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Precipitation as a driver of phytoplankton ecology in coastal waters: A climatic perspective

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ABSTRACT

Climatic change is shaping our planet's ecosystems yet our capacity to predict the consequences and prepare for the future remains rudimentary. Changes to the hydrological cycle mean that large regions of the planet are experiencing changes in precipitation. Responses by phytoplankton were assessed in three regions: 1) globally, 2) in regions that are wet and getting wetter, 3) in regions that are dry and getting drier. Using long-term time-series data the temporal variation in precipitation was compared with variation in chlorophyll *a*, diatoms, dinoflagellates, chlorophytes, chrysophytes and euglenophytes from 106 sites worldwide. The results demonstrate that phytoplankton responses to precipitation depend upon the season and region. In general phytoplankton responded more positively to increased precipitation during summer rather than winter. Increased precipitation during winter was likely to reduce chlorophyll *a*, diatoms and chrysophytes, whereas increasing precipitation in summer was likely to increase chlorophyll *a* and favor chlorophytes. Within regions that are wet and getting wetter chlorophyll *a* increased and dinoflagellate abundances were reduced in wet autumns; while diatom abundances were reduced in wet springs. In dry and drying ecosystems the abundances of chlorophytes decreased during dry springs and summers. The existence of these widespread patterns of phytoplankton abundance associated with inter annual variability in precipitation improves our capacity to predict the future composition of phytoplankton communities in estuarine and coastal water bodies.

1. Introduction

More than 70% of the world's population currently lives in coastal watersheds (Vitousek et al., 1997; Vörösmarty et al., 2000) that impact our estuarine and coastal waters. This situation has resulted in dramatically altered ecosystems due to population growth, agricultural, urban, and industrial development, modified river flow and increased nutrient inputs with sometimes dramatic water quality effects on receiving waters (Boesch et al., 2001; Paerl et al., 2006). The general decline in the environmental condition of our estuaries is likely to be exacerbated by even larger scale effects of climate change and variability (Trenberth, 2011; IPCC, 2013).

The recent increase in CO_2 concentrations during the Anthropocene has stimulated many efforts to observe the impacts and predict the future scenarios for climate, weather, ecosystems and humans. Insights into ecosystem responses have come from laboratory studies, mesocosms, models and long-term observations of natural systems (e.g. Parmesan and Yohe, 2003; Cloern and Jassby, 2012). With their very short generation times phytoplankton responses to short term differences in climate are likely to provide significant predictive insights into long-term climatic responses (Schindler, 1997; Lancelot and Muylaert, 2011; Peierls et al., 2012; Cloern and Jassby, 2012).

Based on both models and observations (Allen and Ingram, 2002; IPCC, 2013) there have already been significant changes to the hydrological cycle. Climatically driven changes to the hydrological cycle are likely to compound other recent engineering impacts such as water extraction, impoundments and diversions in

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terms of effects on aquatic ecosystems where phytoplankton growth is the key biogeochemical process. To examine the potential impacts of changing hydrology on riverine, estuarine and coastal phytoplankton communities we broadly grouped sites into categories of known climatic changes. In particular we adopt the IPCC (2013) definition of two major patterns affecting substantial portions of the planet: 1) generally drying and predominantly less flow in summer, 2) generally wet and getting wetter. For the southwest USA, there already are substantial data on long-term drying with less precipitation in the summer months and longer, more severe droughts (Sheppard et al., 2002). This pattern is also evident in southwestern Australia (Timbal et al., 2006). For the available sites in these mid-latitude, drying regions summer precipitation is rare (Fig. 1) and summer stream flows are often relatively small. In contrast, there are regions along the east coast of Asia, the east coast of the Americas and northern Europe where we can expect increased precipitation (IPCC, 2013) both in winter and summer. Relative to drying regions these tend to receive more precipitation in summer (Fig. 1).

In many temperate ecosystems there is likely to be a reduction in mountain snow pack and a substantial shift in stream-flow seasonality, so that by 2050, the spring stream-flow maximum will come about one month earlier (Barnett et al., 2005). The IPCC (2013) predicts this pattern will be found throughout much of the Mediterranean region and southern parts of central Europe (Douville et al., 2002; Wang, 2005). For example, the Rhine River watershed is predicted to shift from a combined rainfall and snowmelt regime to a more rainfall-dominated regime resulting in increased winter discharge and decreased summer discharge (Middelkoop et al., 2001). Some insights into the responses of phytoplankton to these long-term patterns can be elucidated from relevant time series where observations are available in dry summers or wetter winters.

In this study we treat precipitation as the pressure (c.f. Rapport and Friend, 1979) that causes variation in the more proximal drivers or states such as flow rate, residence time, dilution, advection, salinity, nutrient delivery, populations of grazers, and stratification, mixed layer depth, irradiance; that all influence phytoplankton. If the effects of precipitation on these drivers and states are completely dependent upon site characteristics then consistent responses by phytoplankton are unlikely. The interpretation is further complicated by nonlinear responses and the number of environmental factors that can co-vary with precipitation, including temperature and insolation. Therefore this statistical investigation is unlikely to elucidate the causality and mechanism of precipitation effects on phytoplankton. The monthly time series are most likely to detect effects due to dilution, advection and responses by the faster growing species. Conversely any associations between phytoplankton and precipitation or salinity that persist over a season, a year or many years probably indicates a more fundamental physiological effect or ecological balance. In the ecocline model of estuaries (Attrill and Rundle, 2002) the phytoplankton community composition gradually shifts along a salinity gradient, which is strongly influenced by precipitation.

We hypothesized that precipitation influences phytoplankton ecology in a predictable manner. Thus the phytoplankton inhabiting the large number of diverse water bodies that are experiencing long-term change in regional, local or catchment precipitation may manifest consistent responses. We suggest that a considerable portion of the observed temporal variability in phytoplankton (e.g. Smetacek and Cloern, 2008; Cloern and Jassby, 2010) is a result of the global heterogeneity in the spatial and temporal distribution of precipitation and resulting river flow. In addition to building a better conceptual model of the dynamics of phytoplankton biomass, the analysis conducted herein seeks to investigate precipitation as a driver of phytoplankton community composition in geographically diverse regions. If precipitation is identified as a significant driver of both biomass and community composition, then it is feasible to predict the climatic changes in phytoplankton biomass and composition associated with ongoing changes in the hydrological cycle.

2. Methods

The Scientific Committee for Ocean Research Working Group 137 (SCOR-WG137) has compiled a large number of time series of

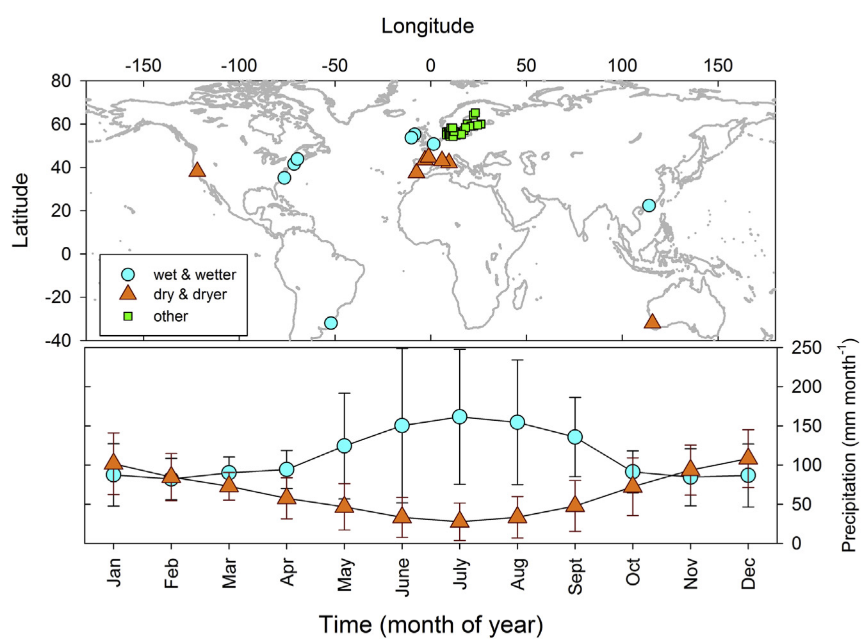

Fig. 1. Sites with long term time series of phytoplankton that reside in areas identified by IPCC (2013) as currently or predicted to be: 1) decreasing in precipitation [triangles], 2) increasing in precipitation [circles]. Other additional sites in the Baltic region [squares] were included in some analyses. Lower panel is NOAA's Earth System Research Laboratory (ESRL) monthly average rainfall and calculated standard deviations for the dryer sites, and wetter sites.