

Variability of Chlorophyll-*a* and SST at Regional Seas Level in Thai Waters using Satellite Data

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ABSTRACT

Satellite-derived measurements were used to investigate the spatial and temporal variability of chlorophyll-*a* (Chl-*a*) and sea surface temperature (SST) at Regional Seas level in Thai waters. As case study, the Gulf of Thailand and Andaman Sea were selected as areas of interest (AOI). The monthly data with 4 km spatial resolution of Chl-*a* and SST ocean color images from January 2003 to December 2009 were collected from the Moderate Resolution Imaging Spectroradiometer (MODIS) and Advanced Very High Resolution Radiometer (AVHRR), respectively. Chl-*a* concentration was relatively low during summer, while in winter Chl-*a* concentration increased and its relationship was inversely proportional with SST. The lowest Chl-*a* concentration was in August 2005 (0.33 mg m⁻³), while the highest was in December 2006 (0.96 mg m⁻³). The lowest SST was in January 2009 (27.12 °C) and the highest was in May 2005 (31.00 °C). Chl-*a* concentration has an important economic effect on coastal and marine environments in terms of fisheries resources and marine aquaculture development. Current direction and wind condition should be taken into account for further spatial and temporal studies of Chl-*a* and SST. Moreover, the influence by suspended sediments caused by re-suspension or river discharge could be a major factor in the variation of chlorophyll along the coast. Therefore, understanding the spatial and temporal patterns of the Chl-*a* concentration is very important particularly for oceanography and fishery management. This study provides baseline information for future research in marine ecosystem-based approach for sustainable fisheries management in this region.

Key words: remote sensing, chlorophyll-*a*, regional seas level

INTRODUCTION

Regional Seas level of Thailand consists of the Gulf of Thailand (GoT) and Andaman Sea, which connect to the Pacific and Indian Oceans, respectively. This region

plays an important role in marine ecosystems for fisheries biodiversity and anthropogenic livelihoods particularly for those dwelling in and nearby the coastal areas. Coastal and marine waters are often characterized optically by high concentration of suspended

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matter, various phytoplankton pigments and colored dissolved organic material derived from seabed resuspension or river discharge (Binding *et al.*, 2003; Kishino *et al.*, 2005).

Four major rivers namely, Bang Pakong, Chaopraya, Mae Klong and Thajeennnd Mae Klong empty into the GoT, while Andaman Sea often has the occurrences of a near-shore eddy field and surface currents. Thus, along the coastal waters, chlorophyll-*a* (Chl-*a*) concentration is affected by river discharge and upwelling or bottom resuspension.

Chl-*a* and sea surface temperature (SST) variability can change the trophic web in marine ecosystems. However, Chl-*a* concentration and SST have been investigated using traditional methods such as mooring arrays and shipboard surveys and such aforementioned approaches consume a lot of cost and time (Otero and Siegel, 2004). Satellite remote sensing can provide synoptic

overviews that enable more effective analysis of the spatial and temporal distribution of Chl-*a* and SST at Regional Seas level. This corresponded with the study by Miller and McKee (2004), Nezlin *et al.* (2005) and Qiu *et al.* (2009) who all reported that Chl-*a* and SST can be measured from space. This study aims to apply remote sensing on marine environments; and to investigate spatial and temporal variability of Chl-*a* concentration and SST at Regional Seas level.

MATERIALS AND METHODS

Study Area

This study focused on the estuarine, coastal and marine environments at regional level (geographic coordinate of study area ranged from between 7° and 14° N to between 95° and 106° E), located in the southern part of Thailand (Figure 1). Thailand is situated

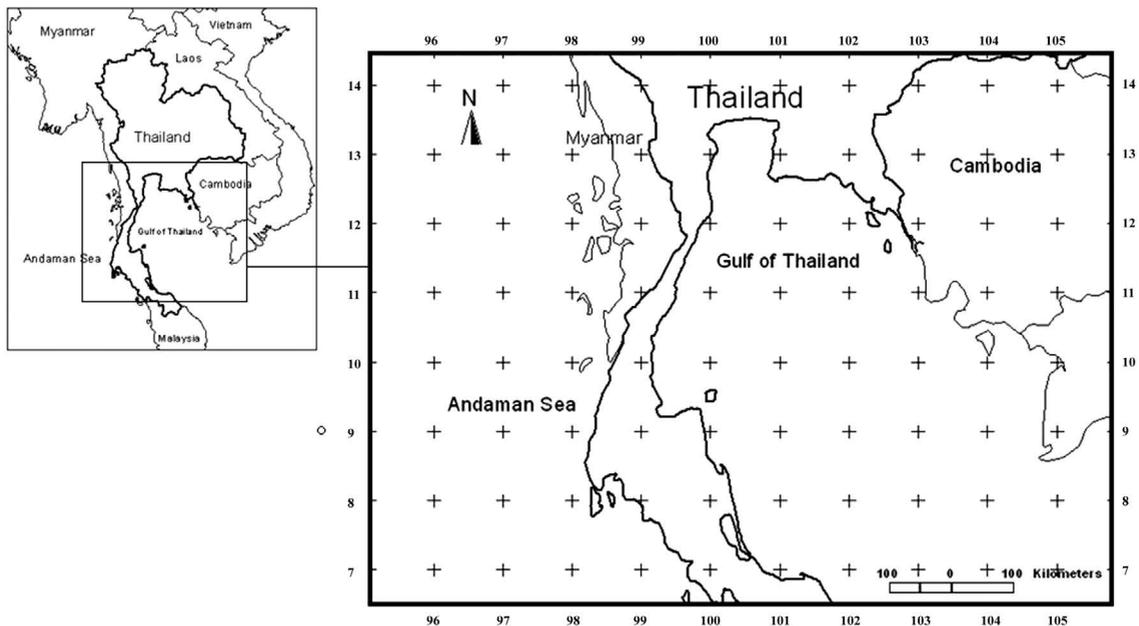


Figure 1. Map of the study area showing the Gulf of Thailand and the Andaman Sea

in the heart of the Southeast Asian mainland, covering an area of 513,115 sq km and extends about 1,620 km from north to south and 775 km from east to west. Thailand borders Lao PDR and Myanmar to the north, Cambodia and the Gulf of Thailand (GoT) to the east, Myanmar and the Andaman Sea to west, and Malaysia to the south. The shoreline length of GoT is about 1,660 km, its mean depth is 45 m and the maximum depth only 80 m, while the coastline length of Andaman Sea is approximately 954 m, has an average depth of about 870 m and maximum depth of 3,777 m.

Data collection and analysis

Satellite ocean color images were collected from the Moderate Resolution Imaging Spectroradiometer (MODIS) and Advanced Very High Resolution Radiometer (AVHRR). MODIS was applied for studying the spatial distribution and seasonal changes of Chl-*a*, while AVHRR was performed to determine the characteristics of sea surface temperature (SST).

Chl-*a* data were received from the MODIS-Aqua sensor. Monthly level data with 4 km resolution were obtained from Distribution Active Archive Center Goddard Space Flight Center National Aeronautic and Space Administration (DAAC/GSFC/NASA) (Savtchenko *et al.*, 2004). A total of 84 images were collected from January 2003 to December 2009. Moreover, the monthly level of SST data with 4 km resolution was also downloaded from <ftp://podaac.jpl.nasa.gov>. In the same manner, a total of 84 images were collected from January 2003 to December 2009. All images were geo-referenced based on the WGS84 UTM zone 47 North coordinate system.

This study attempted to examine the utilization of MODIS Chl-*a* ocean colour image data. Acker *et al.* (2008) employed monthly Chl-*a* data from MODIS to analyze the spatial pattern of chlorophyll concentration and seasonal cycle. The data indicate that large coral reef complexes may be sources of either nutrients or chlorophyll-rich detritus and sediment, enhancing Chl-*a* concentration in waters adjacent to the reef. Lohrenz *et al.* (2008) reported a retrospective analysis of nutrients and phytoplankton productivity in the Mississippi River plume, in which long-term patterns in riverine nutrients flux in the lower Mississippi River were examined in relationship to spatial data and temporal patterns in surface nutrient concentrations, chlorophyll, and primary productivity. The spatial and temporal pattern of Chl-*a* concentration in this study was analyzed using SeaWiFS Data Analysis System (SeaDAS software). Research work was performed at the Laboratory of Marine Bioresource and Environment Sensing, Graduate School of Fisheries Sciences, Hokkaido University, Japan. Image analysis such as Area of Interest (AOI) selection, monthly images composite and map annotation, etc was examined to achieve the objectives of the study.

The SST in coastal and marine environments of Thailand at Regional Seas level was determined in order to understand the relationship between Chl-*a* and SST. The image dataset of SST from the measurements made by AVHRR onboard the National Oceanic and Atmospheric Administration (NOAA) imagery with 4 km spatial resolution was analyzed to reveal pattern changes. Monthly data were also collected from January 2003- December 2009 for comparison with

Chl-*a* characteristics. To provide maps of SST distribution over the Regional Seas level, remote sensing analysis was applied to yield information about the circulation patterns of SST in this region. This analysis corresponded with the previous studies by Qiu *et al.* (2009) who demonstrated that the AVHRR satellite data can be used to estimate SST.

RESULTS AND DISCUSSION

In this study we used satellite measurements to understand the dynamics of the Chl-*a* concentration at Regional Seas level as case study. We attempted to describe the application of remote sensing to investigate the spatial and temporal variability

of Chl-*a* concentration and SST. The global image was limited to AOI regional level [7S, 96W, 14N, 105E]. The monthly mean values with 4 km spatial resolution of Chl-*a* and SST from January 2003 to December 2009 were derived from MODIS and AVHRR around the region respectively.

Table 1 shows that Chl-*a* concentration ranged from 0.33-0.96 mg m⁻³. The lowest Chl-*a* concentration was in August 2005 (0.33 mg m⁻³), while the highest was in December 2006 (0.96 mg m⁻³). The lowest SST was in January 2009 (27.12 °C) and the highest was in May 2005 (31.00 °C). There is no plankton bloom in this region since the Chl-*a* concentration was less than 2 mg m⁻³ (Radiatra and Saitoh, 2008).

Table 1. Monthly mean values showing highest and lowest of Chl-*a* (mg m⁻³) and SST (°C) from January 2003-December 2009 are bordered by a line

Year		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2003	Chl- <i>a</i>	0.77	0.59	0.50	0.46	0.56	0.58	0.63	0.54	0.65	0.81	0.80	0.86
	SST	28.63	28.69	29.38	30.46	30.20	29.40	29.42	28.80	28.75	28.64	29.33	28.26
2004	Chl- <i>a</i>	0.74	0.56	0.51	0.47	0.43	0.56	0.57	0.57	0.62	0.57	0.71	0.80
	SST	27.88	28.07	29.14	30.10	30.46	29.28	29.25	28.57	29.02	29.28	29.19	28.10
2005	Chl- <i>a</i>	0.75	0.60	0.46	0.47	0.54	0.43	0.47	0.33	0.65	0.59	0.67	0.79
	SST	27.89	28.75	28.98	30.50	31.00	29.84	29.65	29.39	29.59	29.56	29.64	28.02
2006	Chl- <i>a</i>	0.64	0.54	0.48	0.43	0.57	0.61	0.40	0.50	0.49	0.67	0.71	0.96
	SST	28.29	28.57	29.70	30.80	30.66	29.86	29.13	29.44	29.09	29.49	29.87	29.00
2007	Chl- <i>a</i>	0.92	0.66	0.60	0.61	0.60	0.60	0.72	0.77	0.50	0.80	0.76	0.86
	SST	27.62	28.35	29.54	30.41	30.51	30.37	29.98	29.11	29.09	29.27	28.65	28.07
2008	Chl- <i>a</i>	0.78	0.65	0.56	0.37	0.57	0.56	0.47	0.46	0.47	0.62	0.73	0.92
	SST	28.51	28.56	29.26	30.40	29.26	29.84	29.13	29.63	29.64	30.02	29.28	27.86
2009	Chl- <i>a</i>	0.94	0.63	0.52	0.43	0.44	0.49	0.43	0.55	0.76	0.67	0.85	0.76
	SST	27.12	28.60	29.99	30.69	30.55	30.22	29.92	29.61	29.51	29.47	29.46	28.59

Spatial and temporal variability of chlorophyll-*a*

The patterns of Chl-*a* concentration in this region were illustrated by monthly image layers composed of each year (Figure 2). Analysis of monthly composite

(Figure 2). Analysis of monthly composite MODIS Chl-*a* images from January 2003 to December 2009 showed seasonal variability. Chl-*a* concentration was higher in winter (November-February) than in summer (March-May).

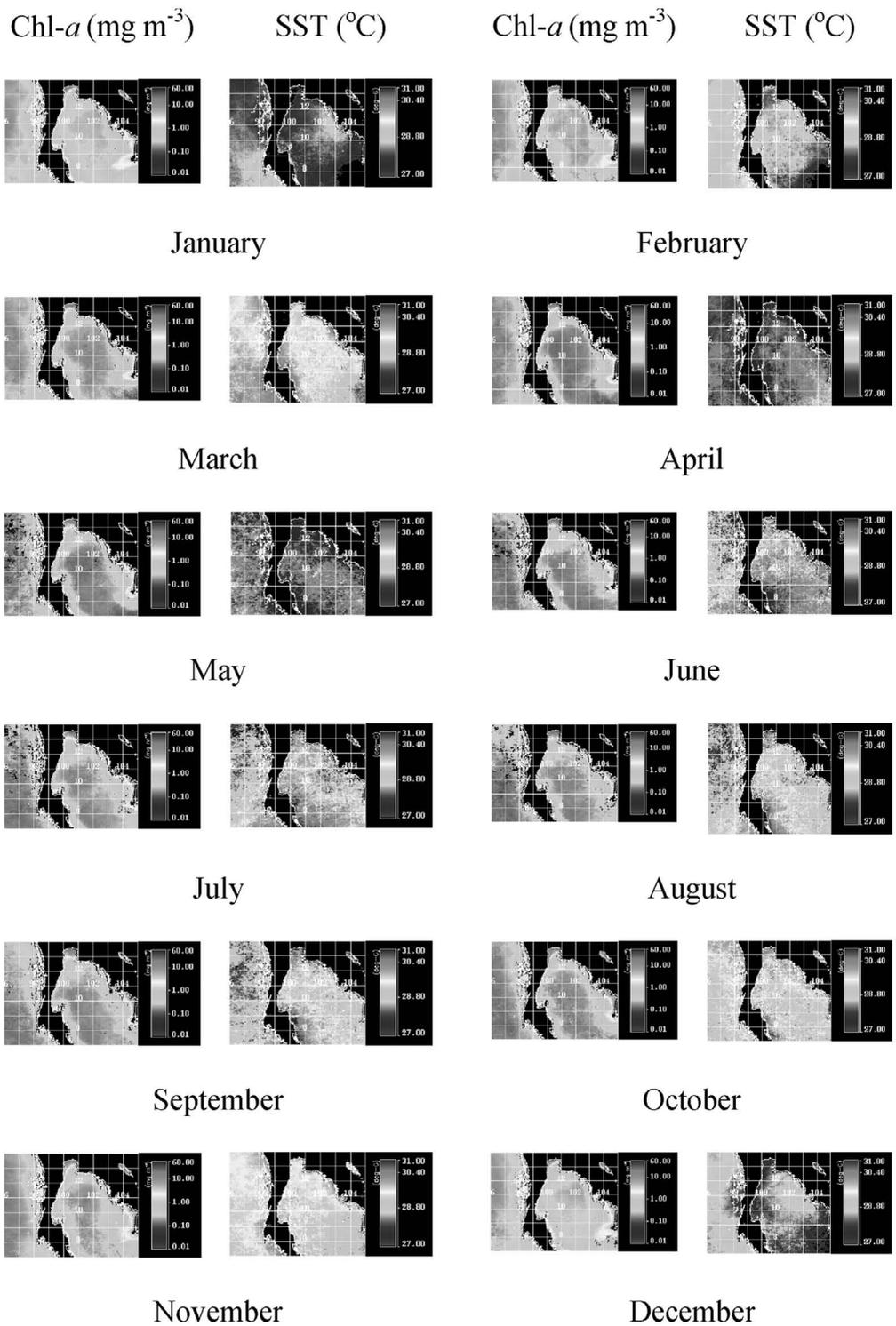


Figure 2. Monthly composite of MODIS Chl-*a* image (mg m⁻³) comparing with AVHRR derived SST image (°C) from January 2003- December 2009

Figure 2 shows that Chl-*a* concentration was relatively low during summer while in winter their concentration increased. This occurrence is consistent with the findings of previous research by Odate and Imai (2003) and Radiarta and Saitoh (2008) who reported that in the summer, Chl-*a* concentration was relatively low, with high concentration occurring only in the narrow areas along the coast and in the estuary areas. In Thai waters, both Andaman Sea and GoT are clearly influenced by the monsoon which reflect seasonal changes in Chl-*a*.

Analysis of the spatial and temporal distribution of ocean color data resulting from the monthly images composite shows variability of Chl-*a* concentration (Figure 2). Chl-*a* concentration also varies depending on geographic location, with high concentration found mostly near the shore and river mouths. However, the presence of suspended

sediments in such areas can lead to overestimation of Chl-*a* concentration (Lips *et al.*, 2010). Thus, the spatial distribution of Chl-*a* located near the coast and river delta were mixed with other components such as organic matter, total suspended solids and sediment (Lihan *et al.*, 2008). Moreover, the influence by suspended sediment caused by resuspension or river discharge would be major factors to variation of chlorophyll along the coast (Radiarta and Saitoh, 2008).

The seasonal cycle of Chl-*a* concentration is shown in Figure 3. The Chl-*a* concentration peaked during winter every year from 2003 to 2009, with the highest concentration (0.96 mg m^{-3}) occurring in December 2006 (Table 1). During summer, Chl-*a* concentration decreased, with the lowest concentration (0.33 mg m^{-3}) occurring in August 2005 (Table 1).

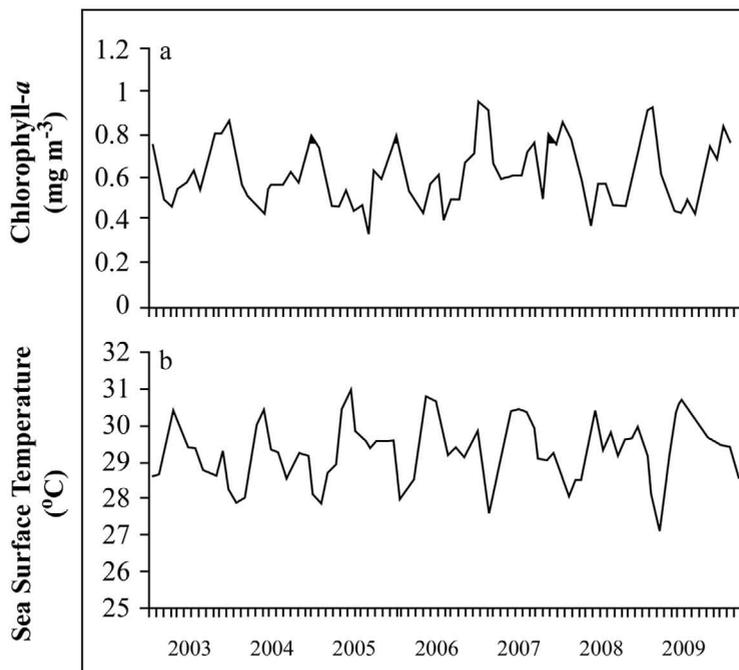


Figure 3. Time series (a) MODIS Chl-*a* concentration (mg m^{-3}) and (b) AVHRR sea surface temperature ($^{\circ}\text{C}$)

Seasonal variability of sea surface temperature

SST in the upper GoT ranged between 27-31°C (Buranapratheprat *et al.*, 2008). The seasonal patterns of SST generally showed an inverse relationship statistically with Chl-*a* (Figure 3). The lowest SST value was recorded every winter and coincided with high Chl-*a* concentration. From January, the temperature began to rise, reaching the maximum (>30 °C) during summer and was similar throughout the region. SST decreased during the rainy season (June-October) until winter, reaching the minimum (<28 °C) in January 2009 (Table 1).

SST and Chl-*a* concentration have an important role in coastal and marine environments on fisheries resources and marine aquaculture development (Radiarta and Saitoh, 2008). In this study the current direction and wind condition were excluded due to lack of information and time limitation so these data should be taken into consideration in future studies. Surface heating should also be included as suggested by Kasai *et al.* (1997).

Satellite estimates have been found to be useful to study spatial and temporal variability of Chl-*a* (Ueyama and Monger, 2005; Navarro and Ruiz, 2006; Radiarta and Saitoh, 2008). They provide synoptic views of spatial distribution unachievable by other means, and are ideally suited to cover the broad range of space and time scales associated with coastal and marine applications (IOCCG, 2000). Understanding the spatial and temporal patterns of the Chl-*a* concentration in this region is very important for oceanography and fishery

management. This region is an important site for mariculture, especially green mussels, oysters and commercial fish cage farming. The GoT is a unique nursery ground of the short-bodied mackerel (*Rastrelliger* sp.) (DOF, 2006).

The biological and physical conditions (i.e. phytoplankton and sea surface temperature) play an important role in culture activities (Bacher *et al.*, 2003). The characteristics of chlorophyll (phytoplankton) and sea temperature are very important for studying biological and physical conditions and for sustainable management of capture and culture fisheries (Radiarta and Saitoh, 2008).

Moreover, the structure, function and processes of marine ecosystems, bringing together biophysical, chemical, geographic and climatic factors, and subsequently integrating such conditions with anthropogenic impacts and activities undertaken in Regional Seas level are very important (Borja *et al.*, 2008).

In recent years, several initiatives in marine ecosystem studies have been developed at a national or Regional Seas level or ecoregions. This was pointed out by Borja and Collins (2009) who confirmed that marine studies undertaken under the scope of a Regional Seas perspective have increased dramatically. However, more investigation is needed to understand the complex biophysical and chemical relationships within this region. More refined data are needed on the loads transfer of the rivers onto the adjacent continental shelf and the influence of the river plumes upon processes within the adjacent littoral areas. In this way, the understanding of

anthropogenic impacts within the rivers and estuaries can be enhanced. The output of this study can be integrated into on-going and future marine investigations, regarding ecosystem-based management (EBM).

Borja and Collins (2009) suggested that more research about atmosphere-ocean interactions together with their influence on ecosystems, species and heat transfer should be conducted. Investigations on water-sediment interface, effects of contamination upon the trophic web, habitats and ecosystem should be undertaken. This study can support the understanding of phytoplankton changes over continental shelf and open sea in Thailand at Regional Seas level. Nonetheless, more effort is needed in developing an understanding of the pattern of water circulation and transport within the shallow water littoral zones and the deep water layers.

Fisheries management in terms of spatial and temporal planning is needed for this region. The collaboration between researchers from institutions (research and development institutes, universities) and stakeholder countries (i.e. Cambodia, Malaysia, Myanmar, Thailand and Vietnam) pursuing the investigations within the region are necessary. Moreover, landlocked countries such as Lao PDR should be involved in terms of anthropogenic activities since the Mekong International River drains into the GoT. In this way, the sustainable use of the seas and the conservation of marine ecosystems at Regional Seas level study can be promoted, such as the Southeast Asian Marine Strategy Framework Directive.

CONCLUSION

Synoptically mapping the *Chl-a* patterns is possible using satellite images. Ocean color time series image data were used to investigate the spatial and temporal variability of *Chl-a*. *Chl-a* concentration was higher in winter and was relatively low during summer. There is an inverse relationship between SST and *Chl-a*. *Chl-a* concentration has an important role in coastal and marine environments on fisheries resources and marine aquaculture development. Collaboration among researchers from institutions such as research and development institutes, universities within the region is crucial for Regional Seas level integrative studies. This study can serve as basis for future research on regional ecosystem-based approach to management and the integrative assessment of marine bioresources in the region.

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LITERATURE CITED

- Acker, J., Leptoukh, J., Shen, S., Zhu, T. and Kempler, S. 2008. Remotely sensed chlorophyll *a* observations of the Northern Red Sea indicate seasonal variability and influence of coastal reef. *Journal of marine system* 69: 191-2004.
- Bacher, C., Grant, J., Hawkins, A.J.S., Fang, J., Zhu, M. and Besnard, M. 2003. Modelling the effect of food depletion on Scallop growth in Sungo Bay (China). *Aquatic Living Resources* 16: 10-24.
- Binding, C.E., Bowers, D.G., Mitchelson-Jacob, E.G. 2003. An algorithm for the retrieval of suspended sediment concentrations in the Irish Sea from SeaWiFS ocean colour satellite imagery. *International Journal of Remote Sensing* 24 (19): 3791-3806.
- Borja, A. and Collins, M. 2009. Regional Seas integrative studies, as a basis for an ecosystem-based approach to management: the case of the Bay of Biscay. *Continental shelf research* 29: 951-956.
- Borja, A., Bricker, S.B., Dauer, D.M., Demetriades, N.T., Ferreira, J.G., Forbes, A.T., Hutchings, P., Jia, X., Kenchington, R., Marques, J.C., Zhu, C. 2008. Overview of integrative tools and methods in assessing ecological integrity in estuarine and coastal systems worldwide. *Marine pollution bulletin* 56: 1519-1537.
- Buranapratheprat, A., Yanagi, T., Matsumura, S. 2008. Seasonal variation in water column conditions in the upper Gulf of Thailand. *Continental Shelf Research* 28: 2509-2522.
- DOF. 2006. **Production by species for whole marine fishery 2002–2006.** In Fishery statistics capture product yearbook 2006. Department of Fisheries (DOF), Bangkok, Thailand
- IOCCG. 2000. **Remote sensing of ocean colour in coastal and other optically complex waters.** In: Sathyendranath, S. (Ed.), Report of the International Ocean Colour Coordinating Group, No. 3. IOCCG. Dartmouth, Canada, p. 140.
- Kasai, H., Saito, H., Yoshimori, A., Taguchi, S. 1997. Variability in timing and magnitude of spring bloom in the Oyashio region, the eastern subarctic Pacific off Hokkaido, Japan. *Fisheries Oceanography* 6: 118-129.
- Kishino, M., Tanaka, A., Ishizaka, J. 2005. Retrieval of chlorophyll *a*, suspended solids and colored dissolved organic matter in Tokyo Bay using ASTER data. *Remote Sensing of Environment* 99: 66-74.
- Lihan, T., Saitoh, S., Iida, T., Hirawake, T. and Iida, K. 2008. Satellite-measured temporal and spatial variability of the Tokachi River plume. *Estuarine, coastal and shelf science* 78: 237-249.
- Lips, U., Lips, I., Liblik, T. and Kuvaldina, N. 2010. Processes responsible for the formation and maintenance of sub-surface chlorophyll maxima in the Gulf of Finland. *Estuarine, Coastal and Shelf Science* 88(3): 339-349.
- Lohrenz, S.E., Redalje, D.G., Cai, W-J., Acker, J. and Dagg, M. 2008. A retrospective analysis of nutrients and phytoplankton productivity in the Mississippi River plume. *Continental Shelf Research*, 28: 1466-1475.

- Miller, R.L. and McKee, B.A. 2004. Using MODIS terra 250 m imagery to map concentration of total suspended matter in coastal waters. *Remote Sensing of Environment* 93: 259-266.
- Navarro, G. and Ruiz, J. 2006. Spatial and temporal variability of phytoplankton in the Gulf of Cadiz through remote sensing images. *Deep-sea Research II* 53, 1241-1260.
- Nezline, N.P., DiGiacomo, P.M., Stein, E.D., Acherman, D. 2005. Stormwater runoff plumes observed by SeaWiFS radiometer in the Southern California Bight. *Remote Sensing of Environment* 98: 494-510.
- Odate, T. and Imai, K. 2003. Seasonal variation in chlorophyll-specific growth and microzooplankton grazing of phytoplankton in Japanese coastal water. *Journal of plankton research* 25: 1497-1505.
- Otero, M.P. and Siegel, D.A. 2004. Spatial and temporal characteristics of sediment plumes and phytoplankton blooms in the Santa Barbara Channel. Deep-sea Research Part II. *Tropical Studies in Oceanography* 51: 1129-1149.
- Qiu, C., Wang, D., Kawamura, H., Guan, L. and Qin, H. 2009. Validation of AVHRR and TMI-derived sea surface temperature in the northern South China Sea. *Continental Shelf Research* 29: 2358-2366.
- Radiarta, I.N. and Saitoh, S. 2008. Satellite-derived measurements of spatial and temporal chlorophyll-*a* variability in Funka, southwestern Hokkaido, Japan. *Estuarine, Coastal and Shelf Science* 79: 400-408.
- Savtchenko, A., Ouzounov, D., Ahmad, S., Acker, J., Leptoukh, G., Koziana, J., Nickless, D. 2004. Terra and aqua MODIS product available from NASA GES DAAD. *Advances in Space Research* 34: 710-714.
- Ueyama, R. and Monger, E.C. 2005. Wind-induced modulation of seasonal phytoplankton blooms in the North Atlantic derived from satellite observations. *Limnology Oceanography* 50: 1820-1829.