PHYTOPLANKTON COMMUNITY IN CAGE CULTURE FARM AREAS

IN THE ANDAMAN COAST OF THAILAND

ประชาคมแพลงก์ตอนพืชในพื้นที่ฟาร์มเลี้ยงสัตว์น้ำในกระชังบริเวณชายฝั่งอันดามันของประเทศไทย

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Abstract

Fish excretory products from cage culture farms combine with nutrients released from the breakdown of excess feed to raise nutrient levels well above normal, creating an ideal environment for phytoplankton blooms. This study was carried out in the Andaman Coast of Thailand to elucidate (a) the impact of cage farms on phytoplankton production, and (b) how water quality affects the phytoplankton community in the area. Phytoplankton and water quality were monitored in cage culture farms from April 2007 to May 2008 in four provinces, (Phang-nga, Krabi, Trang and Satun) along the coast of the Andaman Sea, in southern Thailand. Phytoplankton and water samples were taken from reference and cage farm stations. Reference stations were concurrently sampled from locations outside the cage farm. In our investigation, all water quality variables showed non-significant differences between the reference and cage farm stations at all study sites ($p > 0.05$). The exception was dissolved oxygen concentration at the Ban Kura study site, Phang-ang province. ANOSIM testing indicated significant phytoplankton community differences between reference and cage farm stations at the study sites in Phang-nga and Krabi provinces. However, the study sites in Trang and Satun provinces showed no significant differences. The results were ascertained that *Surirella gracilis*, *Oscillatoria* sp., *Euglena*

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sp., *Navicula radiosa*, and *Nitzschia filiformis* contributed most to the differences between the stations. Those species were predominant at the cage farm stations. Water quality variables in this study [total suspended solids (TSS), pH, salinity and nutrients (NH_3, $NO_2^- + NO_3^{-2}$, PO_4^{-3})] showed a major influence on phytoplankton density in both the reference and cage farm stations. However, nutrient enrichment in cage farm operations contributed only slightly to phytoplankton density.

Keywords: phytoplankton, nutrient, cage farm, water quality, Andaman sea

บทคัดย่อ

ของเสียจากสิ่งขับถ่ายของปลาร่วมกับธาตุอาหารที่มาจากการย่อยสลายของอาหารที่เหลือส่งผลทำให้ระดับธาตุ อาหารเพิ่มสูงขึ้นมากกว่าสภาพปกติ ทำให้เกิดการเพิ่มขึ้นของปริมาณแพลงก์ตอนพืชในสภาพแวดล้อม การศึกษาในครั้งนี้ ดำเนินการในพื้นที่ชายฝั่งอันดามันของประเทศไทย โดยมีวัตถุประสงค์ (ก) เพื่อให้เห็นถึงผลกระทบจากการทำฟาร์มเลี้ยงสัตว์ น้ำในกระชังต่อผลผลิตของแพลงก์ตอนพืช (ข) เพื่อศึกษาผลของคุณภาพน้ำมีผลต่อประชาคมแพลงก์ตอนพืชในพื้นที่ศึกษา อย่างไร โดยทำการสำรวจตรวจติดตามแพลงก์ตอนพืชและคุณภาพน้ำในพื้นที่ฟาร์มเลี้ยงสัตว์น้ำในกระชังตั้งแต่เดือน เมษายน พ.ศ. 2550 ถึงเดือนมีนาคม พ.ศ. 2551 ในพื้นที่ 4 จังหวัด (พังงา กระบี่ ตรัง และสตูล) แนวชายฝั่งทะเลอันดามัน ทางภาคใต้ของประเทศไทย โดยทำการเก็บตัวอย่างแพลงก์ตอนพืชและตัวอย่างน้ำในพื้นที่อ้างอิงและพื้นที่ฟาร์มเลี้ยงสัตว์น้ำ ในกระชัง โดยพื้นที่อ้างอิงจะเก็บตัวอย่างนอกเขตพื้นที่เลี้ยงสัตว์น้ำในกระชัง จากผลการศึกษาพบว่าปัจจัยทางด้านคุณภาพ น้ำทั้งหมดระหว่างพื้นที่อ้างอิงกับพื้นที่เลี้ยงสัตว์น้ำในกระชังพบไม่มีความแตกต่างทางสถิติ (p > 0.05) ในทุกพื้นที่ ทำการศึกษา ยกเว้นค่าความเข้มข้นของออกซิเจนในพื้นที่ศึกษาบ้านคุระ จังหวัดพังงา จากการทดสอบ ANOSIM แสดงให้ เห็นถึงความแตกต่างของประชาคมแพลงก์ตอนพืชระหว่างพื้นที่อ้างอิงและพื้นที่เลี้ยงสัตว์น้ำในกระชังในพื้นที่ศึกษาจังหวัด พังงาและกระบี่ อย่างไรก็ตาม ไม่พบความแตกต่างในพื้นที่ศึกษาจังหวัดตรังและสตูล จากผลการศึกษาพบว่าแพลงก์ตอนพืช ในสกุล *Surirella gracilis*, *Oscillatoria* sp., *Euglena* sp., *Navicula radiosa*, และ *Nitzschia filiformis* มีความแตกต่าง กันระหว่างพื้นที่อ้างอิงและพื้นที่เลี้ยงสัตว์น้ำในกระชัง โดยแพลงก์ตอนพืชในสกุลเหล่านี้จะพบเป็นสกุลเด่นในพื้นที่เลี้ยงสัตว์ น้ำในกระชัง ส่วนตัวแปรทางด้านคุณภาพน้ำ [ปริมาณสารแขวนลอยทั้งหมด พีเอช ความเค็ม และธาตุอาหาร (แอมโมเนีย, ไนไตรต์ + ไนเตรท และออร์โธฟอสเฟส)] พบมีอิทธิพลหลักต่อความหนาแน่นของแพลงก์ตอนพืชทั้งในพื้นที่อ้างอิงและพื้นที่ เลี้ยงสัตว์น้ำในกระชัง อย่างไรก็ตาม ธาตุอาหารที่ปลดปล่อยจากกิจกรรมการทำฟาร์มเลี้ยงสัตว์น้ำในกระชังมีอิทธิพลน้อยต่อ ความหนาแน่นของแพลงก์ตอนพืช

คำสำคัญ: แพลงก์ตอนพืช, ธาตุอาหาร, ฟาร์มเลี้ยงสัตว์น้ำในกระชัง, คุณภาพน้ำ, ทะเลอันดามัน

Introduction

Bioindicators are increasingly being used in coastal zone management as reliable ways to monitor the sustainability and health of coastal ecosystems. They are used to indicate contaminant exposure, to provide early warning of impending environmental damage, to link causes of stressors to ecologically relevant effects, and to assess ecological risk. The distribution and abundance of bioindicators in polluted and unpolluted water can provide useful information on the health of their habitats. The stability of the environment is dependent on low external stress. A stable environment can sustain a diversified floral assemblage, which is

indicative of healthy conditions. Phytoplanktonic organisms are considered to be ecological indicators of water bodies. They can provide information on trends in environmental conditions and how those conditions affect the indicator itself [1]. A number of environmental and biological processes may influence the intensity and species composition of phytoplankton blooms [2]. One of the most important factors influencing rates of cell division in phytoplankton populations is the availability of nutrients [3-5]. Increases in nutrient inputs lead directly to enhanced primary productivity, and phytoplankton may serve as an indicator of the trophic state [6]. Phytoplankton populations have long been used as bioindicators [6-12]. No previous study has provided information on phytoplankton populations throughout the area of cage culture farms on the Andaman coast of Thailand. In this article, the first aimed to determine spatial patterns for selected dominant phytoplankton species and to describe the phytoplankton community characteristics in this area. The second objective was to analyze the potential for external nutrient enrichment from cage culture farms to influence phytoplankton community composition and structure in the estuary. The results may offer tools to indicate base-line conditions for assessment of future change and management.

Materials and Methods

Study Area

The site areas for this study were in four provinces, Phang-nga, Krabi, Trang and Satun, which are along the coast of the Andaman Sea of southern Thailand (Figure 1). The study sites in each province are summarized in Table 1. The climate in this area is influenced by seasonal southwest and northeast monsoons. The dry season extends from December to April, and the rainy season from May to November [13].
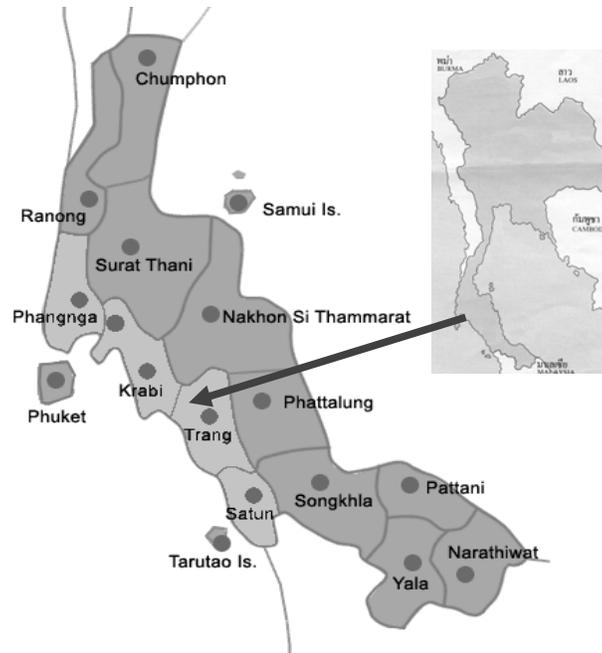
Figure 1 The location of the study sites.

Table 1 The study sites and number of farms in each province

Province	Study sites	Number of farms
Phang-nga	Ban Kura, Kuraburi District	40
	Ban Nam Khem, Taguapa District	52
Krabi	Ban Ba Gan, Ao-Luek District	60
Trang	Ban Torn Harn, Palian District	40
Satun	Ban Ba Gan Kui, Muang District	40

Sampling stations

Surface water samples were collected bi-monthly from fish cage culture farms, and concurrently at reference stations located 1 km outside those farms. The stations were reached by boat and positions were checked using a GPS unit.

Phytoplankton sampling and analytical methods

Phytoplankton was sampled at 30 cm below surface with a conical plankton net of 15 μm mesh size. The samples were fixed in 10% formaldehyde and the phytoplankton (cells, colonies, filaments) enumerated using an inverted microscope at a magnification of 250x. Individual

cells were identified to species level to provide information that would assist in performing community analyses. Identification was conducted with the aid of keys and plates [14-16].

Water sampling and analytical methods

Dissolved oxygen (DO) concentrations, pH and water temperatures were measured *in situ* at 30 cm below surface using a YSI DO meter (model 85) and pH meter (Hanna model HI 991002), respectively. Water salinity (Sal) was measured with a hand refractometer. Three replicate samples of water were collected from 30 cm below the water surface in polyethylene bottles. Samples were kept on ice inside coolers and analyzed soon upon return to the laboratory. TSS were analyzed by the GF/C filtration method [17]. Before determination of ammonia-N (NH_3), nitrite (NO_2^-), nitrate (NO_3^{-2}) and filterable reactive phosphate (PO_4^{-3}) concentrations, samples were filtered through pre-washed GF/C filters. Ammonia-N of water samples was analyzed by the phenolhypochlorite method [18]. Nitrite of water samples was analyzed by the diazotization method [19]. Nitrate was analyzed by the cadmium reduction method. The nitrate in water samples was reduced to nitrite and the original nitrite and nitrite from reduction were analyzed using the same diazotization methods [19]. The filtrable reactive phosphate was analyzed by the ascorbic acid method [19].

Data analysis

A Mann–Whitney U test (M–W) was calculated using SPSS (version 11.5) to test for differences in environmental variables between reference and cage farm stations. Analyses of Similarity (ANOSIM) was used to explore differences in similarity of phytoplankton communities between reference and cage farm stations. A Harmonic rank correlation (r) was computed between the individual and combined environmental parameters and the phytoplankton biomass to examine the ecological significance of environmental variables in the dynamics of the community pattern (BIO-ENV). The software package PRIMER, developed at the Plymouth Marine Laboratory, was used in statistical analyses [20].

Results
Abiotic variables

All abiotic variables showed non-significant differences between the reference and cage farm stations at all study sites ($p>0.05$) (Table 2), with the exception of dissolved oxygen concentration at the Ban Kura study site, Phang-ang province. That difference represented a decrease in dissolved oxygen (M–W U test = 4.0; $p<0.05$) in cage farm stations.

Phytoplankton community

Multivariate analyses were performed to examine community differences between reference and cage farm stations, and to determine whether any spatial patterns in the characteristics of phytoplankton communities persisted over time. The ANOSIM test brought to light significant differences in phytoplankton communities between reference and cage farm stations at three study sites (Ban Kura, Ban Nam Khem and Ban Ba Gan ($p<0.05$). However, the remaining study sites (Ban Torn Harn and Ban Ba Gan Kui) showed no significant differences ($p>0.05$) (Table 3.).

Table 2 Mann–Whitney U test for environmental variables between the reference and cage farm stations on the Andaman Coast of Thailand. n = number of samples

Environmental variables	Ban Kura n = 24	Ban Nam Khem n = 20	Ban Ba Gan n = 30	Ban Torn Harn n = 24	Ban Ba Gan Kui n = 24
	u value	u value	u value	u value	u value
Dissolve oxygen (mg/L)	4.0*	11.0	8.0	15.5	14.0
Salinity (ppt)	13.0	12.0	13.0	12.0	12.0
pH	13.0	13.0	13.0	16.0	9.0
Water temperature (^{o}C)	13.0	12.0	12.0	13.0	12.0
TSS (mg/L)	15.0	16.0	17.0	16.0	17.0
Ammonia-N (mg/L)	16.0	17.0	16.0	15.0	17.0
Nitrite (mg/L)	7.0	18.0	11.0	12.0	13.0
Nitrate (mg/L)	11.0	13.0	12.0	17.0	11.0
Orthophosphate (mg/L)	13.5	17.5	16.0	13.0	16.0

* Significant ($p < 0.05$)

Table 3 Results of ANOSIM and SIMPER analysis of phytoplankton abundance between the reference and cage farm stations

Study site	Global R	p value	SIMPER Average dissimilarity	Most discriminating genera	Contribution (%)
Ban Kura	0.807	0.020*	38.90	*Surirella gracilis*	11.39
Ban Nam Khem	0.298	0.040*	26.73	*Euglena* sp.	14.34
Ban Ba Gan	0.517	0.020*	39.24	*Oscillatoria* sp.	21.01
Ban Torn Harn	-0.052	0.628	35.80	*Navicula radiosa*	5.41
Ban Ba Gan Kui	0.180	0.108	57.65	*Nitzschia acicularis*	7.22

* Significant ($p < 0.05$)

Linking phytoplankton community to abiotic variables

The results from the BIO-ENV procedure, which matches the community density to environmental variables, are shown in Table 4. Before the matching took place, the 8 abiotic variables expected to be most important were selected to help the interpretation of the analysis. The variables chosen were dissolve oxygen, salinity, pH, water temperature, TSS, ammonia-N, nitrite + nitrate and orthophosphate. This procedure identifies the environmental combination that best explains the phytoplankton community pattern.

Ban Kura

Dissolved oxygen, water temperature and orthophosphate produced the strongest correlation with phytoplankton densities at the reference stations, while TSS, ammonia-N and orthophosphate were the variables generating the largest matching correlation (ρw) at the cage farm stations.

Ban Nam Khem

Water temperature, TSS and ammonia-N produced the strongest correlation with phytoplankton densities at reference stations, while pH, water temperature and TSS produced the strongest correlation at cage farm stations.

Ban Ba Gan

Water temperature, ammonia-N and nitrite + nitrate produced the strongest correlation with phytoplankton densities at the reference stations.

Ban Torn Harn

Nitrite + nitrate and orthophosphate produced the strongest correlation with phytoplankton densities at the reference stations, while salinity, water temperature and orthophosphate showed the strongest correlation at the cage farm stations.

Ban Ba Gan Kui

Salinity and nitrite + nitrate produced the strongest correlation with phytoplankton densities at the reference stations. At the cage farm stations, nitrite + nitrate concentration showed the highest correlation with phytoplankton densities.

Table 4 The best combination of phytoplankton densities and water quality variables as measured by Harmonic rank correlation (ρ_w) at the study sites on the Andaman Coast of Thailand. (DO: Dissolved Oxygen; Temp.: Water Temperature; PO_4^{-3} : Orthophosphate; TSS: Total Suspended Solids; NH_3 : Ammonia nitrogen; pH : Water pH; $NO_2^- + NO_3^{-2}$: Nitrite + Nitrate; Sal. : Salinity)

Study sites	Harmonic rank correlation Best variable combination (ρw)	
	Reference area	Cage culture area
Ban Kura	DO, Temp, PO_4^{-3}	TSS, NH_3, PO_4^{-3}
	(0.671)	(0.286)
Ban Nam-Khem	Temp, TSS, NH_3	pH, Temp, TSS
	(0.732)	(0.850)
Ban Ba Gan	Temp, NH_3, $NO_2^- + NO_3^{-2}$	TSS
	(0.696)	(0.589)
Ban Torn Harn	$NO_2^- + NO_3^{-2}$, PO_4^{-3}	Sal., Temp, PO_4^{-3}
	(0.886)	(0.557)
Ban Ba Kan-Kai	Sal., $NO_2^- + NO_3^{-2}$	$NO_2^- + NO_3^{-2}$
	(0.250)	(0.711)

Discussion

Abiotic variables

Environmental parameters, such as temperature, salinity, pH, dissolved oxygen, suspended sediment and nutrient concentrations play an important role in determining phytoplankton community succession and diversity by favoring or limiting the growth of different groups of phytoplankton[21]. Over the duration of the present study no significant differences were observed with respect to temperature, salinity, pH, dissolved oxygen, suspended and nutrient concentrations between reference and cage farm stations (except DO at Ban Kura). The consistent pattern of these parameters is probably due to the fact that the sampling was done in only a small area around the cages. A similar result was reported by Sidik et al.[22] in the cage culture area of Sepanggar Bay, Sabah, Malaysia. Field measurements at the Ban Kura

study site showed DO values at the cage stations were lower than at the reference stations, which possibly resulted from the decomposition of waste from fish cages. High consumption of dissolved oxygen in the fish cage farm leads to redox processes involved in waste degradation. FAO [23] reported that the low concentrations of dissolved oxygen in bottom and surface water close to farm sites was due to the substantial biochemical oxygen demand of released organic wastes and the respiratory demands of the cultured stock.

Phytoplankton community

The dynamics of rapid increases or decreases of plankton populations are an important issue in marine ecology. Anthropogenic inputs in aquatic systems may increase nutrient contents, accompanied by variation in nutrient ratios, which greatly affect phytoplankton composition and production, and thus ecosystem structure and function[23]. Fundamental information on plankton composition, density and physiological state of the organisms is necessary to evaluate the degree of water pollution[24]. *Surirella gracilis*, *Oscillatoria* sp., *Euglena* sp., *Navicula radiosa*, and *Nitzschia filiformis* contributed most to discrimination between the stations in this study. Those species were found only at the cage farm stations. Phytoplankton assemblages at both reference and cage farm stations on the Andaman coast of Thailand were often found to be dominated by the Bacillariophyceae (diatom) in terms of the number of genera and their densities compared to other taxonomic groups. This agrees with the results of Piehler et al. [25], Boonyapiwat [26], and Sarkar et al. [27], who also reported a higher abundance of diatoms in seawater compared to other phytoplankton groups. Sidik et al. [22] recorded a higher abundance of *Coscinodiscus* sp. in cage culture area of Sepanggar Bay, Sabah, Malaysia, which agrees with the present study. It was the dominant diatom genus in the phytoplankton assemblage at both types of stations in this study. *Coscinodiscus* sp. is one of the dominant species in tropical seawater [28-30]. The present study also revealed that some other diatoms could predominant (like *Nitzschia acicularis* and *Nitzschia filiformis* at the Ban Ba Gan Kui study site). Those species contributed to a harmful algal bloom (HAB) in the Bay of Bengal, observed by Sarkar et al. [27]. In this study, their abundance was possibly due to the release of metabolic waste products (feces, pseudo-feces and excreta) and uneaten fish diet inside the cage area. The release of soluble inorganic nutrients (nitrogen and phosphorus) can potentially encourage phytoplankton growth and blooming[23]. Although no harmful algal bloom was observed during this study period, the appearance of HAB is very common in the area, which may affect cage culture activities. Hence, the phytoplankton assemblage in cage farms at Ban Ba Gan Kui, Satun province should be assessed in more detail with respect to red tide in future research.

Linking phytoplankton community to abiotic variables

Phytoplankton community and size composition are also known to be related to environmental variables as well as nutrient availability [6, 31, 32]. The role of abiotic variables on phytoplankton density showed no differences at both the reference and cage farm stations over our study period. Abiotic variables in this study, which included TSS, pH, salinity and nutrients (NH_3, NO_2^- + NO_3^{-2}, PO_4^{-3}), showed a major influence on phytoplankton density. However, no significant differences were found in nutrient concentrations between the reference and the cage farm stations, in the study. Therefore, cage farm operation on the coast of the Andaman Sea seemed to have minor influences on phytoplankton community structure. Nutrient enrichment did not produce detectable environmental effects at the spatial scale of this study, and aquaculture wastes did not exceed the capacity of the system to absorb the induced perturbation. The phytoplankton community may have been influenced more by season and location than by cage farm operation. Similar results were reported by Pitta et al. [33] in eastern Mediterranean fish farms, and by Sidik et al. [22] in the cage culture area of Sepanggar Bay, Sabah, Malaysia. High phytoplankton densities in samples collected during the rainy season (June–November) were observed in both the reference and cage farm stations.

Conclusion

The overall water quality in the cage farm areas on the Andaman coast of Thailand was assessed as good. The results indicated that *Surirella gracilis*, *Oscillatoria* sp., *Euglena* sp., *Navicula radiosa*, and *Nitzschia filiformis* were predominant at the cage farm stations. However, the results from this study showed that nutrient enrichment from cage farm operations had little effect on the phytoplankton community.

Acknowledgments

References

(1)   Vandermeulen, H. 1998. The development of marine indicators for coastal zone management. Ocean. Coast. Manage. 39:63-71.

(2)   Ault, R., Velzeboer, R. and Zammit, R. 2000. Influence of nutrient availability on phytoplankton growth and community structure in the Port Adelaide River, Australia: bioassay assessment of potential nutrient limitation. Hydrobiol. 429: 89-103.

(3)   Hecky, R.E. and Kilham, P. 1988. Nutrient limitation of phytoplankton in freshwater and marine environments: a review of recent evidence on the effects of enrichment. Limnol. Oceanogr. 33: 796-822.

(4)   Howarth, R.W. 1988. Nutrient limitation of net primary production in marine ecosystems. Ann. Rev. Ecol. 19: 89-110.

(5)   Smith, S.V. 1984. Phosphorus versus nitrogen limitation in the marine environment. Limnol. Oceanogr. 29:1149–1160.

(6)   Jaanus, A., Toming, K., Hällfors, S., Kaljurand, K. and Lips, I. 2009. Potential phytoplankton indicator species for monitoring Baltic coastal waters in the summer period. Hydrobiol. 629:157-168.

(7)   Nogueira, M.G. 2000. Phytoplankton composition, dominance and abundance as indicators of environmental compartmentalization in Jurumirim reservoir (Paranapanema River), São Paulo, Brazil. Hydrobiol. 431:115-128.

(8)   Paerl, H.W., Rossignol, K.L., Hall, S.N., Peierls, B.L. and Wetz, M.S. 2009. Phytoplankton community indicators of short and long term ecological change in the anthropogenically and climatically impacted Neuse river estuary, North Carolina, USA. Estuaries Coasts. DOI 10.1007/s12237-009-9137-0.

(9)   Sagert, S., Rieling, T., Eggert, A. and Schubert, H. 2008. Development of a phytoplankton indicator system for the ecological assessment of brackish coastal waters (German Baltic Sea coast). Hydrobiol. 611: 91–103.

(10)   Viličić, D. 1989. Phytoplankton population density and volume as indicators of eutrophication in the eastern part of the Adriatic Sea. Hydrobiol. 174:117-132.

(11)   Webber, M., Edwards-Myers, E., Campbell, C. and Webber, D. 2005. Phytoplankton and zooplankton as indicators of water quality in Discovery Bay, Jamaica. Hydrobiol. 545:177–193.

(12)   Webber, D.F. and Webber, M.K. 1998. The water quality of Kingston Harbour: evaluating the use of the planktonic community and traditional water quality indices. Chem. Ecol. 14: 357–374.

(13)   Tanyaros, S., A. Songrak, R. Anantasuk, S. Sangchan and B. Templer. 2010. Post-tsunami rehabilitation of cage farms on the Andaman coast of Thailand. Aquacult. Inter. 18: 693-703.

(14)   Bellinger, E.G. 1992. A key to common algae: freshwater, estuarine and some coastal species. 4th ed, The Institute of Water and Environmental Management.

(15)   Newell, G.E. and Newell, R.C. 1977, Marine plankton, a practical guide. Hutchinson of London.

(16)   UNESCO. 1995. Manual on harmful marine microalgae. Intergovernmental Oceanographic Commission Manuals and Guides # 33.

(17)   APHA. 1998. Standard methods for the evaluation of water and wastewater. Washington DC, USA.

(18)   Koroleff, F. 1983. Determination of nutrients. in: Grasshof, K, Ehrhardt, M. and Kremling, K. (Eds.), Method of Seawater Analysis. Verlag Chemie, Weinheim. pp 105-160.

(19)   Strickland, D.J. and Persons, T.R. 1972. A practical handbook of seawater analysis. Fishery Research Board of Canada Bulletin. 2nd ed. Ottawa, Canada.

(20)   Clarke, K.R. and Warwick, R.M. 2001. Change in marine communities: an approach to statistical analysis and interpretation", 2nd ed. Plymouth Marine Laboratory. UK.

(21)   Aktan, Y., Tufekci, V., Tufekci, H. and Aykulu, G. 2005. Distribution patterns, biomass estimates and diversity of phytoplankton in Izmit bay (Turkey). Estuarine Coastal Shelf Sci. 64:372-384.

(22)   Sidik, M.J., Rashed-Un-Nabi, M. and Hoque, M.A. 2008. Distribution of phytoplankton community in relation to environmental parameters in cage culture area of Sepanggar Bay, Sabah, Malaysia. Estuarine Coastal Shelf Sci. 80:251–260.

(23)   FAO. 1992. Guidelines for the Promotion of Environmental Management of Coastal Aquaculture Development. Food and Agriculture Organization of the United Nations, Fisheries Department, Italy.

(24)   Telesh, I.V. 2004. Plankton of the Baltic estuarine ecosystems with emphasis of Neva estuary: a review of present knowledge and research perspectives. Mar. Pollut. Bull. 49: 206–240.

(25)   Piehler, M.F., Twomey, L.J., Hall, N.S. and Pearl, H.W. 2004. Impacts of inorganic nutrient enrichment on phytoplankton community structure and function in Pamlico Sound, NC, USA. Estuarine Coastal Shelf Sci. 61:197–209.

(26)   Boonyapiwat, S. 2006. Composition, Abundance and Distribution of Phytoplankton in the Andaman Sea", Preliminary results on the large pelagic fisheries resources survey in the Andaman sea, TD/RES/99 SEAFDEC.

(27)   Sarkar, R.R., Petrovskii, S.V., Biswas, M. and Chattopadhyay, J. 2006. An ecological study of a marine plankton community based on the field data collected from Bay of Bengal. Ecol. Modell. 193: 589–601.

(28)   De, T.K., Choudhury, A. and Jana, T.K. 1994. Phytoplankton community organization and species diversity in the Hugli estuary, Northeast coast of India. Indian J Marine Sci. 23:152-156.

(29)   Esparza-Alvarez, M.A., Herguera, J.C. and Lange, C. 2007. Last century patterns of sea surface temperatures and diatoms (>38 mm) variability in the Southern California current. Mar. Micropaleontol. 64:18-35.

(30)   Verlecar, X.N., Desai, S.R., Sarkar, A. and Dalal, S.G. 2006. Biological indicators in relation to coastal pollution along Karnataka Coast, India. Water Res. 40:3304–3312.

(31)   Guildford, S.J. and Hecky, R.E. 2000. Total nitrogen, total phosphorus, and nutrient limitation in lakes and oceans: is there a common relationship?. Limnol. Oceanogr. 45:1213-1223.

(32) Lassen, M.F., Bramm, M.E., Richardson, K., Yusoff, F. and Shariff, M. 2004. Phytoplankton community composition and size distribution in the Langat river estuary, Malaysia. Estuaries. 27:716-727.

(33) Pitta, P., Karakassis, I., Tsapakis, M. and Zivanovic, S. 1999. Natural vs. mariculture induced variability in nutrients and plankton in the eastern Mediterranean. Hydrobiol. 39:181–194.