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Seasonal and Interannual Changes of Physical-Biological Interactionsin the Western Arabian Sea

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Abstract. The remotely sensed and onboard measured atmospheric pressure, wind speed, wind direction, sea surface temperature, the mixed layer depth temperature, salinity, concentration of nitrates, chlorophyll-*a*, phytoplankton, zooplankton biomass, sardine landings, frequency of fish kill incidents and algal blooms were used, to estimate seasonal and interannual changes in epipelagic communities of the western Arabian Sea and the Sea of Oman in the past 50 years (1960-2010). For the Sea of Oman, declining trends were evaluated for the atmospheric sea level pressure, zonal component of wind speed, concentration of nitrates, annual variability and biomass of diatoms, and sardine landings. These trends were accompanied by rising atmospheric temperature, sea surface temperature, frequency of fish kill incidents and harmful algal blooms. The analysis of the entire Arabian Sea subdivided into 61 two-degrees regions has shown oscillations of sea surface temperature, wind speed, concentration of nitrates, and chlorophyll-a with dominant periods of 12 and 6 months, with no pronounced interannual trends of chlorophyll-*a*, from 1997 to 2010. Monthly time series of chlorophyll-*a* implied high variability in western regions of the sea compared to the eastern ones.

Keywords: Arabian Sea, Chlorophyll-a, Fish kills.

1. Introduction

The western Arabian Sea is acknowledged to be the region of vigorous seasonal changes in structural-functional characteristics of pelagic communitiesdue to the periodic reverse of monsoonal winds affecting geostrophic currents. Physical-biological interactions in these communitieswere studied by numerous expeditions deployed to the region in the past 50 years [1,2,3]. As far as the coastal pelagic ecosystems are concerned, the assessments of physical-biological coupling were fragmental. Harmful algal blooms, coastal hypoxia, and fish kill incidents result in huge losses for the economies of Arabic states. In the Sultanate of Oman, the losses reported over some years have accounted for a hundred tons of dead fish [4].

The Sultanate of Oman has a coastline of about 1700km –along the southern coast of the Gulf of Oman (the Sea of Oman) and the western Arabian Sea. Notoriously different modes of nutrient supply, thermo-haline structure of waters, and coastal circulation should result in different seasonal and interannual changes between these regions. By using the remotely sensed and onboard measured atmospheric pressure, wind speed, wind direction, sea surface temperature, the mixed layer depth temperature, salinity, concentration of nitrates, chlorophyll-*a*, phytoplankton, zooplankton biomass, monthly data on sardine landings, frequency of fish kill incidents and algal blooms, we were aimed to estimate seasonal and interannual changes with a special reference to the Omani coast.

2. Methods and Data

Data on the longwave radiation, zonal and meridianal components of wind speedwere retrieved from the NCAR/NCEP reanalysis database [5], in which the daily averages at 10 m above sea level were extracted for

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the 2°regions along the Omani coast. The sea surface height anomalies were produced from TOPEX/Poseidon, Jason-1 and Jason-2 altimeter data and acquired from the Archiving, Validation and Interpretation of the Satellite Oceanographic data center website (http://www.aviso.oceanobs.com), as well as the MODAS model on sea surface altimetry [6].

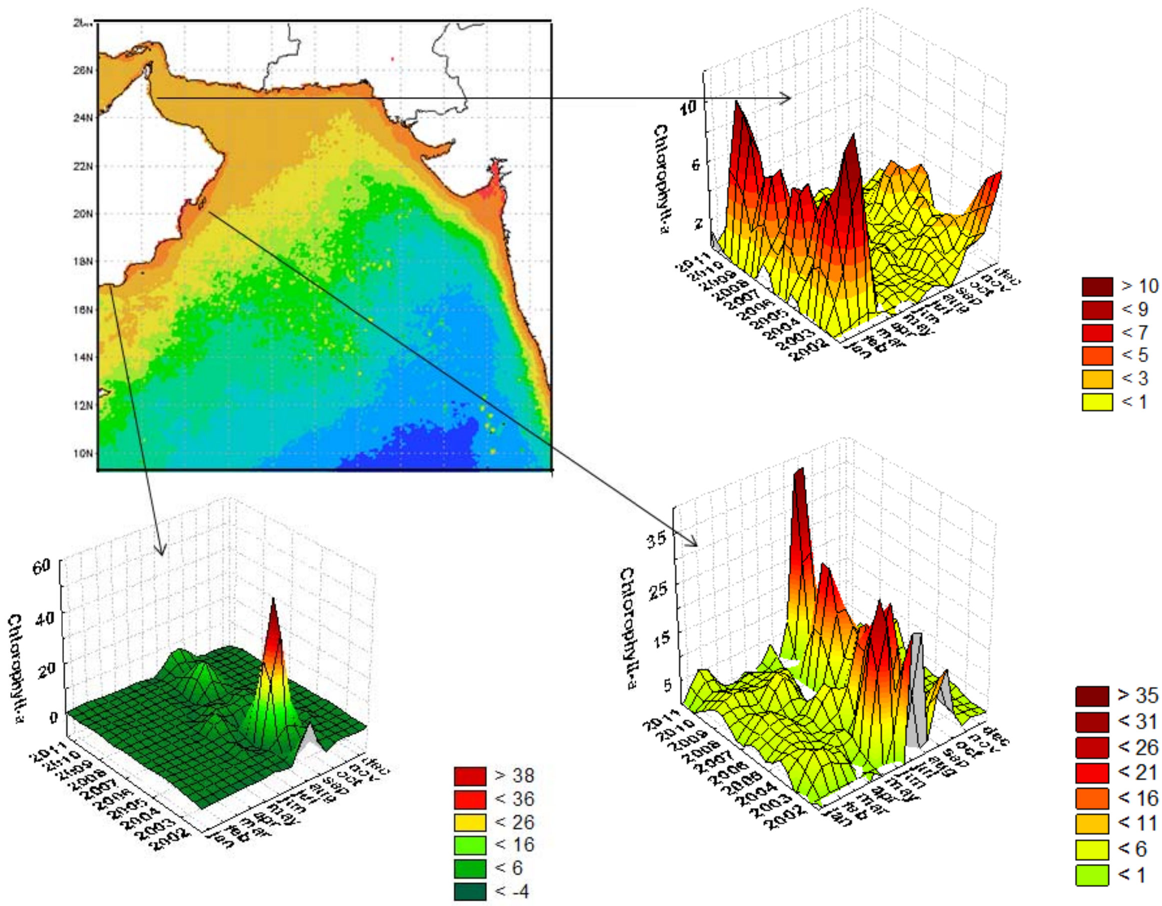

Fig. 1: Interannual changes of chlorophyll-*a* seasonal cycles over regions.Z-axis: concentration of chlorophyll-*a* (log 100*mg m^{-3}),SeaWIFS scanner. Y-axis: years; X-axis: months. Map exemplifies averaged spatial distribution of chlorophyll-*a* (1997-2011).

The assessment of the kinetic energy of mesoscaleeddies was based on the altimeter–derived sea surface height anomalies for the western Arabian Sea (18-25ºN, 58-62ºE), for the period of 1997-2009. The methodology of calculations of eddy kinetic energy was that used by [7].Monthly time series of sea surface temperature and chlorophyll-*a*concentration were acquired using the GES-DISC Interactive Online Visualization and Analysis Infrastructure software as part of the NASA's Goddard Earth Sciences Data and Information Services Center.

Data on CTDs casts and dissolved oxygen were taken from coastal time series, and cruise reports of the Ministry of Fisheries, with a number of CTD casts carried out along the shelf of the western Arabian Sea. Also, we used the Sultan Qaboos University coastal time series (Muscat region-23°31′N, 58°44′E) on temperature, salinity, nitrates, phosphates, and dissolved oxygen concentration. Phytoplankton and zooplankton samples were collected by Niskin bottles and Bongo nets (150µm mesh size) at the same sampling sites. These samples were processed to the lowest taxa possible and counted under a stereomicroscope.

Data on monthly frequency of harmful algal blooms,fish kills and sardine landings along the coast, were retrieved from the archives of the Marine Science and Fisheries Research Center (Muscat, Oman).

3. Results and Discussion

Spectral analysis showed that the six month and/orone year period were the dominant modesin variation of the longwave radiation, wind speed, kinetic energy of eddies, sea surface temperature, concentration of dissolved oxygen, nitrates, chlorophyll-*a*, the abundance of some phytoplankton and mesozooplankton species, frequency of fish kill incidents, and sardine landings. This enabled us to develop the approach to investigate the long-term changes through the analysis of modifications of seasonal cycles over years.In terms of this approach it was shown that seasonal cycles could vary (by magnitudes and peak timing) over years, as well as over regions (the Sea of Oman versus the western Arabian Sea;Fig. 1).

For instance, the chlorophyll-*a* concentration in the western part of the Sea of Oman exhibited maximum in February-March (during the winter monsoon), whereas in the western Arabian Sea, the seasonal peak was pronounced in August-September, which is the time of summer monsoon. The summer peakvaried graduallyover years, in comparison to the winter peak.An explanation to that finds its way through the analysis of regional changes of the wind field.The analysis of the zonal and meridianal components of the wind field showed that in the Sea of Oman, chlorophyllpeaks were associated with maximal speed of the northwarddirected wind and the medium level speed of the wind component directed westward.The ratio between chlorophyll-*a*and wind speed characteristics was different for the western Arabian Sea.

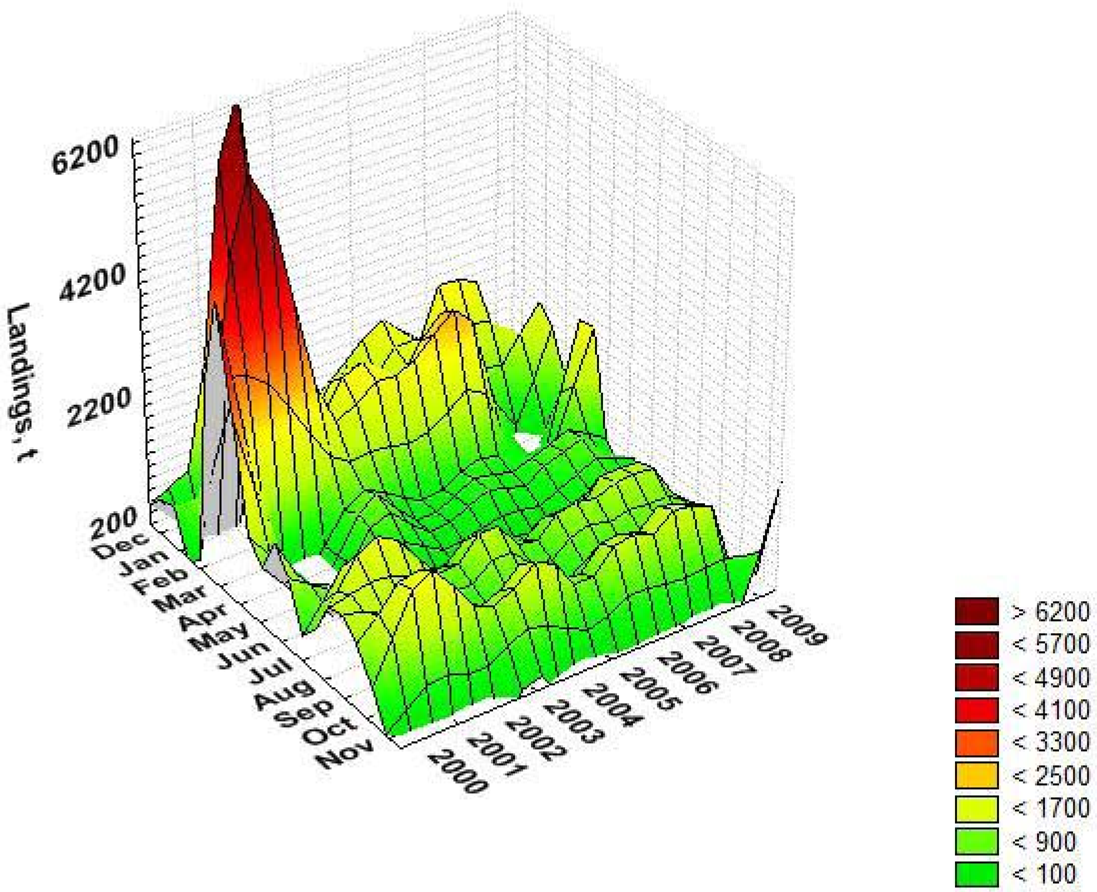

Fig. 2: Interannual changes of the seasonal cycle of sardine landings in the Sea of Oman (the Muscat region).

In the Sea of Oman, monthly frequency of fish kill incidents exhibited a tendency to increase, from January to November. In the western Arabian Sea, the frequency of fish kill incidences was reported to be maximal in December and January.The ridge multiple regression of environmental parameters (listed above) implied that monthly variations of dissolved oxygen and frequency of algal blooms are the two variables explaining 75% of the seasonal variations in fish kill incidents along the Omani coast.

In 1988-2011, the number of harmful algal blooms accompanied by fish kills was 4 times higher for the Sea of Oman (N= 91) compared to the Arabian Sea coast (N= 22), whereas the total number of fish kill incidents was about the same (22 versus 25). This means that the Arabian Sea coast faced more frequent harmful blooms than the Sea of Oman.

To estimate the long-term changes in chlorophyll-*a*, the Arabian Sea was subdivided into 61 2-degree regions, which showed no pronounced interannual trends from 1997 to 2010. Regionally, time series of chlorophyll-*a* implied high variability in western regions of the sea compared to eastern ones.

For the Sea of Oman, declining trends were evaluated for the atmospheric sea level pressure, zonal component of wind speed, concentration of nitrates, annual variability and biomass of diatoms, and sardine landings. For example, the dominance of the winter monsoon period in sardine landings was well pronounced (Fig. 2).

In 2000-2002, seasonal variations of landings reached one order of magnitude [8]. From 2002 to 2009, the seasonal gradient declined and so did the annual landings.Declining trends were accompanied by rising trends of atmospheric temperature, sea surface temperature, frequency of fish kill incidents and harmful algal blooms (Fig. 3).

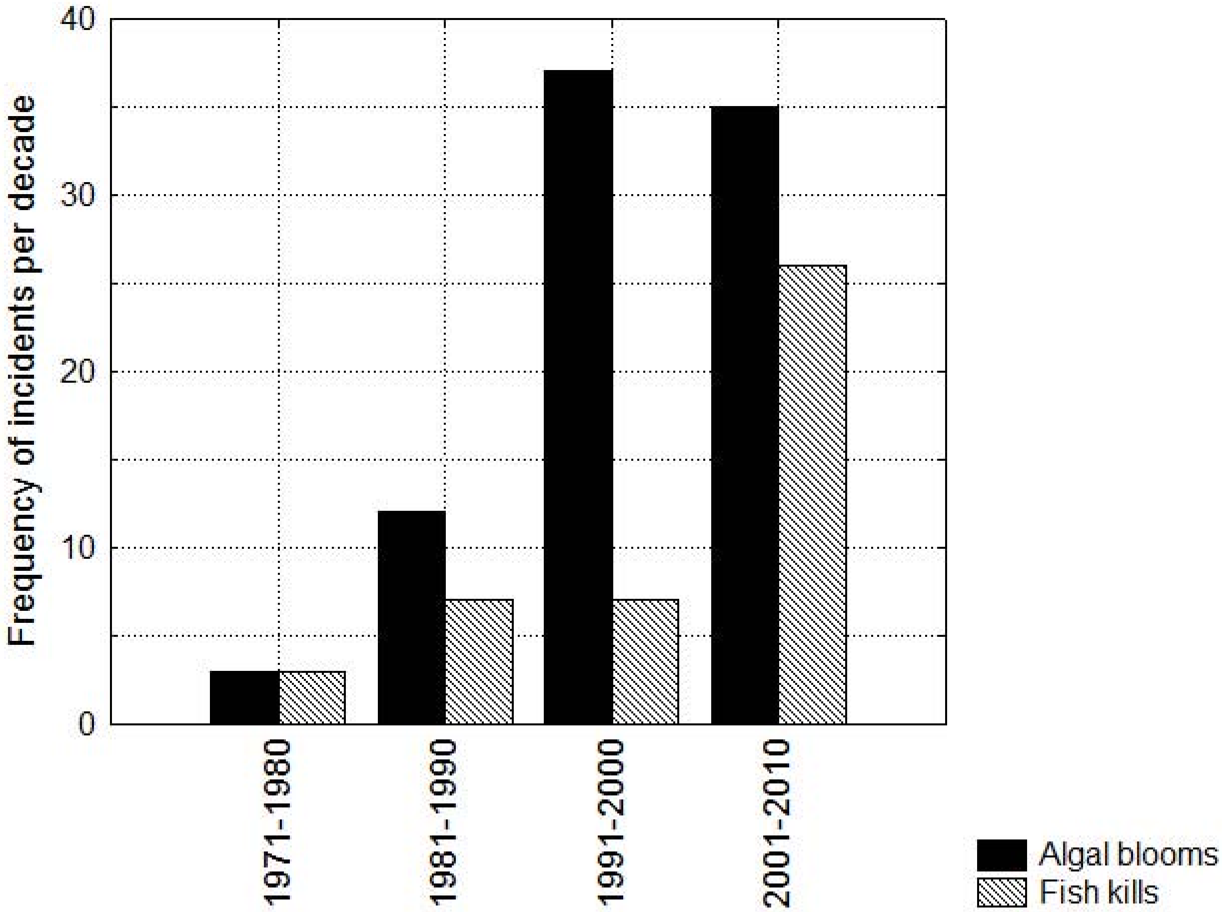

Fig. 3: Interannual changes of fish kills and harmful algal blooms in the Sea of Oman.

Overall, the rising or declining trends reported might be the fragments of the other (more prolonged) variations. For instance, reconstruction of the history of pacific sardines over the past two millennia from sediments showed that sardines tend to vary over a period of approximately 60 years [9].

4. Acknowledgments

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