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Research Article

Temporal variability of economic fish assemblage of the Northern Bay of Bengal in relation to its environment

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Abstract: The Northern Bay of Bengal (NBoB) contributes largely towards the fish production of India and its neighboring countries. A pioneering attempt was made to understand temporal variability of the fish assemblage (exclusively to those of fisheries interest) of the NBoB (20°20′–21°30′N and 87°30′–89°E) in relation to sea surface temperature (SST) (°C), sea surface salinity (SSS), and chlorophyll-a (Chl-*a*) (μg/l) changes. Between 2006 and 2015, the inter-annual variations of SST, SSS, and Chl-*a* were minor. Seasonal variability of SST, SSS, and Chl-*a* was observed and a yearly bi-modal peak of Chl-*a* production was evident. Inter-annual variability of the species dominance (D) was most plausibly explained by the SST*Chl-*a* (Δ AIC = 0) model. Variation of evenness index (J) was explained most plausibility by the Chl-*a* (Δ AIC = 0) model. Seasonal variability of SST and Chl-*a* levels, possibly influence the fish community of the NBoB, therefore, a regular monitoring programme is suggested for understanding the long-term changes of the fish assemblage of the NBoB.

Keywords: Sea surface temperature, Sea surface salinity, Chlorophyll-a, Fish diversity.

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Introduction

Temporal variability of the coastal-marine fish community is of economic interest to millions of fishers, many of whom are fishing with limited resources (Botsford et al. 1997). Wide variability in spatial-temporal gradients of sea surface salinity (SSS) and sea surface temperature (SST) (°C) is common to coastal-marine systems, but many fish aggregate there to spawn and grow so diversity generally remains high (Whitfield 1996; Garcia et al. 2003; Planque et al. 2011). Primary production of these ecosystems oscillates with seasonal cycles, such as the inter-annual variability of the Indian monsoon that controls the primary production of costal fringes of the northern Indian Ocean (Sarangi & Devi 2017).

Long-term changes of SSS, SST affected primary production of the Laizhou Bay of China, and in consequence have triggered a shift in the fish community structure (Jin et al. 2013). Seasonal cycles together with long-term climate change increase the variability of sea surface temperature (SST), which has serious consequences for the primary productivity of coastal bays and often results in altered species composition within the nektonic community, including the fish (Collie et al. 2008; Danell-Jiménez et al. 2009; Lanz et al. 2009). Such changes emphasize the need for long-term ecological

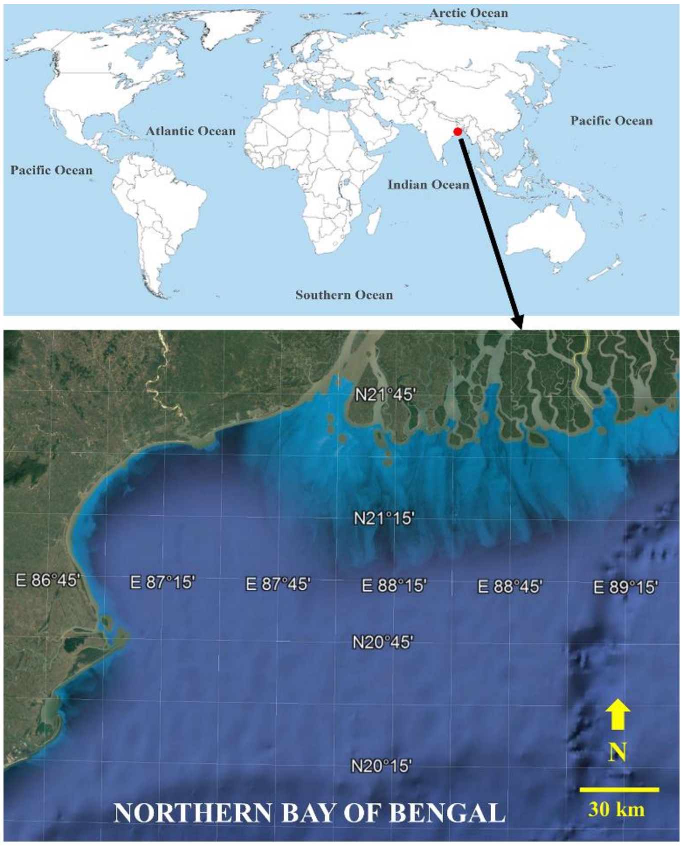

Fig.1. Map of the study area of the Northern Bay of Bengal.

studies of fish communities in relation to environment variables. A traditional way to monitor the changes that may be happening within the fish community to conduct studies on biological diversity. Such studies exist in the estuaries and coastal fringes of the NBoB (Hossain et al. 2012; Mukherjee et al. 2013; Dutta et al. 2016b) but not on offshore.

The Northern Bay of Bengal (NBoB) and its coastal fringes are nursery area for innumerable coastal-marine fish that are commercially harvested by India and Bangladesh (Islam 2003). In recent times, a distinct increase in the movement of fish towards the NBoB, associated with ocean warming, may change the present fish community structure (Burrows et al. 2014).

The Himalayan glaciers are melting at an unprecedented rate so greater variability in the rivers discharging into the NBoB is expected, which may change the usual SSS and SST levels of the NBoB (Unnikrishnan & Shankar 2007; Dube et al. 2009; Brammer 2014). Any higher variability of SSS and SST of the NBoB may affect diversity and distribution of the regional fish-assemblages, so the current structure of the fish community may change in near future (Castillo-Rivera et al. 2002; Vorwerk et al. 2003; James et al. 2008; Mukherjee et al. 2013; Dutta et al. 2016b). Dutta et al. (2016b), working in the Indian half of the NBoB observed nutrient availability after monsoon affects the fisheries productivity of the region.

For identifying possible sources of variability in the fisheries productivity of the NBoB, the current study assessed inter-annual and seasonal (pre-and post-monsoon and monsoon) variations in the SSS, SST, and Chl-*a* levels of the NBoB between 2006 and 2015 and if that had affected the commercially exploited fish assemblages in the region.

Materials and Methods

The study was conducted off the NBoB (20°20′–21°30′ N and 87°30′–89° E) (Fig. 1). The environmental data and fisheries data (biological and or ecological) are meagre for the NBoB. Remotely sensed data was used to build an environmental dataset (i.e. monthly means of SSS, SST, Chl-a) of the NBoB from 2006 to 2015. SSS data were extracted from the Aquarius satellite data (https://aquarius.nasa.gov/) between September 2011 and May 2015.

Between January 2006 and May 2009 SSS data were collected from literature and reports relating to the region. From June 2009 to August 2011, SSS data were collected from onboard a fishing vessel using an Erma Hand Refractometer. SST and hl-a data from 2006 to 2015 were collected through the Moderate Resolution Imaging Spectroradiometer (MODIS) of the Aqua satellite L2/LAC (http://oceancolor.gsfc.nasa.gov). Collection of environmental data from various sources may contribute to some inherent variability in the dataset but till now this is the best information available for the region.

Table 1. Fish assemblage (only of economic interest) of the Northern Bay of Bengal (caught through the trawl + gillnet operations) from 2006 to 2015, along with mean catch per unit effort (CPUE) (tonnes/boat) and standard error.

Sl no.	Family/Group	Species	Common name	Mean CPUE
1	Ariidae	*Arius* spp.	Cat Fish	5.33 ± 1.05
2	Sciaenidae	-	Croakers	4.06 ± 0.62
3	Clupeide	*Tenualosa ilisha*	Hilsa Shad	3.04 ± 0.78
4	Synodontidae	*Harpodon nehereus*	Bombay Duck	3.39 ± 1.09
5	Scombridae	*Rastrelliger kanagurta*	Indian Mackerel	1.89 ± 0.27
6	Latidae, Lutjanidae	*Lates* spp. *Lutjanus* spp.	Perches	1.70 ± 0.13
7	Stromatidae	*Pampus* spp.	Butter fish	1.70 ± 0.24
8	Other Clupeide	-	-	1.36 ± 0.13
9	Crangidae	*Caranx* spp.	Bangada	1.09 ± 0.16
10	Trichiuridae	*Trichiurus* spp.	Hair tail Ribbon Fish	0.92 ± 0.30
11	Mugilidae	*Mugil* spp.	Mullets	1.33 ± 0.18
12	Elasmobranchs	-	Shark, Rays, Skates	1.00 ± 0.13
13	Clupeidae	*Sardinella longiceps*	Indian Oil Sardine	0.94 ± 0.31
14	Engraulidae	*Coilia* spp.	Anchovies	0.97 ± 0.16
15	Carangidae	Caranx spp.	Trevally	0.49 ± 0.12
16	Polynemidae	*Eleutheronema* spp.	Indian Salmon (Threadfin)	0.24 ± 0.08
17	Leionilver	*Leiognathus* spp.	Silver Bellies	0.25 ± 0.15
18	Scombridae	*Scomberomorus* spp.	King mackerel	0.10 ± 0.03
19	Hemiramphidae	*Hemiramphus* spp.	Halfbeak	0.05 ± 0.01
20	Mullidae	*Upneus* spp.	Goat fish	0.04 ± 0.02
21	Muraenesocidae	*Muraenesox* spp.	Eels	0.04 ± 0.01
22	Scombridae	*Euthynnus* spp.	Tuna	0.02 ± 0.01
23	Other Marine Fish	-	-	2.20 ± 0.41
24	Other (Non-Fish)	-	Prawns and Crab	0.93 ± 0.18

The only source of fish assemblage data is the annual fish catch data (CPUE) available from the semi-organized fisheries that operate in the region. These fisheries are only interested in catching selected species of economic importance (Table 1). Fish catch data was collected from the "A Handbook of Fisheries Statistics 2015-16", Department of Fisheries, Government of West Bengal. This data set does not provide any information regarding spatial variability of the fish assemblages of the studied region. It only provides the year wise fish catch data keeping the species composition of the fish assemblage as constant. CPUE data were used as a proxy for fish density as CPUE is a relative abundance index that is often directly related to absolute abundance of fish communities (Hubert & Fabrizio 2007).

The SSS (Shapiro-Wilk normality test: W=0.92, $P<0.001$), SST (Shapiro-Wilk normality test: W=0.88, $P<0.001$) and Chl-*a* (Shapiro-Wilk normality test: W=0.72 $P<0.01$) data were not normally distributed so multiple Kruskal-Wallis tests were conducted (if results were found to be significant then post-hoc tests of Nemenyi were conducted) to evaluate seasonal (i.e. pre-monsoon, monsoon, post-monsoon) variability of those environmental parameters. K-W Chi-square values were reported along with *P*-value and degrees of freedom (DF). According to Paul et al. (2016), "Cost-benefits of using diversity indices have been widely debated, but in absence of a universal choice, an index which performs optimally for a specific case gets the priority over others". Diversity of fish species within the economic fish assemblage of the NBoB is generally low (Table 1; n = 24). Within that some fish species are highly abundant compared to the others (Table 1) owing to habitat conditions and the economic importance of selective species leads to their high catch. Such biasness of the dataset led to the use of species dominance index (D) and species

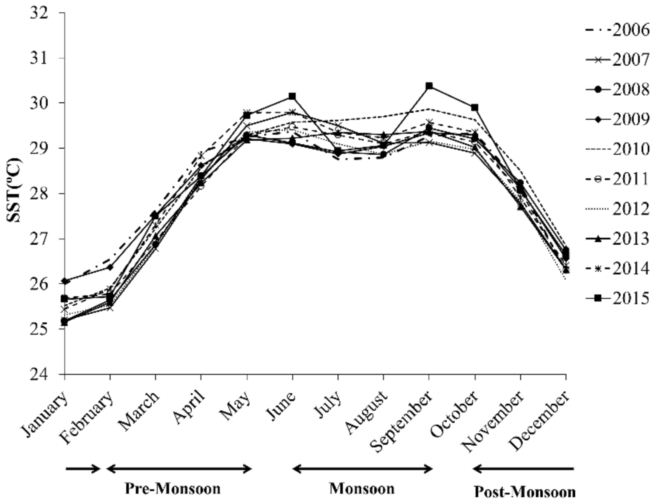

Fig.2. Monthly variations of the sea surface temperature (SST) (°C) level of the Northern Bay of Bengal between 2006 and 2015.

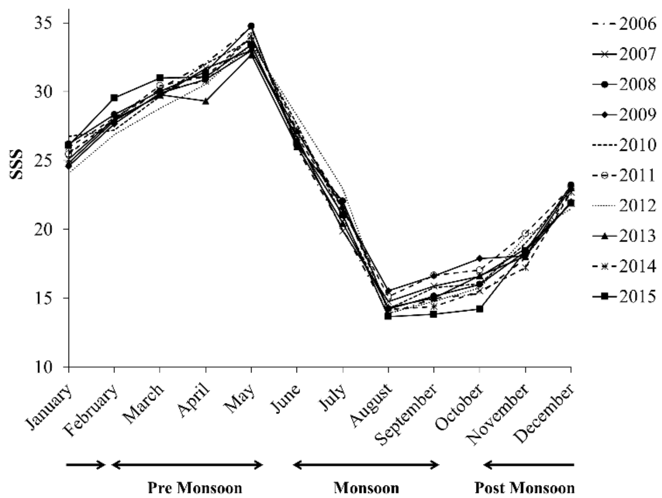

Fig.3. Monthly variations of the sea surface salinity (SSS) level of the Northern Bay of Bengal between 2006 and 2015.

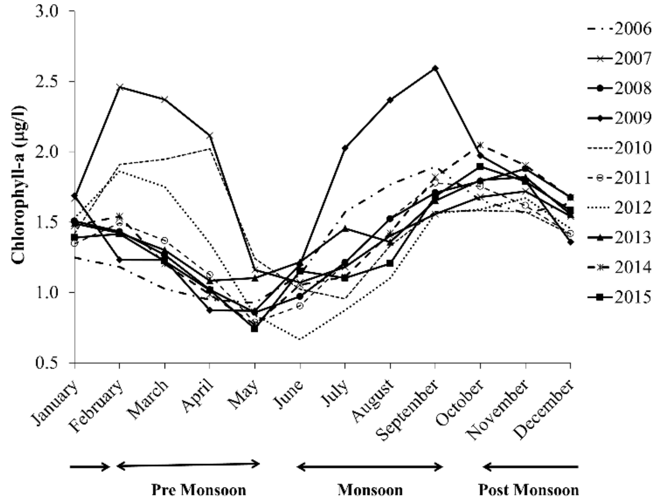

Fig.4. Monthly variations of chlorophyll-a (µg/l) level of the Northern Bay of Bengal between 2006 and 2015.

evenness index of Pielou (J) than other diversity indices (Pielou 1966; Hill 1973; Heip 1974). Annual values of the dominance (D) and the evenness (J) indices were calculated using the PAST software package version 2.15. Index D (W = 0.8, p-value = 0.07) and index J (W = 0.84, *P*-value = 0.054) values were not normally distributed. A matrix was then drawn where annual values (2006–2015) of D and J indices were placed along with the medians of SSS, SST and Chl-*a*. Generalized linear models of log-normal family were built to evaluate the effects of SSS, SST, and Chl-*a* levels and their interactions with the D and J indices. Akaike Information Criterion (AIC) was used for finding the most plausible model out of the candidate models which were constructed for the purpose (Table 2). The dataset was small so the AIC values were corrected to AICc. Δ AIC values were then calculated (distance between AICc of a respective model and the model with least AICc among the candidates). Models with Δ AIC<0.5 had considerable support for the data, models with 0.5<Δ AIC<1 had moderate support for the data, however, models with 2<Δ AIC had less to no support for the data (Burnham & Anderson 2004). Models with Δ AIC <0.5 were assumed to be equally plausible. All analysis was performed on the R 4.0.3 (MAC OSX 64-bit).

Results

During 2006 to 2015 the median SST was 28.81°C; the highest 30.37°C was recorded during June 2015 and the lowest 25.16°C was recorded in January 2013 (Fig. 2). SST did not vary between the years (K-W Chi-squared=2.9; DF=9, P=0.97) but showed significant seasonal variation (K-W Chi-squared=43.8, DF=2, *P*<0.001), SST of pre-monsoon (median 27.89°C, range 25.47-29.78°C) and post-monsoon (median 27.27°C, range 25.15–29.9°C) were lower than the SST of monsoon (median 29.29°C, range 28.35-30.75°C) (Fig. 2).

During the study interval, the median SSS was 23.64, with the highest (34.76) was recorded in May

Table 2. Summary of the generalized linear models built to capture the variability of the dominance (D) and evenness (J) within the fish assemblage of the Northern Bay of Bengal in response to environmental changes between 2006 and 2015. SSS = Sea surface salinity; SST = Sea surface temperature; Chl-a = Chlorophyll-a; * = interactive effects.

Response	Model	AIC	AICc	Δ AIC
Dominance	SSS	48.68	49.18	6.68
	SST	48.84	49.34	6.84
	Chl-*a*	42.80	43.30	0.80##
	SSS* SST	47.37	49.08	6.58
	SST *Chl-*a*	40.79	42.50	0.00#
	Chl-*a**SSS	44.77	46.48	3.98
	SST *Chl-*a**SSS	46.64	50.64	8.14
Evenness	SSS	29.85	30.35	3.71
	SST	30.62	31.12	4.48
	Chl-*a*	26.14	26.64	0.00#
	SSS* SST	28.99	30.7	4.06
	SST *Chl-*a*	25.04	26.75	0.11##
	Chl-*a**SSS	29.30	31.01	4.37
	SST *Chl-*a**SSS	41.27	45.27	18.63

#= Most plausible, ##=Medium plausible,

2008 and the lowest (13.67) was recorded in September 2015 (Fig. 3). SSS did not vary between the years (K-W Chi-squared=0.35, DF=9, *P*=1), but seasonal change was significant (K-W Chi-squared=79.1, D=2, *P*<0.0001). Difference was noticed between the pre-monsoon and post-monsoon levels of the SSS as well as the monsoon and the pre-monsoon levels of the SSS. The median SSS was 30.49 (range 26.89–34.76) in the pre-monsoon, 20.6 (range 14.13-26.75) in the post-monsoon and 18.28 (range 13.67-28.26) in the monsoon (Fig. 3). The minimum and the maximum Chl-awere 0.67µg/l (June 2012) and 2.59µg/l (September 2009), respectively. The median Chl-a was 1.44µg/l but each year there were two peaks, the first was in February and the second was in September of every year (Fig. 4). Inter-annual variation of Chl-*a* concentration was not significant (K-W Chi-squared=5.14, DF=9, P=0.81). Chl-*a* concentration varied significantly between seasons (K-W Chi-squared=23.31, DF=2, *P*<0.001). Chl-*a* level of pre-monsoon (median 1.22µg/l, range 0.74-2.46µg/l) was different from the post-monsoon (median 1.62µg/l, range 1.25-2.05µg/l) and monsoon (median 1.34µg/l, range 0.67–2.59µg/l) (Fig. 4).

Interactive effects of the Chl-*a* *SST (Δ AIC=0) was the most plausible explanation of the inter-annual variability of the species dominance (D) within the fish assemblage (Table 2). Chl-*a* (Δ AIC= 0.8) was the 2nd most plausible model out of the candidate models which explained the variability of the species dominance (D) (Table 2). Inter-annual variability of the species evenness (J) was explained with equal plausibility by two models first by the Chl-a (Δ AIC=0) and second by the interactive effects of Chl-*a* * SST (Δ AIC=0.11) (Table 2). Other candidate models which were built to capture the variability either of the species dominance (D) or species evenness (J) did not demonstrate any such support (Δ AIC>2) for the data (Table 2).

Discussion

In the NBoB, inter-annual variations (i.e. between 2016 and 2015) of SST, SSS, and Chl-*a* levels were not pronounced but strong seasonal changes were observed for all of those environmental drivers. Results showed that the NBoB cools in post-monsoon but remains relatively warm in monsoon, which supports the previous observation of Sarangi & Devi (2017). Arrival and departure of monsoon is often critically linked to the variability of SST level of the NBoB and affects the Chl-*a* production of the region (Vecchi & Harrison 2002; Saranagi & Devi 2016).

Level of SSS dropped in monsoon, may be the result of large freshwater discharge from the Ganges and the Brahmaputra rivers which drain into the NBoB (Madhupratap et al. 2003; Ahammad 2004; Choudhury & Pal 2010). During post-monsoon, SSS level of the NBoB generally increases and positively correlates with phytoplankton production in the coastal fringes of the region (Choudhury & Pal 2010). Increased turbidity of the NBoB during monsoon (PrasannaKumar et al. 2002; Chauhan et al. 2005) reduces the light penetration in the water column and negatively affects the Chl-a production in the region (Gomes et al. 2000; Madhupratap et al. 2003).

During monsoon, nutrients from the surrounding continental land mass accumulate in the NBoB, which positively contribute towards phytoplankton bloom (Madhupratap et al. 2003; Dutta et al 2016b). The bi-modal distribution of Chl-*a* production that was observed supports previous works in the region; such is possibly the consequence of monsoon wind reversals that commonly occur in the Bay of Bengal (Banse 1987; Wiggert et al. 2005; Lévy et al. 2007; Koné et al. 2009; Sarangi & Devi 2017).

Catfish, croakers and hilsa dominated the fisheries catch between 2006 and 2015. Dutta et al. (2016a), suggested that catfish had the highest percentage (15.16%) of landings in the West Bengal coast between 2006 and 2012 followed by croakers (12.14%) and hilsa (10.10%) which supports the present results. Among the demersal fish, croaker, catfish, and hilsa are also the dominant species in the gillnet operations conducted along the West Bengal coast of the NBoB (BOBP 1990).

Inter-annual variability of the fish assemblage showed a close connection with the cycles of Chl-*a* production and/or its interaction with the changes of SST level of the NBoB. The environment of the NBoB varies considerably with monsoon breaks and periodic cyclones that hit the region in stochastic manner (Vecchi & Harrison 2002; Vinayachandran & Mathew 2003). Monsoon brings variability in the subsurface nutrient availability in the NBoB and possibly trigger localized phytoplankton blooms (Vinayachandran et al. 2005; Rao et al. 2006; Piontkovski & Al-Azri 2010). Phytoplankton bloom in the NBoB contributes to a higher fish harvest in the region (Dutta et al. 2016b). Fish population abundance of the coastal fringes of the NBoB varies with SST, primary productivity and monsoon season (Gomes et al. 2000).

Planktivorous fish species dominate the fish assemblages of the coastal fringes of the NBoB (Ullah et al. 2012; Dutta et al. 2017). Interaction of SST and primary production (Chl-a) is known to limit the diversity and composition of the reef fish assemblages along the Brazilian coast (Floeter et al. 2001). SST and Chl-a levels together were limiting factors of fish abundance and distribution in the Gulf of California (Danell-Jiménez et al. 2009; Lanz et al. 2009), which some extent supports the present results. The succession of water masses induced by monsoon and the high nutrient levels caused by the frontal turbulence and topographic upwelling are known to influence the distribution of larval fish abundance and composition in the East China Sea (Hsieh et al. 2011), such is also plausible for the NBoB. A source of environmental variability in the near-shore marine systems is upwelling which brings cooler water in the surface of the BoB (Shetye et al. 1991). Such a phenomenon is known to affect the primary production (i.e. Chl-a) in the NBoB (Akhand et al. 2012), which is consequence may bring variability within the fish community. Hossain et al (2012), suggested that many coastal-marine fish species of the NBoB reproduces between pre-monsoon and monsoon season near the coastal-fringes, and many of them migrate off shore between monsoon and post-monsoon, and contribute to the fish diversity of the NBoB.

Fast melting of Himalayan glaciers coupled with increasing rainfall in the Ganges-Brahmaputra basin may bring variability to the volume of freshwater available of the NBoB (Gomes et al. 2010; Bookhagen & Burbank 2010; Immerzeel et al. 2013). Irregularity in freshwater inputs is known to affect fish migration patterns, spawning habitat, fish diversity and distribution of coastal-marine areas (Drinkwater & Frank 1994) and may have cascading effects on the fish community of the NBoB. Increases in the air temperature and SST (>3 °C) at the regional scale during the last 30 years are possibly responsible for the northward shift in the distribution of warm-water fishes in the Gulf of Mexico (Fodrie et al. 2010), effects of such changes of regional environment on the fish assemblage of the NBoB are completely unknown. It has been observed that after a cyclonic event the base of the marine food web expands and increases the fisheries productivity of the BoB (Rao et al. 2006). For future, assessments of the effects of monsoon breaks and the variability of freshwater discharge on the NBoB, are needed to evaluate the vulnerability of its economic fish assemblages.

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مقاله پژوهشی

تغییرات زمانی جوامع ماهیان اقتصادی خلیج شمالی بنگال در رابطه با محیط

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چکیده: خلیج شمالی بنگال (NBoB) تا حد زیادی به تولید ماهی کشور هند و کشورهای همسایه کمک می‌کند. یک تلاش پیشگامانه به منظور بررسی تغییرات زمانی جوامع ماهیان (به طور انحصاری برای علاقه‌مندان علوم شیلاتی) خلیج شمالی بنگال (۲۰°۲۰'-۲۱°۳۰"N, ۸۷°۳۰'-۸۹°E) در ارتباط با دمای سطحی (SST)، شوری سطحی دریا (SSS) و تغییرات کلروفیل a (Chl-a) انجام شد. بین سال‌های ۲۰۰۶ و ۲۰۱۵، تغییرات سالانه مقادیر SST، SSS و Chl-a جزئی بود. تغییرات فصلی SST، SSS و Chl-a مشاهده شد و اوج سالانه تولید Chl-a دو پیکی مشهود بود. تغییرات سالانه گونه‌های غالب به طور منطقی به وسیله مدل SST*Chl-*a* (ΔAIC=0) و توضیح داده شد. تغییر شاخص یکنواختی (J) با مقدار تقریبی مساوی، توسط مدل Chl-a (Δ AIC=0) توضیح داده شد. تنوع فصلی سطوح SST و Chl-a، احتمالاً بر جوامع ماهیان خلیج شمالی بنگال تأثیر می‌گذارد، بنابراین، یک برنامه نظارتی منظم برای بررسی تغییرات طولانی مدت جوامع ماهیان خلیج شمالی بنگال پیشنهاد می‌شود.

کلمات‌کلیدی: دمای سطح دریا، شوری سطح دریا، کلروفیل a، تنوع ماهی، هند.