

Mud banks and fisheries along the Kerala coast – Myth and reality

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Abstract

Mud banks, a unique coastal oceanographic phenomenon, occurring along the southwest (SW) coast of India during the SW monsoon season, are synonymous with fishery of this region. In this paper we examine the validity of the popular notion that mud banks directly support rich fisheries, using a high temporal resolution water column data collected from the Alappuzha mud bank region from April to September 2014 in conjunction with fisheries data. Our study reveals that the upwelling that occurs during the SW monsoon season along this coast brings oxygen-deficient subsurface water to the upper water column. Escaping the oxygen-depleted waters the fish aggregates within a thin upper layer allowing easy visual identification and capture of fish shoals. This process occurs throughout the coast and is not confined just to the mud banks. Mud bank being calm region the traditional fishermen using non-motorized country crafts were able to carry out fishing only within this region during the SW monsoon. With the induction of motorized and mechanized fishing, the link between mud bank and fishery is becoming less prominent, although the mud banks still continue to be important fish landing centres.

Keywords: mud bank, southwest monsoon, upwelling, suspended sediment, hypoxia, coastal current, pelagic and demersal fishery

Introduction : - Mud banks are unique coastal oceanographic feature that occur seasonally during SW monsoon (June-September) at certain locations along the Kerala coast. They are characterized by high load of suspended sediment, often exceeding 1000 mg/l¹ and largely consisting of clay-size particles with less than 1 μm in size²⁻³. Mud banks are distinguished by very low wave activity (height <0.5 m) in the midst of turbulent monsoonal waves, usually 2 to 5 m in height. Mud banks occur very close to the coast, at a water depth ranging from 7 to 15 m, in a semi-circular shape with a typical alongshore length of 4 km and off shore distance up to 8 km⁴⁻⁵. Although there are about 20 locations where the occurrence of mud bank has been reported in the past (see top right panel of Figure 1), the phenomenon does not occur at all locations every year. However, at some of these sites, especially off Alappuzha (Figure 1), the occurrence is more frequent, almost every year. The mud banks are mostly located in the vicinity of river mouths or lagoons, with the exception of the most prominent system off Alappuzha, which is located well away from the outlet of any river or lagoon. There is a growing perception that the occurrence of mud bank along the Kerala coast used to be more frequent in the past, but of late there has been a declining-trend in their number as well as duration and intensity of their formation, for reasons that are not known. However, there are no robust time-series data to corroborate it.

Mud banks of Kerala are synonymous with rich fisheries. Huge quantities of pelagic as well as demersal fish are harvested from the mud bank regions every year by fishermen using country crafts. The unusually high concentration of suspended mud/sediment leads to the remarkable damping of incoming high monsoon waves⁶⁻⁷. This protects the adjoining beach from erosion, which commonly occurs along the Kerala coast during SW monsoon season⁸⁻⁹. Mud banks of Kerala have great socio-economic relevance as they support livelihoods of fishermen and protect beaches from erosion during the hostile weather conditions.

In spite of the excellent records of mud banks of Kerala, dating as far back as 1678¹⁰ and large body of research resulting in over one hundred research papers and over a dozen doctor of philosophy (PhD) theses¹¹, the phenomenon of mud bank and its link with fishery¹² remains an enigma. The most important questions that still elude us are (1) what triggers the fluid mud formation at select well-defined locations along the Kerala coast during SW monsoon leading to the formation of mud bank, and (2) why fishes, both pelagic as well as demersal, aggregates within the mud bank region. This motivated us to undertake an observational programme in 2014 at Alappuzha, the site of most frequent occurrence of mud bank⁵. While the first question is a subject matter of another paper, in this paper we address the second question.

A multi-institutional observational programme was jointly initiated by Council of Scientific and Industrial Research-National Institute of Oceanography (CSIR-NIO) and Central Marine Fisheries Research Institute (CMFRI), Kochi to collect multi-disciplinary time-series data from Alappuzha mud bank region from April to September 2014. An observational station was selected at Punnapra (76° 22' 16.8'' E and 9° 25' 21.4'' N) in the Alappuzha district at a nominal water depth of 6 m (Figure 1 bottom panel) from where high-resolution in-situ data were collected. The weekly time-series data collection was initiated on 22nd April onboard CMFRI's FV *Silver Pompano*, well ahead of the onset of the SW monsoon and continued up to 20th September 2014 well after the withdrawal of SW monsoon. In addition to CMFRI vessel, which was used mainly for fishing operations and fisheries data collection, a fishing boat was used for collection of oceanographic data and water samples.

Vertical profiles of temperature and salinity were obtained using a Sea Bird Electronics (SBE) 19 plus conductivity-temperature-depth (CTD) probe attached with a turbidity sensor. A 5L Niskin bottle was used for collecting water samples from near surface, 2m, 4m and 6m depths. The data on temperature, salinity, turbidity and dissolved oxygen were collected at weekly interval. An automated weather station (AWS) developed at CSIR-NIO, Goa, was mounted at 10 m height on a building located close to the station (Punnapra) for obtaining the time-series data on wind speed, direction, pressure and relative humidity from 1st May to 30th September 2014. These data were collected at 10 minutes interval with a sampling frequency of 1 second. Daily mean values and standard deviations were calculated for preparing the plots. All the sensors were calibrated before the observations were initiated. The measurement ranges and accuracies of the sensors used for data collection are given in Table 1. The data on average daily rainfall was obtained from tropical rainfall measuring mission (TRMM) having a grid resolution of 0.25° (<http://trmm.gsfc.nasa.gov>) from a location very close to the sampling station. The dissolved oxygen in sea water was measured following the Winkler's method¹³. The fishery data used in the present study consisted of fish catch generated from the landing centres within and outside the mud bank region in Alappuzha. From the above data catch per unit effort (CPUE) has been calculated.

Time evolution of the surface meteorological data showed occurrence of five distinct atmospheric events during the study period (Table 2), each marked by a sudden drop in atmospheric pressure followed by an increase in wind speed, relative humidity and rain fall (shaded region in Figure 2). The 1st event occurred from 4th to 10th May when the atmospheric pressure dropped by 4mb, followed by a strong westerly wind (5 m/s during in-situ observation) and high precipitation (mean value of 27 mm/day). The 2nd event was the onset of southwest monsoon on 6th June 2014 when the

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atmospheric pressure dropped by 6 mb, the wind gust speed exceeded 10 m/s (Table 2) and an average rain fall was 25.7 mm/day. Subsequently, three more episodic atmospheric events were noticed during 12th June to 24th June 2014, 18th to 27th July 2014, and 24th August to 5th September 2014 (Table 2). These three events were associated with marked decrease in atmospheric pressure, increased wind speeds and humidity accompanied by intense rainfall over the study region (Figure 2 and Table 2).

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The above atmospheric events are expected to impact the underlying water column. The high winds and waves associated with these episodic events could potentially transfer large amount of energy through the water column to the bottom boundary layer through frictional coupling and momentum transfer. The onshore upwelling current, discussed in later part, will also aid the movement of bottom sediment. In order to investigate this, we examined the time evolution of water column turbidity measured by the CTD. Consistent with the atmospheric episodes, a corresponding increase in the water column turbidity was observed associated with all 5 episodic events (Figure 3 top panel). For example, during the first event the turbidity of the water column showed an increase from 5 Nephelometric Turbidity Unit (NTU) in the upper 5 meter depth to >20 NTU towards bottom. Note that the gray shaded portion in the figure indicates the depths where the turbidity was in excess of 25 NTU, which is beyond the measurement limit of the CTD turbidity sensor. This implies that the water column close to the bottom had very high suspended sediment load forming the fluid mud layer. From the measurements, the inferred thickness of this layer varied from 0.5 to 2 m. Thus, it appears that the high input of energy to the bottom boundary layer by the sporadic high winds triggered by the atmospheric events along with the prevailing high waves associated with SW monsoon were able to re-suspend the bottom sediments thereby increasing the turbidity of the water column.

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An examination of the time-evolution of the water column temperature showed the appearance of cold subsurface water with time, a signature of upwelling (Figure 3 middle panel). Associated with the onset of SW monsoon the prevailing north-westerly winds along the coast of Kerala (Figure not shown), including Alappuzha, kick-starts the upwelling process, which is a wind-driven Ekman response of the water column. A sharp decline of 3⁰C in subsurface water temperature occurred during the initial phase of upwelling, which further intensified with the progress of SW monsoon. Though the process of upwelling was sustained throughout the SW monsoon of 2014 (June to September), the occurrence of cold waters originating from the bottom was sporadic and in tandem with wind events. This clearly indicated that upwelling intensity was controlled by the strong winds initiated by the atmospheric episodic events. The time-evolution of dissolved oxygen within the

water column showed a progressive decline in concentrations (Figure 3 bottom panel), especially in the subsurface layers, in tandem with the upward propagation of colder waters. The concentrations fell below 50 μM below a thin well-oxygenated surface layer after the onset of SW monsoon, progressively expanding upward along with colder waters. Thus, upwelling brings low temperature ($<26^\circ\text{C}$), high salinity (>35.5 psu, not shown) and oxygen-depleted ($<75\mu\text{M}$) water that is overlain by a thin warm fresher and oxygenated lens within the mud bank. This lens persists because of heavy rain fall during the SW monsoon period resulting in strong stratification in the upper layer which prevents/curtails vertical mixing. The two layered structure is maintained at such a shallow depths, despite strong wind is quite remarkable. The resultant hypoxic conditions in the lower layer within the mud bank have implications to fishery as will be shown below.

To examine the link between the mud bank formation and the fishery, we analyzed the fishery potential of the mud bank and non-mud bank region with the help of fish catch per unit effort (CPUE) data within the Alappuzha district for the 2013, 2014 and 2015. In this district, a unique one-man operated expanded polystyrene thermocol crafts with gill nets were used for fishing along with several other motorised and non-motorised crafts. The CPUE data from 2013 to 2015 showed only minor difference between the mud bank and non-mud bank region (Figure 4). Based on the positive and negative year-to-year difference in the CPUE, we infer that there is no preferential fish aggregation in the mud bank region. Further, examination of different fish species within the mud bank reveals the occurrence of high abundance of a benthic fish *Trypauchen vagina* (not a commercial fishery) considered to be an indicator of mud bank formation. In addition to this, there was a progressive succession of other benthic crustaceans such as *Metapenaeus dobsoni* of higher size popularly known as 'Poovalan Chemmeen' and *Fenneropenaeus indicus*, Indian white shrimp that occurs both within mud bank and non-mud bank regions. The apparent cause for the upward movement of this benthic fish and benthic crustaceans is the presence of hypoxic waters associated with upwelling¹⁴. Apart from the benthic species, notable landings of small pelagic fish such as Indian oil sardines, mackerel and anchovies are the major contributors to the fishery of this region, encompassing both mud bank and non mud bank regions. Note that the small pelagic fishery is closely linked to the occurrence of high phytoplankton (chlorophyll) that is driven by the coastal upwelling. Thus, we infer that the rich fisheries during the upwelling season is not only limited to the mud bank region but all along the coast that comes under upwelling regime. The hypoxic waters brought up by upwelling drives the upward migration of both benthic and pelagic fish to the thin oxygenated layer close to the surface. This makes it easy for fishermen to identify the shoals visually and catch them with ease. Before the advent of motorized crafts and mechanized fishing, the

artisanal fishermen with their country crafts could operate only within the tranquil of the mud bank for fishing. This is perhaps the reason why mud banks are synonymous with fishery. Even today, with the induction of motorized crafts and mechanized fishing along the Kerala coast, traditional fishermen still use non-motorized and non-mechanized crafts within the mud bank to get good fish catch. However, the comparable fish catch data from both within and outside the mud bank region underscores the fact that mud banks *per se* do not support higher fish production; rather it provide a calm condition suitable for fishing and landing the catch during otherwise rough SW monsoon season. In fact, the coastal upwelling process that occurs during southwest monsoon also brings hypoxic waters to the upper water column thereby progressively moving both benthic and small pelagic fishes towards the surface waters, all along the coast.

In summary, present study provides a reason for the aggregation of the pelagic and demersal fishes in the thin, oxygenated upper layer along the coastal regions of Kerala irrespective of the occurrence of mud bank. The coastal upwelling-driven phytoplankton blooms sustain the small pelagic fishery typical of an eastern boundary ecosystem during SW monsoon, while the hypoxic subsurface waters located just beneath the thin warm, lower salinity lens force aggregation of both demersal and pelagic fishes in the upper few meters. Although the coastal current moves southward along the coast of Kerala during SW monsoon season, upwelling progressively moves from south to north with time¹⁵, and the pelagic fishes may also migrate northward for feeding. This process is schematically presented in Figure 5. We conclude that the mud bank regions do not provide any special environment for enhanced fish production, rather they only help the artisanal fishermen to fish in the calm regions when the other near shore regions are turbulent with high waves making the operation of non-motorised country crafts difficult if not impossible.

Acknowledgements

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References

1. Kurup, P.G., Studies on the physical aspects of the mudbanks along the Kerala coast with reference to the Purakkad mudbank. *Bull. Dept. Mar. Sci.*, 1977, **8**, 1-72.
2. Dora, Y. L., Damodaran, R., Jose and Anto, V., Texture of Narakkal mudbank sediments. *Bull. Dept. Mar. Biol. Oceanogr.*, 1968, **4**, 1–10.
3. Venkatachala, B. S., Kar, R. R., Suchindan, G. K., Ramachandran, K. K. and Kumar, M., Study on the sedimentary facies, spore-pollen and palynodebris of Mud Bank and Vembanad Lake, Kerala. *Geophytology*, 1992, **22**, 245–254.
4. Gopinathan, C.K., and Qasim, S.Z., Mud banks of Kerala their formation and characteristics. *Indian J. Mar. Sci.*, 1974, **3**, 105-114.
5. Silas, E.G. Mud banks of Kerala-Karnataka: Need for an integrated study. *Bull. Cent. Mar. Fish. Res.Inst. (Mud banks of Keralacoast)*, 1984, **31**, 2-7.
6. Macpherson, H. and Kurup, P.G., Wave dampening at Kerala mud bank, *Indian J. Mar. Sci.*, 1981, **10**, 154-160.
7. Joseph Mathew, Mytheenkhan Baba, Kurian, N.P., Mud banks of the south west coast of India I: Wave Characteristics, *Jour. Coast. Res.*, **11**, 168-178
8. Erattupuzha, J.J. and Raman, H., Shore erosion and shore protection in Kerala. *Proc. Symp. Coastal Erosion and Protection in Kerala*. Kerala Engg. Res. Institute, Peechi, Trichur, Kerala, 1971, pp.7.1-7.15.
9. Parvathy, K.G., Noujas, V., Thomas, K.V. and Ramesh, H., Impact of mud banks on coastal dynamics, *Aquatic Procedia*, **4**, 1514-1521.
10. Pinkerton, 1860 referred in Kurup, P.G., Studies on the physical aspects of the mud banks along the Kerala coasts with special reference to the Purakad mud bank. *Bull. Dept. Mar. Sci.*, University of Cochin, 1977, **7**, 1-72.
11. Dinesh Kumar, P.K.; Balachandran, K.K., Prasanna Kumar, S. and Ramaiah, N., Workshop on mud bank, *Indian J. Mar. Sci.*, 2014, **42**, 954-955.
12. Regunathan, A., K. J. Mathew, D. S. Rao, C. P. Gopinathan, N. Surendranatha Kurup and A. V. S. Murty, Fish and fisheries of mud bank, *Bull. Cent. Mar. Fish. Res. Inst. (Mud banks of Kerala Coast)*, 1984, **31**, 60-71.
13. Grasshoff, K., Ehrhardt, M., Kremling, K., In *Methods of Seawater Analysis*, Verlag Chemie, Weinheim, 1983, pp. 89–224.
14. Gupta, G.V.M., V. Sudheesh, K. V. Sudharma, N. Saravanane, V. Dhanya1, K. R. Dhanya, G. Lakshmi, M. Sudhakar, and S. W. A. Naqvi., Evolution to decay of upwelling and associated biogeochemistry over the southeastern Arabian Sea shelf *J. Geophys. Res. Biogeosci.*, 2015, **121**, 159–175, doi:10.1002/2015JG003163.
15. Antony, M.K., Unnikrishnan, A.S., on an upwelling front, propagation of upwelling and vertical velocity in the eastern Arabian Sea during monsoon, 1987 *Proceedings of the PORSEC-'92 in Okinawa, Conference for Pacific Ocean Environments and Probing*, 1992, **1**, 527-532.

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Figure 1 Map showing the locations of mud bank along the Kerala coast (filled dark circles in the top right panel). The region of mud bank in the Alappuzha district is denoted by the dark rectangular box enclosing the dark filled circle in the top left panel and the colour shading in the map is for depths in meters. The red broken line in the bottom panel represents the outer periphery of the Alappuzha mud bank, the solid black lines are the depth contours and the filled dark circle within it indicates the location of the sampling station. See text for details.

Figure 2 Time-series of daily averaged data on (a) atmospheric pressure (mb), (b) wind speed (m/s), (c) relative humidity (%) and (d) rainfall (mm/day) during the period 1st May to 30th September 2014. The daily averages in panels (a) to (c) were generated by averaging data acquired at 10 minutes interval and the horizontal shadings are the associated standard deviation. The vertical shadings are the 5 meteorological events (see Table 2 for details) that occurred during the study period.

Figure 3 Time-series data on water column (top panel) turbidity (NTU), (middle panel) temperature (°C) and (bottom panel) dissolved oxygen ($\mu\text{M/l}$) during the period 22nd April to 30th September 2014. The black shading at the bottom of each panel shows the bottom depth. Top panel x-axis labels denotes the date on which water column sampling was carried out, the grey shading near the bottom marks the region where the turbidity is beyond the upper measuring limit of the turbidity sensor, implying prevalence of fluid mud. The white shading in the bottom panel indicates missing data.

Figure 4 Fish catch per unit effort (CPUE; kg/hr) of non-motorized boats in the mud bank and non-mud bank regions of Alappuzha district.

Figure 5 Schematic representation of the coastal upwelling process (bunch of thin lines moving vertically upwards along the coastal region) that co-exists with mud bank. The semicircular solid red line indicates the region of mud bank along the coast of Alappuzha. Upwelling brings cold and nutrient rich water with very low dissolved oxygen from subsurface to the surface along the coast making the waters hypoxic. The upwelling-driven phytoplankton bloom sustains the small pelagic fish such as mackerel and sardines during this period. For feeding, these pelagic fish swim against the coastal current which is southerly along the coast indicated by the solid black arrow close to the coast.

Table 1 Range and accuracy of oceanographic and atmospheric data collected using CTD and CSIR-NIO AWS respectively. See text for details.

Serial Number	Parameter	Range	Accuracy
1.	Temperature	-5 to 35°C	±0.005°C
2.	Conductivity	0 to 9 S/m	±0.0005S/m
3.	Turbidity	0 to 25 NTU	±0.01 NTU
4.	Pressure	0 to 100 m	±0.1 % of full scale (~0.1m)
5.	Wind speed	0 to 60 m/s	±0.2 m/s
6.	Wind direction	0 to 360 degree	±3 degree
7.	Pressure	800 to 1060 mbar	±0.4 mbar
8.	Relative humidity	0 to 100 %	±3%

Table 2 Changes in the surface meteorological parameters associated with the 5 episodic atmospheric events occurred in the Arabian Sea which impacted the study region during 1st May to 30th September 2014. All parameter, except rain fall, are expressed as range and (mean \pm standard deviation). Rainfall is expressed as mean.

Atmospheric event and its duration	Pressure drop (mb)	Wind gust (m/s)	Relative humidity (%)	Rainfall (mm/day)
Episode 1 Low pressure (mean, SD) 4 th to 10 th May 2014	1002.2 – 1006.4 (1005.4 \pm 1.5)	0 – 10.40 (2.06 \pm 2.26)	57.6 – 94.9 (83.2 \pm 10.7)	27.1
Episode 2 Onset of Monsoon (mean, SD) 6 th June 2014	1003.1 – 1005.6 (1003.8 \pm 1.1)	13.51 – 16.40 (15.30 \pm 2.04)	88.4– 98.5 (90.1 \pm 7.8)	25.7
Episode 3 Cyclone (mean, SD) 12 th to 24 th June 2014	1004.4 – 1009.3 (1007.6, \pm 1.2)	0 – 16.70 (3.83, \pm 2.91)	66.3 – 92.7 (83.2, \pm 8.9)	15.2
Episode 4 Depression (mean, SD) 18 th to 27 th July 2014	1006.1 – 1009.4 (1008.8 \pm 1.12)	0 – 13.70 (1.74 \pm 2.40)	64 – 95.2 (85.6 \pm 9.6)	37.0
Episode 5 Depression (mean, SD) 24 th August to 5 th September 2014	1001.9 – 1008.4 (1007.6 \pm 1.21)	0 – 15.7 (4.27 \pm 3.20)	68 – 95.7 (81.9 \pm 10.2)	45.2

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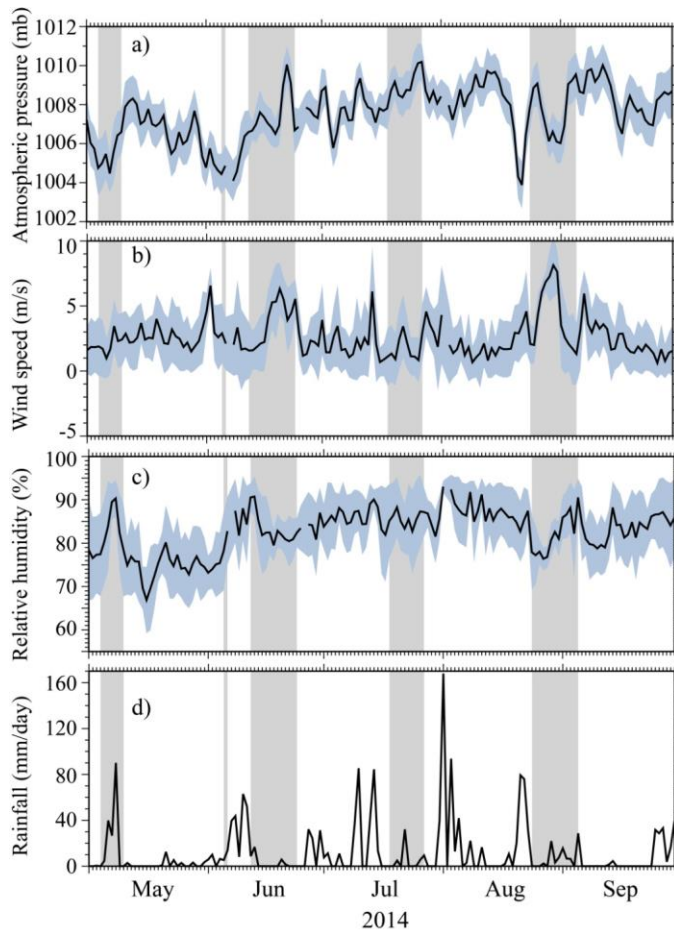


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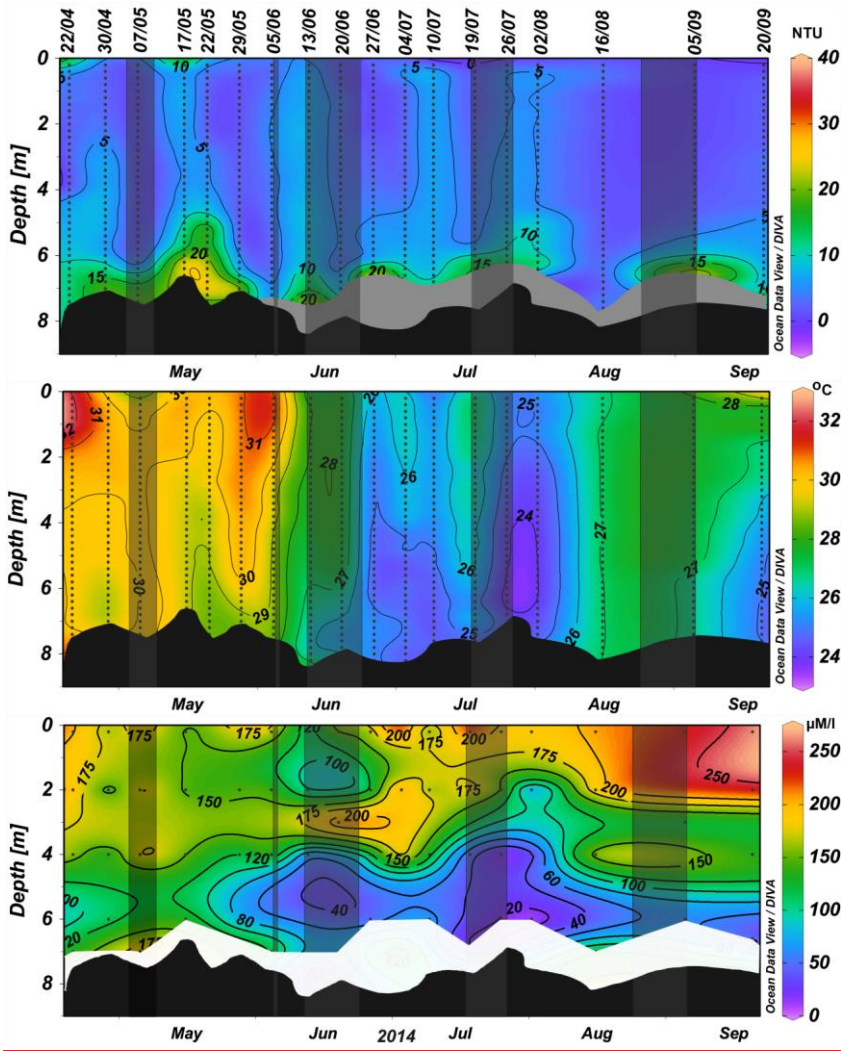


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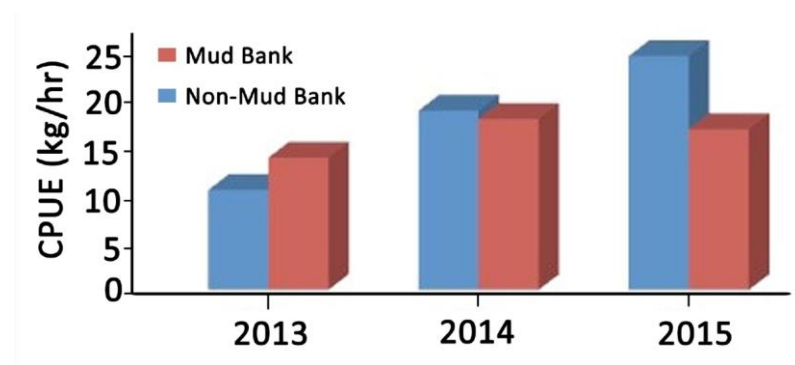


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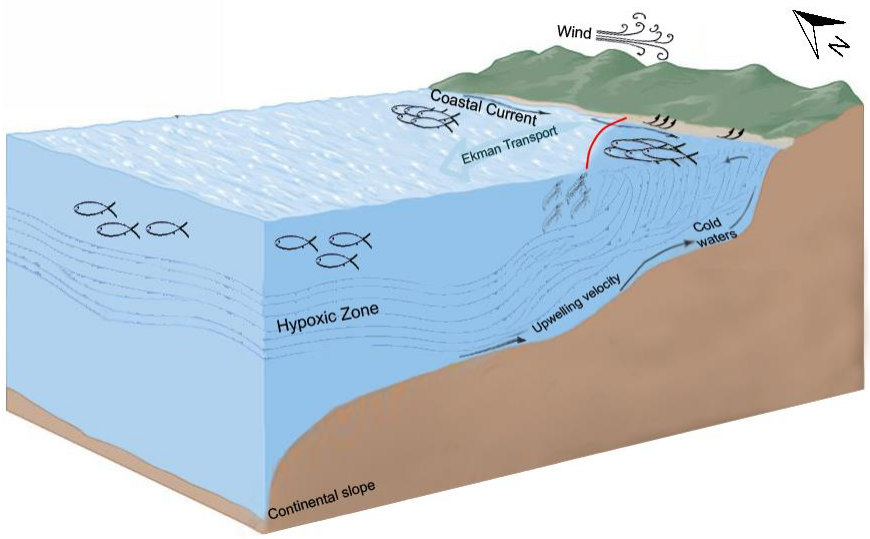


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