorophyll data from the ESA Ocean Colour CCI dataset (OC-CCI version 2.0, http://www.esa-oceancolour-cci.org/). Both datasets were acquired in a prepared-product form, downloaded as a regular global grid of monthly mean values by year. By using these preprepared products, the typical concerns and issues with satellite data (e.g. instrument intercalibration, handling of clouds, aerosols, and ice) were already expertly accounted for and documented by the OISST and OC-CCI product teams.

For both datasets, the global datafields were calculated into 0.5° × 0.5° latitude–longitude grids of mean monthly values by year. This process created a global coverage set of nearly 160 000 individual time series, which were then run through the standard IGMETS analysis to calculate trends for each 0.5° box and IGMETS time-window. The OISST, with temperature data from 1982 to present, qualified for all six IGMETS time-windows (TW05–TW30), while the OC-CCI, with chlorophyll data for 1998–2013, only qualified for the 15-year and shorter time-windows (TW05–TW15). The spatio-temporal trends obtained from these datasets were used to create the visual background fields (Section 2.4.4) and to calculate the spatial frequency tables (Section 2.4.5) used in the report.

Table 2.2. Summary of correlation strengths based on Pearson correlation coefficient (*r*) values, modified from Hinkle *et al*. (2003).

Pearson correlation coefficient (*r*)	Interpretation
–1.00 to –0.70 (< –0.70)	High/strong negative correlation
–0.70 to –0.50 (< –0.50)	Moderate negative correlation
–0.50 to –0.30 (< –0.30)	Low/weak negative correlation
–0.30 to –0.15 (< –0.15)	Negligible negative correlation
–0.15 to 0.15	not plotted
0.15 to 0.30 (> 0.15)	Negligible positive correlation
0.30 to 0.50 (> 0.30)	Low/weak positive correlation
0.50 to 0.70 (> 0.50)	Moderate positive correlation
0.70 to 1.00 (> 0 .70)	High/strong positive correlation

2.3.4 Correlations with SST and chlorophyll

To detect relationships between *in situ* variables and surface seawater temperatures or chlorophyll concentrations, the Pearson product-moment correlation coefficient was calculated for each *in situ* variable against its geographically-corresponding, 0.5° × 0.5° satellite-based SST and chlorophyll time series (as discussed in Section 2.3.3). Satellite data were used, instead of at-site *in situ* data, in an attempt to create a globally uniform correlation base variable (e.g. not all of the sites had *in situ* chlorophyll data, and some did not have even *in situ* temperature data).

The Pearson product-moment correlation is a measure of the strength of a linear association between two variables calculated by trying to draw a best-fit line through these two variables (Hinkle *et al*., 2002). The Pearson correlation coefficient *r* indicates how far away these data points are from that best-fit line. This *r* value indicates the strength of the correlation. Unlike a linear regression, the Pearson product-moment correlation does not declare either variable as dependent or independent and treats all variables equally. Similar to the spatio-temporal trend fields (Section 2.3.4), spatio-temporal correlation fields were run for each of the 0.5° × 0.5° time-series boxes. Table 2.2 provides interpretations for nine, range-based *r* value groupings of the Pearson correlation coefficient.

2.4 Visualization of trends

With results from over 340 time series and thousands of variables spanning multiple time-windows, one major challenge IGMETS faced was presenting the results in a way that quickly discerned spatio-temporal trends and patterns within and among variables and regions. This was done by mapping colour-coded symbols that represented *in situ* trends (Section 2.4.1) and correlations (Section 2.4.2), creating graphical summary tables (Section 2.4.3), adding colour-coded backgrounds of spatially complete satellite trends (Section 2.4.4), and summarizing basin-wide statistics of the background field data in a table format (Section 4.5). With thousands of possible variables and time-window configurations, this printed report still only illustrates a small subset of the many different ways to explore the available datasets. For those results not found in this report, the IGMETS Explorer (Section 2.5) provides an online interface that allows the user to view the full set and variety of all combinations and analyses generated by this first IGMETS analysis.

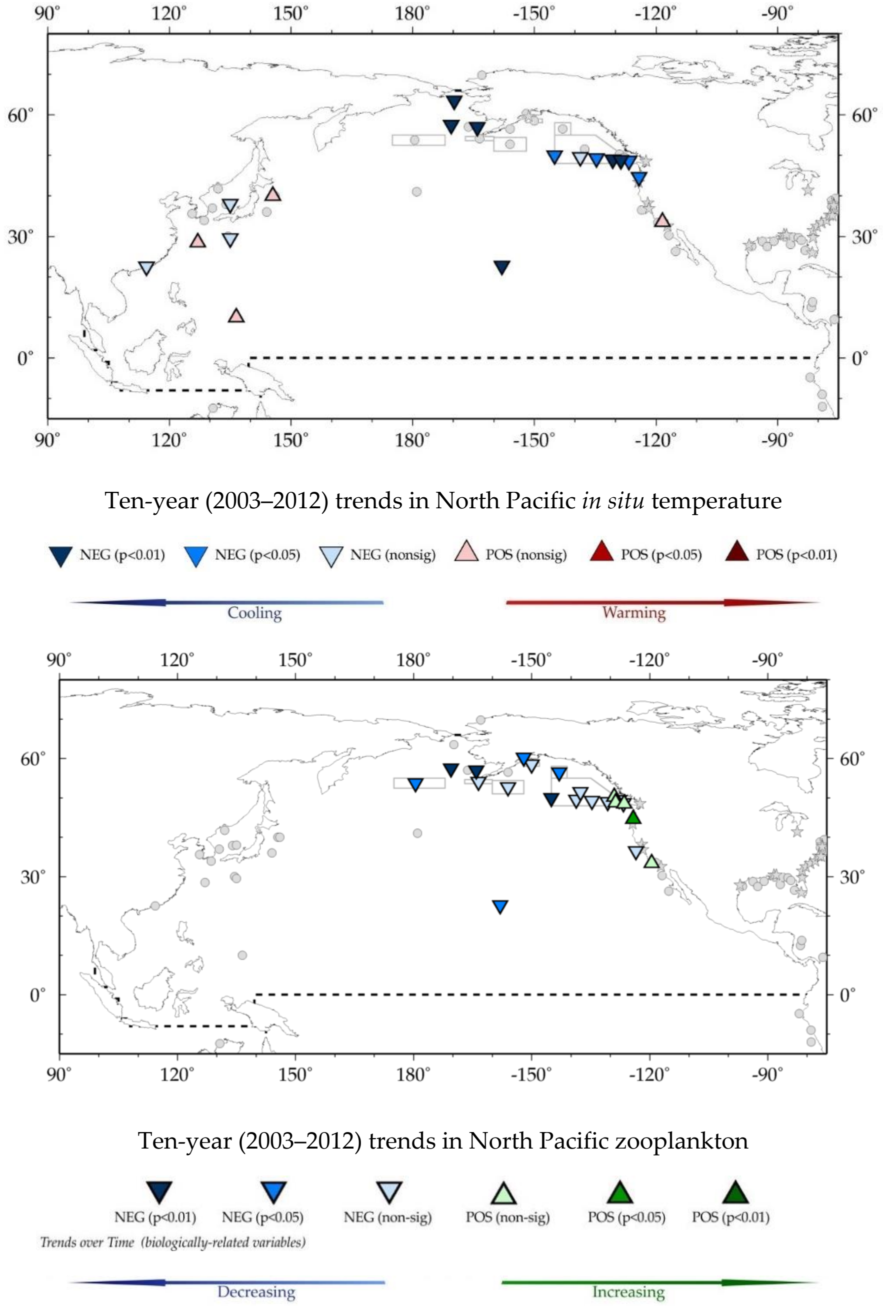


Figure 2.5. Examples of *in situ* trend maps displaying 10-year (TW10) trends in temperature (upper panel) and zooplankton (lower panel) in the IGMETS North Pacific region. Gray circles indicate time series locations in which data were not available or of insufficient years (Section 2.3.2).

2.4.1 *In situ* trend maps

For each *in situ* variable, time-window, and geographic region, IGMETS used colour-coded symbols (triangles) to map both variable trend state and the location of time-series sites (e.g. Figure 2.5). The upward- or downward-pointing orientation of the triangle, along with its base colour (i.e. red, green, or blue) indicates its trend direction. Non-biological variables (e.g. temperature, salinity, nutrients) are illustrated in red for positive/increasing trends and blue for negative/decreasing trends (Figure 2.5, upper panel). Symbols showing the trends in biological variables (e.g. chlorophyll, phytoplankton, zooplankton) are green (if positive) and blue (if negative) (Figure 2.5, lower panel). The shading of the triangle colour indicates the statistical significance of that trend, with the darkest colours representing the strongest trend ($p < 0.01$) and the lightest colour indicating a non-significant trend.

Within a given IGMETS trend map, if a time series did not have the variable being plotted or if its data did not qualify for the current time-window, a gray circle (or star, in the case of an "estuarine" site) was used to indicate the location of the time series. For example, in Figure 2.5, the gray circles mark time-series sites without the displayed variable and/or sites that did not qualify for the TW10 time-window. These gray symbols were also used to indicate time series that were discussed in a different IGMETS regional chapter (e.g. South Pacific, Arctic Ocean, or North Atlantic).

2.4.2 *In situ* correlation maps

Similar to the approach used with the *in situ* trend maps, correlation maps between *in situ* variables and satellite SST or chlorophyll fields were also created (Figure 2.6). Slightly different from the *in situ* trend maps, the up or down orientation of the triangle, along with its base colour (i.e. red, green, or blue) indicate its correlation direction and strength. Correlations against satellite SST use the red/blue symbol colour set (Figure 2.6, upper panel)

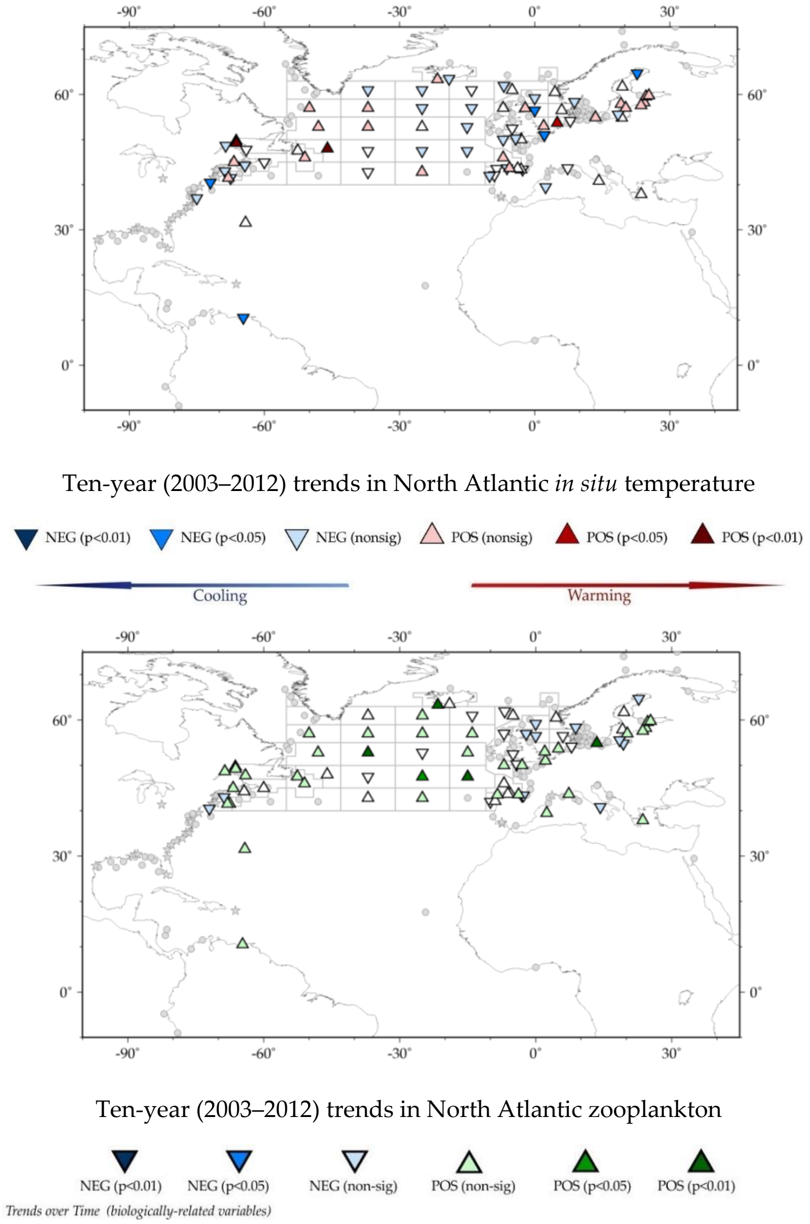


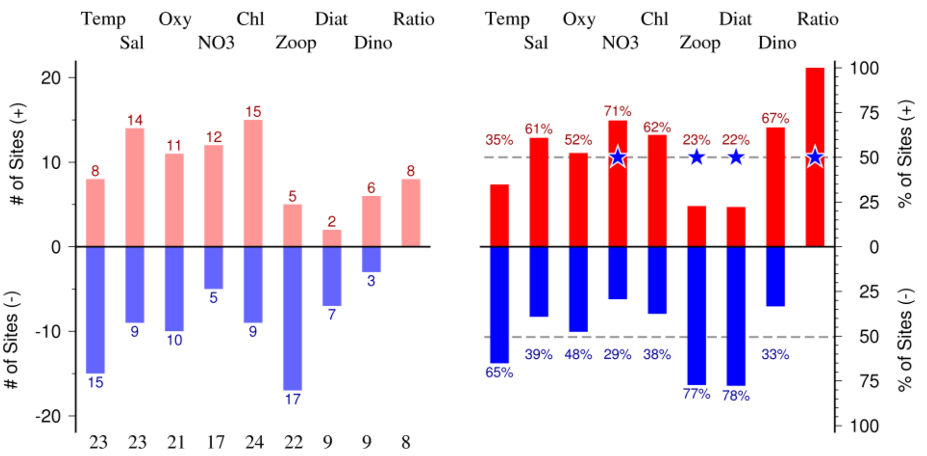
Figure 2.6. Examples of *in situ* correlation maps displaying 10-year (TW10) correlations between zooplankton and satellite SST (upper panel) and satellite chlorophyll (lower panel). Gray circles indicate time series locations in which data were not available or of insufficient years (Section 2.3.2).

and correlations against satellite chlorophyll use the symbol green/blue colour set (Figure 2.6, lower panel). As with the *in situ* trend maps, gray circles and stars indicated non-time-window-qualifying and/or out-of-region time series.

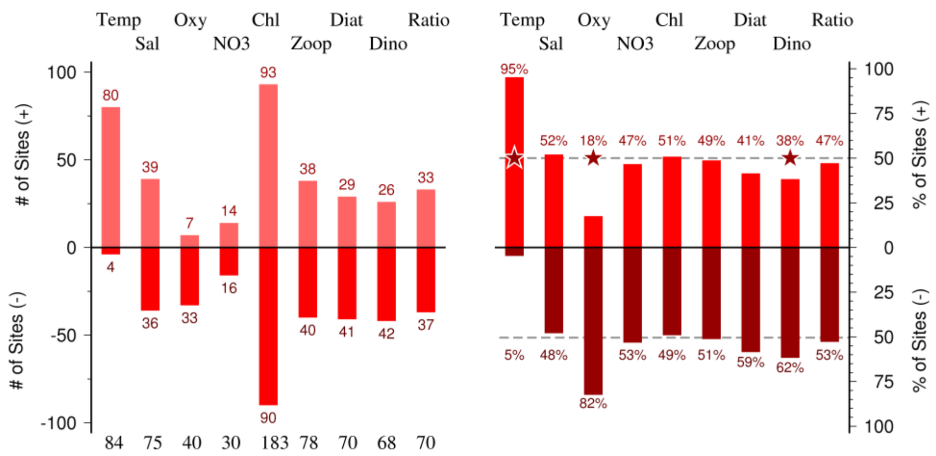
2.4.3 BODE plots

The brief overviews of dynamic ecosystems (BODE) plot is a visualization showing the relative amounts of positive and negative trends (or correlations) within a given time-window and across a set of select *in situ* variables. The upper map in Figure 2.5 has 18 symbols indicating 10-year trends in *in situ* temperature, of which 4 were positive (red) and 14 were negative (blue). The lower map in Figure 2.5 has 22 symbols indicating 10-year trends in zooplankton, of which 5 were positive (green) and 17 were negative (blue). This numerical information, along with that from seven other additional *in situ* variables, is represented in the single BODE plot shown in Figure 2.7a. The left side of the BODE plot shows the number of time-series sites having each respective trend (e.g. 4 positive and 14 negative temperature trends). The right side of the BODE plot shows the same information calculated as a percentage of all sites present with that variable [e.g. 78% (14 of 18) of the sites with temperature data had a negative trend]. A dashed gray line marks the 50% proportion level on both the positive and negative *y*-axis. A coloured star above the figure's upper gray line indicates that the proportion of positive vs. negative trends was statistically different ($p < 0.05$, two-tailed Z test for difference between proportions). In Figure 2.7a, the proportions of positive to negative trends in temperature (Temp), zooplankton (Zoop), and the ratio of diatoms to dinoflagellates (Ratio) were significantly different. The BODE plot can also be used with correlation data. Correlations of *in situ* variables with sea surface temperature, as seen in Figure 2.6 (upper panel), are represented in Figure 2.7b. Correlations of *in situ* variables with satellite chlorophyll, as seen in Figure 2.6c, are represented in Figure 2.7c. The three BODE plot types can be quickly distinguish by their colour sets: trend (red/blue), correlations with SST (red-only), correlations with satellite chlorophyll (green-only).

a) BODE plot of 10-year *in situ* variable trends in the **North Pacific**



b) BODE plot of 10-year correlations with SST in the North Atlantic



c) BODE plot of 10-year correlations with chlorophyll in the North Atlantic

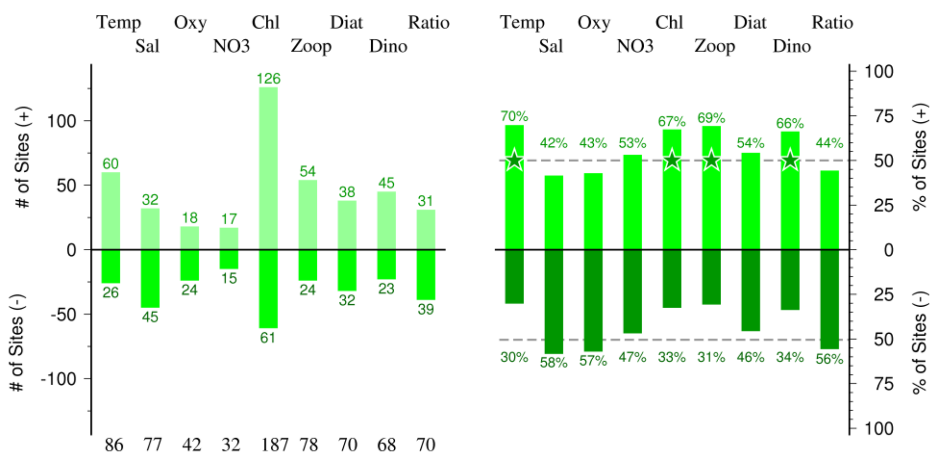


Figure 2.7. Brief overviews of dynamic ecosystems (BODE) plots illustrating *in situ* data (10-year window) (a) trends over time in the North Pacific (*see also* Figure 2.5), (b) correlations with satellite SST in the North Atlantic (*see also* Figure 2.6), and (c) correlations with satellite chlorophyll in the North Atlantic (*see also* Figure 2.6). See Section 2.4.3 for an explanation of the methodology and visualization. Column headings (*In situ* variables): Temp-temperature, Sal-salinity, Oxy-dissolved oxygen, NO3-nitrate, Chl-chlorophyll, Zoop-total zooplankton or copepods, Diat-total diatoms, Dino-total dinoflagellates, Ratio-ratio of diatoms to dinoflagellates.

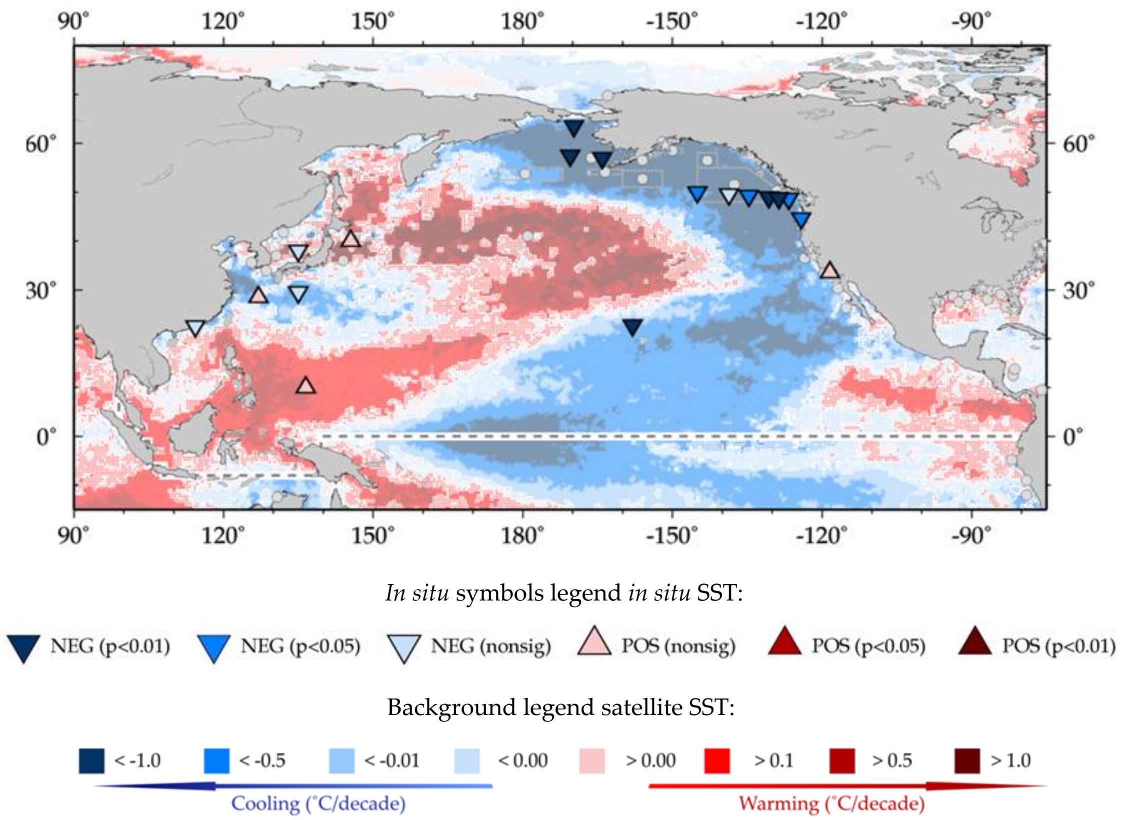


Figure 2.8. Enhanced version of Figure 2.4 (symbols indicating 10-year trends of *in situ* temperature, see also Section 2.4.1) with a background of 10-year trends in sea surface temperature trends calculated from the OISST global SST product (Sections 2.3.3 and 2.4.4). Note that the colours of the *in situ* symbols indicate trend direction and statistical strength, while the colours of the background OISST field represent the direction and rate of change (e.g. °C decade^{-1}).

2.4.4 Spatio-temporal trend backgrounds

While *in situ* time-series data were not available for all the world's ocean, satellite-based data were used to create a global grid of time series to describe the general physical (e.g. satellite sea surface temperature) and biological (e.g. satellite ocean colour chlorophyll) environments that surround and influence the *in situ* time series in the IGMETS study.

As mentioned in Section 2.3.3., the satellite variables were divided in 0.5° latitude–longitude grid boxes and run through the same time-series analysis used for the *in situ* data. Unlike the *in situ* data, these satellite data also share a common method and units, which allows these data to be compared both qualitatively (e.g. is the variable increasing or decreasing) and quantitatively (e.g. at what rate is the variable increasing or decreasing over time). The slope of the SMK trend (Section 2.3.1.1) captures this numerical rate of change, initially °C year^{-1} for temperature and mg m^{-3} year^{-1} for chlorophyll. IGMETS recalculated these rates into units of change per decade and then plotted them as a background trend field using a similar colour scheme to that used for the *in situ* time series (Figure 2.8).

By plotting and comparing different *in situ* variables together with these background trend fields, it is possible to spatially examine how the *in situ* variables generally correspond to changes in the larger spatial area environments surrounding them. For example, were zooplankton in warming ocean areas (e.g. Figure 2.9, upper panel – red background areas) responding differently than those in cooling areas (e.g. Figure 2.9, upper panel –blue background areas)? If a temperature relationship was not clear, were the zooplankton responding instead to increasing or decreasing phytoplankton biomass, as estimated using OC-CCI satellite chlorophyll and plotting it as the background field (e.g. Figure 2.9, lower panel)?

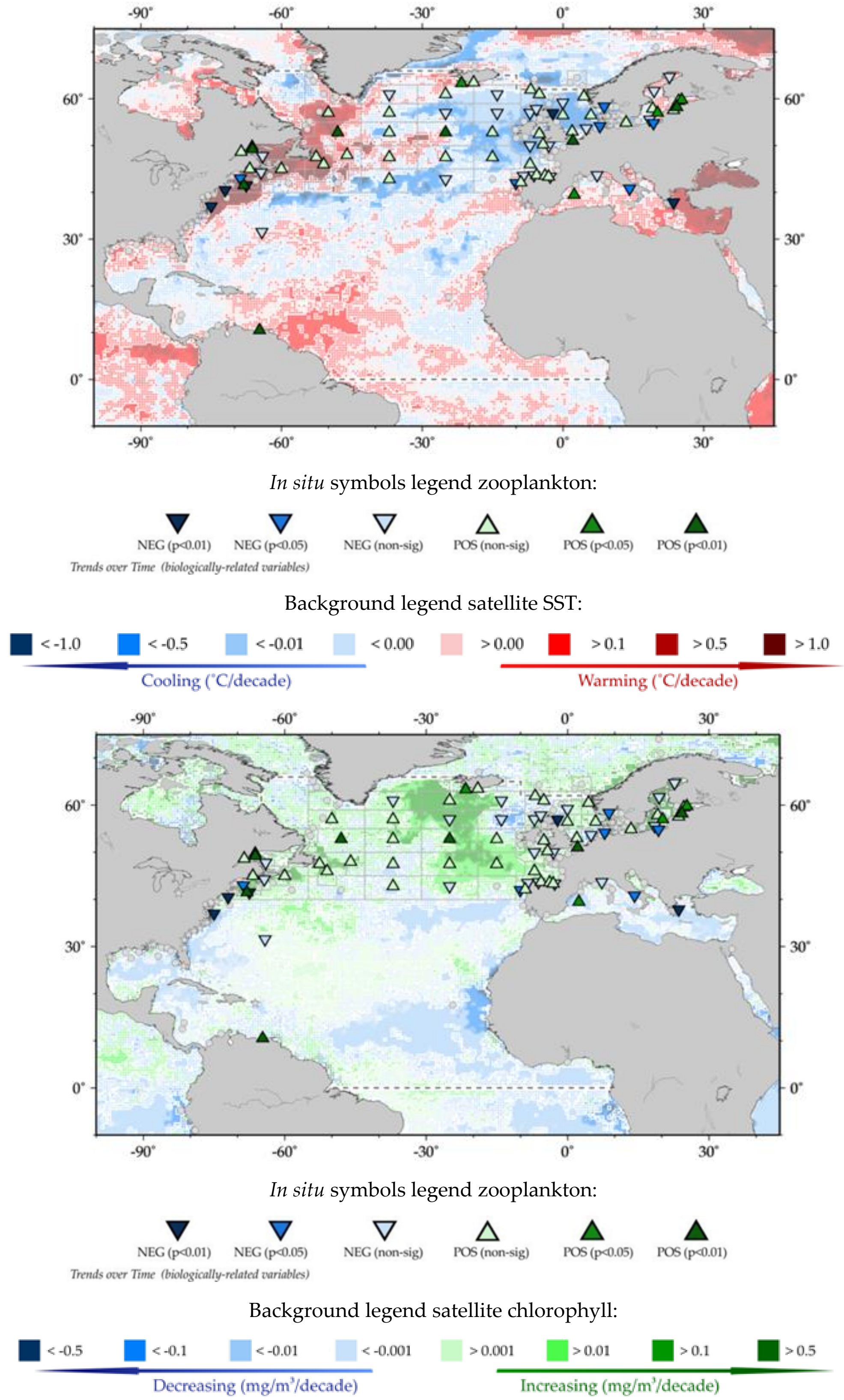


Figure 2.9. Illustrative examples of how spatio-temporal trend fields can be used to look at *in situ* data (zooplankton) in relation to their physical (SST, top) and biological (chlorophyll, bottom) environment.

2.4.5 Spatial frequency tables

Visually, the spatial areas of red- and blue-coloured SST trends (or of green- and blue-coloured chlorophyll trends) within the plotted spatio-temporal trend backgrounds (Section 2.4.4) differ across time-windows both within regions and between regions. For example, in the North Atlantic, the 10-year SST trends visually seem to have roughly equal areas of increasing (red) and decreasing (blue) trend areas (Figure 2.10, left), but this changes to almost entirely increasing (red) trends in the 30-year plot (Figure 2.10, right). To quantify the actual oceanic surface area of these trends, the areas of the various trend categories were calculated by summing the latitude-adjusted surface areas of each 0.5° latitude–longitude satellite data grid falling within that region (e.g. the IGMETS North Atlantic region). These spatial totals were then divided by the total area of that region to give the relative amount (percentage) of area having each trend direction or trend rate category. These subtotals were then recorded in table form, representing each region and the time-windows available for that background variable (Table 2.3).

Within the spatial-frequency table (Table 2.3), the upper table section summarizes the relative spatial areas of the total increasing or decreasing trends, without dividing these trends into any rate-based subcategories. For example, in the North Atlantic (Table 2.3, column 3), 50.3% of the 10-year SST trends were increasing, while 49.7% were decreasing. In contrast, 95.7% of the 20-year SST trends were increasing (Table 2.3, column 5). The lower number in parenthesis in the spatial-frequency table indicates the spatial area of statistically significant ($p < 0.05$) trends. Only 14.6% of the increasing 10-year SST trends were $p < 0.05$, while 95.0% of the increasing 30-years were $p < 0.05$. This noticeable difference in statistical significance is an artefact caused by the smaller number of measurements (n) available in the shorter time-windows. (See Section 2.3.1.2 for a discussion on how time-window length, strength of trend, and variable type affect statistical significance calculations.)

The lower section of the spatial-frequency table divides the trends into the same rate and colour categories as used in the spatial-trends background figures (Figure 2.10). For example, 9.2% of the 20-year SST trends fell in the 0.5–1.0°C decade^{-1} warming category. Of these, all of the trends were statistically significant ($p < 0.05$).

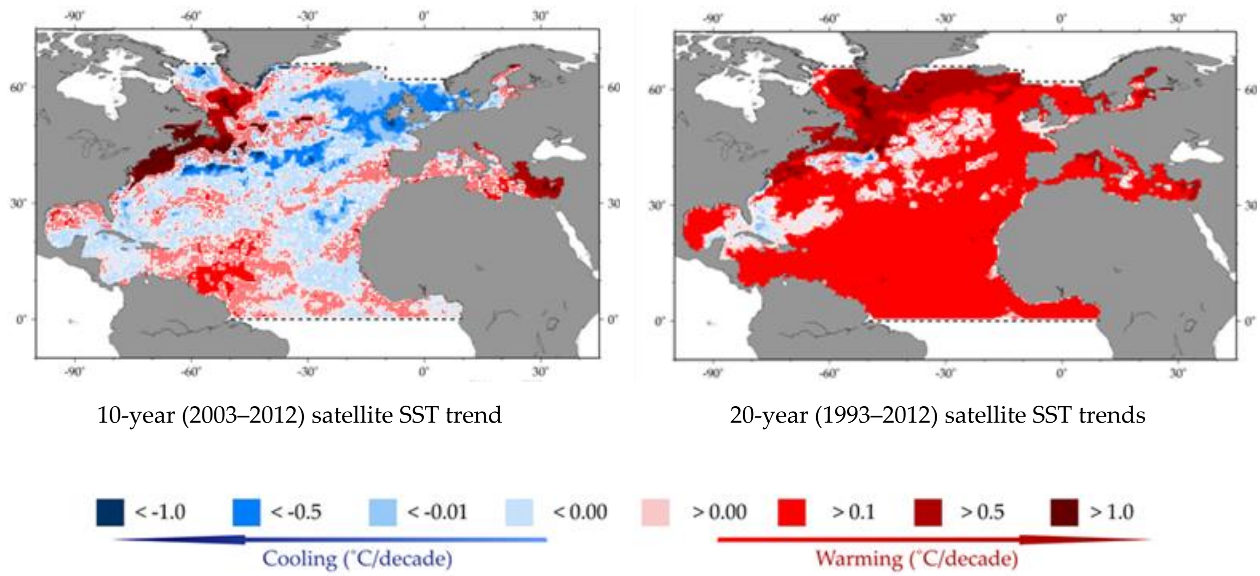


Figure 2.10. Sea surface temperature (SST) trends within the IGMETS-defined North Atlantic region for the 10-year time-window (left panel) and 20-year time-window (right panel) (Table 2.3).

Table 2.3. Spatial-frequency table showing sea surface temperature (SST) trends within the IGMETS-defined North Atlantic region. Percentage values represent the fraction of trends within the entire North Atlantic that fall within that category. Percentages in parenthesis indicate the fraction of trends (within the entire North Atlantic) with a $p < 0.05$ significance level. (See Section 2.3.1.2 for discussion on significance levels, trends, and time-windows).

Latitude-adjusted SST data field surface area = 46.1 million km^2	**5-year** (2008–2012)	**10-year** (2003–2012)	**15-year** (1998–2012)	**20-year** (1993–2012)	**25-year** (1988–2012)	**30-year** (1983–2012)
Area (%) w/ increasing SST trends ($p < 0.05$)	**52.5%** (*13.3%*)	**50.3%** (*14.6%*)	**76.8%** (*54.8%*)	**95.7%** (*87.4%*)	**98.1%** (*95.0%*)	**99.1%** (*97.3%*)
Area (%) w/ decreasing SST trends ($p < 0.05$)	47.5% (*18.6%*)	49.7% (*15.5%*)	23.2% (*7.1%*)	4.3% (*1.1%*)	1.9% (*0.6%*)	0.9% (*0.3%*)
> 1.0°C decade^{-1} warming ($p < 0.05$)	13.5% (*8.1%*)	3.4% (*3.3%*)	0.9% (*0.9%*)	0.7% (*0.7%*)	0.1% (*0.1%*)	0.0% (*0.0%*)
0.5 to 1.0°C decade–^{1} warming ($p < 0.05$)	18.0% (*4.6%*)	5.0% (*4.1%*)	5.4% (*5.4%*)	10.0% (*10.0%*)	9.2% (*9.2%*)	6.7% (*6.7%*)
0.1 to 0.5°C decade^{-1} warming ($p < 0.05$)	17.0% (*0.6%*)	27.3% (*7.1%*)	**56.3%** (*47.4%*)	**77.1%** (*74.3%*)	**83.3%** (*82.5%*)	**86.7%** (*86.4%*)
0.0 to 0.1°C decade^{-1} warming ($p < 0.05$)	4.1% (*0.0%*)	14.6% (*0.2%*)	14.2% (*1.2%*)	8.0% (*2.4%*)	5.4% (*3.2%*)	5.6% (*4.2%*)
0.0 to –0.1°C decade^{-1} cooling ($p < 0.05$)	3.9% (*0.0%*)	13.1% (*0.1%*)	10.0% (*0.2%*)	2.6% (*0.1%*)	1.3% (*0.1%*)	0.7% (*0.1%*)
–0.1 to –0.5°C decade^{-1} cooling ($p < 0.05$)	13.3% (*0.7%*)	29.2% (*8.7%*)	12.4% (*6.1%*)	1.4% (*0.8%*)	0.6% (*0.4%*)	0.2% (*0.1%*)
–0.5 to –1.0°C decade^{-1} cooling ($p < 0.05$)	15.7% (*6.6%*)	6.7% (*6.1%*)	0.7% (*0.6%*)	0.2% (*0.2%*)	0.1% (*0.1%*)	0.0% (*0.0%*)
> –1.0°C decade^{-1} cooling ($p < 0.05$)	14.6% (*11.3%*)	0.6% (*0.6%*)	0.2% (*0.2%*)	0.0% (*0.0%*)	0.0% (*0.0%*)	0.0% (*0.0%*)

2.5 The IGMETS time series Explorer

This initial IGMETS analysis and summary report featured seven geographic regions and one global overview, six time-windows, 18 *in situ* variables, and three background fields, generating a set of over 2500 possible image combinations (i.e. 8 × 6 × 18 × 3 = 2592). This number easily reaches 100 000 after including possibilities to select correlations vs. trends, to plot data subsets based on statistical significance level, or to focus on estuarine vs. open-ocean sites. While only a small number of these figures could be included in this report, the full figure set and interactive options are available in the IGMETS Explorer (http://igmets.net/explorer) (Figure 2.11).

The Explorer is an online companion to the IGMETS report, providing interactive (point and click) access and expansion to the figures and tables shown throughout the report. It further provides information on the participating time series found in each of the report chapters and the Annex. As IGMETS work continues, new data and sites will be added to the Explorer and to the IGMETS Metabase (http://igmets.net/metabase).

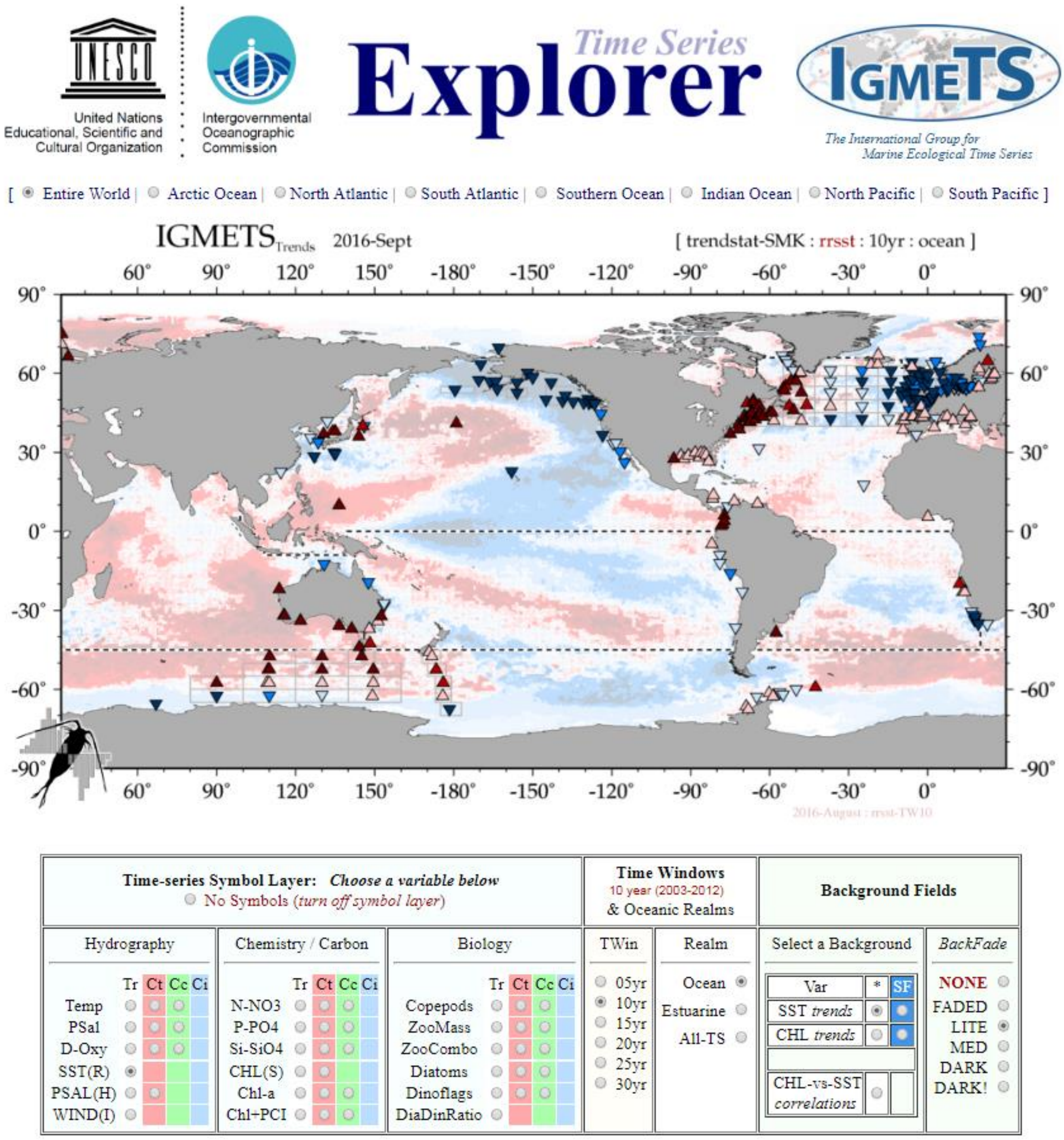


Figure 2.11. An example screenshot from the IGMETS time series Explorer available online at http://Igmets.net/explorer.

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