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Impact of Accidental Spillage of Oil and Hazardous Chemicals in Mumbai Bay Subsequent to Ship Collision on 7 August 2010, on Marine Ecology

(Interim Report)

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Maharashtra Pollution Control Board, Mumbai

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EXECUTIVE SUMMARY

Two cargo ships MSC Chitra and MV Khalijia 3 collided in the mouth area of Mumbai Harbour on 7 August 2010 (0937 h) resulting in leakage of 600 to 800 t of furnace oil and about 120 containers onboard the vessel Chitra, some of them containing pesticides and hazardous chemicals like organophosphorus pesticides and sodium hydroxide, fell in the sea. National Institute of Oceanography, Mumbai (NIO) on its own initiative started studies to assess the impact of the accident on the ecology of the Mumbai Bay and adjacent coastal areas, from 10 August to 8 September 2010. Subsequently, this study and its continuance were supported by the Maharashtra Pollution Control Board (MPCB). The objectives of the investigation were (i) to study the impact of spilled oil and hazardous materials on water quality, sediment quality, and flora and fauna of pre-selected sites, (ii) to conduct eco-toxicological investigations for evaluating the impact of oil and other hazardous substances on selected marine organisms of the affected sites and (iii) to suggest adequate mitigation measures to safeguard the sensitive coastal ecosystem of Mumbai and adjacent areas in the event of ship accidents and spillage in future.

This Interim Report which is based on the monitoring conducted by NIO under 4 series (Series I: 10 – 13 August 2010; Series II: 18-22 August 2010; Series III: 26-30 August 2010 and Series IV: 6-8 September 2010 is prepared to meet the agreed terms of reference of MPCB.

Study area

The hydrodynamics suggest that the flushing of the inner zones of the Mumbai Bay is a delayed process.

Under the influence of contaminants such as sewage and industrial effluents entering the Bay its water quality is characterized by high nutrients and marked depletion in DO during low tides in the inner Bay. Accumulation of Cr, Hg, Zn, C_{org} and PHc in the Bay sediments has also occurred. High and variable population of plankton induced by organic pollution especially in the inner Bay is common. The mangrove habitat along the shore has been degraded due to increasing

anthropogenic pressures. The Bay supports high standing stock of zooplankton and intertidal macrobenthos.

Model Prediction

ICMAM – Project Directorate, Chennai as well as NIO modelled the spill assuming leakage rate of 3 t/h for about 3 days. The modelling results in both cases predicted that the spilled oil would hit the shores of Colaba, Uran, JNPT, Vashi, Trombay, Sewri etc. within the Mumbai Bay. The modelling results of NIO also predicted oil pollution in coastal areas south of the Bay mouth namely Mandva, Kihim, Alibaug etc. within 3 days of the spill. These predictions broadly matched the feedback from the field observations.

Tentative findings of intertidal monitoring

Among the 15 shore locations monitored on 10 August 2010, Colaba, Uran and Vashi had oil landfall. Intertidal areas of Trombay and Kihim and mangrove habitats at Vashi and Trombay were affected by oil. Some containers which had gone overboard and washed ashore were noticed at Dighodi and Uran with spilled materials like tea bags, sugar and biscuit packets, etc. strewn around. The west coast of Mumbai from Girgaon to Juhu was not affected by the oil spill.

The nearshore water quality of Series I revealed that the general water quality was comparable to the background except for PHc the concentrations of which were abnormally high (497-12075 µg/l) at Kihim, Uran, JNPT, Colaba and Mandva. During, Series II (after 8 days) majority of the shore segments except Uran 2 and Trombay revealed a marked recovery with much lower PHc levels (31.4 - 53.2 µg/l). The west coast of Mumbai showed expected water quality with the PHc values comparable to the background. Overall, the impact of the oil spill on the nearshore water quality was limited to enhanced levels of PHc in water at localized sites for a period of a week or so from the time of plugging the spill.

Increase in PHc in sediment of the intertidal zone was insignificant compared to the expected background at several sites except a marginal increase at Alibaug, Mandva and Trombay.

Considerable reduction in chlorophyll *a* (av < 1 mg/m^3) and increase in phaeophytin resulting the poor ratios of chlorophyll *a* / phaeophytin (< 1) when compared with the values of September 2009 was probably due to mortality of phytoplankton caused by increased levels of PHc in water at Uran, Trombay and Colaba. Abundance of zooplankton and macrobenthos however, did not indicate any clear trend. Corals, barnacles, oysters and gastropods inhabiting the oil coated shore at Colaba were seen alive and did not show visible signs of acute stress. Mangroves (*Avicennia marina*) at JNPT, Vashi and Trombay were coated with oil up to a height of 0.5 to 1 m. High mortality of mangrove seedlings due to the oil spill was recorded at Trombay.

Tentative findings of subtidal monitoring

The concentrations of PHc in water varied widely from as low as 5.2 µg/l at station 3 to the highest of 16902 µg/l at station 8 during Series I. However, as in the case of nearshore zone, the PHc values attained ambient status within a short period of 11 days (Series II) after the oil spill. The rest of the water quality parameters did not indicate any significant difference in comparison to expected background.

The levels of PHc in sediment (ND-22.1 µg/g, wet wt) in the Mumbai Bay were comparable to the background indicating no significant contamination of the bed by accidentally spilled oil.

The bacterial count of TVC, TC and FC varied widely without any trend both in water and sediment of the Mumbai Bay. In the Bay they are known to be associated with the sewage releases.

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Chlorophyll *a* and phytoplankton populations indicated the possibility of phytoplankton mortality due to the oil spill in the initial stage (Series I). However, the recovery of phytoplankton in the affected areas of the Bay was fairly quick (Series II). A noticeable reduction in zooplankton standing stock and diversity was evident during Series II as compared to Series I. Similarly the abundance of fish eggs and fish larvae decreased to the extent of 90 and 76% respectively during Series II. It appears that the impact of the oil spill on zooplankton was delayed unlike the phytoplankton. High variability in standing stock and diversity of subtidal macrobenthos was mainly associated with substratum characteristics and monsoonal disturbances and there was no evidence for the impact of oil on their standing stock in the Mumbai Bay.

The comparable levels of PHc in fish from Mumbai Bay during the pre- and post-spill periods preclude the possibility of its accumulation in fishes following the oil spill.

The fate of the contents of the containers with pesticides and hazardous chemicals going overboard is yet to be established.

Future plan

Periodic monitoring of the Mumbai Bay and 100 km length of the coastline between Bassein and Alibaug will be continued until March 2011. Based on the results discussed in this report particular attention will be given to the recovery of intertidal ecology of spill-affected sites.

Ecotoxicological studies to assess neuro-toxicological impact on selected biota will be periodically undertaken.

Apart from the calibration of model, the weathering of selected fuels in the marine environment of Mumbai will be quantified in different seasons to generate information base for use in future.

A hypothetical leakage of a water soluble organophosphorus pesticide at the seabed will be modelled for different scenarios to assess the volume of the water column that might have levels to cause acute toxicity to organisms.

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*** Source: media/web sites**

COMMON ABBREVIATIONS

General

Av	-	Average
B	-	Bottom
BOD	-	Biochemical Oxygen Demand (mg/l)
C_{org}	-	Organic carbon (%)
DO	-	Dissolved Oxygen (mg/l)
cfu	-	colony forming unit
Eb	-	Ebb tide
Fl	-	Flood tide
Max	-	Maximum
Min	-	Minimum
NH_4^+-N	-	Ammonium nitrogen (μmol/l)
NO_2^--N	-	Nitrite nitrogen (μmol/l)
NO_3^--N	-	Nitrate nitrogen (μmol/l)
N_{Total}	-	Total nitrogen (μmol/l)
P_{Total}	-	Total phosphorus (μg/l)
PHc	-	Petroleum Hydrocarbons (μg/l)
Phenols	-	Total phenols (μg/l)
PO_4^{3-}-P	-	Reactive phosphate phosphorus (μmol/l)
S	-	Surface
SS	-	Suspended Solids (mg/l)

Microbiology

ECLO	-	*Escherichia Coli* Like Organisms counted on MacConkey medium
M-FC-ECLO	-	ECLO count on M-FC media for coliforms

MF	-	Membrane Filter
PALO	-	*Pseudomonas aeruginosa* Like Organisms
PKLO	-	*Proteus / Klebsiella* Like Organisms
SFLO	-	*Streptococcus faecalis* Like Organsims
SHLO	-	*Shigella* Like Organisms
SLO	-	*Salmonella* Like Organisms
TC	-	Total *Coliforms*
TVC	-	Total Viable Counts
VCLO	-	*Vibrio cholerae* Like Organisms
VLO	-	*Vibrio* Like Organisms
VPLO	-	*Vibrio parahemolyticus* Like Organisms

1 INTRODUCTION

1.1 Background

Two cargo ships MSC Chitra and MV Khalijia 3 collided in the mouth area of the Mumbai Harbour on 7 August 2010 at 0937 h. Consequently, the container ship MSC Chitra drifted and grounded near the Prong Reef Light House (Figure 1.1.1). The accident resulted in leakage of a few hundred tonnes (600 - 800) of the ship's fuel - Furnace oil. Due to the grounding and tilting of MSC Chitra, several containers, some of which containing hazardous and toxic substances like organophosphorus pesticides; sodium hydroxide etc fell into the sea (Figures 1.1.2 and 1.1.3).

National Institute of Oceanography (NIO), Mumbai on its own started observations and conducted sampling in the affected area of Mumbai Harbour/Thane Creek coastal system (hence forth referred as Mumbai Bay) commencing from 10 August 2010.

With this background, the Maharashtra Pollution Control Board (MPCB) approached the NIO to study and report the consequences with respect to the oil spill and the release of hazardous chemicals in Mumbai Bay and associated coastal system. NIO submitted the study proposal which has been accepted by the MPCB. The objectives of the study are as follows:

1.2 Objectives

i) To study the impact of spilled oil and hazardous materials on water quality, sediment quality and flora and fauna of the pre-selected sites.

ii) To conduct ecotoxicological investigations for evaluating the impact of oil spill and other hazardous substances on selected marine organisms of the affected sites, and

iii) To suggest adequate mitigation measures to safeguard the sensitive coastal ecosystem of Mumbai and adjacent areas in the event of ship accidents and spillages in future.

NIO has undertaken extensive sampling in the Mumbai Bay and associated coastal system soon after the accident and post-spill period during August 2010 (Figure 1.1.1). This has resulted in acquisition of valuable data.

As agreed, terms of reference require that the NIO to submit the findings of the studies into three parts as follows:

Part I: Interim Report

Interim Report to be submitted on the basis of data already acquired by NIO after the accident (August - September 2010) referred as Phase I.

Part II: Rapid Report

Rapid Report to be submitted on the basis of Phase II (September - October 2010) (Section 1.3.6) studies.

Part III: Comprehensive Report

Comprehensive Report to be submitted on the basis of all the study phases (September 2010 - March 2011)

1.3 Scope of work

As mentioned in Section 1.1, NIO on its own started field observations and sample collection in the Mumbai Bay coastal system during the spill and post-spill periods. This has resulted in acquiring vital data pertaining to water quality, sediment quality and biological characteristics as well as spill-affected intertidal areas and mangroves. Also based on available data on physical processes viz; tides, currents, circulation and bathymetry available with NIO, numerical modelling of the oil spill to predict its probable trajectory and landfall areas was undertaken. The modelling results suggested preferential transport of the oil into the Mumbai Bay with the landfall on the coastline of the Bay. The information generated through these field studies and modelling will be used to select critical areas for assessment of impacts on marine ecology.

NIO has generated a fairly extensive environmental database for the marine ecological status of the Mumbai Bay and adjacent coastal systems for the last two decades. NIO routinely monitors the coastal waters of Maharashtra and Gujarat including the marine environment off Mumbai, under the Coastal Ocean Monitoring and Prediction System (COMAPS) programme of the Ministry of Earth Sciences (MoES) commencing from 1992. This long-term database can be usefully utilized to delineate the changes if any in the marine environmental quality of the Mumbai Bay and adjacent areas due to the accidental spillage of oil and chemicals. In the proposed study the COMAPS stations for which long-term data are available will be also sampled. Spill-affected intertidal areas including those which sustain mangroves will be selected as monitoring sites and will be periodically sampled.

Investigations of marine oil spills worldwide have shown that the water column except in the vicinity of the oiled coastline is freed from the petroleum residues fairly quickly due to various weathering processes such as evaporation, dilution, sedimentation etc. However, the left-over oil which could be fairly high in the present case considering the nature of the spilled oil, would be transported to the intertidal area under high tidal influence where it may get weathered and remain stranded for a much longer duration.

Hence the shore biota of the oiled intertidal areas would be severely affected. Thus, unlike phytoplankton, zooplankton and pelagic fishes which would be freed from the oil pollution relatively quickly, the intertidal biota will be under the influence of oil for a much longer duration.

A significant part of the weathered oil could sink to the seabed thereby increasing its burden in the seafloor sediments. Hence, subtidal benthic organisms could also be exposed to higher concentrations of oil for a longer duration. Therefore, the status of intertidal and subtidal sediments and associated biota will be particularly addressed during the proposed study. Long-term studies subsequent to oil spills have shown that the oil stranded on beaches or in sea floor sediments is biodegraded though the process is slow and the local ecology of the affected areas recovers after a lapse of time – in some instances after a decade or so though the process of recovery commences within a year or so of the spill.

The hazardous substances like chlorinated pesticides, heavy metals, polychlorinated biphenyls etc persist for a long duration in the environment and also bioaccumulate in marine organisms. Furnace oil and pesticides are of concern in the present context. While monitoring of oil in the environment and its impact on biota is straight forward, a similar investigation for pesticides requires the information on its chemical composition if its effect is to be monitored. This is crucial because unlike chlorinated pesticides which are persistent and not easily biodegradable, the commonly used organophosphorus pesticides quickly degrade by hydrolysis on exposure to sunlight, air, and soil. These pesticides are however, highly toxic. Hence, they could have significant and immediate neurotoxicological impact on the marine food chain which needs to be investigated through ecotoxicological studies.

The studies will essentially involve establishment of the pre-accident status based on the available information as well as post-oil/pesticide spill scenario with respect to water quality, sediment quality and biota. The results will be utilized to assess the impact of the oil/pesticide spill on the marine environment of the Mumbai Bay and adjacent coastal area (Figure 1.1.1). To achieve above scope the following studies are proposed:

1.3.1 Physical processes

The data on tides and winds and their role in transporting the miscible (water soluble) and floating pollutants will be evaluated using the predicted tide and local wind as well as available data on current and circulation pattern. A calibrated two dimensional (2D) pollutant dispersion model will be used to delineate the area of spread of pesticides in the water column for a few hypothetical locations and the duration of its persistence. Similarly an oil spill transport model will be used to predict the fate of the spill and its landfall.

1.3.2 Water quality

Water quality will be assessed at about 15 to 20 locations covering the coastal stretch between Bassein and Alibaug. Out of these, 2 to 3 stations will be monitored temporally for 12 h at the interval of 1 h whereas other stations will be spot sampled. The samples collected at the surface and the bottom (wherever the water depth exceeds 3 m) will be analyzed for salinity, Suspended Solids (SS), pH, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Phosphate(PO_4^{3-}-P), Nitrate(NO_3^--N), Nitrite(NO_2^--N), Ammonia (NH_4^+-N), Petroleum Hydrocarbons (PHc) and Phenols.

1.3.3 Sediment quality

Subtidal sediments will be collected from all the water quality stations. Intertidal samples will be collected from 5 to 6 transects from the impact area. Subtidal and intertidal sediments will be studied for texture, selected metals (depending on their content in oil and pesticides), organic carbon, phosphorus, and PHc.

1.3.4 Biological characteristics

The status of flora and fauna of the above subtidal locations will be evaluated based on phytoplankton pigments, population and generic diversity; zooplankton biomass, population and group diversity; macrobenthic biomass, population and group diversity; fishes and mangroves. Intertidal macrobenthos will be assessed from transects selected for intertidal observations. Studies on mangroves will be considered from 2 or 3 critical locations. Selected marine organisms will be studied for accumulation of PHc and pesticides. Experimental trawling will be undertaken at Thane Creek. The catch samples will be used to estimate accumulation of oil and pesticides.

1.3.5 Ecotoxicological studies

Ecotoxicological studies related to neurotoxicological impact on biota, rupture of DNA, and oxidative stress on selective organisms will be considered.

1.3.6 Period of study

Field studies are proposed for a period of 7 months (September 2010-March 2011) with sampling in the study area (Figure 1.1.1) for about 100 days under three phases as per details given below.

Study Period	No of days	Study area	Parameters
Phase II a)September-October 2010 b) October 2010	15-17 10-12	All stations Selected subtidal stations + all intertidal stations	All parameters All parameters
Phase III a) November 2010 b) December 2010 c) January 2011	10-12 15-17 10-12	Selected subtidal stations + all intertidal stations All stations Selected subtidal stations + all intertidal stations	All parameters All parameters All parameters
Phase IV a) February 2011 b) March 2011	10-12 15-17	Selected subtidal stations + all intertidal stations All stations	All parameters All parameters

Note: Initial study conducted during August-September to be considered as Phase I.

: Ecotoxicological and biomonitoring of pollution studies will be also be carried out during the above study period.

1.4 NIO's initiative

The incidence of the collision of MSC Chitra and Khalijia 3 occurred on Saturday, 7 August 2010 at 0937 h. The detailed news and seriousness of the accident was broadcasted and published in the media on Sunday, 8 August 2010. Noting the importance and seriousness of the accident, NIO contacted MPCB on 9 August 2010 and discussed the various options pertaining to the oil spill and intimated the course of action proposed by the NIO including the immediate visit of NIO Scientists to collect water, sediment and biotic samples at the affected sites, wherever possible. NIO also offered its assistance to assess the status of the oil spill.

On Tuesday, 10 August 2010, NIO initiated its own action plan for the investigations. Three teams were deputed for physical verification of the coastal segments and shore based samplings. These teams individually visited spill affected segments (Figure 1.4.1) namely

i) Alibaug – Dharamtar,

ii) Uran - Navi Mumbai, and

iii) Trombay - Colaba - Mahim

On 11 August 2010, the team members of NIO and MPCB had a joint visit to the accident site and assessed the prevailing status of the affected area. On 12 and 13 August 2010, NIO carried out subtidal sampling (Figure 1.4.2) in the Mumbai Bay region. In all, the Series I of the study was carried out between 10 and 13 August 2010. The subsequent studies of Series II (18 – 22 August 2010), Series III (26 - 30 August 2010) and Series IV (6 - 8 September 2010) were undertaken for monitoring the recovery of the affected coastal system.

1.5 Approach strategy for Phase I study

To assess the status of the affected coastal segments of the Mumbai Bay during and post-spill periods in respect of water quality, sediment quality, and flora and fauna consequent to spillage of the oil and release of hazardous chemicals/pesticides, about 22 stations (Figure 1.4.2) in the subtidal environment were sampled and adequately monitored during Series I (Figure 1.4.2). Considering that the ultimate landfall areas of the spilled oil and hazardous cargos would be the shore environment of the Mumbai Bay and adjacent coastal systems, about 15 strategically located and logistically approachable intertidal transects were selected for detailed investigations during Series I (Figure 1.4.1). Also, few locations along the west coast of Mumbai such as Girgaon, Worli, Dadar, Mahim and Juhu were also considered for sampling due to their vulnerability to the oil spill.

During Series II (18 – 22 August 2010), Series III (26 - 30 August 2010) and Series IV (6 - 8 September 2010) studies the sampling locations for both subtidal and intertidal areas were modified based on critical areas identified by the Series I results. Accordingly, the subtidal (16) and intertidal (3-4 transects) sampling locations were considered for regular monitoring.

It was proposed to run a 2D model (Oil Soft) based on available data of physical parameters to predict probable trajectory and landfall areas of the oil spill. It was also proposed to compare the model results with the observed fate of the spill and upgrade the model if required for better predictions.

NIO has generated a fairly extensive environmental database for the marine ecological status of Mumbai Bay and adjacent coastal systems for the last two decades. NIO is also routinely monitoring the marine environment off Mumbai, under the COMAPS programme of the Ministry of Earth Sciences since 1992. This long term database can be usefully utilised to delineate the changes, if any, for impact assessment of the marine environmental quality of Mumbai and adjacent areas due to the recent oil/hazardous cargo spills.

This Interim Report is based on the results of the Series I and II investigations conducted during spill and post-spill period (August 2010) and also supported by available information on Series III and Series IV wherever possible.

2 THE ACCIDENT AND SPILL SCENARIO

2.1 The accident

On 7 August 2010, MSC Chitra (Panama) fully cellular container ship (33113 gt, built in 1980) and MV Khalijia 3 (St Kittls Nevls) bulk carrier (25525 gt, built in 1985) collided at the mouth region of Mumbai Harbour. The accident took place around 0937 h at Lat 18^o 51′ 99′′N and Long 72^o 49′ 03′′E (Figure 1.1.1).

MSC Chitra sailed out of JNPT at 0730 h on Saturday 7 August 2010. She was towed by a tug and escorted by a pilot upto J3, which is the outer limit of JNPT. JNPT pilot turned back as soon as MSC Chitra entered point F2 which is the main channel to the Mumbai Bay and also the entry point to the Mumbai Harbour (Figure 1.1.1).

MV Khalijia 3 was anchored at point W1 (depth of 10 m) off Prong's Light House. Around 0930 h MV Khalijia 3 entered in the main navigational channel heading for MbPT (Figure 1.1.1). Chitra had maintained its outbound course along the channel at 9.5 knots, while the Khalijia 3 after crossing the channel at 2 to 3 knots turned sharpely towards the port and re-entered the channel. On re-entering its bow hit the Chitra (Figure 1.1.1).

It was reported that both the ships were on different frequencies rendering communication impossible. The MbPT tug rescued all 37 crew members and brought them to the port.

Soon after collision Khalijia 3 was brought to MbPT for repairs as its hull portion was damaged (Figure 2.1.1). As a result of collision, the Chitra started tilting and drifting due to rough sea conditions. By 8 August 2010 (1 day), the Chitra tilted 70 to 75^o on the rocky sea bottom near Colaba due to which the onboard containers began falling in the sea (Figure 1.1.3).

The 35 m wide Chitra, a 1980 built vessel with an unladden weight of 33113 t contained about 2662 t of furnace oil, 284 t of diesel and 88 t of lubricating oil onboard at the time of accident. The ruptured tanks of the vessel had about 1200 t of furnace oil on the tilted port side. The rest was at starboard side. It was carrying a total of 1219 containers of which 512 were on ship deck and remaining were in the hold. Among them, 31 containers were loaded with cargo of hazardous chemicals including 6 containers of pesticides. The other cargo was engineering goods, biscuits, medicines, milk powder, coffee/tea packets etc.

2.2 Leakage of oil and its transport

Soon after the accident, oil in fuel tanks started leaking at the rate of 2 to 3 t/h due to rupture in tanks (Figure 1.1.2). However, it was difficult for the Indian Coast Guard (ICG) to find exact location since the port side of the ship was resting on the rocks. It was also difficult to contain the spill due to rough sea conditions.

By next day i.e. on 8 August 2010 the spill covered an area within radius of about 2 nautical miles. The spilled oil affected Navy Nagar area at Colaba to a significant extent (Figure 2.2.1). Hence ICG started the operation to contain the spill. They sprayed dispersants on the spill area in an attempt to disperse the spilled oil on water.

Within 2 days (by 9 August 2010) the shores along Mumbai Bay including mud flats at Sewri, BARC, Mahul, Uran, Elephanta etc were coated by spilled oil to a varying degree (Figures 2.2.2 and 2.2.3). Small oil patches were also reported at Rewas, Mandva, Kihim etc in the Raigad District.

By Monday evening (10 August 2010) the oil leaking from the ship gradually stopped. However, the threat of spillage remained since other fuel tanks were also prone to get damaged due to rocky seabed. By this time, the spilled oil covered 20 km^2 area upto Vashi in the inner Mumbai Bay coating stretches of mangrove habitats (Figure 2.2.4). Vikroli, Bhandup and Airoli located further inland were also affected. The sites along the open coast and south of Mumbai Bay namely Mandva, Pirawadi, Gharapuri, Khardanda, Awas, Kihim, Alibaug were also reportedly hit by the spill. However, the locations along the open coast north of the spill site such as Girgaon, Dadar, Juhu, Manori were visually free from the spilled oil.

On the 4th day (11 August 2010), the situation along Vashi shores worsened with entire mangrove swamps smeared with a thick layer of oil.

The beaches along Sasvane, Mandva etc were worst affected having a 6 cm deep oil coating. The segments which were marginally affected initially were now extensively damaged as more oil reached in the inner segments of the creek. It was reported that no more oil spilled from the ship since 16 August 2010.

2.3 Falling of cargo containers and their fate

The ship was carrying a total of 1219 containers. Of them 707 were in the hold and 512 were on the deck which were vulnerable to go overboard and falling in the sea due to tilting of the ship after the grounding. It was reported that over 120 containers had fallen in the sea.

The details of fallen cargo containers are as follows:

Container (No)	Type of cargo	Details
6	Pesticides	53063 kg: organophosphorus pesticides 10546 kg: pyrethroid pesticides
32	Hazardous chemicals	251000 kg: caustic soda and mancozeb
82	Assorted items	Engineering goods, biscuits, tea, coffee, milk, green beans

The details of organophosphorus pesticides (Items 1 to 4), hazardous chemicals (Items 5 and 6) and pyrothroid pesticides (Items 7 and 8) loaded in the containers are as follows:

1) Dichlorvos formulation: 1120 boxes: 18298 kg
2) Quinalphos formulation (25% ec) : 420 boxes : 4720 kg
3) Acephate 75 sp (lancer) : 200 boxes: 2320 kg
4) Indacloprid, 20 sl formulation: 300 boxes : 2900 kg
5) Mancozeb solid (80% wp) : 1000 bags: 26708 kg

6) Caustic soda (NaOH), solid : 22000 bags : 5,52,200 kg

7) Deltamethrin 5% wp solid : 504 cartons : 9374 kg

8) Deltamethrin (technical), solid : 332 cartons : 6175 kg

Though the rate of falling of the containers was high due to sudden tilting of the ship at 70 to 75^o (Figure 1.1.3), only few containers fell in the sea by 10 August 2010 (day 3) while only one container had fallen on 11 August 2010 (day 4) when the tilting decreased to 50 to 55^o. By 14 August 2010 (day 7) the tilting further improved to 45^o. Some of the containers were connected to each other by chains and were difficult to handle due to size.

The fallen containers experienced different fates. Indian Navy carried out a thorough survey of Mumbai Harbour called 'Operation Pathfinder' using a specialised survey ship to aid in clearing navigational dangers and restoring normal operations in the Mumbai Bay including Mumbai Port Trust (MbPT), Jawaharlal Nehru Port Trust (JNPT), Bharat Corporation Petroleum Limited (BPCL), Hindustan Petroleum Corporation Limited (HPCL) etc. About 10 to 12 containers which were either floating or sinking in the navigational channel (Figure 2.3.1) were retrieved and sent to the port. From 12 August 2010 (day 5) MbPT started an exercise called 'Raasta Saaf' and the ports were partially opened with convoy based navigation escorted by Naval helicopters and a mine sweeper ship with side sonar equipment alongwith two survey boats.

After the fall some containers sank while some of them remained floating and transported due to wave action ultimately hitting the shores (Figures 2.3.2 to 2.3.4). Thus 18 containers reached Navi Mumbai coast while 15 containers hit the coast in the vicinity of Uran. Total 26 pieces were retrieved from the sea. They also hit the mangrove areas (Figure 2.3.3). Some of them got opened during the transport spilling the contents (Figure 2.3.4). For example 40 Aluminium bottles supposedly containing pesticides reached sandy beaches of Nagaon at Uran and Elephanta (Figure 2.3.5). A total of 56 containers have been retrieved from different beaches. Of the 9 containers washed ashore near Pirawadi and Mankeshwar beaches at Uran on 9 August 2010, some were broken spilling packets of milk powder, tea, coffee and green beans (Figure 2.3.6). It is of concern that none of the containers filled with pesticide canisters were retrieved. Some loose containers washed on the beaches were collected by locals. However, there were conflicting reports regarding number of containers. One report states that 250 containers were fallen out of which 189 containers were untraceable including 8 containing hazardous chemicals. One container having hazardous chemicals was secured from the beach. Around 300 canisters containing Ammonium phosphate were salvaged from Alibaug region. A report (19 August 2010) states that out of 293 containers fallen overboard, 10 had sunk, 77 washed ashore, 14 retrieved and 18 were transported ashore at JNPT.

As per report published on 27 August 2010 a salvage operation to stabilize MSC Chitra by unloading the containers from the deck was to be started by 28 August 2010 (Figure 2.3.7). It was supposed to help to get the ship in upright position and stop the falling of the containers. The 300 odd containers were to be removed from the deck and transported to MbPT/JNPT within a week. It was to be followed by stabilization work of the ship by using ballast water to balance the ship. Until then 1200 t of water has been added in two tanks of the vessel.

2.4 Follow-up action by concerned agencies

Soon after the collision two Chetak Helicopters of the Indian Coast Guard (ICG) fitted with TC buckets sprayed nearly 4000 litres of type 3 dispersants to disperse the oil slick. Two Dornier aircrafts from Daman Air Base were monitoring the spread of the oil spill and commissioned five ships for general surveillance and clean-up. Navy operated its helicopters and ships equipped with sonar to search and locate the sunken containers. The BARC was also alerted since their seawater intake was located in the Thane Creek. Singapore based ‘Smit’ began its operations to salvage Chitra.

On 11 August 2010, Chief Minister, Deputy Chief Minister and some ministers, and Government officials of Maharashtra State carried out an aerial survey. The Disaster Management Plan of MbPT was activated on the same day. NEERI and BARC also collected samples for analysis. NEERI was also asked to give a preliminary report by MPCB.

On 12 August 2010 Municipal Corporation of Greater Mumbai (MCGM) which was keeping vigil and check on the seafood brought to the city markets advised citizens not to consume Bombay ducks, mandeli and prawns which were considered to be contaminated. The state department of fisheries of Raigad also advised not to consume fish for some time.

As reported on 12 August 2010, the State Food and Drug Administration (FDA) also collected samples for analysis. The fishermen community pointed out that the ban on fishing during monsoon imposed by the Government of Maharashtra was in force and that the fish sold in the markets was imported from other states and hence free from oil contamination.

On 12 August 2010 Indian Navy began escorting the ships in and out of the harbour and also started carrying out a thorough survey of the Mumbai Harbour under the project called ‘Operation Pathfinder’.

MPCB took the stock of the damage along the Navi Mumbai coast and the Thane Creek and also collected samples of marine flora as well as water samples for further study.

The local Gram Panchayats in Raigad District retrieved the containers transported in the nearshore zone and handed over them to police. The DG (shipping) commenced the retrieval of some of the floating containers using floating cranes.

The State Government instructed the Collectors of Mumbai (City), Mumbai (Suburban), Thane and Raigad to alert the emergency system and collect/remove the oil that hit the shoreline.

The State Fisheries Department advised fishermen not to venture into the sea.

Cleaning operations of the affected beaches were undertaken at Navy Nagar (Colaba), Uran, Elephanta, Alibaug etc by the Indian Coast Guard, local volunteers, Home Guards, National Cadet Corps (NCC), National Social Service (NSS), Fishermen, Indian Oil Corporation (IOC) etc. (Figure 2.4.1). Experts from U.K. and Singapore helped in cleaning operations at Elephanta.

Some dead birds were found coated by oil slick (Figure 2.4.2). Bombay Society for the Prevention of Cruelty to Animals (BSPCA), Parel treated a masked dooby, a migratory bird found injured near Marine Drive, however, it did not survive. On 11 August 2010, two birds a Falcon and a Duck with their wings coated with oil were admitted to the Parel Veterinary Hospital. Coincidentally, a whale shark was washed ashore and ray fishes in good numbers were found dead on the Uran coast during this period.

The Energy and Resource Institute (TERI) was in the process of cleaning oil residue at Awas and Alibaug through bioremediation using ‘Oil Zapper’; a cocktail of bacteria (Figure 2.4.3).

Fishermen claimed that their fishing nets cast in the sea were coated with oil in addition to financial loss since the customers were not willing to buy fish. The contamination of the mangrove habitats was confirmed by the initial reports of the State Government.

The Environment Minister, Government of India assessed that the removal of spilled oil would take at least 45 days. He promised to sponsor programmes aimed at studying the Mumbai’s fragile coastal habitats, marine life and ecology in order to identify the impacts of the spill on marine ecology.

3 STUDY AREA

The available reports and official informations indicated that the coastal regions of Mumbai (openshore and harbour area), and Raigad and Thane districts were affected by the oil spill. Hence the monitoring for the study was confined to the coastal area between Bassein and Alibaug which forms the part of the Mumbai Metropolitan Region (MMR) (Figure 3.0.1).

3.1 Mumbai Metropolitan Region (MMR)

MMR is the largest coastal urban settlement in India extends over an area of 4400 km^2. The region is typical of the Deccan Basaltic terrain with flat top mountains bordering the narrow low lying coastal strip that is traversed by five rivers and many creeks / inlets. Mumbai's historical records indicate that there were several islands around Mumbai City during 1670. Today, these islands have become one continuous landmass, which is known as "Greater Mumbai". There are two major creeks namely Vasai or Bassein Creek towards north and Thane Creek towards South East. The other minor creeks are Manori, Malad, Mahim, Panvel, Nava - Sheva and Dharamtar (Figure 3.0.1).

The general coastal circulation off MMR is dominated by the annual cycle of monsoon winds. The nearshore waters of MMR are subjected mainly to semi-diurnal tides, and there exists an asymmetry in both period and range. The mean tide ranges at Mumbai are 1.6 and 3.9 m during neap and spring respectively. The spatial variability of nearshore currents is considerable due to the presence of rocky outcrops, tidal creeks, bays and islands.

Mangroves are the most important component of MMR coastal ecosystem which prevent soil erosion and provide habitat for aquatic species such as shrimps and fishes as well as for avifauna.

MMR coastal region is considered as the industrial capital of India with around 9000 industries ranging from chemicals, fertilizers, iron and steel, oil refineries and thermal power. The main issues in MMR coastal region are land use pattern, residential and industrial water supply, waste disposal, coastal pollution and depletion of coastal habitats like wetlands and mangroves. As a result, many coastal ecosystems are highly disturbed and seriously threatened encountering problems like pollution, habita destruction, reclamation, siltation, erosion, flooding, saltwater intrusion and many other human induced activities.

Initially the oil spill occurred in the mouth region of Mumbai Harbour and subsequently spread quickly mainly in Mumbai Harbour / Thane Creek (Mumbai Harbour and Thane Creek form the major portion of the Mumbai Bay Figure 1.1.1). Several creeks/estuaries join the Bay discharging large volumes of freshwater during monsoon. Some prominent water bodies are Kalva Creek, Panvel Creek, Karanja Creek, Patalganga Estuary and Dharamtar Creek (Amba Estuary) and coastal area between Mandva and Alibaug. Hence, Mumbai Bay is described in greater details as follows:

3.2 Mumbai Bay

The length of the Mumbai Bay from the mouth to the head, is about 27 km with a width of 15 km at the mouth (off Colaba) narrowing to a few hundred meters at the head represented by the inner Thane Creek (Figure 1.4.2).

Differential weathering of the interlayered soft tuffs and resistant basaltic flows (Deccan Traps) by seawater has created several bays and creeks around Mumbai including the Mumbai Bay. The Bay is V shaped semi-enclosed basin that opens to the Arabian Sea at its southwest approach and connected at its northern extremity to the Ulhas Estuary through a narrow channel (Kalva Creek). The Bay though broad is shallow, forcing frequent dredging to maintain the navigational depths in the channel and at the berths. The water depth decreases in the upstream due to the positive bed gradient and the creek is barely navigable beyond the Vashi bridge for medium size fishing crafts. The tidal inlet of Dharamtar, Nava Sheva and Panvel are the major tributaries to the creek discharging into its eastern shore. Mumbai and Jawaharlal Nehru Ports located within the Bay are the major gateways for India’s import - export and handle over 45 million t traffic annually which includes crude oil and its products, fertilizers, rock phosphate, sulphur, food grains, metals, chemicals, containerized cargo etc.

Mumbai City with a human population density of 25,000 persons/km^2 generates 2200 mld of domestic sewage out of which a considerable volume enters the Bay, largely untreated. The satellite city of Navi Mumbai and other townships in the Vashi-Panvel sector also release sewage to the Bay. Nearly 8% industries of the country are located around Mumbai in 2 large industrial clusters namely, Chembur-Thane-Belapur belt and Kalyan-Ulhasnagar-Ambarnath belt. These industries release their effluents into the Bay / Ulhas Estuary.

3.2.1 Hydrography

The quality of water-spread area of the Bay is mainly influenced by tides which induce flushing and dispersion of pollutants entering the system. The monsoonal freshwater flow, though important in flushing the inner zone, is not high enough to cause significant changes in the hydrography of the outer Bay.

Tides (1.2 - 5 m) in the region are semi-diurnal type with an appreciable diurnal inequality. The flood tidal front advances in north-easterly direction and ebbs to south-west. Variations in the tides in the Mumbai Bay are as follows:

Location	Range (m)		Time lag from Apollo Bunder (min)
	Spring	Neap	
Apollo Bunder	5.0	1.6	-
Pir Pau	4.3	1.4	10-15
Vashi	4.2	1.2	10-30
Airoli	4.9	1.6	12-45
Thane	4.9	1.5	15-60

It is evident that the tidal range markedly decreases upto Vashi as compared to that at the Apollo Bunder but increases in the inner creek and the range at Thane is only marginally lower than that at the Apollo Bunder. This increase appears to be due to the funnel shape geometry of the Bay that is conducive for accumulation of seawater with the advance of the tidal front in the lower creek. The tide at Thane lags by 30 to 45 min with respect to the tide at the Apollo Bunder with the lag more pronounced for the neap tide.

Current speeds and directions within the Bay and associated tributaries are largely due to the tidal movements and show little variation from non-monsoon to monsoon. The maximum current speed in the outer Bay exceeds 1 m/s and the variation in the water column at any given time is not significant. Lateral variations in the speed however occur with current in the eastern area being somewhat stronger. The maximum current speeds decrease in the inner creek and are typically around 0.8 m/s, decreasing markedly during neap tide. As expected for a tide dominated system, the alongshore components are fairly strong with the dominance of seaward component while cross-shore components are relatively weak. Their relative magnitude and directions are indicative of net seaward movement over a tidal cycle though shoreward drift can be significant around the change of tide.

Excursion lengths and average current speeds observed for the Bay based on the available drogue trajectories are as follows:

Tide	Excursion length (km)		Av current speed (m/s)	
	Flood	**Ebb**	**Flood**	**Ebb**
Spring	11.5	11.5	0.5	0.55
Neap	5.5	6.0	0.25	0.3

Excursion lengths during flood and ebb are more or less of a similar magnitude as expected for tidal creeks devoid of large volumes of external water inputs. The overall circulation pattern suggests that the pollutants entering the creek upstream of the bridge at Vashi tend to oscillate within the creek system and flushing to the sea is a delayed process. These pollutants would however be considerably diluted under the influence of tide induced turbulence and advection.

During monsoon however, the creek receives voluminous land run-off and the discharge of near freshwater through the Ulhas estuary, which flushes the inner creek to a large extent.

3.2.2 Water quality

The water quality of the Mumbai Bay would be a balance between the fluxes of pollutants received by the water body and their dispersion by tidal flushing as well as their decay and removal from the water column by processes such as degradation, adsorption on suspended solids, sedimentation and biotic uptake. Although the bulk contaminants through the domestic wastewater are organic matter and nutrients, substantial quantities of heavy metals and PHc are also associated with these releases.

The monthly variations of water temperature in the Bay exhibit a bimodal pattern with maximum during May and October, and minimum during August and February in accordance with the air temperature. Temporal variations are small as expected for tropical areas and changes in the vertical are minor suggesting a thermally well-mixed water body. The average pH in the Bay varies between 7.6 and 8.3 and the variations are random.

The average SS (23 - 53 mg/l) in the Bay is relatively high and renders the waters turbid and muddy. Spatial and temporal trends are not discernible though at a given sampling time the bottom water invariably sustains higher SS. This is because the SS is largely of natural origin and results from the dispersion of fine-grained material from the bed and the intertidal mudflats under the influence of tidal currents and turbulence during rough sea conditions. Markedly enhanced SS can occur during monsoon due to high wind induced turbulence and the values often exceed 200 mg/l in the outer Bay when the measurements coincide with the increased wave activity.

Salinity in the inner Bay is generally low (5 - 25 ppt) during July-September due to influence of freshwater runoff while at the port area it exceeds 30 ppt, except during the days of high precipitation. This results in a longitudinal salinity gradient increasing from Thane at the head to Colaba at the mouth of the Bay. There is a sharp increase in salinity in the inner Bay after the withdrawal of monsoon and values upto 35.7 ppt are common. Salinity then increases gradually in the following months and reaches 37 to 38 ppt from late May to early

June. With the salinity in the middle and outer Bay areas remaining around 36 to 37 ppt, a weak salinity gradient, but in the reverse direction, develops along the length of the creek. Temporal changes in salinity in the port area are minor during dry season though small random variations are possible.

Average DO of about 4.5 ml/l at the Bay mouth decreases progressively in the upstream direction and falls to below 3.5 ml/l at the head of the Bay during August. This decrease is from about 4 ml/l to around 2 ml/l during May at the respective locations. This trend is attributed to the non-availability of oxygen rich monsoon flow during May for the oxidation of organic matter and the increase in temperature decreases the solubility of oxygen and also accelerates microbial mediated oxidation of organic matter. Under the influence of high organic load, the DO seldom exceeds 2.5 ml/l in the interior Bay and values falling below 1 ml/l have been recorded during March-May.

The average concentrations (μmol/l) of phosphorus and nitrogen compounds in the Bay vary as follows:

Segment	PO_4^{3-}-P	NO_3^--N	NO_2^--N	NH_4^+-N
Outer Bay	1.9	24.6	2.8	0.4
Mid-Bay	4.0	40.7	3.8	1.9
Inner Bay	11.0	34.9	22.8	15.3

The concentrations of PO_4^{3-}-P and NO_3^--N in the coastal waters along the Maharashtra coast are generally below 3 and 15 μmol/l respectively while those of NO_2^--N and NH_4^+-N are often below 1 μmol/l. Hence, there is marked enhancement of nutrient levels in the Bay. Their sources can be wastewaters from domestic sectors, fertilizer industries and spillages of fertilizers during unloading operations in the port. It is also evident that the inner Bay area often sustains abnormal levels of NO_2^--N and NH_4^+-N. This is typical of inshore waters under environmental stress. In oxic waters, the nitrite is an intermediate product of bacterial oxidation of ammonia to nitrate. The accumulation of nitrite is an indication of proliferation of *Nitrobactor* bacteria under stress conditions.

These contents however are highly variable in monsoon depending upon the extent of low drainage which has a ability to restrict the ingress of tidal seawater.

The concentrations of PHc and phenols in water do not indicate deterioration in water quality due to these contaminants and their levels are comparable to the nearshore waters along the coast of Maharashtra. The concentrations of PHc even in the vicinity of the Marine Oil Terminal (MOT) at the Butcher Island are low. It is possible that by virtue of high SS and significant tide-generated turbulence the PHc is adsorbed and removed from the water column and swift currents transport the contaminants and distribute them over a wide area.

3.2.3 Sediment quality

Sediment of the Bay is largely derived from weathering of surrounding basaltic landmass. The strong currents sweeping the Bay disperse the fine-grained and poorly sorted sediment from the bed and from extensive mudflats along the intertidal zone into the water column. This fine grained SS can scavenge the trace pollutants entering the Bay and ultimately transfer them to the bed on settling, thus enriching the bed material with pollutants.

The sediment is dominated by montmorillonite, degraded chlorite, illite and to some extent silica. The 10 to15 m thick acoustically transparent clay beds as revealed through shallow seismic reflections indicate recent sedimentation. A yearly load of 8.4 million m^3 of fine grained sediment is estimated to be transported to the central reaches of the Bay via Ulhas, Panvel and Dharamtar creeks. The oscillating tidal movements spread this material fairly uniformly over the 240 km^2 area of the Bay. Based on ^{210}Pb profiles a sedimentation rate of 1.9 cm/y has been established for the inner Bay which decreases to 0.4 cm/y in the outer zone.

The pollutants of major concern are heavy metals and some organic compounds, the concentrations of which even in waters receiving their fluxes are often low and variable making assessment of level of contamination difficult through analysis of water. However, most of such micro-pollutants are adsorbed by the SS in water and transported to the bed on settling of particles. Hence, the concentration of such pollutants progressively increases in sediments of areas receiving their fluxes. It is therefore possible to assess the status of marine environmental quality through analyses of sediment and comparing the observed levels with a suitable background. The constituents considered for the assessment of the sediment quality are heavy metals, C_{org}, phosphorus and PHc.

Natural sediments always carry heavy metals to a varying degree depending on the source rock as well as the environment of deposition. This lithogenic contribution may be taken as a background for assessment of sediment contamination by anthropogenic metals. As the sediment in the Bay is derived from basalts, which are generally rich in heavy minerals, the concentration of some metals may be naturally high in the sediment of the Bay. Based on the concentrations of metals in marine sediment about 15 to 20 km off the mouth of the Bay and off Murud (about 110 km south of Mumbai) it is considered that the sediment in the open Bay area is largely free from accumulation of heavy metals excepting chromium, mercury and to some extent zinc. The concentration of mercury suggested an enhancement (by 3 to 4 folds) in sediment with respect to the baseline value (0.1 µg/g; dry wt) in some zones of the Bay.

The Bay receives 1.8 million kg/d of BOD load through domestic wastewater alone. Part of this organic load gets deposited on the bed when the particles settle. In view of the high BOD load entering the Bay – mainly through sewage, the surficial sediment is expected to sustain high concentrations of C_{org}. However, the C_{org} content in the sediment barely exceeds 2.5%. This load is marginally higher than expected (1 - 2%, dry wt) for nearby unpolluted marine sediments and is much lower than anticipated. It is possible that under tropical temperatures, the excess organic loads are rapidly oxidised and re-mineralised by rich bacterial populations at the sediment water-interface apart from being consumed by detritevorous benthic organisms such as polychaetes and molluscs which thrive in the Bay.

Domestic wastewater is also a potential source of phosphorus to the sediment. However, the observed concentrations indicate insignificant accumulation (770 - 1500 μg/g, dry wt) in basalts of the central west coast of India.

Nearshore sediments along the coast which is free from direct influence from oily wastes, sustain PHc of < 0.1 to 0.3 μg/g (wet wt). The concentrations in the Bay which vary in the range of 0.2 to 10.1 μg/g (wet wt) indicate patchy distribution. The average PHc levels are higher by about 3 times than expected for clean areas. In areas of high PHc contamination, the levels in excess of 10 μg/g (wet wt) and ranging upto 1000 μg/g (wet wt) have been reported particularly around oil terminals. However, even off MOT, the concentrations of 0.3 to 0.7 μg/g (wet wt) have been commonly observed. This may be because; the strong currents prevailing in the Bay may not allow settling the lighter residue which gets transported to a longer distance beyond the mouth of the Bay.

3.2.4 Flora and fauna

The populations of pathogen-like organisms such as total coliforms are markedly high in the interior Bay perhaps due to the influence of sewage releases in the vicinity and their decrease in the eastern segment, as expected.

The availability of nutrients in high concentrations triggers high growth of phytoplankton resulting in an enhanced chlorophyll *a* content of the Bay with the average at different stations varying between 4.6 and 39.2 mg/m^3. Though the concentrations vary over a wide range, the overall trend suggests a decrease in their levels from the interior to the outer Bay. The levels of phaeophytin are generally lower than those of chlorophyll *a* and average is between 0.3 and 14.3 mg/m^3. Hence, the prevailing ecological condition in the Bay is conducive to the growth of phytoplankton even in the presence of high turbidity. Phytoplankton cell counts vary from 103 x 10^3 to 5024 x 10^3/l and indicate the population comparable to the trend exhibited by chlorophyll *a*. Generic diversity is high and varies from 11 to 20 genera averaging at 15 no with the phytoplankton community dominated by *Skeletonema, Nitzschia, Thalassiosira* and *Rhizosolenia.*

Mangroves occur in varying density along the banks of the Thane, Dharamtar, Karanja and Panvel creeks. *Avicennia marina* and *Avicennia alba* are predominant and form thick stands in the more saline regions. The supralitoral regions support mangroves like *Salvadora persica* and obligate halophytes such as *Suaeda maritima* and *Sesuvium portulacastrum*. The mangrove habitats however have been destroyed or degraded in several areas due to human interference. Species like *Bruguiera parviflora, B.gymnorrhiza, Carapa obovata, Kandelia candel, Lumnitzera racemosa, Rhizophora mucronata* and *Sonneratia caseolaris* have either disappeared from many areas or under severe threat of extinction.

Zooplankton biomass varies widely (0.1 – 281.6 ml/100m^3) with high biomass confined to the inner and the middle Bay associated with high phytoplankton production. The average population also varies widely (100 - 779409 no/100m^3) though not necessarily proportionate to the variations in the biomass. In line with the biomass and population, the group diversity also varies widely (4 - 17 no) and randomly. The populations are generally dominated by copepods, cladocerans and decapods often contributing more than 80% to the community. Decapods are higher in number, sometimes contributing more than 10% to the population. They are mainly represented by *Lucifer, Alpheids, Acetes* and zoea. Larvae of economically important species like *Macrobrachium* sp, *Metapenaeus affinis, M.monoceros*, *M.dobsoni* and Palaemonids are only occasionally encountered. The contribution of fish eggs and larvae to the zooplankton population is low and seldom exceeds 0.2%. Within the Bay, *Stolephorus indicus* dominate the larval population followed by *Coilia dussumieri, Johnius dussumieri, Thryssa purava* and *Gobius planiceps*. Other economically important species like *Harpadon nehereus, Ilisha elongata* and Mugilidae are occasionally present.

Macrobenthic faunal standing stock in terms of population (0 – 2850 $10^4/m^2$) and biomass (0 – 12.1 g/m^2, wet wt) at the intertidal segment vary widely. The macrobenthos is dominated by polychaetes and crustaceans over other important groups like molluscs, echinoderms and foraminiferans in the Bay region. In all, about 103 species of polychaetes have been recorded in the intertidal regions of the Bay. In the subtidal zone, the high populations are confined to the interior Bay, while, the dredged areas sustain low macrobenthic standing stock. The faunal group diversity of the subtidal macrobenthos varies between 0 and 6 no with the populations dominated by polychaetes followed by amphipods.

Sassoon Dock and Ferry Wharf located within the Bay contribute more than 60 and 20% to the total fish landings of the Mumbai District and the Maharashtra State respectively. However, fishes are harvested from the open sea and contribution of the fish caught in the Bay to the landings is insignificant. In fact, commercial-scale fishing operations are absent in the Bay.

The Mumbai coast offers assorted intertidal marine habitats (110.5 km^2) like rocky/sandy/muddy and mangroves for a variety of resident and migratory birds. Marine turtles are sometimes sighted along the Mumbai coast and are mainly represented by Logger head (*Caretta caretta*) and Olive Ridley (*Lepidochelys olivacea*). Other turtles like Hawksbill (*Eretmochelys imbricata*), Leather back (*Dermochelys coriacea*) and Green (*Chelonia mydas*) are occasionally sighted. The marine mammals are chiefly represented by Dolphin and Porpoise in the coastal waters of Mumbai though whales are rare.

3.3 Patalganga Estuary

The Patalganga River (Lat $18^o48'$N, Long $73^o40'$E) (Figure 1.1.1) originates from the hilly range of Sahyadri near Khopoli, flows westward through the Khopoli City and ultimately joins to Dharmatar Creek near Kharpada village. The tail-waters of the Khopoli power project are let into the river near Khopoli. Bhogeswari, Bhogwati and Balganga Rivers also join in the southern segment of

Patalganga. Patalganga and Bhagwati are navigable to a short distance by small vessels.

Many industries have been established in the vicinity of the Patalganga River which includes Patalganga Industrial Area and Karjat MIDC. The river is a main source of water supply to these industries and also to nearby villages. However, due to the ongoing industrial and domestic discharges the estuary has become polluted.

3.4 Amba Estuary

Amba River which originates in the Western Ghats follows a narrow and meandering course along her length of over 140 km before opening into the Mumbai Bay (Figure 1.1.1). A Konkan type Bandhara constructed across the river at Nagothane (about 50 Km upstream) impounds the river flow which forms the source of supply of freshwater through the MIDC water supply scheme.

The lower reaches of the river often referred to as the Dharamtar Creek are navigable upto the Dharamtar Jetty by medium size crafts, under all tidal conditions. During dry season when the inflow of freshwater in the Amba Estuary is meagre, the estuary is dominated by ingress of seawater from the Bay during flood tide. Hence, the quality of the Mumbai Bay water would greatly influence the ecology of the Amba Estuary apart from the impact of direct release of effluents in Amba Estuary and outflow from the Patalganga Estuary.

4 MODEL PREDICTIONS

The transport and fate of spilled oil is largely controlled by the meteorological, hydrodynamic, chemical and biological processes as discussed in Section 6.

4.1 Oil spill trajectory

The Integrated Coastal and Marine Area Management Project Directorate (ICMAM-PD), Chennai a body of the Ministry of Earth Sciences (MoES) predicted a preliminary oil spill trajectory and fate of Mumbai oil spill (Figure 4.1.1) on 9 August 2010 through numerical modelling and the same was made available to the Indian Coast Guard and the NIO, RC, Mumbai. The assessment made by ICMAM-PD is summarised below.

ICMAM-PD used an Oil Spill Modelling and Trajectory Prediction System in ”Forecast Mode” to predict the trajectory and fate of the accidental oil spilled on 7 August 2010 at 09:37 h. in the navigational channel of the Jawaharlal Nehru Port Trust (JNPT) and the Mumbai Port Trust (MbPT). After the collision, oil started leaking from MSC Chitra into the coastal waters until 1800 h on 9 August 2010. The spill location was at 72° 49' 1.80" E, 18° 51' 59.40" N which was about 5 nautical miles SW from the Mumbai shoreline (Figure 1.1.1).

A trajectory model (OILMAP) was used for the prediction of movement spreading and direction of the spilled oil, while, the fate model (ADIOS) was utilized to evaluate the weathering processes at spatial and temporal scales. The spill rate of 2 to 4 t/h from 1000 h on 7 August 2010 to 1800 h on 9 August 2010 was considered as reported. Accordingly the model was set for 56 h of continuous oil spill of 174 t of furnace oil No.6 at the rate of 3 t/h. Wind data was obtained from the National Centre for Environmental Prediction (NCEP). Tidal currents were generated using the MIKE 21 model as well as the information available for the Mumbai coast and the Thane Creek. The hourly recorded wind data obtained from the India Meteorological Department (IMD) (Santacruz) was also used in the model.

The oil trajectory simulation was carried out for 6 days. However, under the environmental conditions fed in the model, the spilled oil was predicted to hit the coast at the end of 4 days. The modelled spill moved into the Mumbai Harbour and spread in the creek under the prevailing current stream and wind direction. For the first 24 h, the oil moved towards Uran, Butcher Island and Elephanta Island, and then to the Colaba coast. The next day, the spill also dispersed in the mouth zone of the Mahul Creek and along the northern coast of the creek and spread upto the Trombay area. It also moved further into the creek hitting the mangrove zones around BARC and Navi Mumbai. The predicted movement of the spill was also confirmed by the ICG based on field observations.

The fate analysis suggested landfall of the spill at several locations along the coast on 8 August 2010 (Figure 4.2.1). Under continuous leak of the source, the maximum area covered by the spilled oil was predicted at 52 km^2 at 0300 h on 10 August 2010. Out of the total oil spilled, about 67.1% reached the coast, 11.4% evaporated and only 21.5% remained at sea, at 0300 h on 10 August 2010. This was further reduced to 9% by 1200 h and less than 1% oil remained at sea by 1800 h on 10 August 2010. The details are summarised in following table:

Details of oil weathering and mass balance

Date / Time	Fate			Spilled oil		Spread area (km^2)	Path of slick
	Surface (%)	Ashore (%)	Evaporated (%)	Volume (%)	Quantity (t)		
7/8/2010 12:00 pm	3.5	0	0.1	3.6	6.3	1.8	Towards MbPT
8/8/2010 12:00 am	23.7	0	1.3	25.0	43.5	15.2	Uran shallow waters Butcher & Elephanta
8/8/2010 12:00 pm	39.7	3.7	3	46.4	80.7	36.1	
9/8/2010 12:00 am	27.5	34.9	5.6	68.0	118.3	37.9	Sewri, Mahul, BARC
9/8/2010 12:00 pm	34.6	46.3	8.4	89.3	155.4	37.1	
10/8/2010 12:00 am	25.5	63.6	10.9	100.0	174.0	49.5	Trombay and Navi Mumbai
10/8/2010 12:00 pm	8.4	79.4	12.2	100.0	174.0	30.6	
11/8/2010 12:00 am	0.5	86.6	12.9	100.0	174.0	7.4	~0.25% oil is on sea surface
11/8/2010 12:00 pm	0.2	86.5	13.3	100.0	174.0	3.8	

The results of rapid oil spill trajectory and fate modelling reveals that the predicted trajectory more or less matched the ICG's feedback - that the oil patches reached the Butcher and Elephanta Islands and Uran on 8 August and subsequently to Sewri and BARC.

From the model the impact of oil in the JNPT and MbPT channels, Butcher and Elephanta Islands, Sewri, BARC and Mahul areas were estimated to be 50 to 52 km^2 surface area. The fate analysis suggests that 13.5% oil evaporated and 86.5% oil landed on the coastline within 4 days.

4.2 Modelling by NIO, RC, Mumbai

NIO, RC, Mumbai also carried out predictive modelling of the oil spill with the model domain consisting of the Mumbai Harbour - Thane Creek and associated smaller creeks as well as the coastal area between Versova and Revdanda up to a distance of about 25 km from the shoreline. A two dimensional numerical model Hydrodyn - Oil Soft was used for this purpose.

The bathymetry for the model domain was derived from the NHO Chart No 211 and the tide data for Revdanda and Appolo Bunder were obtained from the Tide Table of the Maharashtra Maritime Board. The other inputs provided were location of the spill; type of spilled oil and its flow rate; and meteorological parameters such as wind speed and direction, air temperature, and atmospheric pressure. The meteorological data used in modelling are presented in Table 4.2.1.

The rate of seepage of oil considered was 3 t/h starting from 0940 h on 7 August and continuing for 72 h.

At the time the leakage started, with the flood tide in progress the spill moved into the creek under the influence of weak currents and westerly winds. As the ebb commenced the spill tended to move slowly towards the mouth but the consistent westerly winds pushed the spreading spill towards north-west to the shores of Colaba.

In general, portion of oil leaked between the HW time and 2 h before HW, hit the Colaba shore. The spill reached mid-level intertidal areas of the western shore of Colaba on 7 August 2010 at 2340 h which was pushed further shoreward on the next high tide and moved into the Mumbai Harbour under favourable wind conditions as evident from Figure 4.2.1. The probable spread and trajectory of the spill at 1040 h on 9 August 2010 are illustrated in Figure 4.2.2. Part of the oil reached Appolo Bunder on 8 August 2010 at 0840 h but did not hit the shore. The spill moved upto the Elephanta Island by 1240 h on the same day. The Alibaug and Uran coasts were affected on 9 August 2010 at about 1040 h and also hit the Nava Sheva coast at around 1240 h on the same day.

Runs were continued for another week without any fresh oil entering the sea but tracking the total spill that occurred during 7 to 10 August 2010. The movement of the oil after 10 days from the start of the spill is illustrated in Figure 4.2.3 which indicates the extent of the coastline affected by the oil.

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Under the prevailing meteorological conditions the total area of the film floating on water surface would cover an area of 2.5 km^2 after 3 days. However, the area affected by the oil spill was to the tune of 50 to 60 km^2 as the patches traversed long distances under the influence of the tidal increments. This floating oil amounted to 138 t with an average thickness of 0.06 mm. However, in reality the spill would break into several patches under the prevailing environmental conditions. The weathering during these 3 days is presented in Figure 4.2.4. After 5 days of plugging the leak the spread increased to 3.3 km^2 and the floating oil quantity was reduced to 54 t with an average thickness of 0.01mm. The weathering processes are presented in Figure 4.2.5.

Comparison of the results predicted by the model with the post-spill field observations indicated that the reported oiling of the shore areas at many locations matched fairly well. However, certain locations in the inner Thane

Creek for example oiling of intertidal zone of Trombay were not indicated in the model output. This discrepancy could be due to reasons such as changes in bathymetry in the shallow areas and consequent changes in current regime and/or change in local wind regime in time and space.

4.3 Further study

Future study is aimed at the calibration of model for hydrodynamics such as currents so that the currents simulated by the model are matched with the observed currents. Further, the model results will be verified with the actual field observations with respect to the concentrations of PHc (dissolved and dispersed). Quantities in terms of fate processes (evaporation, dissolution, emulsification etc) alongwith the shore deposition will also be estimated.

A hypothetical leakage of a water soluble pesticide such as acephate on the seafloor will be modelled for different scenarios to assess the areas of concern in which the concentration of the pesticide would be above the lethal level. A 2D water quality model will be used to make the predictions.

5 STUDIES CONDUCTED

The details of selection of sampling locations and their positions are described below.

5.1 Vulnerable areas and sampling strategy

NIO has been conducting monitoring of the Mumbai Bay including Thane Creek since 1992. Hence, an adequate database on the environmental status of this region is available.

Subsequent to the oil spill, NIO in association with MPCB, conducted physical verification of spill affected beaches and the bay waters. As discussed in Section 4 an oil spill in the mouth region of the Bay during monsoon when the onshore forcing is dominant, would be transported in the inner zones. Based on the spill track predicted through numerical modelling (Figures 4.1.1, 4.2.1 to 4.2.5), the NIO listed around 15 vulnerable sites along the coastal segments of the Mumbai Bay and adjacent area for sampling of intertidal zones (Figure 1.4.1). Some of the critical areas are Colaba and Trombay which are located along the east coast of the Mumbai Bay; Vashi in the inner Thane Creek; Mandva, Kihim and Alibaug which are situated along the open coast south of the Bay; Uran, JNPT are along the north east coast of the Bay. These include rocky and sandy beaches, mangrove areas and other areas which are logistically accessible. Sampling stations in the subtidal zone were so selected that they would be along the predicted path of progressive transport of the spill. Accordingly, 22 subtidal stations from the mouth of the Mumbai Bay (spill site) to the inner segment of Thane Creek (Vashi) were sampled (Figure 1.4.2).

Though there were no reports of oil contamination of the intertidal zone along the west coast of Mumbai, a few intertidal sites in this stretch namely Girgaon, Dadar, Mahim, Juhu etc were included for sampling just in case the stray oil patches are transported northward contaminating the region(Figure 1.4.1).

A subtidal station in Mumbai Bay was also considered for sampling over 12 h so that variation in the contamination of PHc due to the spill transport by the reversing tide could be studied.

5.2 Baseline for comparison of post-spill scenarios

NIO has been investigating the Mumbai Bay and its associated creek systems at number of locations with respect to water quality, sediment quality and biota since 1992. Since the spill occurred during monsoon, it was considered prudent to use the data sets of recent monitoring conducted in September 2009 as the baseline to assess changes in the ecology, if any, due to the spilled oil.

Hence, the data generated on water quality, sediment quality, and flora and fauna on the basis of the observations recorded during September 2009 were compiled and collated with the findings of the post-spill monitoring to ascertain changes in the marine environmental quality of the region due to the impact of the spilled oil and hazardous chemicals.

5.3 Sampling period and locations

A total of 22 subtidal stations and 15 intertidal transects (Figures 1.4.1 and 1.4.2) were monitored during 4 Series of sampling Series in phase I of the study as given below.

Sampling Series	Period
I	10 to 13 August 2010
II	16 to 21 August 2010
III	23 to 28 August 2010
IV	1 to 9 and 24 September 2010

The station/transect positions with respective dates of sampling are as follows:

Intertidal locations

Transect	Transect	Position	Date			
			Series I	Series II	Series III	Series IV
I	Alibaug	18^{0}38’38.8”N 72^{0}52’10.6”E	10/08/10	20/08/10		
II	Kihim	18^{0}43’22.2”N 72^{0}51’48.8”E	10/08/10			
III	Dighodi	18^{0}48’16.1”N 72^{0}52’10.8”E	10/08/10			
IV	Mandva	18^{0}48’15.71”N 72^{0}52’51.4”E	10/08/10	20/08/10		
V	Dharamtar	18^{0}42’12.3”N 73^{0}01’44.0”E	10/08/10			
VI	Uran 2	18^{0}51’28.4’N 72^{0}55’24.3’E	10/08/10		23/08/10	
VII	Uran 1	18^{0}51’58.8”N 72^{0}55’21.4”E	10/08/10		23/08/10	
VIII	JNPT	18^{0}55’43.4”N 72^{0}57’12.5”E	10/08/10			
IX	Vashi	19^{0}03’49.9”N 72^{0}58’39.3”E	10/08/10 12/08/10	16/08/10 19/8/10	23/08/10	01/09/10 07/09/10
X	Trombay	19^{0}01’39.4”N 72^{0}57’11.4”E	10/08/10 12/08/10	16/08/10 19/08/10		01/09/10 07/09/10
XI	Colaba	18^{0}54’20.5”N 72^{0}48’11.9”E	10/08/10 13/08/10		25/08/10 27/08/10	24/09/10
XII	Girgaon	18^{0}57’12.7”N 72^{0}48’47.2”E	10/08/10			
XIII	Dadar	19^{0}01’48.10”N 72^{0}50’12.7”E	10/08/10			
XIV	Mahim	19^{0}02’36.4”N 72^{0}50’13.9”E	10/08/10			
XV	Juhu	19^{0}05’46.2”N 72^{0}49’35.3”E			23/08/10	25/08/10

Subtidal locations

Station	Position	Date			
		Series I	Series II	Series III	Series IV
1	18^0 52'11.5" N 72^0 49'09.3" E	13/ 8 / 2010	21 / 8 / 2010	28 / 8 / 2010	8 / 9 / 2010
2	18^0 52'47.1" N 72^0 50'14.0" E	11 / 8 / 2010	20 / 8 / 2010	27 / 8 / 2010	8 / 9 / 2010
3	18 53'04.7" N 72^0 50'58.5" E	11 / 8 / 2010	-	-	-
4	18^0 53'21.9" N 72^0 51'09.7" E	11 / 8 / 2010	20 / 8 / 2010	27 / 8 / 2010	8 / 9 / 2010
5	18^0 57'20.9" N 72^0 55'05.2" E	13 / 8 / 2010	19 / 8 / 2010	26 / 8 / 2010	6 / 9 / 2010
6	18^0 57'45.0" N 72^0 54'48.6" E	12 / 8 / 2010	-	-	-
7	18^0 57'49.2" N 72^0 54'32.2" E	12 / 8 / 2010	-	-	-
8	18^0 58'24.8" N 72^0 55'21.1" E	12 / 8 / 2010	-	-	-
9	18^0 58'29.0" N 72^0 55'37.7" E	12 / 8 / 2010	-	-	-
10	18^0 58'40.5" N 72^0 55'58.6" E	13 / 8 / 2010	-	-	-
11	18^0 58'52.5" N 72^0 55'34.9" E	12 / 8 / 2010	19 / 8 / 2010	26/8/2010	6 / 9 / 2010
12	19^0 01'11.55" N 72^0 57'48.06" E	12 / 8 / 2010	18 / 8 / 2010	25 / 8 / 2010	7 / 9 / 2010
13	19^0 02'37.0" N 72^0 58'38.0" E	13 / 8 / 2010	18 / 8 / 2010	25 / 8 / 2010	7 / 9 / 2010
14	19^0 03'55.0" N 72^0 58'10.0" E	12 / 8 / 2010	18 / 8 / 2010	25 / 8 / 2010	7 / 9 / 2010
15	19^0 04'31.2" N 72^0 57'27.9" E	12 / 8 / 2010	18 / 8 / 2010	25 / 8 / 2010	7 / 9 / 2010
16	19^0 06'04.5" N 72^0 58'14.3" E	-	18 / 8 / 2010	25 / 8 / 2010	8 / 9 / 2010
17	19^0 00'02.9" N 72^0 56'49.3" E	-	19 / 8 / 2010	26 / 8 / 2010	6 / 9 / 2010
18	18^0 59'46.8" N 72^0 59'25.5" E	-	19 / 8 / 2010	26 / 8 / 2010	6 / 9 / 2010
19	18^0 58'44.6" N 72^0 52'34.6" E	-	19 / 8 / 2010	26 / 8 / 2010	6 / 9 / 2010
21	18^0 56'32.9" N 72^0 51'38.0" E	-	20 / 8 / 2010	27 / 8 / 2010	8 / 9 / 2010
22	18^0 55'01.0" N 72^0 53'53.4" E	-	20 / 8 / 2010	27 / 8 / 2010	8 / 9 / 2010
23	18^0 54'03.9" N 72^0 54'29.6" E	-	20 / 8 / 2010	27 / 8 /2010	8 / 9 / 2010

5.4 Sampling frequency and methodology

Station 13 was sampled for 8 h (Series I) and 7 h (Series II) with 1 h sampling frequency for water quality (temperature, pH, salinity, DO and nutrients) while chlorophyll *a* and zooplankton were collected every 2 h. BOD, SS, phenols, TP/TN, PHc were collected during low and high tides. Surface sediment samples at each subtidal station and intertidal transect were collected only once. Other stations and transects were spot sampled in duplicate for water quality (temperature, pH, DO, nutrients) and sampled once for PHc, BOD, SS, phenols and TP/TN, while chlorophyll *a* and zooplankton samples were collected in duplicate. Samples for phytoplankton (surface, bottom), benthos (quadruplets) and bacteria (surface water and sediments) were also collected.

Sampling for all parameters was conducted using recommended procedures as follows:

Sampling methodology

A Niskin sampler (5 l capacity) was used for collecting sub-surface water samples. Sampling at the surface was done using a polyethylene bucket. Water samples for PHc were collected at 1 m below surface.

For the analyses of metals, P, C_{org}, PHc and benthos subtidal sediment samples were collected using a van-Veen grab of 0.04 m^2 area. The samples after retrieval were preserved for analyses in the shore laboratory.

For microbiological analysis, surface water was collected directly in a sterilised glass bottle. Sediment sample was obtained using a van-Veen grab and transferred directly into sterilised polyethylene bag.

The samples for estimation of chlorophyll *a* were kept in ice box immediately after collection on board. Phytoplankton samples of 500 ml were preserved in Lugole's solution.

Oblique hauls for zooplankton were made using a Heron Tranter net (mesh size 0.2 mm, mouth area 0.25 m^2) provided with a calibrated digital flow meter. All collections were of 6 min duration. Samples were preserved in 5% formalin.

5.5 Analysis of samples

Measurements for nutrients were done on Shimadzu UV Mini 1240 spectrophotometer. Chlorophyll was estimated using Turner Design Fluorometer and PHc was estimated on Shimadzu, RF5301 PC flurospectrophotometer.

Recommended oceanographic procedures were followed for analysis of samples.

5.6 Work-up and analysis of PHc

5.6.1 Seawater

Water sample (1 l) was extracted with hexane and the organic layer was separated, dried over anhydrous sodium sulphate and reduced to 10 ml at 30^{o}C. The intensity of the extract was measured at 360 nm (excitation 310 nm) with Saudi Arabian Mix Crude residue (stabilized at 100^{o}C for 30 min) (SAM) as a standard using fluorescence spectrophotometer. The concentrations are expressed as SAM equivalents.

5.6.2 Sediment

Sediment (~ 100 g) was refluxed with KOH-methanol mixture and extracted with hexane. Then the residue was subjected to clean-up procedure by alumina column chromatography and the PHc content was estimated by measuring fluorescence using SAM standard as described above.

5.6.3 Biota

Tissue preserved at -20^{o}C was thawed and homogenised. It was saponified using KOH-methanol mixture, centrifuged and filtered. The filtrate was extracted with n-hexane, organic layer washed with distilled water, dried, evaporated to a small volume, chromotographed on alumina and fluorescence measured as described above.

6 BEHAVIOUR OF OIL AND HAZARDOUS CHEMICALS WHEN SPILLED

At the time of collision MSC Chitra was carrying diesel (284 t), lubricating oil (88 t) and furnace oil (2662 t) on board. It was also loaded with some containers having organophosphorus pesticides, pyrothroid pesticides and hazardous chemicals. Because of spillage of oil and containers going overboard subsequent to the accident, it is necessary to understand the behaviour of oil and concerned pesticides and chemicals on entering the marine environment. Hence, their general behaviour in marine environment is described below.

6.1 Oil

Oil is a general term used for crude oil, its products and residues. The products include petrol, diesel, kerosene, furnace oil etc. Lubricating oils also belong to petroleum group but several additive chemicals are mixed to them to get selective lubricating properties.

Behaviour of oil when spilled in a marine environment largely depends upon physico-chemical characteristics of the oil, weathering processes working on it and their cumulative effect, meteorological factors, toxicity of the oil, geographical and physical status of a water body where the oil is spilled, and quantity and rate of the spillage.

6.1.1 Physico-chemical characteristics of oil

Some of the vital physical factors that influence the fate of spilled oil are boiling point range, pour point, API gravity (specific gravity), viscosity etc.

A low boiling product such as petrol would evaporate almost completely while a small fraction of a high boiling oil such as heavy fuel oil would evaporate leaving behind a non-degradable residue. A product having low pour-point and low viscosity namely petrol is a thin liquid that would spread on the water surface effectively further aiding other weathering processes. Denser liquids having specific gravity (lower API gravity) comparable to water have a tendency to sink particularly when get associated with suspended particulate matter.

General composition of oil is as follows:

a) Aliphatic hydrocarbons: Aliphatic hydrocarbons are straight chain saturated compounds, related to methane and ethane, and iso-alkanes, which are branched chain compounds like isobutene and isooctane. The compounds with 5 to 7 C atoms are liquids and those having higher number are solids. The paraffin waxes (C_{22} - C_{30}) and petroleum jelly (C_{30} - C_{70}) are the higher homologs of paraffins.

b) Alicyclic hydrocarbons: The alicyclic hydrocarbons are saturated (cycloalkanes) or unsaturated (cycloalkenes) containing 5 to 6 C atoms arranged in a ring. They are also known as naphthenes and comprise 30 to 60% of petroleum with the dominance of saturated forms. Some naphthenic hydrocarbons found in petroleum are cyclobutenes, limonenes, cyclopentenes, cyclohexenes etc.

c) Aromatic hydrocarbons: Aromatic hydrocarbons which are one, two or polycyclic type, comprise around 25% of the total crude oil. Some members of aromatic hydrocarbons are benzene, toluene, naphthalene, biphenyl, 1, 8-dimethyl phenanthrene, 3-methyl chrysene, 1-methyl pyrene, perylene, 3,4 - banzo [a] pyrene, banz [a] anthracene, acenaphthene, acenaphthylene, anthracene, fluorine, 2-methylnaphthalene etc.

d) Non-hydrocarbons: The major non-hydrocarbons are organic compounds containing N, S and O (NSO) and metals like Ni, V, Cu, Zn and Fe. Contribution of non-hydrocarbons to a oil varies from 2 to 50% and origin of a crude oil largely influences the composition of these constituents. The O compounds are generally in the form of phenols, carboxylic acids, ketones, esters etc. The N compounds include substituted pyrine and quinoline compounds, pyrroles, indoles, carbozones and benzcarbazones. Most of the sulphur in crude oil is present as methyl-ethyl sulphite, cycloalkyl thiol, n-pentyl mercapton etc. Most abundant metals namely Ni and V are found in the form of petroporphyrin complexes and occur in the range of 0.03 to over 300 µg/l in crude petroleum.

The chemical characteristics that influence the behaviour of an oil spill is composition i.e. type and percentages of hydrocarbons, non-hydrocarbons and insolubles present in the oil. For example aliphatic and aromatic hydrocarbons are hydrophobic and lowly soluble, hence have little tendency to mix, dissolve and disperse in the water column. Non-hydrocarbons however form part of the water column as they are soluble in water. The insolubles on the other hand would persist for a long time forming part of a residue on seabed and beaches.

6.1.2 Weathering processes

Once oil enters the sea, several processes start acting simultaneously resulting in alteration in its physical and chemical properties. These processes include spreading, drifting, evaporation, dispersion, dissolution, emulsification, photooxidation, microbial degradation and sedimentation (Figure 6.1.1). Though each process has a typical effect, the resultant impact is generally a cumulative one. Evaporation and dissolution are the two major processes, which are mainly responsible for removing major fraction of spilled oil from the marine environment in case of lighter products. Thus, both together can remove more than 90% of hydrocarbons lighter than n-C_{10} within few hours of spill occurrence.

a) Spreading: Spreading of crude oil on the water surface begins as soon as oil spills into the sea and largely depends upon volume of oil and its physical characteristics namely density, viscosity and pour point. The environmental factors such as wind velocity, current and temperature also influence spreading. The four main physical forces influencing spreading on a calm seawater surface are gravitation force, surface tension, inertia and frictional or viscous drag force. Aromatic and aliphatic hydrocarbons with < 9 C atoms have greater tendency to spread while compounds with higher molecular weights do not tend to spread on water.

Spreading accelerates evaporation leading to increase in viscosity and pour point of the residue. Presence of NSO compounds in petroleum also facilitates dissolution and once soluble compounds are lost, spreading decreases considerably.

b) Drift: Drift is a large-scale phenomenon that determines the movement of an oil spill and is primarily controlled by wind, waves and surface currents. Thus for instance, when the wind velocity is the determinant force in drift movement, a slick can move at a rate of 3% of the wind velocity in the same direction as that of the wind. However, prediction of drift of a spill on the basis of wind pattern alone is difficult because of the current and wave perturbations.

c) Evaporation: Evaporation is the major process that removes the low boiling components of petroleum from the sea surface. The composition of oil and its physical properties, wind velocity, air and sea temperatures, turbulence, intensity of solar radiation and surface area of the spill, all affect evaporation rates of hydrocarbons.

Evaporation rate for a specific hydrocarbon is a function of its vapour pressure, which in turn is inversely related to the molecular weight. The compounds with vapour pressure greater than that of n C_{18} do not persist in a spill for longer period while those with lesser vapour pressure do not evaporate appreciably. Under normal conditions losses of aromatic hydrocarbons by evaporation are 100 times greater than losses by dissolution and that the evaporation rate for aliphatics may be 10,000 times greater than their rate of dissolution. Loss of volatile hydrocarbons, mostly by evaporation, increases the density and kinematic viscosity of the residual oil resulting in break-up of the slick into smaller patches. Agitation of these patches enhances incorporation of water due to increased surface area resulting in water-in-oil emulsion called as chocolate mousse.

d) Dissolution: Dissolution is another physical process in which, the low molecular weight hydrocarbons as well as polar non-hydrocarbon compounds are lost to the water column. Rate of dissolution for various constituents of oil depends on several factors such as their properties (molecular structure) and their relative abundance as well as the physico-chemical characteristics of the environment (salinity, temperature, turbulence etc). The water solubility of hydrocarbons drop drastically as one goes to higher carbon numbers.

Branched alkanes demonstrate greater solubility for a given carbon number than their straight chain counterparts. Ring formation also enhances solubility for a given carbon number or molar volume. The degree of saturation is inversely proportional to solubility for both chain and ring structures. The solubility is also inversely related to the molecular weight of the hydrocarbons within each group. The addition of a second or third double bond increases the solubility proportionately and the presence of a triple bond increases solubility to a greater proportion than presence of two double bonds.

e) Dispersion and emulsification: Dispersion, mechanical action of breaking waves and turbulence in the water flow cause the spilled oil to break-up into small droplets which diffuse in the water column to form oil-in-water emulsions. Oil begins dispersing immediately on contact with water and the process is most significant during the first 10 h or so. Once emulsion is formed, the particles continue to break further and by 100 h dispersion usually overtakes spreading. Although, such oil-in-water emulsions are not very stable in natural aquatic environment, they are considerably stabilized by the suspended particles, natural or added emulsifiers or dispersants. Unsterilized particles tend to resurface and again form into a slick. The fate of oil-in-water emulsion appears to be dispersion in the water column or association with solid particulate matter or detritus and eventual biodegradation or incorporation in bottom sediments.

Water-in-oil emulsion formed during weathering tends to be more coherent semisolid lumps called “chocolate mousse”. Experimental and limited field studies have shown that these persistent emulsions contain roughly 80% water and bacteria or solid particulate matter do not seem to be required for their formation. Also, the rate of formation of emulsions under comparable conditions varies dramatically with the nature of crude oil.

f) Photooxidation: Several petroleum hydrocarbons present in spilled oil degrade in presence of sunlight and oxygen into polar hydroxyl compounds such as aldehydes, alcohols, ethers and ketones and finally to lower molecular weight carboxylic acids. As these products are hydrophilic, they change the solubility behaviour of the slick. Photoxidation is inversely proportional to the film thickness and directly proportional to the wave length of incident light. It is a slow process and may take days to weeks to obtain significant results. Such reactions occur more rapidly in aromatic and branched chain aliphatic hydrocarbons than straight chain aliphatic hydrocarbons.

g) Biodegradation: Biodegradive processes influencing the fate of petroleum in aquatic environment include microbial degradation, ingestion by zooplankton and uptake by aquatic invertebrates and vertebrates.

Microorganisms, capable of oxidizing petroleum hydrocarbons and related compounds, are widely spread in nature. Over 200 species of bacteria, yeast, and filamentous fungi are known to metabolise one or more hydrocarbon compounds ranging in complexity from methane to compounds of over 40 C atoms. Microorganisms utilize oil as a source of carbon and energy, ultimately degrading oil to CO_2 and water. The rate of microbial degradation varies with chemical complexity of the crude, microbial populations and environmental conditions. The degradation by naturally occurring population of microorganisms in the aquatic environment is generally slow and their impact on the oil spill may be noticeable after some duration. However, 40 to 80% of a crude oil spill can be biodegraded by microororganisms. Alkanes and cycloalkanes degrade faster than Polycyclic Aromatic Hydrocarbons (PAHs). Thus, the concentrations of oxygenated compounds may increase by 3 times after about 4 weeks of microbial reactions.

h) Sedimentation/agglomeration: Most oils when spilled undergo processes of transport and weathering, which increase the density of oil on the sea surface. Hence, heavier fractions of oil are more likely to sink or remain suspended in the water column. Oil and sand when mixed together by wave action causes the oil to sink by incorporation of particulate matter and even by incorporation of high-density organisms, such as barnacles. Some heavy crudes are however, denser than seawater and immediately sink to the bottom after a spill.

Oil sinking offshore or in coastal waters is subject to movement due to oceanic and coastal currents, tides, up-welling, down-welling, density currents and littoral processes. Asphaltenes, the highest molecular weight compounds, persist with little alteration to form tarry residues that ultimately settle to the seafloor or become stranded along coastlines or on adjacent beaches, after storms.

A loss of low boiling constituents also would result in increase in density of the spill which would eventually sink as soon as its density becomes more than that of water has. This process is accelerated by incorporation of spill particles with the suspended matter which generally originate from the bed sediment.

The capacity of a certain oil to sink as a function of their weathering is also a function of its composition which determines the specific gravity/density. Thus denser oils have more tendencies to sink during the weathering processes. Generally oil sinks after extensive modifications which are the cumulative effect of all weathering processes. Mostly the dispersed portion of the spill would initially incorporate with suspended particles and would settle while chocolate mousse would require more residence time to sink due to increase in density. Generally, petroleum products do not form chocolate mousse.

Coating of birds and fish that would get entangled with the slick would be immediate threat to the biota in the spill area. Bioaccumulation of the dispersed/dissolved portion is the major route that would affect the biota negatively leading to high mortality in initial stages. Though most of the ingested portion would be eliminated in the feces and would return to the water column, part of it would associate with tissues and gut permanently.

The above discussion implies that (i) contamination of water column, (ii) beach pollution and (iii) ingestion by biota and coating of animals leading to mortality are the major areas of concern in a event of spill taking place in a marine environment.

6.1.3 Metereological factors

Metereological factors namely wind, air temperature, rain etc have greater impact on fate of the oil spill in marine environment. For example, wind directs movement of oil slick and facilitates in removing the lighter fraction in the spilled oil while high air temperature causes increase in evaporation rates of the constituents in the oil. Rains however have a negative effect resulting in re-entry of the vaporised portion of the oil onto the earth. Aerosoles are known to be formed because of association of vaporised fractions with dust and moisture aided by lower temperatures. Winds also help spreading and drifting of oil slicks.

6.1.4 Impact on flora and fauna

Toxicity of an oil mostly falls in two general categories. The first category includes effects associated with coating or smothering of an organism with oil. Such effects are associated primarily with the higher molecular weight, water-insoluble hydrocarbons. In the event of a spill of crude oil and very high boiling residues, the various tarry substances that coat the feathers of birds and cover intertidal organisms such as clams, oysters, and barnacles belong to this variety. Although some organisms such as tubeworms and barnacles are surprisingly little affected by such coatings, the effect on organisms such as aquatic birds can be devastating.

The second category of toxicity involves disruption of an organism's metabolism due to the ingestion of oil and the incorporation of hydrocarbons into lipid or other tissues in sufficient concentrations to upset the normal functioning of the organisms. This is due to the cumulative effect of the individual constituents present in an oil. It is generally agreed that aromatic hydrocarbons are the most toxic, followed by cycloalkanes, then olefins, and lastly alkanes. There is also a definite tendency for toxicity to be positively correlated with the molecular size of the hydrocarbons.

Most toxic effects caused by ingestion of oil in water, however are believed to be due to low molecular weight (C_{12} – c_{24}) alkanes and low molecular weight aromatics.

6.1.5 Geographical and physical status of a water body

When oil spills at high seas and away from the shore, it can have higher exposure to weathering processes namely spreading, drifting, evaporation, dissolution, dispersion, emulsification etc before it hits the coast. Hence, if such spills are small, they are likely to weather and sink before the landfall thereby sparing the intertidal biota from toxic effects of the spill. On the contrary, oil spilled nearshore and in a semi enclosed water body such as estuary, creek, bay and lagoon can hit the coast within minutes to hours depending on the location of the spill and environmental conditions. Once on the coast it would persist for a longer duration until removed physically or by natural processes. In high energy zone and rough sea conditions, the spill washed ashore would re-enter the water and would be removed after several tidal cycles. In low energy zone, however the oil would persist for long time. Similarly, at sandy/silty beach the spilled oil would penetrate deeper in the sediment aided by tide and wave action. At a rocky beach however, it may re-enter the sea if the wave action is high but in a low energy zones it would form coating on rock surface and also would persist for longer duration in water pools/ditches in between the rocks.

6.1.6 Quantity and rate of spillage

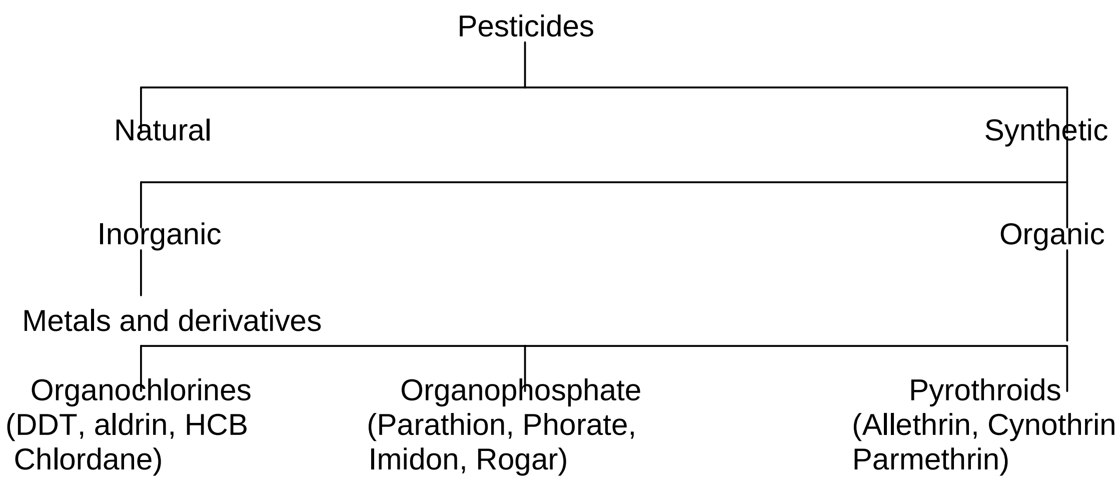
It is obvious that when oil is spilled at a high rate and in large quantity, it could have disastrous effect on the marine ecology as it would be difficult to contain the spill due to its large size. Such spills form large patches of few square kilometre area or several fragmented patches in several square kilometre area. While a spill in small quantity and at a low rate can be easily contained and recovered.

Large spills of crude oil and high boiling products generally form large patches which restrict air - water interaction. Smaller spills and that released at a slow rate are broken into small patches which can be recovered more easily. Slicks of such spills may be drifted as isolated patches in different directions depending upon tide and currents at the time of their release.

6.2 Pesticides

Pesticide is a general term applied to any substance intended for preventing, destroying, repelling or mitigating any pest. It is also called as insecticide.

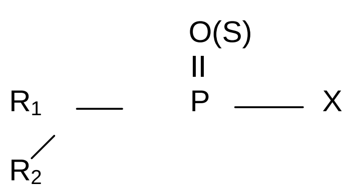
Pesticides are classified as follows:



Though Organochlorines were used extensively in India, their wide-scale applications have been stopped after India became signatory to the Stockholm Convention on Persistent Organic Pollutants. In recent years the use of synthetic phyrothroids has increased due to their low persistence, low side effects and high potency.

6.2.1 Organophosphorus pesticides

The pesticides loaded on the ship belong to a class of organophorus pesticides. They are synthetic and normally the derivatives of phosphoric / phosphonic / phosphorothioic / phosphonothioic acids. Their general structure is



Substituation in the side chain 'x' changes their reactivity and toxicity. They are solids or semi solids with varied colours depending on the side chain.

Generally, they are slightly soluble in water and have high oil-water co-efficient, low vapour pressure and low volatility. On oxidation they produce higher toxic forms while their hydrolysis yield water soluble compounds which are non-toxic. They are freely soluble in most of the polar organic solvents. They are marketed as emulsificable concentrates, mettable powder, formulations, granules, fogging formulations, smokes etc. Most of these liquid formulations are inflammable and miscible with water. They are used to control insects vectoring which are found in food, commercial crops and infestations in domestic and commercial buildings and in man and domestic animals. They are highly toxic to man with LD_{50} of 5 mg/kg to 0.5 - 5 g/kg. Though true chronic poisoning following exposure does not occur, they are rapidly transformed and excreted. Their acute intoxication or chronic exposure may lead to long term or delayed effects such as inhabitation of cholinesterase by phosphorylation. The detoxication route is hydrolysis when they are exposed to sunlight, air and soil.

Organophosphorus pesticides are known to be sufficiently stable to reach marine ecosystem after agricultural use. They are toxic to invertebrates and vertebrate aquatic animals even at nanogram per litre concentrations. Shrimp and fish are particularly sensitive to them.

a) Dichlorvos: Dichlorvos is colourless to yellow liquid with boiling point of 74^{o}C. Its chemical name is 2, 2 - dichlorovinyl dimethyl phosphate ($C_4\ H_7\ CI_2\ C_4$ P). It is denser than water with the density of 1.314 g/ml. This highly volatile liquid is stable to heat but hydrolysed by water at the rate of 3% per day and the rate is high in alkaline water. It is corrosive to iron and steel.

Dichlorvos is highly toxic and WHO termed it as highly hazardous. It is known to inhibit enzyme cholinesterase, and disrupts nervous and muscular systems. The pesticide is mainly useful to control household pests and protecting stored products from pests. LD_{50} for Goldfish is reported to be 10 to 40 μg/l (48 h).

b) Acephate: It is a colourless to white crystal form having melting point of 90 to 91^oC. Chemically it is 0, S dimethyl-acetyl phosphoramidothiote ($C_4H_{10}NO_3PS$). It is denser than water and its water solubility is 79 g/100 ml. Acephate is also highly soluble in polar organic solvents.

It is available in following formulations: wettable powder, soluble powder, soluble extruded powder, granules, water soluble bags and liquid. It is mainly used to control pests on cereals, oil bearing plants, fruits, vegetables etc.

Acephate is mostly practically non-toxic to marine/ estuarine fish; it shows enhanced toxicity to freshwater organisms. LD_{50} (96 h) for sheepshed minnow at 910 ppm shows practically non-toxic nature of the pesticide. It acts as anticholinesterase agent but has low bioaccumulation.

It is known as a stable compound in acidic condition but does degrade through hydrolysis in alkaline medium (at pH 9 half life 18 d). The pesticide is not persistent in clay soil under anaerobic condition and rapidly degrades in sediment. It is known to degrade to methamidophos, another toxic compound.

c) Quinalphos: Its chemical name is O,O-diethyl-O-(Quinoxaline-2-yl) phosphorothioate ($C_{12}H_{15}N_2O_3PS$). The odourless and colourless crystalline solid (density 1.306) has melting point of 31 to 32^oC and it decomposes at 120^oC. Quinalphos is lowly soluble in water but possesses high solubility in most of the organic solvents. It is stored at 4^oC, since it shows rapid degradation and short residual life at atmospheric conditions. WHO termed it as moderately toxic pesticide. Quinalphos activity is by inhibition of chlolinertarase.

6.2.2 Synthetic pyrothroids

The pyrothroid loaded on the ship was ‘deltamethrin’ in solid form. It belongs to a class synthetic pyrothroid compounds which are analogues of pyrothrins, natural products found in chrysanthemum flowers. They are used as pesticides to control a wide range of insects.

These pesticides are sparingly soluble in water and lowly reactive. They also have low volatility and they bind to solid. Generally, they are not persistent in the environment due to their rapid degradation within days to months.

They are highly toxic to fish and some invertebrates. They are also known to exhibit sublethal effects on fish and crustaceans such as oxidative stress, increased respiration, osmoregulation disruptions etc.

Deltamethrin (decamethrin) is chemically [cyano- (3-phenoxy phenyl) - methyl] 3- (2, 2-dibromoethyl) - 2, 2 - dimethyl - cyclopropone 1-carboxylate ($C_{22} H_{19} Br_2 NO_3$). It is colourless and odourless crystalline powder with very low solubility in water (0.002 mg/l) but it is highly soluble in organic solvents. Though it is stable to light, heat and air; it is unstable to alkaline media. The pesticide has density of 1.5 g/cm^3 with melting point of 98^{o}C and boiling point of 300^{o}C at which temperature it decomposes.

It is not cholinesterase inhibitor and termed as moderately hazardous as per EPA and FAO. Though its mammalian exposure is classified as safe, it is highly toxic to aquatic life particularly fish having LC_{50} (96 h) in the range of 0.4 to 2 μg/l. Its water quality criteria for freshwater is 0.0004 mg/l. It accumulates in fish but imparts mortality to crustaceans. Though it is highly toxic to zooplankton, it is not acutely toxic to molluscs.

6.2.3 Other

a) Indacloprid: Indacloprid or imidacloprid is a chlorinated analogue of nicotine. Chemically it is neonicotinoid represented by a structure N-[1-[(6-chloro-3-pyridyl)methyl] 4,5-dihydroimidazol-2-yl] nitramide ($C_9H_{10}ClN_5O_2$). The colourless crystals have melting point of 136.4 to 143.8^{o}C. It has low water solubility of 0.51 g/l at 20^{o}C. It is employed in controlling a variety of crops including rice, grains, cereals, vegetables, sugarcane and tobacco. It is also applied for cockroach control.

It is not persistent in water at 0.65 µg/l. It has high dissipation rate (DT_{50}) of 1 to 2 years and has low partition co-efficient in water. It does not react with an acid or base at room temperature. At pH 9 its DT_{50} is 355 days. However, its decomposition by photolysis in water is high (half life 1.4-10 d). The microbial action is comparatively slow in water and sediment with half life of 30 to 50 d. It's decomposition by hydrolysis is not the major route for its transformation.

Imidacloprid's toxicity to organisms is through blocking acetylcholine receptors. WHO assigned it as moderately toxic. Though it has high leaching properties and does not accumulate in biota, its toxicity varies from organisms to organisms. For example LD_{50} (48 h) is 13 µg/l for saltmarsh mosquito. LD_{50} (96 h) is 58200 and 34.1 µg/l for sheepshed minnow and mysid shrimp respectively.

b) Mancozeb: It is a zinc ion coordination product with manganese ethylene – 1, 2 dithiocarbonate polymer. Chemically it is [1, 2–Ethazne diybis (carbanodithio) (z-)] manganese zinc salt $[(C_4H_6N_2S_4Mn)_x(Zn)_y]$. It is used as a fungicide for onion, pears, landscape, table and rois in grapes, wine grapes. It is a grayish yellow powder with melting point of 192 to 194^{o}C.

It is inert to atmospheric oxidation. It's water solubility is 6.20 µg/l while its half life for hydrolysis route is 166 d. It is known to decompose by heat and expand to moisture and air. Hence it is stored at 4^{o}C. It is applied as 50% wettable powder. Its toxicity is not through choline inhibition but acts as wide spectrum or fungal diseases. It imparts toxicity by inhibiting enzyme activity by complexing with metal containing enzyme including those with production of ATP.

In fish it distrupts biochemistry leading to mortality while in phytoplankton it retards growth, physiology, population etc and mortality. In molluscs and zooplankton it shows intoxication. The freshwater toxicity to rainbow trout is at 0.46 ppm. The pesticide does not accumulate in clams not induce cell dysfunction.

6.3 Hazardous chemicals

6.3.1 Sodium hydroxide

The inorganic chemical is commercially known as caustic soda and is a solid. The highly corrosive material dissolves in water exothermally and shows pH above 7.5 in a scale of 7.5 to 14, the alkali range. If dissolved in large quantities in seawater, it would increase temperature and enhance alkaline strength of seawater.

It strongly reacts with acids producing salts and water. It also acts as strong alkaline reagent (OH^-) during hydrolysis reactions.

7 LIMITATIONS OF STUDY

7.1 Authorisation

The region of oil spillage namely the coastal waters, the bay waters, the coastline including beaches, mangroves, ports etc falls under multiple government agencies namely Mumbai Port Trust (MbPT); The Indian Coast Guard (ICG), Maharashtra Pollution Control Board (MPCB), Department of Environment and Forest (DoEF); Government of Maharashtra, Municipal Corporation of Greater Mumbai (MCGM); Collectors Raigad, Navi Mumbai, Mumbai etc. Hence, it was necessary to take permissions from different agencies or a nodal agency for monitoring of the Bay waters, beaches, mangroves etc. Moreover no agency which could serve as the nodal agency for authorisation had approached NIO to undertake the monitoring soon after the spillage occurred. Inspite of these shortcomings NIO had taken initiative on its own to start monitoring of the oil spill on 10 August 2010.

7.2 Logistics

During such an emergency state of accidental oil spill in the coastal waters, after authorisation from a Government agency, NIO had to immediately plan and execute the monitoring studies to assess the status of the affected coastal segments by the oil spill. This required immediate field survey which included collection of water, sediment and biological samples. Immediate availability of suitable boats for the survey team to work onboard is a pre-requisite. In monsoon, the fishing operations are banned, hence availability of suitable boat became difficult. Also necessary clearances from Customs and Coast Guard required to take up the survey in the oil spill affected coastal areas, was difficult in monsoon period. NIO was already working on the assigned R & D and sponsored project activities. Therefore, in this emergency situation the ongoing programmes either had to be stopped temporarily or re-scheduled in order to accommodate these studies. In the present case, NIO has initiated the shore based survey on an urgent basis by rescheduling the available infrastructure (9 and 10 August 2010). With due authorisation and clearance by concerned agencies NIO could start the boat survey of the oil affected coastal segments only after a period of 4 days of oil spill and commenced the sampling from 11 August 2010.

7.3 Weather

In general, coastal oceanographic studies are rarely considered during the monsoon period due to heavy wind and wave conditions which make sampling difficult on a fishing boat. Hence the monitoring work was conducted as soon as workable conditions in comparatively calmer weather were available.

7.4 Sampling

In general, considerable difficulties in a boat operation and sampling prevailed especially during monsoon period. Therefore, some selected parameters of water, sediment and biological qualities were considered for sampling and assessment of environmental traits. In some cases, sampling had to be abandoned due to rough weather.

7.5 Manpower

The availability of trained manpower for the survey, sampling and analysis became very imminent for this monitoring work. Considering the enormous pressure on the ongoing sponsored project works, NIO had successfully re-scheduled its available technical and scientific manpower to undertake the oil spill studies as an emergency measure.

8 PRESENT STUDY AND OBSERVATIONS

The observations in respect of water quality, sediment quality and flora fauna which have been possibly affected by the recent oil spill at the Mumbai Harbour within 3 to 4 weeks of the occurrence of the spill are presented below as findings of the present study.

The sampling locations (Figures 1.4.1 and 1.4.2) have been categorised in different segments namely (1) mouth region of the Mumbai Bay(spill site), (2) Central Bay, (3) Inner segment (Thane Creek), (4) coast southward of Mumbai, and (5) west coast of Mumbai on the basis of their topography as follows:

Area	Subtidal station	Shore transect
Bay mouth	1 to 4, 23	Uran 1, Uran 2, Colaba
Central Bay	5 to 12 and 17 to 22	JNPT, Trombay
Inner segment of Bay	13 to 16	Vashi
Southward coast of Mumbai	-	Mandva, Dighodi, Kihim, Alibaug
West coast of Mumbai	-	Girgaon, Dadar, Mahim, Juhu

The first 3 segments are integral parts of Mumbai Bay while others are not located in the Bay but along the adjoining coast, hence not included in the subtidal environment of Mumbai Bay.

The field studies with respect to water quality, sediment quality, and flora and fauna at the subtidal and intertidal environments were carried out under 4 sampling Series during the present study (Phase I) as given below.

Series	Period
I	10 - 14 August 2010
II	18 - 21 August 2010
III	25 - 28 August 2010
IV	6 - 8 September 2010

The observations recorded during the study period were discussed in two categories namely intertidal and subtidal environments as follows:

8.1 Intertidal environment

An oil slick while travelling on the water surface ultimately strikes the shoreline beaches depending upon prevailing currents, tides, wind etc.

In general, the beach residue is not expected to cause gross variations in temperature, salinity, DO, BOD, nutrients etc; while phenols may marginally increase below the surface water. It is however likely that SS in the surface water gets associated with the spill material thereby affecting its mobility. Hence, apart from abnormally high concentrations of PHc it is expected that the intertidal water quality would not suffer.

For a spill occurring in the coastal area, the ultimate landfall of oil is the intertidal area where large quantity of oil can get accumulated. The deposition may result in higher contamination during the initial stages in water and sediment. In later stages however, these concentrations would decrease due to loss of hydrocarbons, by weathering and tidal removal.

Consequent to the oil spill from MS Chitra which occurred at the mouth of Mumbai Bay on 7 August 2010, NIO conducted shore-based field survey from 10 to 25 August 2010 along the coast between Alibaug and Juhu including the Mumbai Bay. The intertidal environmental status of these transects in respect of water quality, sediment quality and biota is described below.

8.1.1 Alibaug

a) Field observation (10 August 2010; 1100 h)

Severe wave action along the shore of Alibaug (Figure 8.1.1a) with highly turbid water and some tar balls at the intertidal area (Figure 8.1.1b) were noticed. No oil was seen by the survey team as well as local people.

b) Water quality

The transect was characterised by PHc content of 116.5 and 31.4 μg/l on 10 and 20 August 2010 (sampling Series I and II respectively). The average temperature remained around 30^{o}C, average pH and SS varied from 8 to 7.7

and from 50 to 195 mg/l respectively. The highly oxygenated waters had high DO (5.7-7.0 mg/l), and low BOD. The salinity varied from 14.5 to 20 ppt while PO_4^{3-}-P, NO_2^--N and NH_4^+-N remained low. NO_3^--N varied in the range 6.9 to 11 μmol/l.

c) Sediment quality

PHc concentration in intertidal sediment was 26.1 μg/g, wet wt.

d) Flora and fauna

Phytoplankton: The variations of chlorophyll *a* (13.0 - 14.2 mg/m^3) and phaeophytin (1.1 - 1.2 mg//m^3) were in a narrow range (Table 8.1.1). The ratios of chlorophyll *a*/phaeophytin were high (10.8-12.9) suggesting a congenial environment for the growth of phytoplankton. A bloom of *Asterionella japonica* was noticed constituting 95% of the total phytoplankton population.

Zooplankton: In all seven groups of zooplankton were recorded with the dominance of foraminiferans at this transect during Series I. The other prominent groups were decapod larvae and chaetognaths.

Macrobenthos: Macrobenthic samples were collected during the Series II. The biomass averaged at 6.5 g/m^2, with average faunal abundance of 517 no/m^2. The macrobenthic group diversity averaged at 2 no with gastropods dominating the macrobenthic population.

8.1.2 Kihim

a) Field observation (10 August 2010; 1630 h)

Several scattered oil patches were seen on the Kihim beach (Figure 8.1.2a) during sampling (Figures 8.1.1a and 8.1.1b).

b) Water quality

During the sampling Series I of 10 August 2010, the transect had high PHc of 7490.6 μg/l in water. The other water quality parameters were comparable with that of Alibaug except NH_4^+-N (8.1 μmol/l) and NO_3^--N (40 - 40.8 μmol/l) which were high.

c) Flora and fauna

Phytoplankton: Chlorophyll *a* (6.5 - 9.0 mg/m^3) and phaeophytin (2.4 - 3.8 mg/m^3) varied in narrow ranges (Table 8.1.1). The ratios of chlorophyll *a*/phaeophytin varied from 2.4 to 2.7. The phytoplankton cell count was 996 nox10^3/l and represented by 17 genera.

Zooplankton: A total of 6 groups of zooplankton was recorded at this transect during Series I with foraminiferans dominating the populations.

Macrobenthos: During Series I the biomass averaged at 0.9 g/m^2 with average faunal abundance of 156 no/m^2. Only 3 macrobenthic groups were identified with the amphipods dominating the macrobenthic population.

8.1.3 Dighodi (10 August 2010; 1430 h)

a) Field observation

The broken container washed ashore and lying in a mangrove area was noticed (Figure 8.1.3a) along with tea packets from the broken container spread all over the area. The beach was visually free from oil patches though some deposits of tar balls were visible along the high water line. The mangroves in the area were also free from oil coating (Figure 8.1.3b).

b) Water quality

Dighodi waters contained PHc of 83.9 μg/l. As in the case of Kihim, the water had relatively high concentration of NO_3^--N (33.7 - 35.4 μmol/l).

c) Sediment quality

The concentration of PHc in sediment was negligible (ND).

d) Flora and fauna

Phytoplankton: The concentrations of chlorophyll *a* and phaeophytin varied in a narrow range. (Table 8.1.1). The average cell count (235.2 nox10^3/l) was lower than Kihim but the generic diversity (15 genera) was comparable.

Zooplankton: In all, five groups of zooplankton were recorded with foraminiferans as the most dominant group followed by copepods.

Macrobenthos: The biomass of macrobenthos ranged from 0.02 to 8.2 g/m^2 (av 2.7 g/m^2), with the faunal abundance averaging at 156 no/m^2. Four faunal groups with the dominance of polychaetes represented macrobenthic fauna.

Mangroves: The transect sustained dense mangroves (Figure 8.1.3b). A few containers washed ashore were seen lying in the mangrove area. These mangroves were however free from coating by oil.

8.1.4 Mandva

a) Field observation (10 August 2010; 1300 h)

This area was free from oil patches which also corroborated the observations of the local inhabitants.

b) Water quality

During sampling Series I, PHc was high (497.5 μg/l) but decreased to 36.1 μg/l in the Series II. The water quality of this area was comparable with that of Alibaug.

c) Sediment quality

The sediment PHc content was 15.7 μg/g, wet wt. and indicated absence of significant contamination by oil.

d) Flora and fauna

Phytoplankton: The phytopigments and cell count were of the order expected for the region (Table 8.1.1). The generic diversity was comparable with that at Dighodi.

Zooplankton: A total of four groups of zooplankton was recorded at this site during Series I with foraminiferans and copepods dominating the populations.

Macrobenthos: Macrobenthic biomass averaged at 0.5 and 0.3 g/m^2 during Series I and II and the respective faunal abundance averaged at 93 and 84 no/m^2. Isopod was the dominant group during Series I while brachyuran was the major group in the subsequent Series.

8.1.5 Dharamtar

a) Field observation (10 August 2010; 1730 h)

The sites around Dharamtar Jetty (Figure 8.1.5a) which is located on the Amba Estuary (Figure 8.1.5b) was found free from oil during the survey.

b) Water quality

The transect located along the eastern coast in the mid-segment of Amba Estuary sustained low PHc (30 μg/l) and high pH of 8.8. Though DO was high and BOD, PO_4^{3-}-P and NO_2^--N were low; NO_3^-N and NH_4^+-N levels were high upto 33.7 and 13.4 μmol/l respectively.

c) Sediment quality

The content of PHc in sediment was 9.1 μg/g, wet wt.

d) Flora and fauna

Phytoplankton: The concentrations of chlorophyll *a* (2.3 - 2.6 mg/m^3) and phaeophytin (2.4 - 3.4 mg/m^3) varied in a narrow and comparable range (Table 8.1.1). The poor ratios (0.8 - 1.0) of chlorophyll *a*/phaeophytin were evident from the results (Table 8.1.1). The cell counts (av 88 nox10^3/l) and generic diversity (8 genera) were also low.

Zooplankton: In all nine groups of zooplankton were recorded at this transect during Series I with foraminiferans as the most dominant group. Copepods, decapod larvae and gastropods were also in good numbers.

Macrobenthos: During Series I, the biomass was low (av 0.05 g/m^2) and faunal abundance averaged at 144 no/m^2 with only polychaetes representing macrobenthos.

8.1.6 Uran 1

a) Field observation (10 August 2010; 1030 h)

Five containers were seen crashed ashore on the Uran beach (Figure 2.3.2) with its contents like tea bags, biscuits, sugar bags etc scattered around (Figure 2.3.6). The nearshore water had patches of oil film (Figure 8.1.6a). Local people informed that 8 containers had washed on the shore on the night during 9 August 2010.

b) Water quality

On 10 August 2010, PHc levels were abnormally high of 4996.3 μg/l which substantially decreased to 53.2 μg/l on 23 August 2010. The other water quality parameters did not reveal any gross changes (Figure 8.1.6b).

c) Flora and fauna

Phytoplankton: The concentrations of chlorophyll *a* (0.4 mg/m^3) and phaeophytin (0.4 mg/m^3) were low and associated cell counts of phytoplankton (22.4 nox10^3/l) were the lowest recorded for intertidal segment of the present study (Table 8.1.1). However, the generic diversity (11 genera) did not reveal any noticeable reduction. Overall the poor ratio of chlorophyll/phaeophytin (1.0) suggested that the environment was not conducive for phytoplankton growth at this segment.

Zooplankton: Only three groups of zooplankton were recorded at this site during Series I. The groups like copepods and foraminiferans were prominent but less in numbers.

8.1.7 Uran 2

a) Field observation (10 August 2010; 1130 h)

Oil patches were noticed close to the shore (Figure 8.1.7a) and nearshore waters indicating contamination by oil. The rocky areas were also seen coated with oil (Figure 8.1.7b). One broken container was seen floating near the shore.

b) Water quality

PHc levels were abnormally high (12075.6 μg/l) on 10 August 2010 (Series I) but decreased substantially to 124.7 μg/l on 23 August 2010 (Series II). The other water quality parameters were in the expected ranges.

c) Flora and fauna

Phytoplankton: The region also revealed low concentrations of chlorophyll *a* (0.5 mg/m^3) and phaeophytin (0.6 mg/m^3) with poor ratio (0.8) of chlorophyll *a* / phaeophytin (Table 8.1.1). However, due to high suspended load and oily residues the cell counts could not be carried out.

8.1.8 JNPT

a) Field observation (10 August 2010; 1245 h)

One broken container was found floating near the shore. Mangroves were seen coated with oil to a height of about 0.5 to 1 m.

b) Water quality

On 10 August 2010, PHc content indicated mild contamination by oil. The other water quality parameters did not reveal any unusual deterioration.

c) Flora and fauna

Phytoplankton: During Series I phaeophytin (2.8 - 3.1 mg/m^3) was in excess of chlorophyll *a* (1.9 - 2.2 mg/m^3) with unusually poor ratio (0.7) of chlorophyll *a* / phaeophytin indicating an unhealthy condition of phytoplankton cells (Table 8.1.1). A noticeable reduction in cell counts (59.2 nox10^3/l) and generic diversity (9 genera) was evident. These results suggested higher mortality rate of phytoplankton over the production during the Series I.

Zooplankton: In all 8 groups of zooplankton were recorded at this site during Series I. Copepods were the most dominant group whereas groups like chaetognaths, *Lucifer* sp and decapod larvae were also common.

Mangroves: Mangroves (*Avicennia marina*) were seen heavily coated with oil for upto a height of 0.5 to 1 m.

8.1.9 Vashi

a) Field observation (10 August 2010; 1725 h)

The oil coated intertidal segment as well as mangroves were noticed at this site (Figure 8.1.9a). Also gastropods moving on the oiled sediments were noticed (Figure 8.1.9b).

b) Water quality

During all the 4 sampling Series, PHc content increased marginally from 69.7 to 182.3 μg/l. The other water quality parameters varied as follows:

Parameter	Series			
	I	II	III	IV
pH	7.9	7.4	7.5	7.5
Salinity	6.2	16.5	7.6	14.9
NO_3^--N	12.7	62.3	36.3	17.3
NO_2^--N	37.6	3.8	9.6	10.0
NH_4^+-N	79.9	18.3	17.2	20.1

Except for pH which was unusually low other parameters were in the ranges expected for the Thane Creek.

c) Sediment quality

The PHc concentration in sediment was 3.6 μg/g, wet wt and did not indicate significant contamination by oil.

d) Flora and fauna

Phytoplankton: The concentrations of chlorophyll *a* (4.8 - 5.3 mg/m^3) and phaeophytin (5.0 - 5.1 mg/m^3) were comparable (Table 8.1.1) with ratios (0.9 - 1.0) of chlorophyll *a* / phaeophytin indicating delicate balance between life and mortality of phytoplankton. The cell count (490.4 nox10^3/l) was high with phytoplankton belonging to 11 genera.

Zooplankton: A total of eleven groups of zooplankton were recorded with copepods as the most dominant group. The decapod larvae foraminiferans and fish larvae were in good numbers during Series IV.

Macrobenthos: The biomass, faunal abundance and groups of macrobenthos averaged at 0.3 g/m^2, 57 no/m^2, and 2 no respectively. Polychaete was the dominant group.

Mangroves: Mangroves dominated by *Avicennia marina* were seen coated with oil upto a height of about 0.75 m along the intertidal segment (Figure 2.2.4). The sediment at this site also had a coating of oil.

8.1.10 Trombay

a) Field observation (10 August 2010; 1215 h)

Mangroves were found coated with oil upto a height of about 0.75 m (Figure 8.1.10a). Mangrove seedlings and pneumatophores were also coated with oil (Figure 8.1.10b). However, some fauna such as mud skippers and crabs were active in the mangrove area on the sediment contaminated with oil (Figure 8.1.10c). A few mangrove plants were selected and tagged for monitoring, on 12 August 2010 (Figure 8.1.10d).

b) Water quality

There was an abnormal increase in PHc content from 54.7 μg/l on 10 August to 2909.8 μg/l on 16 August 2010. However, the other water quality parameters did not reveal any deviations.

c) Sediment quality

Surprisingly though the water sustained high concentration of PHc, the sediment of Series I collection sustained low concentration of PHc (41.1 μg/g, wet wt) and the concentration further reduced (2.8 μg/g, wet wt) in the subsequent collection of Series II.

d) Flora and fauna

Phytoplankton: The concentrations of chlorophyll *a* (2.3 - 2.9 mg/m^3) and phaeophytin (2.7 - 2.8 mg/m^3) were comparable (Table 8.1.1). The low ratios of chlorophyll *a*/phaeophytin (0.8-1.1) and low phytoplankton cell count (87.2 nox10^3/l) and generic diversity (11 genera) like that of JNPT was observed at this transect. The above results indicated that the site was not congenial for phytoplankton growth during the initial period. However, much improved conditions in reference to chlorophyll *a* (9.8 - 10.8 mg/m^3) and the ratio of chlorophyll *a*/phaeophytin (2.5 - 3.1) during IV Series were noticed. (Table 8.1.1).

Zooplankton: In all nine faunal groups of zooplankton with dominance of copepods were noticed at this site during Series I. During Series II, the population counts and group diversity (2 no) were noticeably reduced. Foraminiferans were the dominant group during this period.

Macrobenthos: The average biomass of macrobenthos decreased from 0.9 g/m^2 during Series I to 0.1 g/m^2 during Series III. The respective decrease in faunal average abundance was from 250 to 138 no/m^2. The faunal diversity was poor (0-2 groups) with the dominance of polychaetes.

Mangroves: The mangroves (*Avicennia marina*) had oil coating upto a height of 0.8 m from the bed level (Figure 8.1.10a). The mangrove seedlings (Figure 8.1.10e) and pneumatophores (Figue 8.1.10b) were also coated with oil on 10 August 2010. *Salvadora persica* were also recorded along the upper intertidal area. Crabs and mud skippers however were active on the oil-contaminated sediments (Figure 8.1.10d). The growth of oil affected mangroves was estimated upto 0.15 m in 8 to 10 days (Figure 8.1.10c). The seedling density of 12 to 30/m^2 recorded during Series I (Figure 8.1.10e) had fallen to near-zero during Series II resulting significant obliteration of seedlings under the adverse impact of oil (Figure 8.1.10f). The leaves of the oil affected mangroves had dried and their growth was stunted as recorded on 14 October 2010 (Figure 8.1.10g).

8.1.11 Colaba

a) Field observation (10 August 2010; 1545 h)

The oil coated rocks and tidal pools were commonly noticed at this site (Figures 8.1.11a and 8.1.11b) with some areas having live corals (Figure 8.1.11c). Oysters, barnacles and variety of gastropods inhabited the intertidal segment.

b) Water quality

Very high PHc value (1825 µg/l) recorded on 10 August 2010 suggesting contamination due to oil spill, decreased to 50 µg/l on 25 August 2010. Other water quality parameters were in the accepted ranges.

c) Sediment quality

The sediment was sandy with unusually low concentration of PHc (0.06 µg/g; wet wt) during Series I collection and increased several folds (35.6 µg/g, wet wt) in the sample of the Series II.

d) Flora and fauna

Phytoplankton: The lower concentration of chlorophyll *a* (3.4 mg/m^3) as compared to phaeophytin (3.7 mg/m^3) resulted a poor ratio of 0.9 and indicated an unhealthy conditions of phytoplankton cells which could be due to oil spill (Table 8.1.1). The cell counts (206 nox10^3/l) and generic diversity (11 no genera) were comparable with those of Mandva and Dighodi sites.

Macrobenthos: This transect was studied during 3 Series. The standing stock of macrobenthos fluctuated without clear trend. Polychaete and gastropod were the dominant faunal groups present during Series I but were replaced by amphipods during Series II and III. During Series I the intertidal area was observed to be coated with oil (Figure 8.1.11a). A film of oil coating was noticed at the intertidal water pools adjacent to areas where sand and gravel were present during subsequent Series (Figure 8.1.11b). The live corals at rocky intertidal segments in Colaba appeared to be unaffected by the oil spill (Figure 8.1.11c). Also the barnacles, oysters with their spat, gastropods and crabs were seen alive (Figure 8.1.11d) and the spawning of gastropod (Figure 8.1.11e) appeared to be unaffected by oil contamination.

8.1.12 Girgaon

a) Field observation (10 August 2010; 1630 h)

The sampling site and the zone around was free from oil contamination.

b) Water quality

During sampling Series I PHc was 109.3 µg/l which could be considered marginally elevated. The other water quality parameters were in expected ranges.

c) Sediment quality

The PHc level in sediment was low (0.04 µg/g, wet wt) and indicated that the sediment was free from oil contamination.

d) Flora and fauna

Phytoplankton:

The concentration of chlorophyll *a* (5.5 mg/m^3) was higher than that of phaeophytin (3.3 mg/m^3) with chlorophyll *a*/phaeophytin ratio of 1.7 indicating conducive conditions for phytoplankton. The phytoplankton cell count (428 nox10^3/l) and generic diversity (15 genera) were as expected for the coastal area of Mumbai (Table 8.1.1).

Macrobenthos:

Girgaon was sampled during Series I. The biomass (av 5.5. g/m^2), faunal abundance (av 74 no/m^2) and group diversity (av 2 no) of macrobenthos did not indicate any abnormality.

8.1.13 Dadar

a) Field observation (10 August 2010; 1800 h)

The sampling area was free from visual patches of oil.

b) Water quality

The PHc was low (37.9 µg/l) and other water quality parameters were in expected ranges.

c) Sediment quality

The PHc content in sediment was low (0.03 µg/g, wet wt) indicating absence of contamination by oil.

d) Flora and fauna

Zooplankton:

Six groups of zooplankton were identified in the sample obtained during Series I with foraminiferans as the dominant group.

Macrobenthos:

The biomass (av 2.8 g/m^2), faunal abundance (av 463 no/m^2) and group diversity (av 2 no) of macrobenthos were as expected with polychaetes and amphipods as the dominant groups.

8.1.14 Mahim

a) Field observations (10 August 2010; 1845 h)

The site did not indicate presence of any oil.

b) Water quality

The PHc concentration was low (26.5 µg/l) at this site on 10 August 2010 with other parameters in the ranges expected for Mahim Bay.

c) Sediment quality

As expected, the PHc burden in sediment was low (0.04 µg/g, wet wt).

d) Flora and fauna

Phytoplankton:

The higher concentrations of chlorophyll *a* (5.7 mg/m^3) than that of phaeophytin (1.9 mg/m^3) indicated conditions supportive for the proliferation of phytoplankton (Table 8.1.1).

Zooplankton:

Among seven groups of zooplankton recorded at this location foraminiferans and copepods were the most dominant with good numbers of polychaetes and mysids.

Macrobenthos:

The site was characterized by low biomass (av 0.02 g/m^2), with polychaetes and sergestids in the population.

8.1.15 Juhu

a) Field observations: (25 August 2010; 1330h)

This site sampled during Series III was visually free from oil patches.

b) Water quality

PHc content in water (37.5 µg/l) did not indicate significant contamination by oil. The other water quality parameters were in expected ranges.

c) Sediment quality

The PHc content was 43.5 µg/g, wet wt.

d) Flora and fauna

Zooplankton: A total of six groups of zooplankton was recorded with foraminiferans as the most dominant group.

8.1.16 Impact assessment of oil spill

a) Field observation

Out of the 16 shore locations visited on 10 August 2010; Uran 1, Uran 2, Trombay and Colaba had deposits of oil in varying intensities. Mangroves at

Trombay were coated with oil up to about 0.5 to 1 m height under the high tidal influence in the Thane Creek. Pneumatophores popularly termed as the breathing roots of mangroves, as well as the mangrove seedlings were also coated with oil in this zone. Few containers washed ashore in damaged condition, broken members of containers and materials like tea bags, biscuits, sugar bags etc had deposited on the intertidal zone at Uran. The coastal segments of Kihim and Mandva were affected with low level oil contamination. The nearby areas like Alibaug, Dighodi and Dharamtar on the contrary were free from visible oil contamination though a, few containers and their contents like tea and sugar bags had washed ashore at Dighodi. Vashi water in the Thane Creek was also affected but to a minor extent. However, mangroves were affected by oil at Vashi. Although the shoreline along Colaba was coated with oil, the intertidal organisms including corals were active and alive. The shoreline along the west coast of Mumbai including Girgaon, Dadar, Mahim and Juhu were visually free from oil.

b) Water quality

PHc: Chronic petroleum inputs to the coastal area of Mumbai are a common feature which is added through anthropogenic sources such as effluents from refineries and petrochemical industries, sewage, ship traffic and many other pathways. The oil thus added undergoes several weathering processes (Section 6) which result in its removal from the environment. Thus, the concentration of PHc in water and sediment of coastal marine area of Mumbai would be a net result of the quantity entering the system through a variety of routes and that is removed by weathering. This balance would therefore be the background concentration which should be known to analyze the post-spill levels in proper perspective. Unlike petroleum associated with chronic sources, accidental oil spillages add large volume of oil in a confined area and concentrations of PHc in water and sediment can shoot-up to abnormal levels.

Available data for 2007-10 on the levels of PHc in coastal marine water of Mumbai is compiled in the Table 8.1.2 indicate that the concentrations of PHc expected in the coastal water of Mumbai were 2.3 to 72.4 μg/l. However, the data presented above is for the subtidal area. It may be mentioned here that information is lacking on the concentration of PHc in water associated with the intertidal areas of Mumbai. Considering that the intertidal areas receive land runoff during monsoon and many point releases are in the vicinity or on the intertidal zone, the levels of PHc in the intertidal waters could be higher.

PHc concentrations in water collected from the intertidal zones of Mumbai and regions around varied as follows:

Zone	Transect	Concentration (µg/g, wet wt)			
		Series I	Series II	Range	
				Series I	Series II
Bay mouth	Uran 1	4996.3	53.2	1825.4-12075.6	50.0-124.7
	Uran 2	12075.6	124.7		
	Colaba	1825.4	50.0		
Central Bay	JNPT	95.1		54.7 - 95.1	2090.8
	Trombay	54.7	2090.8		
Inner Bay	Vashi	69.7	114.4	69.7	114.4
Coast southward of Mumbai	Mandva	497.5	36.1	83.9 - 7490.6	31.4-36.1
	Dighodi	83.9	-		
	Kihim	7490.6	-		
	Alibaug	116.5	31.4		
West Coast of Mumbai	Girgaon	109.3	-	26.5 - 109.3	37.4
	Dadar	37.9	-		
	Mahim	26.5	-		
	Juhu		37.4		
Amba estuary	Dharamtar	30.0	-	30.0	-

As expected abnormally high concentrations (1825.4 - 12075.6 µg/l) of PHc were recorded in the intertidal zone around the Bay mouth and at the south-eastern coastal segments of the Bay during Series I with Mandva at the south-western periphery having significantly high level of PHc (497.5 µg/l). The worst affected zones were Uran 1, Uran 2, Colaba and Kihim. Other intertidal zones did not indicate high concentration of PHc.

The results indicate that in the Series II of monitoring the PHc content at Uran 1, Uran 2 and Colaba had decreased substantially (50-124.7 µg/l) and were comparable to the baseline. It appears that under rough monsoonal conditions and high tidal flushing the oil content in water had widely dispersed and/or flushed out of the Bay. Thus, the impact of accidental oil spill on affected intertidal area was short lived – probably a week and the nearshore water were relieved of its excess PHc.

In the Series II measurements only Trombay area sustained unusually high concentration of PHc, while, all other sites had levels comparable to the background. Petroleum being immiscible with water, it could be an instance of oil getting trapped in a confined area that could have been washed off from contaminated intertidal sediment.

It is evident from the concentrations of 26.5 to 109.3 µg/l in nearshore waters that the west coast of Mumbai was probably free from contamination by the accidental oil spill.

Other water quality parameters:

Unlike open ocean region, even uncontaminated coastal waters are subject to significant short-time natural variations due to varying tide and season as well as temporally changing geochemical processes. For coastal and inshore areas of Mumbai that receive a variety of wastes, such variations can be high for some water quality parameters. Thus for instance, the DO in natural coastal waters is generally above 3.5 ml/l, while, in the inshore creeks of Mumbai receiving sewage, the DO depletes to low value – even close to zero, at low tide and increases to 1 to 2 mg/l at high tide. Similarly, in waters free from organic pollution, NO_2^--N and NH_4^+-N seldom exceed 1 µmol/l, however, in coastal waters of Mumbai abnormally high concentrations of these constituents are not uncommon. Evidently, these background variations should be considered while interpreting the post-oil spill water quality of the Mumbai region. Based on the available results of periodic monitoring of the Mumbai area, the range of water quality parameters are compiled in Table 8.1.3.

It is also required to understand the changes expected in parameters other than PHc subsequent to an oil spill. The literature information indicates that the single most important parameter that can influence the organisms of the affected area is DO which can be depleted due to oil layer that prevents air – sea interaction and retards photosynthesis due to insufficient solar radiation penetrating the oil layer. There can be delayed increase in nutrients resulting from large-scale mortality of plankton and their decomposition releasing the nutrients to the water column. However, such impacts generally occur in confined areas or when the spilled oil covers a large sea surface.

Comparison of results in Table 8.1.3 wherein post-oil spill water quality is presented with the background described in Section 3.1, clearly indicates that the post-spill water quality is comparable with the background and no significant changes in DO and nutrients are discernible. This is expected since the oil spill was small, the oil layer in patches covered a small area and swift tidal movements continuously renewed the water mass under the oil layer transporting water from nearby areas not affected by the spill. High monsoon induced turbulence also assisted in efficiently breaking the oil layer into patches.

c) Sediment quality

The PHc concentration in the intertidal sediment observed in different sampling zones during the Series I of sampling is as follows:

Zone	Transect	Concentration (µg/g, wet wt)	Range of concentration (µg/g, wet wt)
Mouth of Bay	Uran 1	-	0.06
	Uran 2	-	
	Colaba	0.06	
Central Bay	JNPT	-	41.1
	Trombay	41.1	
Inner segment of Bay	Vashi	3.6	3.6
Coast southward of Mumbai	Mandva	15.7	0.03 - 26.1
	Dighodi	0.03	
	Kihim	-	
	Alibaug	26.1	
West coast of Mumbai	Girgaon	0.04	0.03 - 0.04
	Dadar	0.03	
	Mahim	0.04	
	Juhu	-	
Amba estuary	Dharamtar	9.1	9.1

As evident from above data, during Series I, relatively high levels of PHc were recorded only at few transects.

The published data indicate that the hydrocarbon content of sediments range from 100 to 12000 µg/g, dry wt with most values less than 1000 µg/g, dry wt in marine areas affected by sinking oil. The PHc content of sediments from unpolluted coastal areas and marginal seas or basins is usually below 70 μg/g, dry wt**.** The results of analysis of the present study are calculated based on wet weight basis. On the basis of 50% moisture content in sediment the observed values presented on wet weight basis would be double when considered on dry weight basis. Hence the values (11.5 to 22.4 µg/g, wet wt) found for Central Bay (stations 19 and 21) during Series II and III though higher than the background are indicative of mild sediment contamination due to the accidental oil spill. The results for 2007-2010 (Table 8.1.4) reveal that the concentration in subtidal sediments were 0.2 to 10 µg/g, wet wt. Comparison of these results with the observed values as given above also indicates no serious contamination of sediments by oil spill.

At Colaba, however, high level of PHc was observed (35.6 µg/g, wet wt**)** during Series II of sampling. Such high concentration of PHc was absent at other locations during Series II. Hence other locations did not indicate any serious contamination of intertidal sediments.

d) Flora and fauna

Phytoplankton:

The results of pigments revealed a significant reduction in the concentration of chlorophyll *a* (0.4 - 0.5, av 0.5 mg/m^3) and phaeophytin (0.4 - 0.6; av 0.5 mg/m^3) in the tidal waters at Uran as compared to the rest of shore-based locations (Table 8.1.1). In general, the locations like JNPT, Trombay, Colaba and Dharamtar also indicated moderate reduction in chlorophyll *a* (1.9 - 3.5 mg/m^3) as compared to the rest except Uran (Table 8.1.1). The locations like Dighodi, Mandva, Alibaug, Kihim, Vashi, Girgaon and Mahim revealed elevated levels of chlorophyll *a* (5.1 - 14.2 mg/m^3) as compared to above locations (Table 8.1.1). The highest chlorophyll *a* value of 14.2 mg/m^3 was recorded at Alibaug, whereas Kihim which is very close to Alibaug showed relatively reduced chlorophyll *a* (6.5 - 9.0 mg/m^3). In general, the phaeophytin did not indicate any clear trend due to high fluctuations in their values. However, the average concentration of phaeopigment for the entire area of present study was higher than that of chlorophyll *a* (Figure 8.1.16a) suggesting possible mortality of phytoplankton at various shore segments due to the oil spill.

This is further supported by the significant reduction in the ratios (<1) of chlorophyll *a*/phaeophytin which indicated unhealthy conditions of the cells at selected shore locations like Uran, Vashi, JNPT, Trombay and Colaba as compared to the rest (Table 8.1.1, Figure 8.1.16b). Although, Kihim was affected by the oil spill, being an open coast, probably the fast and effective replenishment of water mass could have aided the recovery of phytoplankton.

The tidal waters at the shore generally supported higher pigment values due to high nutrient availability. The shore segments of Uran, JNPT, Trombay, Colaba and Kihim which were affected by oil indicated reduction in chlorophyll *a* which could be due to the phytoplankton mortality caused by the oil spill. Again, the end of monsoon period supports good primary production in the coastal system of Mumbai due to high nutrient fluxes through land drainage and low saline conditions which favour estuarine species. Accordingly, the Mumbai Bay recorded higher concentration of chlorophyll *a* during September 2009 (Table 8.2.5). Hence, the low chlorophyll *a* recorded at selected shore locations could be attributed to the phytoplankton mortality caused by the oil spill.

Zooplankton: The zooplankton results described in Section 8.1.4 clearly indicated wide variability in the group diversity and group dominance of zooplankton in the study area. Overall, Trombay and Vashi which were affected by oil had very poor diversity of zooplankton during Series II and III respectively. Similarly, Uran 1 revealed very poor diversity during Series I. The possibility of zooplankton mortality due to the oil spill at these segments cannot be ruled out. The rest of the coastal segments studied did not indicate any clear trend.

Macrobenthos: The oil coated intertidal segments were noticed at Vashi, Trombay and Colaba (TIFR).

Colaba showed increasing trend in macrobenthic abundance and diversity from Series I to Series III. This could be due to natural variability under monsoon conditions. During Series I most of the intertidal area was observed to be coated with oil. A film of floating oil was noticed at the intertidal water pools adjacent to areas where sand and gravel were present during Series II.

At Trombay, a gradual reduction in standing stock and diversity was noticed between Series I and Series III studies (Figures 8.1.16c to 8.1.16d). However, further study is required to know the exact trend.

Sampling of most of the intertidal segments was done in Series I anticipating oil contamination of these locations. However, majority of these sites were free from oil contamination and showed normal distribution of macrobenthic diversity. Therefore, fresh set of transects which were reported to be oil affected were selected for future observations.

Mangroves: Mangroves of the Mandva - Dighodi segment were free from oil coating. However, some of the mangroves within the Mumbai Bay, especially at JNPT, Vashi and Trombay, were coated with oil up to a height of 0.5 to 1 m from the ground level. These zones are dominated by *Avicennia marina* followed by *Salvadora persica.* Hence, these species were mainly affected by the oil. Seedlings and pneumatophores of *Avicennia* at Trombay were also covered by oil leading to high mortality of the seedlings. Crabs and mudskippers were however active on the oil contaminated mangrove sediment. The observations conducted after a month indicated that the growth rate of the oil coated mangroves was stunted and their leaves had dried. In fact the large stretches of mangroves unaffected by the spill also had dry leaves. Hence, it is possible that dried leaves were unrelated to oil spill and associated with some wide spread infection on mangroves along Mumbai coast that had also been reported in the past.

8.2 Subtidal environment

Observations on water quality, sediment quality and flora and fauna of the subtidal environment of Mumbai Bay and adjacent coastal area are as follows:

8.2.1 Field observations

At the spill site 2 to 3 m wide fairly long black coloured ribbons were seen emerging from the grounded ship and directed towards Harbour area (Figure 1.1.2). It seems that the leakage was through a narrow rupture site of the ship. In the mouth region a large patch having streaks of black colour with a large spread out of shining oil film around was evident. Relatively smaller patches were also visible in the region. A continuous coating of Colaba shore with black oil was clearly visible from the seaward side.

In the Central Bay around Butcher Island large patches of atleast 500 x 100 m size having fading black colour with brownish tinge were seen possibly indicating high dispersion of oil parcels on the water surface during transport (Figures 8.2.1 to 8.2.2). A resultant drift of these patches towards Mahul-Trombay shores was also observed.

Around Trombay the slick was in more dispersed form spread out in larger area (Figures 8.2.3 to 8.2.4).

At Vashi the oil slick was seen drifting towards the upstream during high tide (Figure 8.2.5). During low tide a large patch possibly the same that travelled upstream was seen drifting downstream. It appeared that even after 6 days of the spill occurrence some portion of the slick which neither hit the shore nor dispersed in the water column remained oscillating in the Bay water with the tide.

8.2.2 Water quality

A spill oil of petroleum origin generally contains hydrocarbons as the major constituent which is immiscible with water and possesses low reactivity. Hence it is known that the oil may not be directly involved chemically in the water quality processes even though it is present in abnormally high levels. However, its constituents have the ability to influence the water quality due to their physical presence in the water column.

Water quality recorded at different subtidal stations (Figure 1.4.2) is described below.

a) PHc

The PHc concentrations (μg/l) in the spill affected areas given in Table 8.1.2 are summarised below.

Area	Series I (11-14 Aug 2010)	Series II (18-21 Aug 2010)	Series III (25-27 Aug 2010)	Overall (11-27 Aug 2010)
Mouth	5.2 - 261.5	5.3 - 40.0	2.6 - 36.0	2.6 - 261.5
Central Bay	6.2 - 16902	7.2 - 73.8	3.8 - 62.8	2.7 - 16902
Inner segment	67 - 6684.8	3.6 - 22.6	6.2 - 94.1	3.6 - 6684.8

The PHc content varied widely and was as low as 2.6 to the highest of 16902 μg/l during 3 sampling series. In the mouth area the concentration was 2.6 to 261.5 μg/l with the maximum value recorded at the spill site (station 1) during Series I. The water in the Central Bay sustained concentration as high as 16900 μg/l though the distribution of PHc was extremely patchy during Series I (Figure 8.2.6). In this segment abnormally high concentrations of 2817 to 16902 μg/l occurred at stations 7 to 9 located around Butcher Island. Other stations in the vicinity also had high levels of upto 251.8 μg/l. Figure 8.2.7 clearly illustrates that the PHc content progressively increased towards the Inner Bay from Ist to IIIrd sampling Series I to III.

PHc content of 3.6 to 6684.8 μg/l was recorded in the Inner Bay around Vashi.

The concentrations of PHc during sampling Series II and III (18 - 27 August 2010) were below 94 μg/l. The stations 7, 8 and 9 in the Central Bay which had recorded high PHc in Series I could not be sampled during the other Series due to logistic difficulties. The lower levels of PHc during Series II and III possibly indicate that the dissolved and dispersed oil in water had weathered and diluted under the prevailing tidal movements and monsoon driven turbulence

(Figure 8.2.8). The model predictions (Section 4) indicated that only 0.2% of the spilled oil would have remained on the surface after 4 days.

The lower values obtained during Series II and III (18 - 27 August 2010) - 11 days after the occurrence of the spill, were more or less comparable with the monitoring results of September 2009 wherein the PHc ranged between 2.3 and 10.4 μg/l for the inner Bay (Table 8.1.2).

b) Temperature

Water temperature generally regulates species distribution, their composition and activity of life associated with aquatic environment. Since the aquatic animals are cold blooded, water temperature regulates their metabolism and ability to survive and reproduce effectively. Hence, artificially induced changes may alter indigenous ecosystem.

A spill in the form of large patches and thin films on the surface water layer known to increase water temperature below the surface by insulating water - air interface and absorbing higher solar radiation. The intensity depends upon energy of the ecosystem and size as well as thickness of the oil layer on the water surface. For example high tidal waves would fragment the surface oil layer enhancing the air-water interaction.

In the present study water temperature (^{o}C) varied as follows:

Zone	Series		
	I	II	III
Mouth	26.5 - 29.0	26.2 - 29.7	27.0 - 29.7
Central Bay	27.0 - 29.5	26.5 - 29.5	25.9 - 29.8
Inner Bay	29.0 - 29.1	28.5 - 29.5	27.0 - 29.8

Thus the water temperature was in a range of 25.9 to 29.8^{o}C for the Bay as against the air temperature range of 25.6 to 35^{o}C. Hence, the observed water temperature variations were natural and related to changes in air temperature.

c) pH

The principal system that regulates pH of water around 7.8 to 8.3 is the carbonate system consisting of CO_2, H_2CO_3, HCO_3^- and CO_3^{2-}. In biologically active tropical water, large diurnal changes from 7.3 to 9.5 may occur naturally because of photosynthesis. In the nearshore and estuarine/creek systems influx of freshwater, particularly during monsoon can affect the buffering effect and the pH often remains below 8. These areas also vulnerable to pH changes due to release of degradable organic matter. It is known that pH range of 5 to 9 is not directly harmful to the aquatic life. Such changes can make many common pollutants more toxic.

Though presence of a spill may not interfere the buffering system, its surface layer can restrict photosynthesis; hence can induce changes in pH.

Variations of pH of water recorded in the present study were as follows:

Zone	Series		
	I	II	III
Mouth	7.6 - 8.5	7.6 - 8.5	8.1 - 8.6
Central Bay	7.5 - 7.9	7.3 - 7.8	7.1 - 8.3
Inner Bay	7.1 - 7.5	7.3 - 7.8	7.1 - 7.4

Thus the pH varied in range 7.1 to 8.5 which is unusual for seawater where changes are generally in range 7.8 to 8.3. The pH recorded during September 2009 was in 7.7 to 8.3 ranges.

d) SS

SS of natural origin generally constitute clay, silt and sand from land drainage, bed sediment and shore erosion. Anthropogenic SS is contributed through solid waste in polluted areas.

A refined petroleum product generally does not contribute to SS. However, the oil particles dispersed in the water column may get associated with the SS by adsorption followed by sinking to the seabed when SS settles.

SS (mg/l) in the Bay were as follows.

Zone	Series		
	I	II	III
Mouth	86 - 1221	49 - 1345	38 - 5376
Central Bay	67 - 1972	28 - 391	35 - 3930
Inner Bay	50 - 593	21 - 360	43 - 1032

The SS varied in 21 to 5376 mg/l range. This range was 11 to 91 mg/l during September 2009. The bulk of the SS in the Mumbai waters is mainly derived from the bed and shore sediments dispersed by currents and turbulence. The SS during present monitoring varied widely with values often exceeding 300 mg/l compared to the narrow range of 11 – 91 mg/l observed in September 2009. This is probably because of strong monsoon winds prevailed during August 2010 that enhanced turbulence in shallow coastal waters disturbing the settled sediments.

e) Salinity

Normally seawater salinity is 35.5 ppt which may vary depending upon balance between evaporation and precipitation. The variations are more pronounced in the nearshore zones, bays, creeks and estuaries with tide and season having pronounced influence. An oil spill does not influence the salinity in the area of its occurrence.

During August 2010, salinity (ppt) of the Mumbai Bay varied in the following ranges:

Zone	Series		
	I	II	III
Mouth	19.4 - 31.8	15.3 - 34.6	25.8 - 35.4
Central Bay	12.9 - 32.4	11.0 - 33.0	20.2 - 31.5
Inner Bay	12.0 - 16.3	1.8 - 29.9	12.3 - 26.4

The variations which occurred over wide ranges were due to the influence of monsoon run-off. It also decreased towards the inner segment as generally observed for bays/creeks/estuaries. The salinity recorded during September 2009 was relatively high (24.8 – 36.1 ppt) as the measurements coincided with the fag end of the monsoon.

e) DO and BOD

High DO is a measure of good oxidising conditions in an aquatic environment. In unpolluted waters equilibrium is maintained between its generation through photosynthesis and dissolution, and consumption by respiration and decay of organic matter. Influx of degradable organic matter and certain pollutants consume DO more than that the water body can replenish creating under saturation conditions increasing oxygen demand. It is observed that at concentration of DO below 2 ml/l a good and diversified aquatic life may not be maintained and it is considered that the level of DO should not fall below 3 ml/l for prolonged periods.

A spill neither contains any readily oxidisable matter to deplete DO. Hence oil spills do not directly influence DO and BOD of a water body. The surface layer of oil however can limit dissolution of DO from the atmosphere in water. As discussed in Section 6 this possibility is unlikely in the present case.

DO (mg/l) for the Bay area is given below.

Zone	Series		
	I	II	III
Mouth	4.4 - 6.3	1.3 - 6.3	3.2 - 5.4
Central Bay	3.2 - 5.4	1.3 - 7.0	1.6 - 5.1
Inner Bay	2.9 - 4.1	ND - 7.6	ND - 5.7

As evident from above data that DO was variable from ND to 7.6 ml/l. As discussed in Section 3 inshore areas of Mumbai are prone to low DO during ebb tide due to the impact of sewage. This is also supported by DO records of September 2009 for the Bay Mouth (1.9 – 7.1 mg/l) and the Inner Bay (1.6 – 6.0 mg/l). Thus the low DO values recorded during the present monitoring was not due to the impact of the spilled oil.

BOD (mg/l) recorded for the region is summarised below.

Zone	Series		
	I	II	III
Mouth	1.9 - 4.8	0.6 - 5.4	1.3 - 3.5
Central Bay	2.5 - 4.8	<0.1 - 5.1	0.6 - 3.5
Inner Bay	1.6 - 2.5	<0.1 - 6.3	<0.1 - 4.1

The BOD of the Bay water varied in the range <0.1 to 6.3 mg/l for samples with sufficient initial DO. The samples containing low or no DO were not analysed and could have much higher BOD. The values compared well with the BOD observed in September 2009 (0.6 – 4.3 mg/l). Thus the BOD values remained comparable between the pre- and post-spill periods.

g) Nutrients

Dissolved phosphorus and nitrogen compounds which are major nutrients for phytoplankton, influence the productivity at the primary level in aquatic bodies. Phosphorus is present predominantly as reactive phosphate while combined inorganic nitrogen is present as nitrate, nitrite and ammonium (NH_3 + NH_4^+). These species are interconvertible through oxidation-reduction processes depending upon DO content and other processes in the ecosystem.

Presence of oil in an ecosystem does not interfere directly into the processes of consumption and regeneration of nutrients as discussed in Section 6. The PO_4^{3-}-P (μmol/l) content in the Bay varied as follows:

Zone	Series		
	I	II	III
Mouth	1.3 - 3.4	2.7 - 4.2	1.4 - 3.0
Central Bay	0.8 - 5.2	3.5 - 11.7	2.0 - 11.8
Inner Bay	4.2 - 5.2	ND - 6.3	ND - 4.1

The concentrations which varied in the range ND to 11.8 μmol/l were broadly comparable with the results of September 2009 (0.8 – 8.2 μmol/l) as expected in the Bay.

Levels of NO_3^--N, NO_2^--N and NH_4^+-N observed in the Mumbai Bay during August 2010 are summarised below.

Nutrient	Content (μmol/l)
NO_3^--N	1.1 - 124.6
NO_2^--N	ND - 38.1
NH_4^+-N	ND - 121.6

The monitoring results for September 2009 of these nutrients are given in the following table:

Nutrient	Content (μmol/l)
NO_3^--N	3.6 – 78.5
NO_2^--N	0.1 – 17.5
NH_4^+-N	0.7 – 9.4

The results of the two sets of monitoring results are more or less comparable and indicate no measurable impact of oil spill on their concentrations. As discussed in Section 3 the inshore waters of Mumbai often have high and variable concentrations of NO_3^--N, NO_2^--N and NH_4^+-N under the influence of sewage released in the system.

h) Phenols

Phenols are generally present in levels of few microgram per litre as microbiologically produced polyphenols in natural waters. Effluents originating from industries such as pesticides, dye and pigment, coal, refinery, paper, leather, petrochemical etc can raise its levels in an aquatic system. Phenols present in fungicides, antimicrobials etc and leather preservatives, pharmaceuticals, dyes, pesticides, resins etc also find their way to marine ecosystems through domestic and industrial effluents.

Phenols are present in a group of NSO compounds in residual fractions of crude oil. However their concentration in fuel oils is generally low to significantly contribute to the marine environment subsequent to an oil spill.

The concentration of phenols in the water of the Mumbai Bay is given below.

Zone	Series		
	I	II	III
Mouth	58.3 - 107.3	36.2 - 90.0	74.2 - 103.4
Central Bay	22.1 - 174.2	24.5 - 143.3	52.3 - 978.4
Inner Bay	42.7 - 170.9	15.1 - 52.6	54.7 - 86.6

Phenols ranged from 15.1 to 978.4 μg/l without any particular trend in their distribution. Except occasional high concentrations, the observed levels are comparable with the monitoring results of September 2009 (31.7 – 107.5 μg/l) in most instances indicating no significant contribution by the spilled oil.

i) Diurnal variations

The tidal variations at Vashi (station 13) in the Inner Bay conducted on 13, 18 and 25 August 2010 (Figures 8.2.9 to 8.2.11) did not indicate any discernible pattern of the parameters studied with the progress of the tide.

8.2.3 Sediment quality

Oil dispersed in the water column gets adsorbed onto the suspended particulate matter which on settling transfers the oil to the bed sediments. The immiscible surface oil layer also becomes heavier due to the loss of low boiling constituents and eventually sinks. The residues of weathered oil transported to the bed are redistributed by the bottom currents and turbulence in shallow areas. Such residues in the form of tar lumps and tar balls are strewn on the intertidal area during favourable monsoon circulation along the coast of India.

In some areas of restricted water exchange, sediment is known to serve as a long term sink for petroleum residues for periods of years to decades.

PHc in surface sediment (μg/g, wet wt) of the subtidal stations in Mumbai Bay (Table 8.1.4) was as follows.

Station	Series I	Series II	Series III
1	ND	0.7	1.3
2	-	1.0	0.8
4	-	7.0	1.8
5	5.7	0.3	1.6
10	7.3	-	-
11	4.4	7.9	1.6
12	7.0	9.4	6.0
13	9.1	1.8	5.8
14	-	3.5	4.4
15	2.6	2.2	0.6
16	-	1.2	1.1
17	-	0.2	4.7
18	-	0.3	1.3
19	-	0.5	18.8
21	-	11.5	22.1
22	-	7.3	2.3

Based on above data, the PHc accumulation of ND to 22.1 μg/g, wet wt was in following ranges in different sampling Series.

Zone	Series I	Series II	Series III
Mouth	ND	0.7-7.0	0.8-1.3
Central Bay	4.4-7.3	0.2-11.5	1.3-22.1
Inner Bay	2.6-9.1	1.2-3.5	0.6-5.8
Range	ND-9.1	0.2-11.5	0.6-22.1

The highest accumulations of 11.5 and 22.1μg/g, wet wt occurred at station 21 in the Central Bay towards the port area.

Marginal increases in the levels were recorded at stations 11 and 12 in the Series II from 4.4 to 7.9 and 7.0 to 9.4 μg/g, wet wt respectively. A marked increase in the accumulation was also evident in the Central Bay during the Series III.

The PHc content of the Bay sediments (μg/g, wet wt) recorded during the earlier monitoring events was as follows:

Zone	Premonsoon (March 1999)	Monsoon (September 2009)	Premonsoon (2007-2009)	Postmonsoon (2009)
Mouth	32.4	0.5 - 0.6	-	1.0 - 10.1
Central Bay	7.6-41.4	-	-	2.2 - 3.4
Inner Bay	42-42.8	1.0 - 4.0	4.8 - 10.0	0.2 0.9

Comparison of these data with the results of present study shows that the levels of PHc had not increased in the region due to the oil spill. In fact concentrations recorded in March 1999 exceeded the results of the present monitoring. As discussed in Section 8.1.16, in areas affected by accidental oil spills, the sediment burden of PHc increases several folds. This however was not seen in the Bay sediments.

8.2.4 Flora and fauna

Bacteria, phytoplankton, zooplankton and benthos from the subtidal zone of the Mumbai Bay (Thane Creek-Mumbai Harbour) were monitored during Series I to IV of Phase I (Figure 1.4.1). The results are described below.

a) Bacteria

TVC, TC, FVC, ECLO, SHLO, SLO, PKLO, VLO, VPLO, VCLO, PALO and SFLO in the surface water and the sediment from all the water quality stations were determined and the results are given in Tables 8.2.1 and 8.2.4.

Seawater: The TVC counts varied widely (1000 - 296000 no/ml) with the highest average counts of 120666 no/ml at the harbour mouth during Series II (Table 8.2.1). No clear trend in their distribution between the harbour and Thane Creek was observed. TC (20 - 1500 no/ml) and FC (10 - 760 no/ml) also varied in a wide range without any trend. SLO occurred only in Thane Creek, while, SFLO was not detected in the study area. Bacteria like ECLO, SHLO, PKLO, VLO, VPLO, VCLO and PALO varied randomly as expected for areas receiving untreated sewage.

In general, the bacterial counts of the present study (Table 8.2.2) were much higher than that of September 2009 (Table 8.2.3) for some class of bacteria. However, the distribution of ECLO, SHLO, PKLO, VLO, VPLO, VCLO and PALO was broadly comparable between two periods (2009-2010). Hence, the impact of the oil spill on the distribution and abundance of bacteria in surface water in the Bay was not evident.

Sediment: The bacterial counts (no/g) in surface sediments of the Mumbai Bay during the present study are given in the Table 8.2.3.

The bacterial counts in sediment were many folds higher than in water as expected and their distribution was random. Thane Creek sustained relatively higher counts than the harbour region.

As evident from Tables 8.2.1 and 8.2.4, the bacterial counts in general, were higher during present study as compared to September 2009. The distribution and abundance of bacteria in sediment were more related to sewage releases to the Mumbai Bay rather than impact of the oil spill.

b) Phytoplankton

The distribution of phytopigments, cell counts and total genera for different periods of the present study is compared in the table given below.

Parameter	Series I	Series II	Series III	Series IV
Chlorophyll *a* (mg/m^3)	0.9-12.3	0.9-45.5	1.4-34.5	0.8-42.6
Phaeophytin (mg/m^3)	-	1.2-22.1	0.3-4.6	0.6-7.5
Ratio of Chl *a*/Phaeo	0.6-2.8	0.1-19.9	1.1-34.5	0.9-11.4
Cell counts ($nox10^3/l$)	60.3-1294.6	75-50488	-	-
Total genera (no)	8-19	7-21	-	-

It is evident from above data that the concentrations of chlorophyll *a* widely varied (Table 8.2.5), whereas, phaeophytin did not reveal any clear trend. The ratios of chlorophyll a/phaeophytin also varied widely having lower values during Series I as compared to the rest suggesting severe to moderate environmental stress on phytoplankton especially during Series I. The higher ratios clearly suggested good phytoplankton production in the study area from Series II to IV.

The cell counts and generic diversity of phytoplankton also revealed wide variability in the study area. However, the cell counts were comparatively low during Series I than Series II, suggesting possible impact of the oil spill on phytoplankton. In general, the generic diversity of phytoplankton revealed a comparable trend between Series I and Series II.

The results of monitoring under Series I to IV are compared with earlier data (September 2009) in Table 8.2.6.

The comparison reveals reduction in the concentration of chlorophyll *a*, ratio of chlorophyll *a* / phaeophytin, and the cell counts during the Series I as compared to September 2009.

However, the values of phytopigments, cell counts and generic diversity of Series II to IV were comparable with the data of September 2009. The marked reduction in phytopigments and cell counts during Series I could be due to the mortality of phytoplankton which are sensitive to petroleum hydrocarbons in water (Section 8.2.2). The results of subsequent monitoring suggested that the recovery of phytoplankton occurred in a short span.

c) Zooplankton

The standing stock and group diversity of zooplankton widely varied in the study area during Series I and II (Tables 8.2.6 and 8.2.7, Figures 8.2.12 to 8.2.15) comparison of results with relatively high concentration of PHc with those with near background levels of PHc (stations 7, 8 and 9) indicate no clear trends and suggests that zooplankton were not grossly affected during the time of spill in Series I as evident form table below.

Parameter	Averages	
	Series I	**Series II**
PHc (µg/l) in water	2428.5	20.9
Zooplankton Biomass (ml/100 m^3)	23.4	2.8
Population (nox10^3/100m^3)	451	71
Total groups (no)	14	11
Fish eggs (no/100 m^3)	18	1
Fish larvae (no/100 m^3)	115	37

It is evident from above table that the distribution and abundance of zooplankton were found to be normal during the time of oil spill in Series I. However, Series II revealed considerable reduction in the standing stock of zooplankton although the water quality indicated near normal PHc level. Similarly a drastic reduction in the abundance of fish eggs and larvae during series II as compared to series I was noticed.

d) Macrobenthos

The distribution of subtidal macrobenthic faunal standing stock and diversity for the study area is given in the table below.

Period	Biomass (g/m^2, wet wt.)	Population (no/m^2)	Total groups (no)
Series I	0-19.2	0-11700	0-4
Series II	0-3.2	0-450	0-4
Series III	0-5.7	0-5075	0-3
Series IV	0-13.5	0-6300	0-2

It is evident from above data that high variability in standing stock and faunal group diversity was noticed for the subtidal macrobenthos of the study area (Figures 4.2.16 to 4.2.18). A reduction in standing stock during Series II and Series III as compared to Series I and Series IV was evident. However, the faunal group diversity which was on a narrow range indicated a reduction during Series III to Series IV as compared with Series I and Series II. Overall, both faunal standing stock and group diversity showed a noticeable reduction during August 2010 as compared to September 2009 (Table 8.2.9). This may be due to natural variability associated with disturbance to substrate conditions because of monsoonal activities.

e) PHc in biota

Commercial fishing in Mumbai Bay is at low level especially during monsoon. Experimental trawling conducted in the study area during 19-21 August 2010 (Series II) revealed a small catch <5 kg/h. Some selective species from this catch were analyzed for PHc content and the results are given below.

Fish	Station	Concentration (μg/g, wet wt)
Croaker (*Johnius belengeri)*	1	1.3
Cat fish (*Arius arius*)	1	3.9
Croaker (*Johnius elongatus)*	13	3.4
Cat fish (*Arius cadatus*)	13	0.6
Croaker (*Johnius carutta*)	13	3.2
Croaker (*Johnius carutta*)	22	1.7

From the available literature, PHc in fishes of the Mumbai Bay is compiled in the following table:

Fish	Concentration (μg/g, wet wt)
Bombay Duck	3.4
Cat fish	8.4
Indian mackerel	2.9
Anchovy	1.0 - 9.6
Dhoma	0.8 - 10.8

The comparison of the present results with those reported in the past indicated that there was no evidence for the accumulation of PHc in fishes subsequent to the spill. In fact the values of the present monitoring are lower than reported earlier.

8.2.5 Impact assessment of oil spill

The physical observations show that prevailing circulation pattern influenced by tide, currents and wind during the period of spillage has high impact on small but continuous leakage (3 days) of oil resulting in transporting of major spill in the Mumbai Bay and some fraction directed towards the coast south of Mumbai Bay. Highly fragmented parcels of the slick on the water surface could be due to high turbulence and wave action prevailed in monsoon. It was also aided by properties of the constituents of the spilled oil. Presence of isolated patches of oil on water surface would lead to highly variable distribution of dissolved and dispersed fractions in the water column. Hence, adverse impact on flora and fauna of the affected areas would be highly uneven from one sampling location to the other.

b) Water quality

PHc concentrations recorded during Series I (11 to 14 August 2010) revealed high concentrations in isolated patches in the Inner and the Central Bay.

The relatively low PHc levels (<100 μg/l) during subsequent sampling Series suggested that the small residual dissolved and dispersed fraction of the spilled oil in water had possibly diluted and weathered thereby reliving the Bay water from excess PHc (Figures 8.2.6 and 8.2.8).

The past data for PHc in water of the Bay indicate that the levels though variable are generally in 2.3 to 72.4 μg/l range (Table 8.1.2). Thus it is evident that the impact of the spilled oil on the PHc content was short-lived. The Central Pollution Control Board (CPCB) has set water quality standards for coastal waters and marine outfalls. The primary water quality criteria for use in salt pans, shell fishing, mariculture and ecologically sensitive zone (Class SW-I) specifies concentration of 0.1 mg/l (100 μg/l) of oil and grease (including petroleum products).

High SS content in the Bay was possibly inherited from disturbances of bed sediment and land drainage during monsoon period. Wide variations in salinity (1.8 to 35.4 ppt) were also due to monsoonal runoff. Variable DO sometimes falling to low values and high concentrations of NO_2^--N, NO_3^--N and NH_4^+-N in some instances are in agreement with the past data sets for the Bay and have been considered to be due to release of sewage to the Bay. The overall assessment indicates that the impact of the spill on water quality of the Bay was limited to abnormally high concentrations of PHc in water confined to localized areas that too for a short duration of less than a week and background levels had attained at the majority of stations within 11 days from the accident. The variations in other quality parameters though indicated a deteriorated marine environment, these variations could be explained based on the past monitoring records and particularly of September 2009.

c) Sediment quality

PHc concentrations in the subtidal sediment of the Mumbai Bay were ND to 9.1, 0.2 to 11.5 and 0.6 to 22.1 µg/g, wet wt during Series I to III respectively (Table 8.1.4).

The accumulation of PHc in sediments reported for Mumbai for the pre-spill period (2007-2009) was 0.2 to 10.1 μg/g, wet wt. Hence the values of 11.5

to 22.4 µg/g, wet wt for Central Bay (stations 19 and 21) during Series II and III were marginally higher than the background in some instances.

d) Flora and fauna

Bacteria: The bacterial counts of TVC, TC, FC and other selective bacteria widely varied and without any trend both in water and sediment at the Mumbai Bay during the present study (August/September 2010). The bacterial counts both in water (Tables 8.2.1 and 8.2.2) and sediment (Tables 8.2.3 and 8.2.4) were relatively higher during the present study as compared to those of September 2009. The large variations in bacterial populations are common in areas receiving sewage and also influenced by land drainage. A short-lived small oil spill in a polluted coastal system is unlikely to have altered significantly the distribution and abundance of bacteria in the system.

Phytoplankton: The concentration of chlorophyll *a* (av 5.2 mg/m^3) and phaeophytin (av 2.3 mg/m^3) in the surface waters during the Series I was lower than the results of September 2009 thereby suggesting possible reduction in their levels. Moreover, the average concentration of phaeophytin similar to the shore sampling results remained higher than that of chlorophyll *a* (Figure 8.1.16a) leading to low chlorophyll *a* / phaeophytin ratios (av < 1) during the Series I. These results indicated a possible mortality of phytoplankton due to the oil spill (Figure 8.1.16b). The concentration of chlorophyll *a* (av 20.6 mg/m^3) and their cell counts (75 - 50488 nox10^3/l) increased considerably during Series II. The chlorophyll *a*/phaeophytin ratios significantly improved during Series II (av 11.7), Series III (av 6.5) and Series IV (av 3.3) supporting the inference of adverse impact of the oil spill on phytoplankton immediately after the spill (Series I). Such recovery of phytoplankton has been commonly reported following oil spills due to fresh recruits from the adjacent waters unaffected by oil. Blooms of phytoplankton were recorded in the Mumbai Bay during Series II of the present study as well as in September 2009. Such blooms could be due to higher input of freshwater, organic load and nutrients to the coastal system through land drainage which could favour typical estuarine species to grow in abundance for a short period. Also the reduction in zooplankton standing stock noticed during Series II could have reduced the grazing pressure on phytoplankton. However, the Mumbai Bay probably returned to normal conditions with respect to phytopigments during Series III and IV of study (Table 8.2.5).

Zooplankton: The results presented in Section 8.2.4 clearly revealed a noticeable reduction in zooplankton standing stock and group diversity in the Mumbai Bay especially during Series II as compared to Series I. It was also found that major groups like copepods, decapods, *Lucifer* sp and chaetognaths were coated with oil (Figures 8.2.19 and 8.2.20). Some organisms had oil in their digestive track (Figure 8.2.21a) and/or within their body (Figure 8.2.19). The high PHc content in water probably resulted in mortality of zooplankton leading to low biomass recorded in Series II. In fact there was 89% reduction in biomass and 86% decrease in population during Series II as compared to Series I within a short period which was unusual (Table 8.2.6; Figures 8.2.12 and 8.2.14). Considerable reduction in fish eggs (90%) and larvae (76%) during Series II in reference to Series I was also evident within a short period of about a week (Table 8.2.7; Figures 8.2.13 and 8.2.15). This suggests that the impact of the oil spill on phytoplankton was immediate whereas it was delayed to be reflected in the standing stock of zooplankton.

The comparison of Thane Creek with Harbour mouth open coastal system clearly revealed reduction in zooplankton standing stock in both coastal systems during the Series II of the study. Both coastal systems revealed considerable reduction in zooplankton standing stock during August 2010 as compared to September 2009 (Table 8.2.8).

M**acrobenthos:** High variability in standing stock and faunal group diversity were noticed in the distribution of subtidal macrobenthos of the Mumbai Bay during the present study [Section 8.2.4(d)] with reduction in these parameters when compared to September 2009 results (Table 8.2.9). However, this conclusion should be treated with caution since seasonal variability of macrobenthos in the Mumbai Bay is common which may be due to substrate changes inducted by monsoon activities and high freshwater influx to the system. This possibility appears more likely in view of comparable PHc in sediments in pre- and post-spill periods (Section 8.2.3).

PHc in biota: Generally organisms from coastal regions show consistently low levels of hydrocarbons in the range of 0.1 to 10 μg/g, wet wt. It has been reported that tissues of organisms exposed to petroleum contained 10 to 100 times more hydrocarbons than the tissues of marine animals unexposed to the contamination.

It is known that fish generally avoid spill affected areas. The general avoidance thresholds are < 1 mg/l of Water Soluble Fraction (WSF) of PHc for seawater.

The PHc content in fish from the Mumbai Bay reported in literature was 0.1 to 10.8 μg/g, wet wt which was comparable to the levels recorded in fishes from normal coastal areas. The concentrations of PHc in the post-spill period varied in the range 0.8 - 3.9 μg/g, wet wt which was even below the levels reported earlier for the pre-spill period.

Hence, there was no evidence for accumulation of PHc in the fish samples collected after the occurrence of oil spill.

8.3 Impact assessment of spills of pesticides and hazardous chemicals

It was reported that some metal canisters containing pesticides and hazardous chemicals reportedly washed ashore on the beaches. However, their fate was not known. Their possible fate on spillage in sea would be as follows:

8.3.1 Organophosphorus pesticides

There were 3 pesticides namely dichlorvos, acephate and quinolphos loaded on the ship.

A pesticide if spilled in the sea would dissolve in water. The lethal concentration of it to fish would exist only in the localized area of spillage.

Whether such concentration would persist in the Bay would depend on the mass of the pesticide entering the water, rate of its dissolution, dilution by diffusion and advection etc. Nevertheless, it has high potential to cause fish mortality in the affected areas. Hydrolysis is slow at pH 4 but rapid at pH 9 which is nearer to the seawater pH. Biodegradation may occur, especially under acidic conditions with slow hydrolysis, or where populations of acclimated micro-organisms exist, as in polluted waters. Its decomposition rate by hydrolysis is over 3% per day in seawater.

8.3.2 Synthetic pyrothroids

A synthetic pyrothroid; deltamethrin when spilled in water would tend to sink as its solid form is heavier than water. Being sparingly soluble, its spillage may not cause large-scale mortality of pelagic organisms though demersal animals may be at high risk at the site of spillage.

The pesticide would slowly decompose by hydrolysis in seawater at pH above 7.5. It has a tendency to bind with solids and hence may remain in the bed sediment before being hydrolysed.

8.3.3 Hazardous chemicals

a) Sodium hydroxide

Sodium hydroxide is highly soluble in water and the process is exothermic. The spillage of sodium hydroxide in bulk could enhance pH and temperature of seawater and extent to which this could happen would depend on several factors as discussed under Section 6. The impact on biota would depend on the extent of increase in pH and temperature rise. In view of the buffering capacity of seawater and rapid dispersion impact would be on short duration.

9 TENTATIVE FINDINGS AND PROPOSED STUDIES

9.1 Ship accident and NIO's initiative

The ships MSC Chitra and MV Khalijia 3 collided in the mouth area of Mumbai Bay on 7 August 2010, at 0937 h. Subsequently, MSC Chitra drifted and grounded near the Prong Reef Light House. The accident resulted in the leakage of 600 to 800 t of furnace oil and about 120 containers onboard the vessel - some of which containing pesticides and hazardous chemicals like organophosphorus pesticides and sodium hydroxide fell in the sea. NIO on its own conducted assessment of impact of the accident on marine ecology of the Mumbai Bay and adjacent coastal areas commencing from 10 August 2010.

The initial study by NIO considered selective parameters of water quality, sediment quality and flora and fauna. For this purpose 15 shore locations and 22 subtidal stations were sampled. These investigations were carried out in four series between 10 August and 8 September 2010. The tentative findings based on the observations and proposed plan for future studies are presented below.

9.2 Tentative findings

9.2.1 Model Prediction

ICMAM – Project Directorate, Chennai as well as NIO modelled the spill assuming leakage rate of 3 t/h over about 3 days. ICMAM used OILMAP to predict the movement and spreading of the spilled oil and ADIOS to evaluate the weathering processes at spatial and temporal scales in the Mumbai Harbour – Thane Creek model domain. NIO used the Hydrodyn-Oilsoft software with the project domain extended also to the coastal area between Versova and Revdanda upto a distance of 25 km from the coast. The modelling results in both cases predicted that the spilled oil would hit the shores of Colaba, Uran, JNPT, Vashi, Trombay, Sewri etc. within the Mumbai Bay. The modelling results of NIO also predicted the pollution of coastal areas south of the Bay mouth namely Mandva, Kihim, Alibaug etc within 3 days of the spill. These predictions broadly matched the feedback of the field observations.

9.2.2 Intertidal environment

Among the 15 shore transects investigated in the Mumbai Bay and adjacent areas on 10 August 2010; Colaba, Uran and Vashi had oil landfall. Intertidal area of Trombay and mangrove habitats at Vashi and Trombay were also found coated with oil. Low level of oil contamination was noticed at Kihim beach. Some containers which had gone overboard following the accident and washed ashore were noticed at Dighodi and Uran with spilled materials like teabags, sugar and biscuit pockets, etc strewn around. The west coast of Mumbai from Girgaon to Juhu was unaffected by the oil spill.

The nearshore water quality of Series I revealed that the salinity, SS, DO, phosphate, nitrate, nitrite, ammonia and phenols were in the ranges expected for the region with no measurable impact of the accidental oil spill as expected. However, the concentrations of PHc were abnormally high (498-12075 µg/l) at Kihim, Uran, Colaba and Mandva during Series I under the influence of slick drifted into the coast. During, Series II (after 8 days) majority of the shore segments sampled excepting Uran 2, Trombay and Vashi revealed a marked recovery with much lower PHc levels (<53.2 µg/l). The west coast of Mumbai had expected water quality with the PHc values comparable to the background revealing the absence of any significant impact of the oil spill in this zone. Overall, the impact of the oil spill on nearshore water quality was limited to enhanced levels of PHc in water of localized sites for a period of a week or so from the time of the occurrence of oil spill. The recovery which was fairly fast was probably due to high wave generated turbulence and land runoff associated with the monsoon season.

Increase in PHc in sediment of the intertidal zone was insignificant compared to the expected background at several sites with only a marginal increase at Alibaug, Mandva and Trombay. Considerable reduction in chlorophyll *a* (av < 1 mg/m^3) and ratios of chlorophyll *a*/phaeophytin (< 1) when compared with the values of September 2009 was probably due to mortality of phytoplankton as an impact of increased levels of PHc in water at shore locations like Uran, Trombay and Colaba. Mortality of phytoplankton in marine areas affected by oil has been well-documented. Abundance of zooplankton and macrobenthos at the shore segments did not indicate any clear trend. Corals, barnacles, oysters and gastropods inhabiting the oil coated shore at Colaba were live and did not show visible signs of acute stress. Mangroves (*Avicennia marina*) at JNPT, Vashi and Trombay were coated with oil up to a height of 0.5 to 1 m.

High mortality of mangrove seedlings was noticed at Trombay due to smothering by oil.

9.2.3 Subtidal environment

Due to uneven distribution of dispersed and dissolved oil in the water column, the concentrations of PHc in water varied widely from as low as 5.2 µg/l at station 3 to the highest of 16902 µg/l at station 8 during Series I. However, as in the case of nearshore zone, the PHc values in the water of the Bay attained normal and ambient status within a short period of 11 days (Series II) after the oil spill. The rest of the water quality parameters indicated no significant differences in comparison with the expected background.

The levels of PHc in sediment (ND - 22.1 µg/g, wet wt) in the Mumbai Bay were comparable to the background indicating insignificant contamination of the bed by accidentally spilled oil. It is possible that since the oil spill was relatively small, the sinking residue was widely dispersed under tidal and monsoonal conditions leading to only minor transport to the bottom sediment of a given area.

The bacterial count of TVC, TC and FC varied widely without any trend both in water and sediment of the Mumbai Bay. In the Bay they are known to be associated with the sewage releases .

The results of chlorophyll a and phytoplankton populations indicated the possibility of phytoplankton mortality due to the oil spill in the initial stage (Series I). However, the recovery of phytoplankton in the affected areas of the Bay was fairly quick (Series II). Fast recovery of phytoplankton in areas affected by small oil spills through recruitment from nearby sites unaffected by oil has been fairly well-established.

A noticeable reduction (86-89%) in zooplankton standing stock and diversity was evident during Series II as compared to Series I values, wherein high PHc occurred in water. Similarly the abundance of fish eggs and larvae decreased to the extent of 90 and 76% respectively during series II. It appears that the impact of oil spill on phytoplankton of the affected areas was immediate whereas it was delayed in case of zooplankton.

High variability in standing stock and diversity of subtidal macrobenthos was mainly associated with substrate changes and monsoonal disturbances and there was no evidence of the impact of the oil on their standing stock in the Mumbai Bay.

The comparable levels of PHc in fish from Mumbai Bay during the pre- and post-spill periods precludes the possibility of its accumulation in fishes following the oil spill.

The fate of the contents of the containers with pesticides and hazardous chemicals going overboard is yet to be established.

9.3 Proposed studies

As given in Section 1 of this report NIO will continue monitoring of the Mumbai Bay and 100 km length of the coastline between Bassein and Alibaug. These studies will be spread over a period of 7 months (September 2010 – March 2011) as follows:

Phase	Period
II	September-October 2010
III	November-December 2010 and January 2011
IV	February - March 2011

Based on the results discussed in this report particular attention will be given to the recovery of intertidal ecology of spill-affected sites.

Ecotoxicological studies to assess neuro-toxicological impact on biota, rupture of DNA and oxidative stress on selective organisms will be done.

Apart from the calibration of model, the weathering of selected fuels in the marine environment of Mumbai will be quantified in different seasons to generate information base for use in future.

A hypothetical leakage of water soluble organophoshorus pesticide such as acephate at the seabed will be modelled for different scenarios to assess the volume of the water column that might have levels to cause acute toxicity to organisms.

Table 4.2.1: Details of metereological parameters recorded at Santacruz during August 2010

Date	0830 Temp ^{0}C		1730 Temp ^{0}C		Rainfall	Wind(0830)		Wind(1730)		Total Cloud Amount(okta)	
	D.B.	W.B.	D.B.	W.B.	mm	Direction	Speed(kmph)	Direction	Speed(kmph)	0830	1730
1	26.2	25.4	28.0	25.8	077.0	SW	16	W	18	8	8
2	27.4	25.8	28.0	25.4	010.4	W	12	SW	14	8	8
3	27.4	26.0	28.2	26.4	034.0	WSW	14	SW	10	8	8
4	28.4	26.0	29.6	26.4	022.5	WSW	12	SW	12	6	7
5	28.6	26.4	30.8	27.0	000.8	SW	6	SW	12	7	6
6	28.4	25.0	29.0	26.6	Trace	SW	8	W	14	7	7
7	27.2	25.4	25.0	24.6	000.8	W	6	W	6	8	8
8	27.6	26.4	30.2	26.6	045.7	SSW	10	SW	20	7	7
9	28.6	26.4	28.0	24.6	003.4	SW	12	SW	14	6	8
10	28.8	26.6	30.4	26.6	008.9	W	6	WSW	12	5	6
11	28.0	26.2	28.8	26.0	001.1	CALM	0	SW	12	7	6
12	26.0	29.6	25.6	26.4	013.1	CALM	0	WNW	6	8	7
13	26.6	25.4	29.4	26.0	020.0	CALM	0	NW	10	7	7
14	26.8	25.8	29.4	26.6	003.3	CALM	0	W	6	7	7
15	27.8	26.8	30.6	26.8	016.0	CALM	0	W	6	5	6
16	27.0	26.2	28.8	27.0	005.8	CALM	0	CALM	0	8	7
17	26.8	26.2	28.0	27.2	158.2	CALM	0	NW	8	6	7
18	26.0	25.4	25.6	24.5	108.7	CALM	0	CALM	0	8	8
19	25.4	24.6	28.2	26.6	090.2	CALM	0	CALM	0	7	7
20	26.8	26.0	26.0	25.2	024.5	CALM	0	CALM	0	7	8
21	26.0	25.2	28.6	26.0	010.8	CALM	0	CALM	0	8	7
22	26.0	25.0	29.6	26.2	011.6	CALM	0	W	8	7	5
23	27.6	26.0	30.0	26.2	002.5	CALM	0	NW	16	6	7
24	26.0	25.0	29.6	26.2	007.3	CALM	0	WNW	12	7	7
25	26.8	25.6	28.8	26.4	008.9	CALM	0	NW	6	8	8
26	26.0	25.2	29.0	26.2	021.4	CALM	0	CALM	0	7	7
27	27.0	26.4	26.6	25.6	036.4	CALM	0	CALM	0	8	8
28	27.0	26.0	30.2	27.2	012.8	CALM	0	WSW	12	7	7
29	27.0	26.6	26.6	25.6	044.0	W	6	SW	10	8	8
30	26.6	25.6	26.2	25.2	138.0	SW	14	WSW	12	8	8
31	26.4	25.4	25.4	25.0	098.4	SW	16	SW	14	8	8

Source: Indian Meteorology Department, Mumbai

Table 8.1.1: Distribution of phytopigments along the shore transects during August-September 2010

Transect	Date	Chlorophyll *a* (mg/m^3)	Phaeophytin (mg/m^3)	Ratio of chl *a* to phaeo
Alibaug	10/8/2010	14.2	1.1	12.9
		13.0	1.2	10.8
Kihim	10/8/2010	6.5	2.4	2.7
		9.0	3.8	2.4
Dhigodi	10/8/2010	5.9	4.8	1.2
		6.9	4.3	1.6
Mandva	10/8/2010	5.1	2.4	2.1
		2.7	4.4	0.6
Dharamtar	10/8/2010	2.6	3.4	0.8
		2.3	2.4	1.0
Uran 2	10/8/2010	0.5	0.6	0.8
Uran 1	10/8/2010	0.4	0.4	1.0
JNPT	10/8/2010	1.9	2.8	0.7
		2.2	3.1	0.7
Vashi	10/8/2010	5.3	5.0	1.0
		4.8	5.1	0.9
Trombay	10/8/2010	2.9	2.7	1.1
		2.3	2.8	0.8
Colaba	10/8/2010	3.4	3.7	0.9
Girgaon	10/8/2010	5.5	3.3	1.7
Mahim	10/8/2010	5.7	1.9	3.1
Juhu	25/8/2010	11.53	9.70	1.2

Table 8.1.2: PHc (µg/l) in seawater at subtidal stations sampled during Series I to IV and 2007-2010

Station	Series I	Series II	Series III	Series IV	April-2007	Feb-2008	May-2009	Sept-2009	Jan-2010	May-2010
1	261.5	7.6	8.0	40.7	14.1	23.5	3.3			
2	12.4	28.9	10.5	16.1	9.4	25.0				
3	5.2	-	-	-						
4	28.4	5.3	2.6	74.5						
5	157.7	1.4	10.1	1.4						
6	148.4	-	-	-						
7	2817.0	-	-	-						
8	16902.2	-	-	-						
9	8769.3	-	-	-					10.5	
10	6.2	-	-	-						
11	149.9	73.8	62.9	73.8					13.4	11.1
12	251.6	23.5	11.9	23.5					11.1	9.7
13 (Fl)	132.5	3.6	7.5	9.0	26.4	15.7	8.9	2.3	9.6	8.9
13 (Eb)	136.7	20.1	48.1	21.4	14.1		4.9	4.9	6.7	72.4
14	67.5	12.9	7.7	12.9			7.1	10.4	10.8	9.3
15	6684.8	15.9	6.2	15.9						
16	-	22.6	94.1	22.6						
17	-	7.2	3.7	7.2						
18	-	15.7	10.1	15.7						
19	-	13.4	18.1	13.4						
21	-	12.4	12.3	12.4						
22	-	32.1	25.8	32.1						
23	-	40.0	36.0	40.0						

Table 8.1.3: Water quality of intertidal transects along Mumbai Bay and adjoining coast (Series I-IV)

Shore transects	**pH**	**Salinity (ppt)**	**DO (mg/l)**	**PO_4^{-3}-P (µmol/l)**	**NO_3^--N (µmol/l)**	**NO_2^--N (µmol/l)**	**$(NH_4^+ + NH_3)$-N (µmol/l)**
Alibaug	7.6-8.0 (7.8)	14.5-22.0 (17.3)	5.7-7.0 (6.3)	1.6-4.5 (2.9)	6.4-11.2 (8.9)	1.2-1.9 (1.6)	3.1-6.7 (5.0)
Kihim	8.2-8.2 (8.2)	16.1-16.3 (16.2)	7.0-7.0 (7.0)	2.7-2.8 (2.7)	40.0-40.8 (40.4)	1.2-1.2 (1.2)	7.3-8.1 (7.7)
Dighodi	8.2-8.2 (8.2)	19.0-19.4 (19.2)	6.3-7.0 (6.7)	2.7-3.8 (3.3)	33.7-35.4 (34.5)	0.7-0.7 (0.7)	5.4-7.8 (6.6)
Mandva	7.7-8.1 (7.9)	19.7-20.6 (20.1)	6.3-7.9 (7.2)	2.7-4.3 (3.3)	9.9-28.0 (18.9)	0.9-4.0 (2.3)	3.2-4.9 (3.9)
Dharamtar	8.6-8.6 (8.6)	26.6-26.4 (26.4)	6.7-6.7 (6.7)	2.6-2.6 (2.6)	15.0-21.7 (18.4)	1.2-1.2 (1.2)	11.3-13.4 (12.3)
Uran 1	7.8-8.1 (7.9)	10.9-20.0 (15.4)	6.3-7.3 (6.9)	1.6-3.0 (2.4)	10.2-20.5 (15.5)	2.2-8.2 (5.3)	1.8-2.9 (2.2)
Uran 2	7.7-7.7 (7.7)	1.5-20.7 (17.6)	6.3-6.7 (6.5)	1.5-2.9 (2.0)	9.9-34.5 (18.1)	2.7-7.9 (4.4)	2.2-3.9 (2.9)
JNPT	7.8-7.8 (7.8)	14.2-14.4 (14.3)	6.3*	4.4-4.5 (4.4)	29.3-30.6 (30.0)	10.5-14.3 (12.4)	1.8-3.6 (2.7)
Vashi	7.5-7.9 (7.7)	1.9-6.0 (3.9)	3.8-7.3 (5.4)	2.7-8.3 (5.1)	10.0-55.4 (19.9)	4.0-39.6 (13.9)	4.4-85.7 (30.5)
Trombay	7.3-7.8 (7.6)	12.6-15.9 (14.6)	2.2-4.8 (3.1)	3.8-10.9 (6.2)	28.7-48.9 (35.6)	3.0-21.6 (9.2)	11.9-21.9 (15.6)
Colaba	7.4-8.0 (7.7)	19.6-30.3 (25.8)	4.8-7.0 (6.1)	1.4-3.5 (2.2)	7.3-56.7 (23.0)	0.1-9.8 (2.8)	1.0-7.4 (3.8)
Girgaon	7.4*	15.6*	6.7*	5.3*	34.2*	4.6*	6.3*
Dadar	7.5*	15.1*	1.5*	3.2*	23.5*	17.1*	18.7*
Mahim	7.6*	9.0*	6.7*	9.0*	36.1*	23.9*	25.9*
Juhu	7.2-7.3 (7.2)	29.1-29.9 (29.5)	6.3-6.7 (6.5)	2.7-2.9 (2.8)	6.8-17.7 (12.2)	4.6-4.7 (4.6)	6.8-7.0 (6.9)

* Single observation

Table: 8.1.4: PHc (µg/g, wet wt) in subtidal sediment during Series I to III and 2007-10

Station	Series I	Series II	Series III	Jan 2010	Sept 2009	May 2009	Feb 2008	April 2007
1	0.02	0.7			0.6	1.0	9.9	10.1
2		0.95			0.5	3.5	8.1	
3								
4		7.0						
5	5.7	0.32	1.6					
6								
7								
8								
9								
10	7.3							
11	4.4	7.9	1.6	2.2				
12	7.0	9.4	6.0	3.4				
13	9.1	1.8	5.8	0.9	4.0	6.3	10.0	9.7
14		3.5	4.4	0.2	1.0	4.8	5.0	
15	2.6	2.2	0.6					
16		1.2	1.1					
17		0.2	4.7					
18		0.3	1.3					
19		0.5	18.8					
21		11.5	22.1					
22		7.3	2.3					
23								

Table 8.2.1: Bacterial counts (cfu/ml) in surface water in Mumbai Bay during August-September 2010 (Series I-IV)

Parameter	Harbour mouth			Thane Creek		
	min	max	av	min	max	av
Series I						
TVCND	1900	12700	7800	3000	40000	12900
TC	30	250	103	20	170	72
FC	20	180	65	10	90	29
ECLO	30	180	70	10	80	28
SHLO	ND	ND	ND	20	60	40
SLO	ND	ND	ND	10	10	10
PKLO	40	80	58	30	160	93
VLO	110	1180	615	20	1040	341
VPLO	0	0	0	10	10	10
VCLO	20	500	158	10	980	285
PALO	10	80	37	30	100	64
SFLO	ND	ND	ND	ND	ND	ND
Series II						
TVC	80000	170000	120666	3200	140000	33957
TC	550	810	673	40	640	444
FC	170	600	390	20	380	189
ECLO	50	520	257	10	400	183
SHLO	200	800	500	20	700	235
SLO	ND	ND	ND	30	30	30
PKLO	100	100	100	20	440	235
VLO	40	960	367	40	1200	447
VPLO	40	40	40	10	900	397
VCLO	100	960	530	40	1200	386
PALO	1160	1600	1320	110	2000	504
SFLO	ND	ND	ND	ND	ND	ND
Series III						
TVC	1000	190000	31477	1000	190000	31829
TC	60	1500	477	100	1500	515
FC	40	600	235	50	600	232
ECLO	20	800	198	20	800	191
SHLO	60	260	155	100	260	167
SLO	ND	ND	ND	ND	ND	ND
PKLO	100	600	297	100	600	300
VLO	120	1800	728	100	1800	679
VPLO	30	30	30	30	30	30
VCLO	110	1800	722	100	1800	674
PALO	70	1000	463	80	1000	423
SFLO	ND	ND	ND	ND	ND	ND
Series IV						
TVC	8000	50000	22800	12000	296000	104157
TC	180	270	220	150	900	413
FC	20	150	90	50	760	198
ECLO	60	170	120	50	480	188
SHLO	ND	60	30	90	220	146
SLO	ND	ND	ND	10	20	15
PKLO	500	500	500	10	600	244
VLO	10	420	150	10	900	282
VPLO	ND	ND	ND	10	900	275
VCLO	10	420	150	40	560	189
PALO	10	100	70	10	1140	196
SFLO	ND	ND	ND	ND	ND	ND

Table 8.2.2: Bacterial counts (cfu/ml) in surface water at Mumbai Bay during September 2009

Parameter	Harbour mouth			Thane Creek		
	Min	Max	Av	Min	Max	Av
TVC	1000	20300	10180	13400	27300	18475
TC	10	10	10	40	40	40
FC	10	10	10	10	60	28
ECLO	10	30	20	10	40	25
SHLO	80	80	80	10	180	83
SLO	ND	ND	ND	ND	ND	ND
PKLO	20	380	128	30	130	78
VLO	60	380	198	20	250	163
VPLO	0	0	0	20	180	100
VCLO	60	380	198	20	250	113
PALO	20	20	20	80	80	80
SFLO	10	20	15	ND	ND	ND

Table 8.2.3: Bacterial counts (cfu/g) in sediments at Mumbai Bay during September 2010 (I-IV Series)

Parameter	Harbour mouth			Thane Creek		
	Min	Max	Av	Min	Max	Av
Series I						
TVC	-	-	-	380000	1500000	942000
TC	-	-	-	ND	2000	600
FC	-	-	-	ND	2000	600
ECLO	-	-	-	ND	2000	600
SHLO	-	-	-	ND	ND	ND
SLO	-	-	-	ND	ND	ND
PKLO	-	-	-	ND	ND	ND
VLO	-	-	-	ND	16000	3600
VPLO	-	-	-	ND	8000	1600
VCLO	-	-	-	ND	2000	600
PALO	-	-	-	ND	6000	1200
SFLO	-	-	-	ND	ND	ND
Series II						
TVC	240000	31000000	15620000	600000	36000000	11533333
TC	ND	3000	1500	ND	7000	3167
FC	ND	1500	750	ND	2000	917
ECLO	ND	1000	500	ND	3000	1333
SHLO	ND	ND	ND	ND	4000	333
SLO	ND	ND	ND	ND	ND	ND
PKLO	ND	ND	ND	ND	2000	500
VLO	ND	1000	500	ND	5000	2250
VPLO	ND	ND	ND	ND	ND	ND
VCLO	ND	1000	500	ND	5000	2250
PALO	ND	2000	1000	ND	16000	4167
SFLO	ND	ND	ND	ND	ND	ND
Series III						
TVC	510000	2000000	1255000	700000	23000000	6690909
TC	ND	4000	2000	ND	10000	4583
FC	ND	2000	1000	ND	7000	2909
ECLO	ND	ND	ND	ND	6000	2000
SHLO	ND	ND	ND	ND	3000	636
SLO	ND	ND	ND	ND	ND	ND
PKLO	ND	ND	ND	ND	2000	818
VLO	1000	1000	1000	ND	11000	3000
VPLO	1000	1000	1000	ND	ND	ND
VCLO	ND	ND	ND	ND	11000	3000
PALO	ND	ND	ND	ND	7000	1818
SFLO	ND	ND	ND	ND	ND	ND
Series IV						
TVC	600000	3000000	1733333	180000	2490000	1653000
TC	ND	7000	3667	ND	6000	2200
FC	ND	3000	1667	ND	2000	800
ECLO	ND	2000	1000	ND	3000	600
SHLO	ND	ND	ND	ND	1000	100
SLO	ND	ND	ND	ND	ND	ND
PKLO	ND	2000	667	ND	40000	4100
VLO	ND	2000	1000	ND	7000	1900
VPLO	ND	2000	667	ND	1000	100
VCLO	ND	1000	333	ND	6000	1800
PALO	ND	1000	667	ND	7000	1000
SFLO	ND	ND	ND	ND	ND	ND

Table 8.2.4: Bacterial counts (cfu/g) in sediments at Mumbai Bay during September 2009

Parameters	Harbour mouth			Thane creek		
	Min	Max	Av	Min	Max	Av
TVC	12000	224000	61600	104000	120000	109333
TC	1000	1000	1000	ND	ND	ND
FC	1000	1000	1000	ND	ND	ND
ECLO	1000	1000	1000	1000	1000	1000
SHLO	1000	2000	1500	ND	ND	ND
SLO	ND	ND	ND	ND	ND	ND
PKLO	9000	9000	9000	ND	ND	ND
VLO	2000	18000	9200	3000	3000	3000
VPLO	6000	12000	9000	2000	2000	2000
VCLO	1000	18000	5600	1000	1000	1000
PALO	ND	ND	ND	2000	2000	2000
SFLO	ND	ND	ND	ND	ND	ND

Table 8.2.5: Distribution of phytoplankton in Mumbai Bay during September 2009 and August-September 2010

Parameter		**Harbour mouth**		**Thane Creek**	
		S	**B**	**S**	**B**
Chlorophyll *a* (mg/m^3)	Sep 2009	4.8-39.2 (11.8)	5.3-35.0 (11.3)	2.4-17.6 (8.82)	4.6-16.2 (9.04)
	Series I	0.9-7.5 (4.44)	1.3-7.2 (4.4)	1.1-12.3 (3.89)	0.5-10.8 (3.88)
	Series II	5.1-10.76 (6.65)	2.2-6.6 (4.1)	9.7-45.5 (25.63)	0.9-9.0 (3.42)
	Series III	3.4-4.3 (3.8)	2.5-5.0 (3.7)	2.6-34.5 (9.0)	1.4-7.8 (3.50)
	Series IV	3.3-7.1 (5.6)	2.3-6.1 (4.33)	2.6-22.3 (6.87)	0.8-20.5 (6.79)
Phaeophytin (mg/m^3)	Sep 2009	2.0-12.3 (3.7)	0.6-14.3 (5.49)	0.3-2.1 (1.01)	0.5-3.2 (1.45)
	Series I	0.8-5.5 (3.68)	0.9-5.2 (3.44)	0.8-6.7 (2.32)	0.7-6.5 (2.83)
	Series II	1.6-3.6 (2.35)	3.5-22.1 (9.88)	1.2-10.4 (3.47)	1.9-11.6 (3.68)
	Series III	1.9-2.7 (2.28)	1.5-3.1 (2.33)	0.3-3.0 (1.48)	0.7-4.6 (1.85)
	Series IV	0.7-1.1 (0.93)	1.1-2.4 (1.56)	1.9-6.9 (3.3)	0.6-7.5 (3.54)
Ratio of Chl *a* to Phaeo	Sep 2009	0.6-5.5 (3.3)	0.9-15.1 (4.73)	2.2-34.6 (10.51)	2.0-21.4 (10.14)
	Series I	0.9-1.5 (1.18)	0.8-1.6 (1.2)	0.8-2.6 (1.65)	0.6-2.8 (1.42)
	Series II	2.1-5.1 (3.07)	0.1-1.4 (0.75)	3.2-19.9 (8.51)	0.2-3.4 (1.05)
	Series III	1.3-2.0 (1.73)	1.4-2.1 (1.65)	1.4-34.5 (7.17)	1.1-3.9 (1.64)
	Series IV	4.7-7.1 (5.87)	1.0-5.1 (3.43)	0.9-5.9 (2.10)	1.1-4.2 (1.97)
Cell count (nox10$^{3/}$l)	Sep 2009	127.2-5024.0 (1580.8)	210.4-1669.6 (556)	103-652 (324.2)	150.4-395.2 (244.48)
	Series I	92-592 (291.8)	77.6-513.2 (206.2)	60.3-1308 (266.78)	64.2-1294.6 (236.97)
	Series II	154.1-756 (506.03)	188-512 (352)	701.6-50488 (15727.78)	75-805 (264.132)
Total genera (no)	Sep 2009	13-18 (15)	14-18 (15)	11-16 (14)	12-20 (17)
	Series I	10-15 (13)	9-19 (13)	9-18 (13)	8-13 (11)
	Series II	11-12 (4)	8-10 (9)	8-21 (13)	7-12 (9)

Table: 8.2.6: Distribution of zooplankton biomass (ml/100m^3), population (nox10^3/100m^3), total groups (no), fish eggs and larvae (no/100m^3) and PHc in water in the study area (Series I and II)

Stn	Series I						Series II					
	PHc	Fish eggs	Fish larvae	Biomass	Population	Total groups	PHc	Fish eggs	Fish larvae	Biomass	Population	Total groups
1	261.5	132	452	14.5	276.5	17	7.6	4	8	1.2	24.9	13
2	12.4	0	56	10	164.9	15	28.9	0	11	1.25	19	13
3	5.2	0	40	3.2	75.7	14	-			-	-	-
4	28.4	1	452	28.7	302.1	15	5.3	7	63	6	203.9	15
5	157.7	0	353	49.4	753.4	15	1.4	0	31	2.3	101.8	13
6	148.4	1	19	5.2	120.7	18	-			-	-	-
7	2817	0	34	10.8	556.6	16	-			-	-	-
8	16902.2	0	178	63.8	1169.4	13	-			-	-	-
9	8769.3	4	196	63.6	898	13	-			-	-	-
10	6.2	6	27	8.7	278.2	15	-			-	-	-
11	149.9	0	13	19.5	424.9	12	73.8	1	15	1.95	42.9	12
12	251.6	0	10	21.2	329.6	11	23.5	1	0	0.5	2.2	5
13	134.6	0	10	5	157.9	12	11.9	0	0	0.6	38	8
14	67.5	0	12	39.5	979.6	12	12.9	0	1	0.35	4.6	8
15	6684.8	0	9	8.1	274.1	13	15.9	0	7	0.5	9.6	8
16	-			-	-	-	22.6	0	0	0.25	0.9	7
17	-			-	-	-	7.2	2	5	1.1	26	10
18	-			-	-	-	15.7	0	24	7.4	277.1	11
19	-			-	-	-	13.4	0	6	2.25	26.2	11
21	-			-	-	-	12.4	0	7	1.15	13.7	9
22	-			-	-	-	32.1	1	170	7.85	99.1	14
23	-			-	-	-	40	7	290	10.9	238.5	15
Av	**2426.4**	**10**	**124**	**23.4**	**450.8**	**14**	**20.3**	**1**	**40**	**2.8**	**70.5**	**11**

Table: 8.2.7: Distribution of fish eggs and larvae in the study area during Series I and II

Station	Fish eggs	% of occurrence	Fish larvae	% of occurrence
Series I				
1	132	100	452	100
2	0	-	56	100
3	0	-	40	100
4	1	100	452	100
5	0	-	353	100
6	1	50	19	100
7	1	-	34	100
8	0	-	178	100
9	4	100	196	100
10	5	100	26	100
11	0	-	13	50
12	0	-	10	100
13	0	-	10	100
14	0	-	12	100
15	0	-	9	100
Av	**10**	**30**	**124**	**93**
Series II				
1	4	50	8	100
2	0	-	11	100
4	7	100	63	100
5	0	-	31	100
11	1	50	15	100
12	1	50	0	-
13	0	-	0	-
14	0	-	1	50
15	0	-	7	100
16	0	-	0	-
17	2	100	5	100
18	0	-	24	100
19	0	-	6	50
21	0	-	7	100
22	1	50	170	100
23	7	100	290	100
Av	**1**	**29**	**40**	**71**

Table 8.2.8: Comparison of present study (Series I and II) on zooplankton in Mumbai Bay with that of September 2009*****

Parameter		Harbour mouth	Thane Creek
Biomass ($ml/100m^3$)	Sep 2009	0.9-144.3 (31.6)	0.1-281.6 (66.8)
	Series I	3.2-28.7 (14.18)	0.1-86.1 (24.12)
	Series II	0.6-8.6 (2.8)	0.1-13.4 (2.7)
Population ($nox10^3/100m^3$)	Sep 2009	100-779409 (249197.9)	132-186952 (72344.4)
	Series I	75.8-321.7 (159.4)	0.051-1385.1 (465.6)
	Series II	14.4-237.3 (83.8)	0.6-437.3 (65.7)
Total groups (no)	Sep 2009	4-14 (9)	11-17 (14)
	Series I	14-17 (15)	6-18 (13)
	Series II	11-17 (13)	4-17 (10)
Major groups	Sep 2009	Copepods, *Lucifer* sp, decapod larvae, lamellibranchs.	Copepods, decapods larvae, *Lucifer* sp. medusae.
	Series I	Copepods, decapod larvae, *Lucifer* sp ,	Copepods, chaetognaths, *Lucifer* sp. ,
	Series II	Copepods, chaetognaths, foraminiferans.	Copepods, chaetognaths, decapod larvae.

*NIO, COMAPS data

Table 8.2.9: Comparative study of subtidal macrobenthos between September 2009 and August-September 2010

Parameter		Harbour mouth	Thane Creek
Biomass	Sep 2009	0-2.3 (0.5)	0.7-12.1 (2.9)
	Series I	-	0-19.2 (1.2)
	Series II	0.03-3.2 (0.4)	0-1.5 (0.3)
	Series III	0-0.2 (0.1)	0-5.7 (0.4)
	Series IV	0-0.05 (0.01)	0-13.5 (0.8)
Population	Sep 2009	0-1150 (261)	475-2850 (1359)
	Series I	-	0-11700 (1039)
	Series II	50-450 (194)	0-350 (131)
	Series III	0-25 (10)	0-5075 (480)
	Series IV	0-75 (19)	0-6300 (339)
Total groups	Sep 2009	0-6 (2)	2-5 (3)
	Series I	-	0-4 (2)
	Series II	1.0-2.0 (1)	0- 4 (1)
	Series III	0-1 (1)	0-3 (1)
	Series IV	0-2 (1)	0-2 (1)

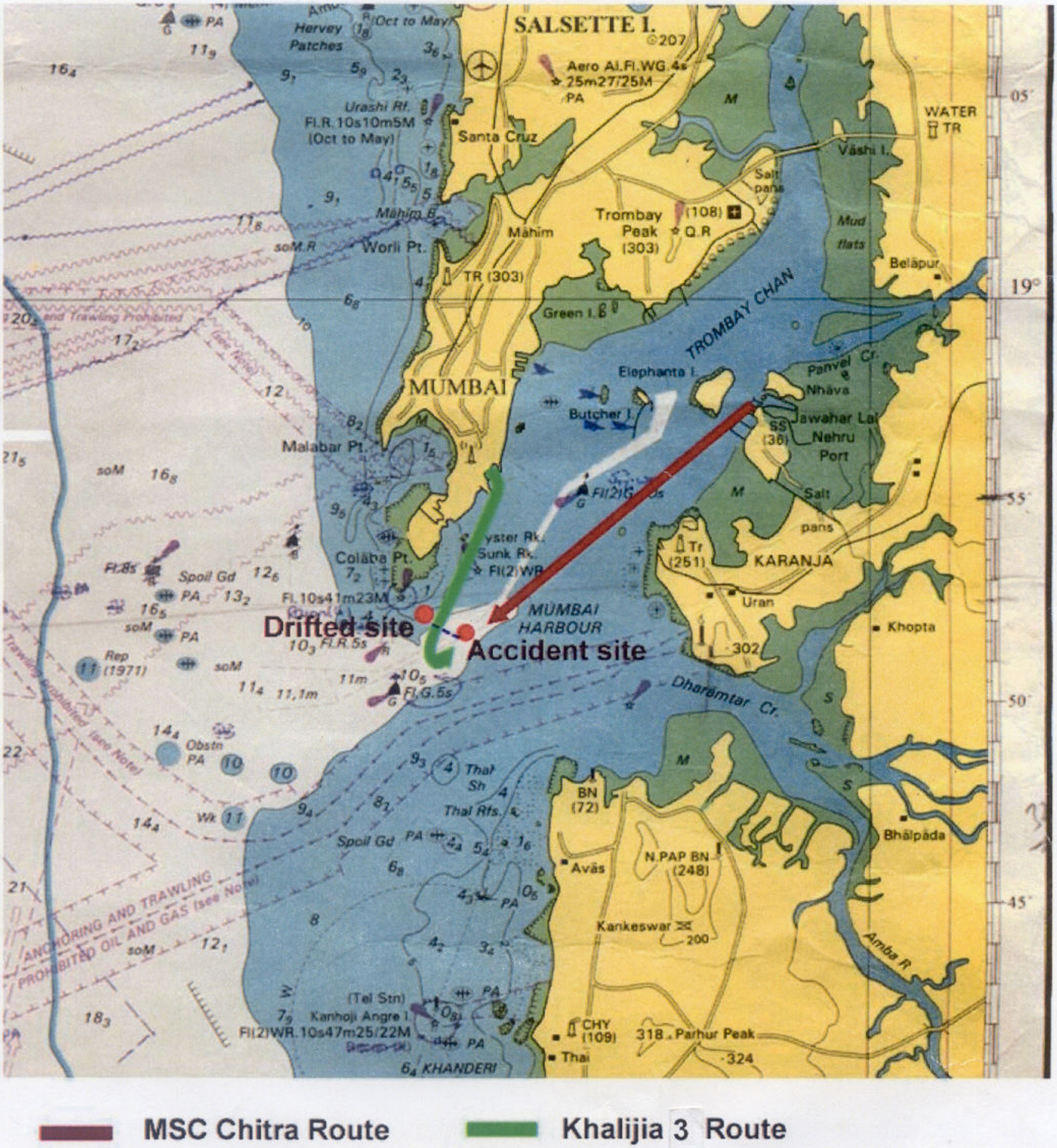


Figure 1.1.1: Accident and grounded sites of MSC Chitra on 7 August 2010

Figure 1.1.2: Tilting and grounding of MSC Chitra after accident

Figure 1.1.3: Several cargo containers falling in the sea

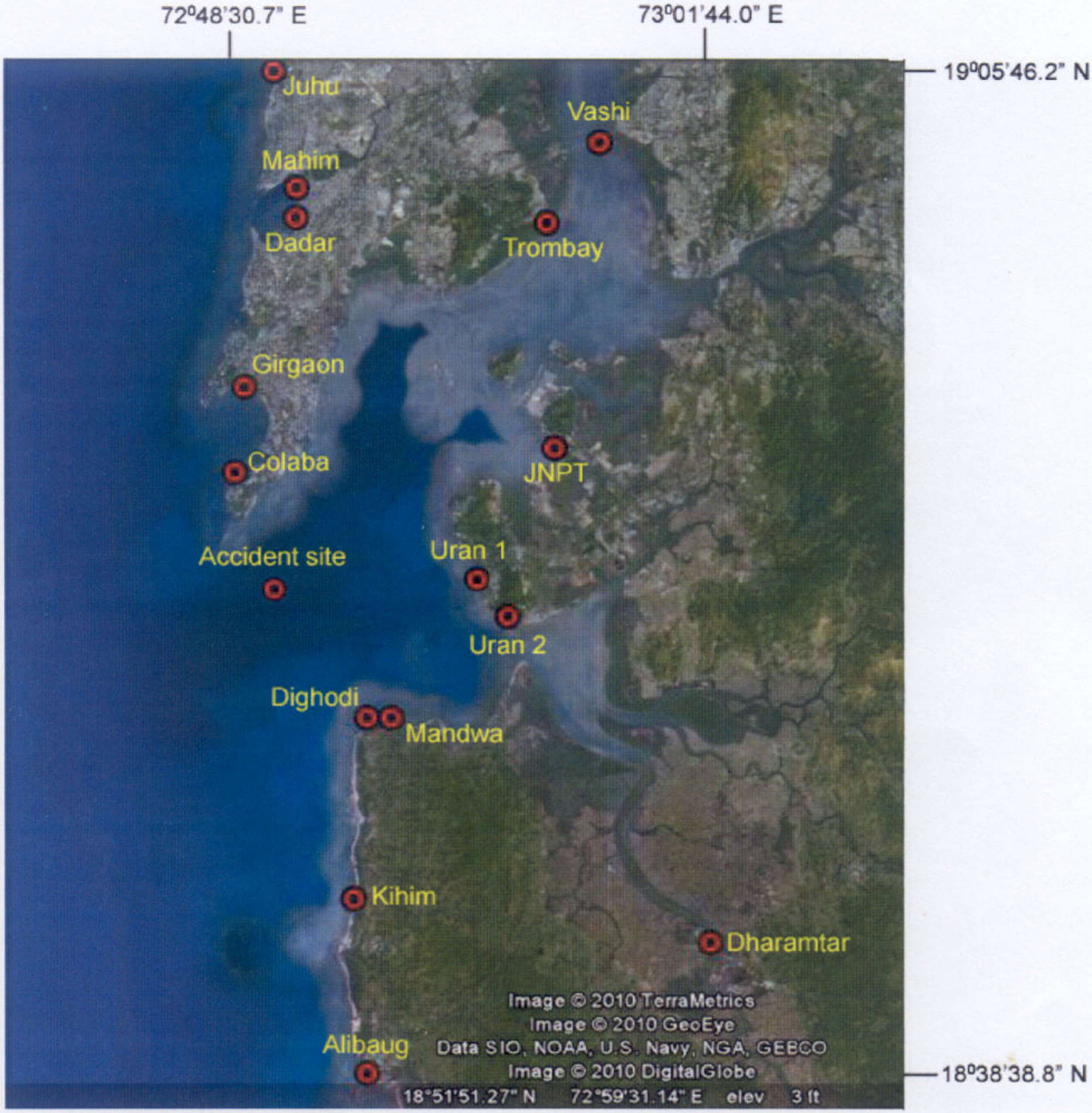


Figure 1.4.1: Shore sampling locations at Mumbai Bay and adjacent coastal system during initial study (Phase I)

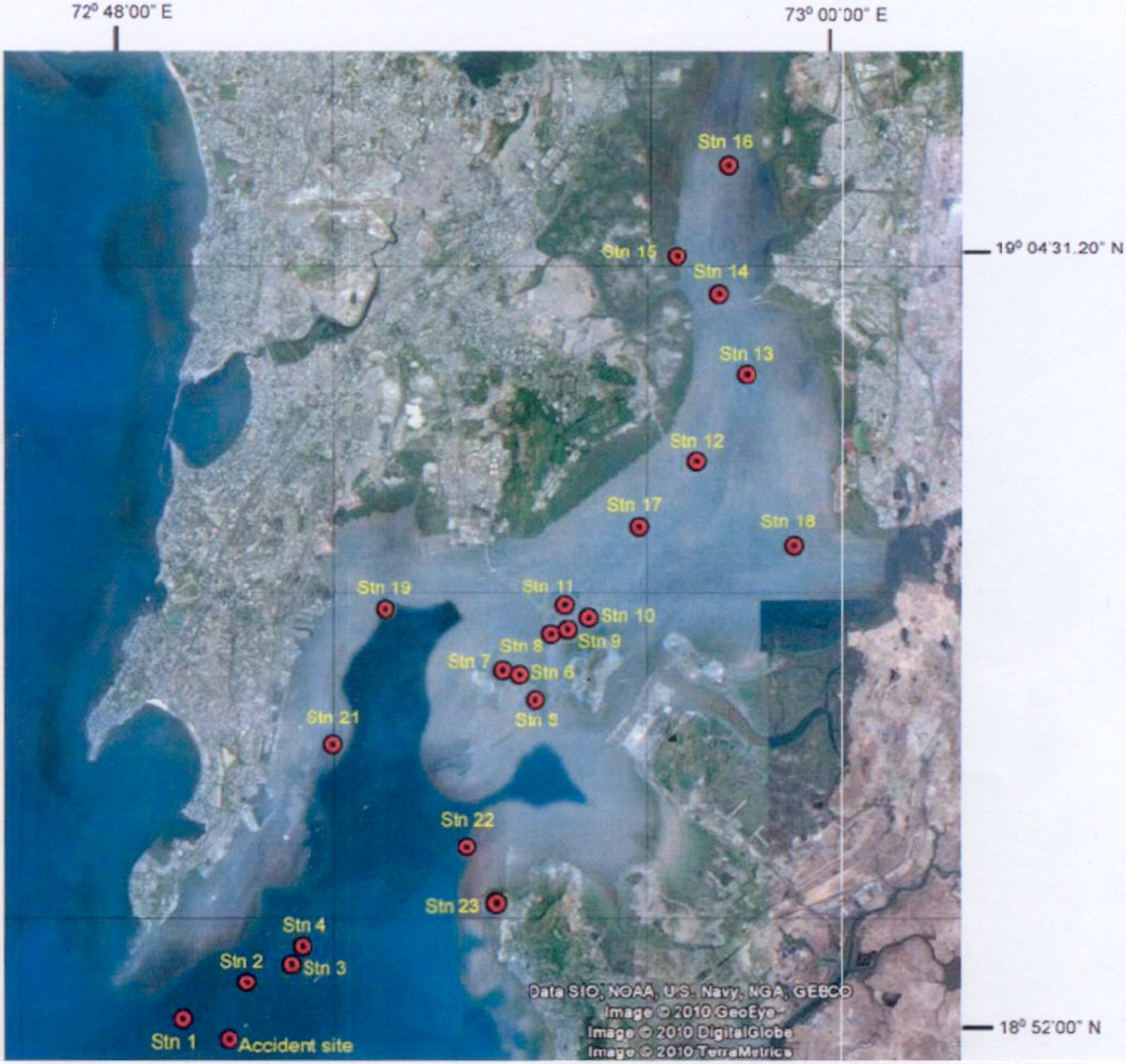


Figure 1.4.2: Subtidal sampling locations in Mumbai Bay during initial study (Phase I)

Figure 2.1.1: Damaged Khalijia 3 after the accident

Figure 2.2.1: Oil coated shore at Geeta Nagar (Colaba)

Figure 2.2.2: Oil coated shore along Elephanta beach

Figure 2.2.3: Oil coated along Uran

Figure 2.2.4: Oil coated mangroves along Vashi Bridge

Figure 2.3.1: Containers floating in the navigational channel of Mumbai Bay

Figure 2.3.2: Containers washed on shore at Uran

Figure 2.3.3: Containers washed in the mangrove area at Dighodi

Figure 2.3.4: The damaged container spilling the content on shore

Figure 2.3.5: Retrieved canisters washed ashore from a broken container

Figure 2.3.6: Spilled materials from the broken containers at Uran

Figure 2.3.7: Salvage operation at the grounding site of the MSC Chitra

Figure 2.4.1: Beach cleaning at Uran

Figure 2.4.2: Carcass of a bird coated by oil slick

Figure 2.4.3: Oil residue collected for bioremediation

Figure 3.0.1: Map showing Mumbai Metropolitan Region (MMR)

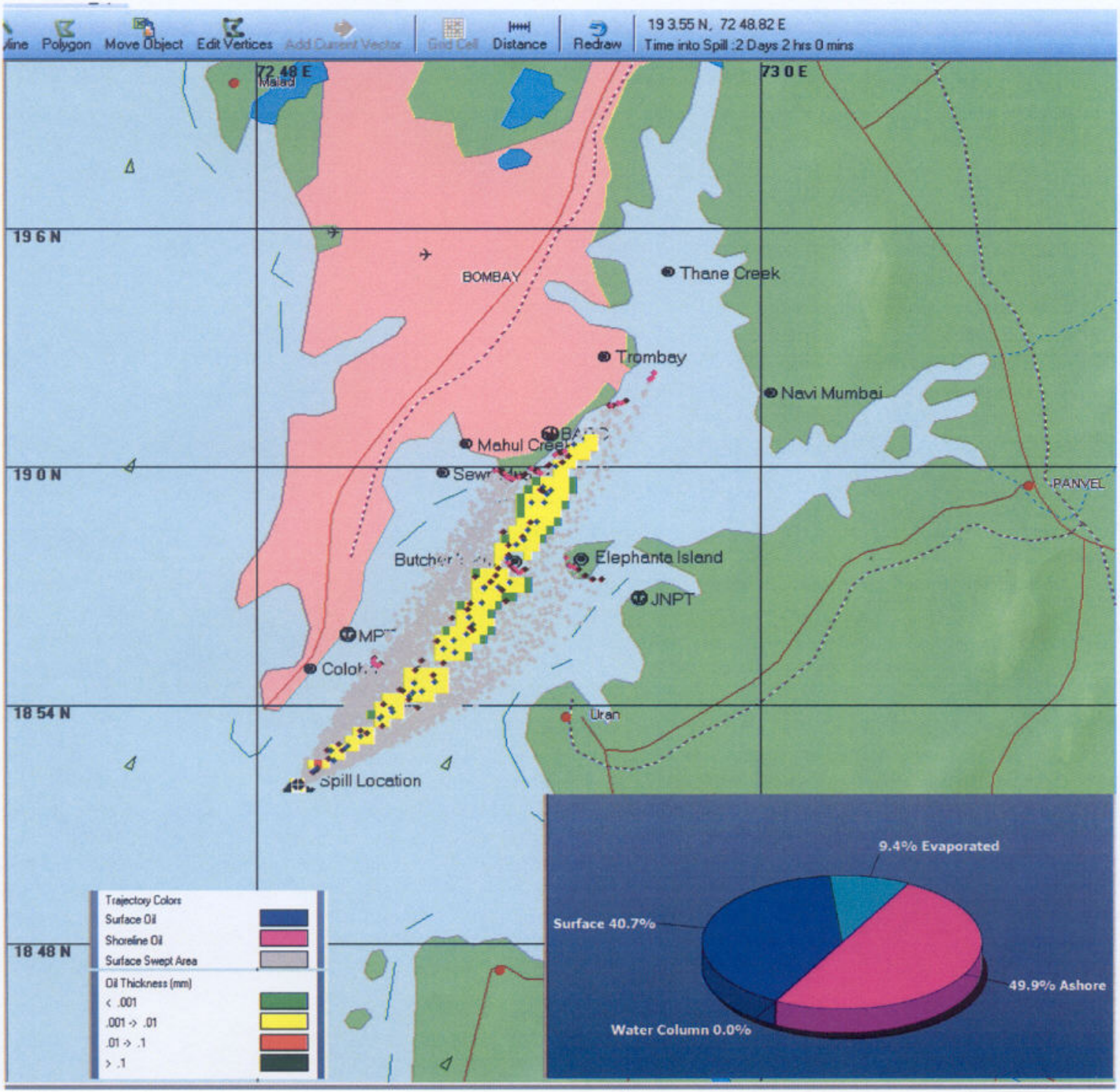
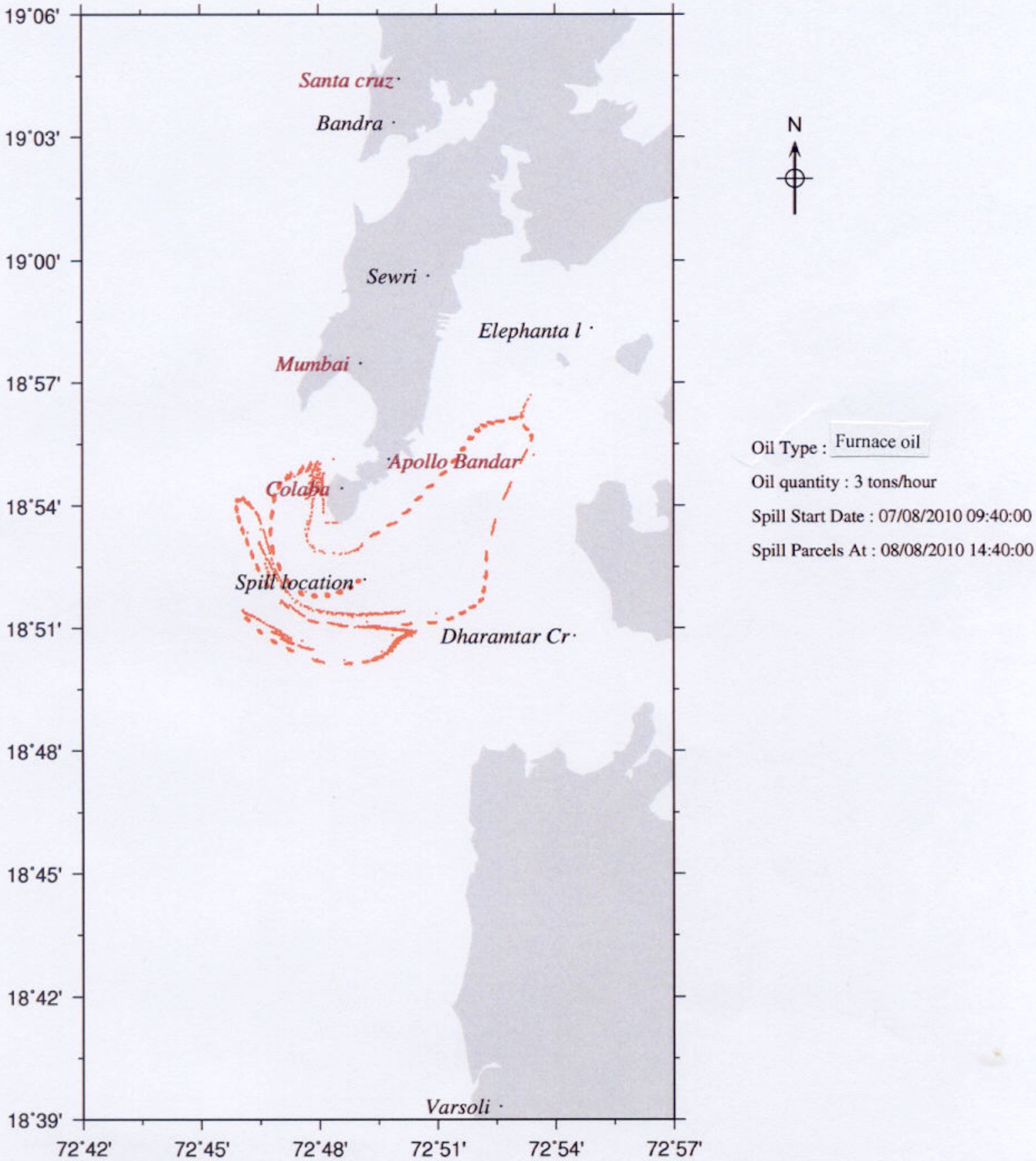


Figure 4.1.1:Predicted oil trajectory and mass balance at 1200 h on 9 August 2010



Created By: Environ Software(P) Ltd. Created On: Fri Nov 26 14:35:07 IST 2010

Figure 4.2.1:Predicted trajectory of oil spill on 8 August 2010 at 1440 h

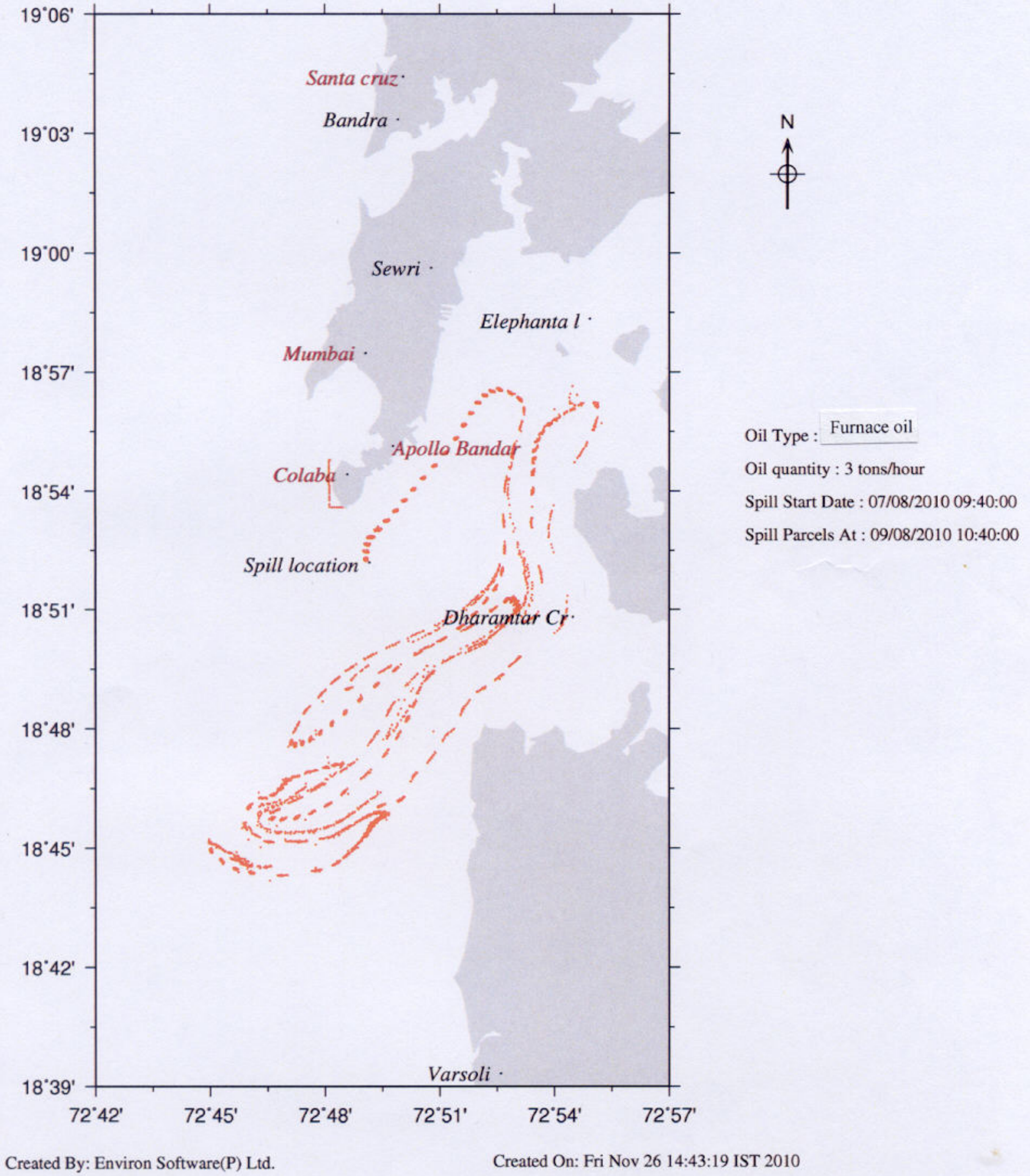


Figure 4.2.2: Predicted trajectory of oil spill on 9 August 2010 at 1040 h

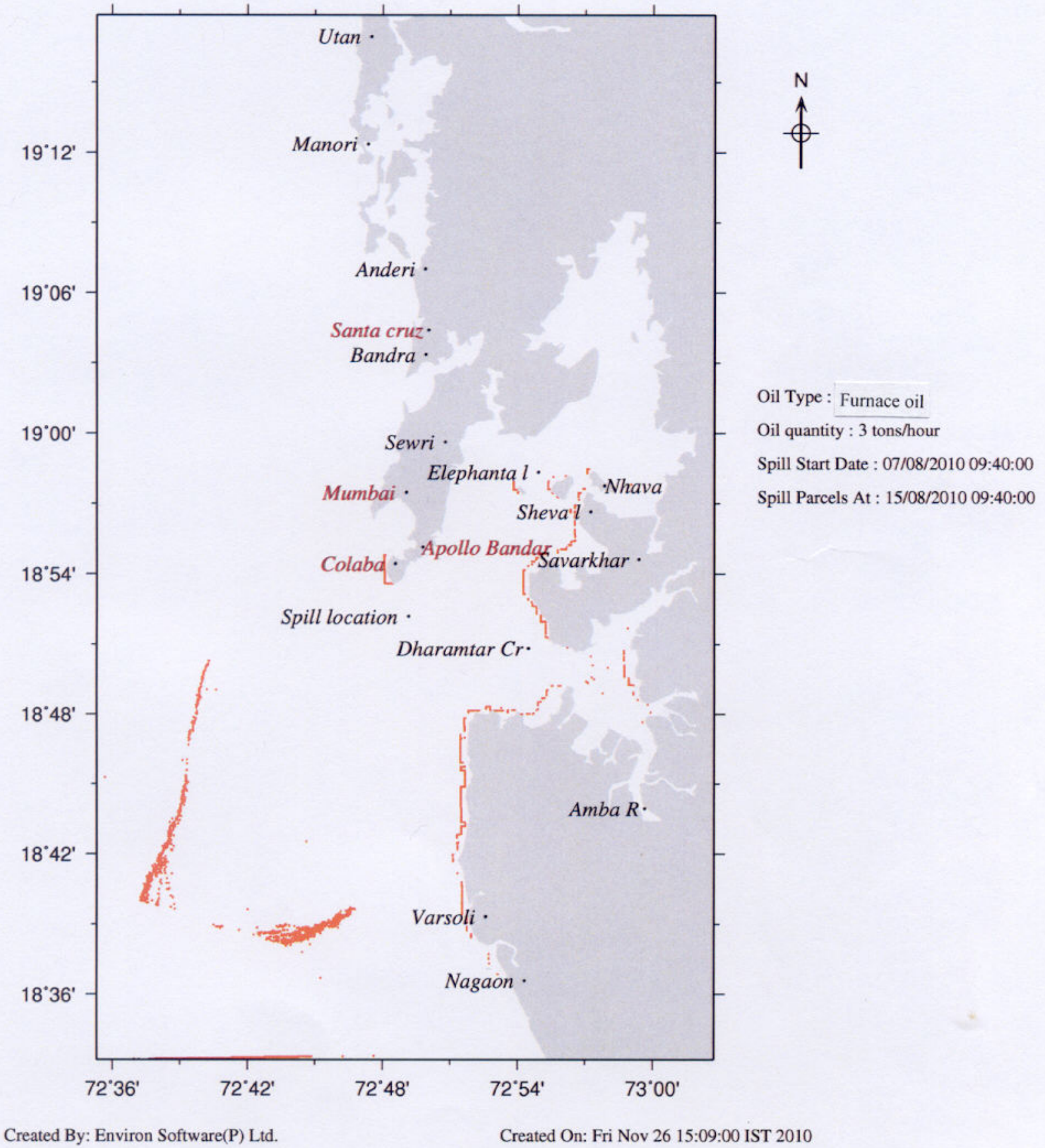


Figure 4.2.3: Predicted trajectory of oil spill on 15 August 2010 at 0940 h

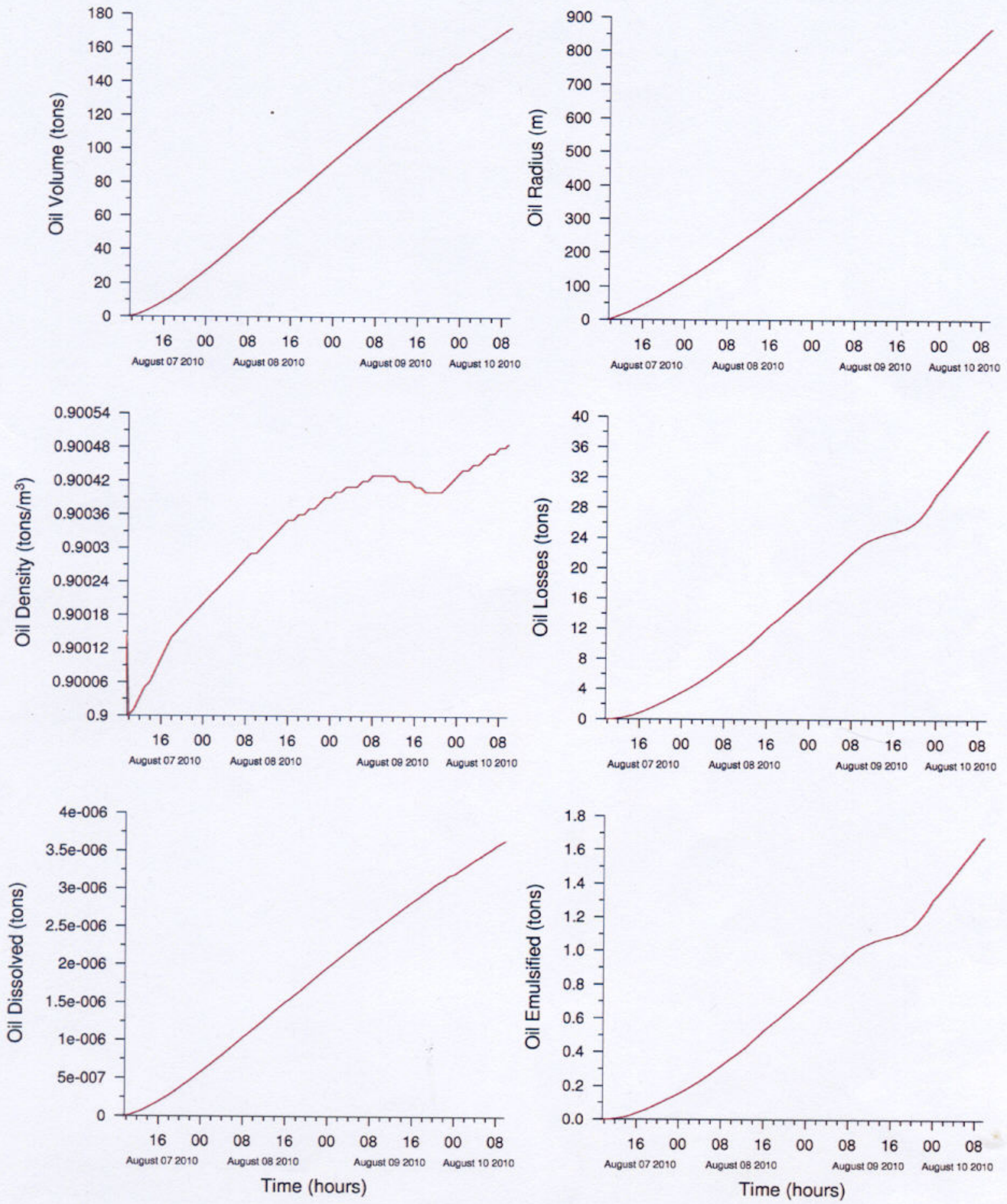


Figure 4.2.4: Predicted temporal variations of weathering processes in the Mumbai Bay for 3 days

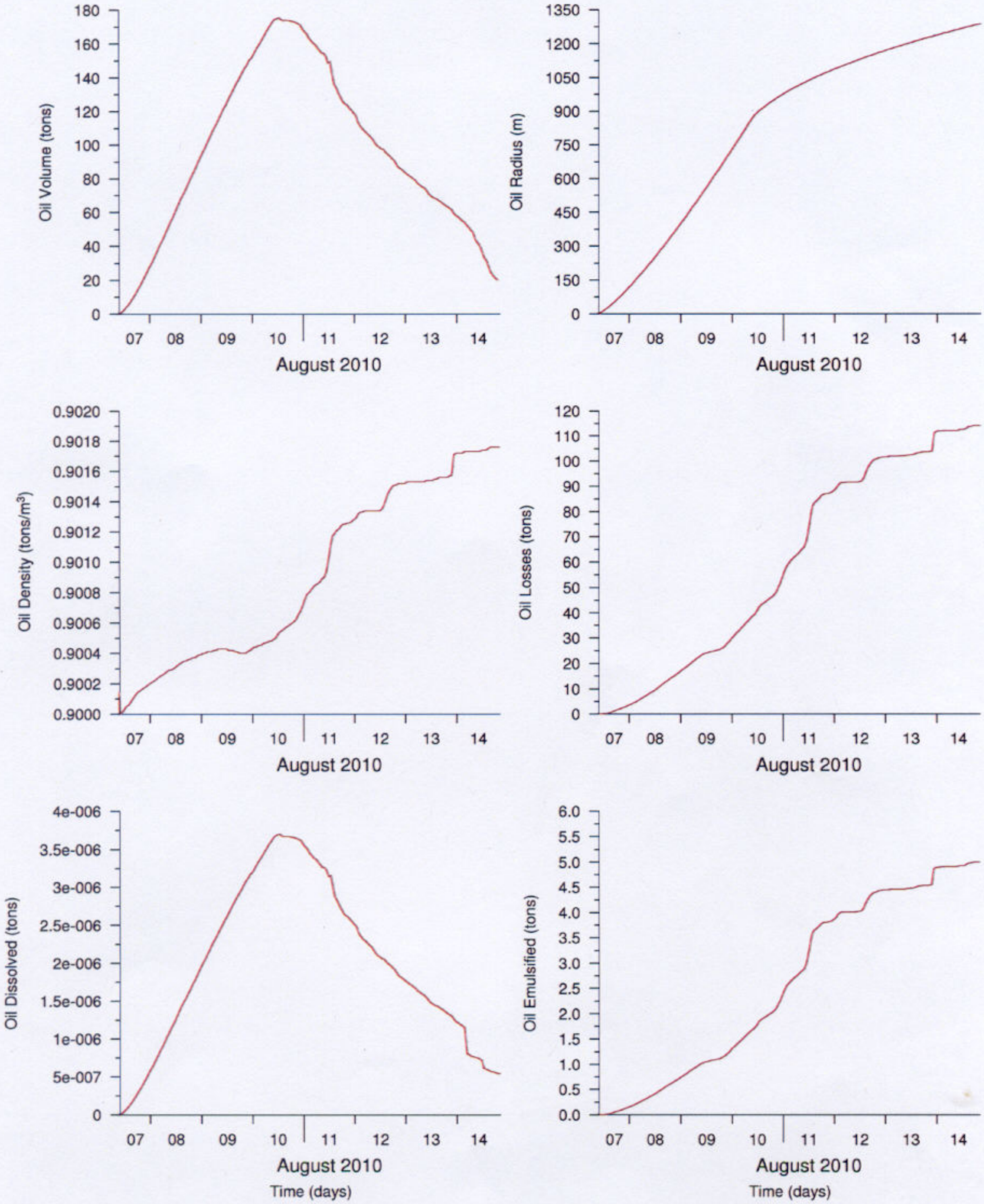


Figure 4.2.5: Predicted temporal variations of weathering processes in the Mumbai Bay for 7 days

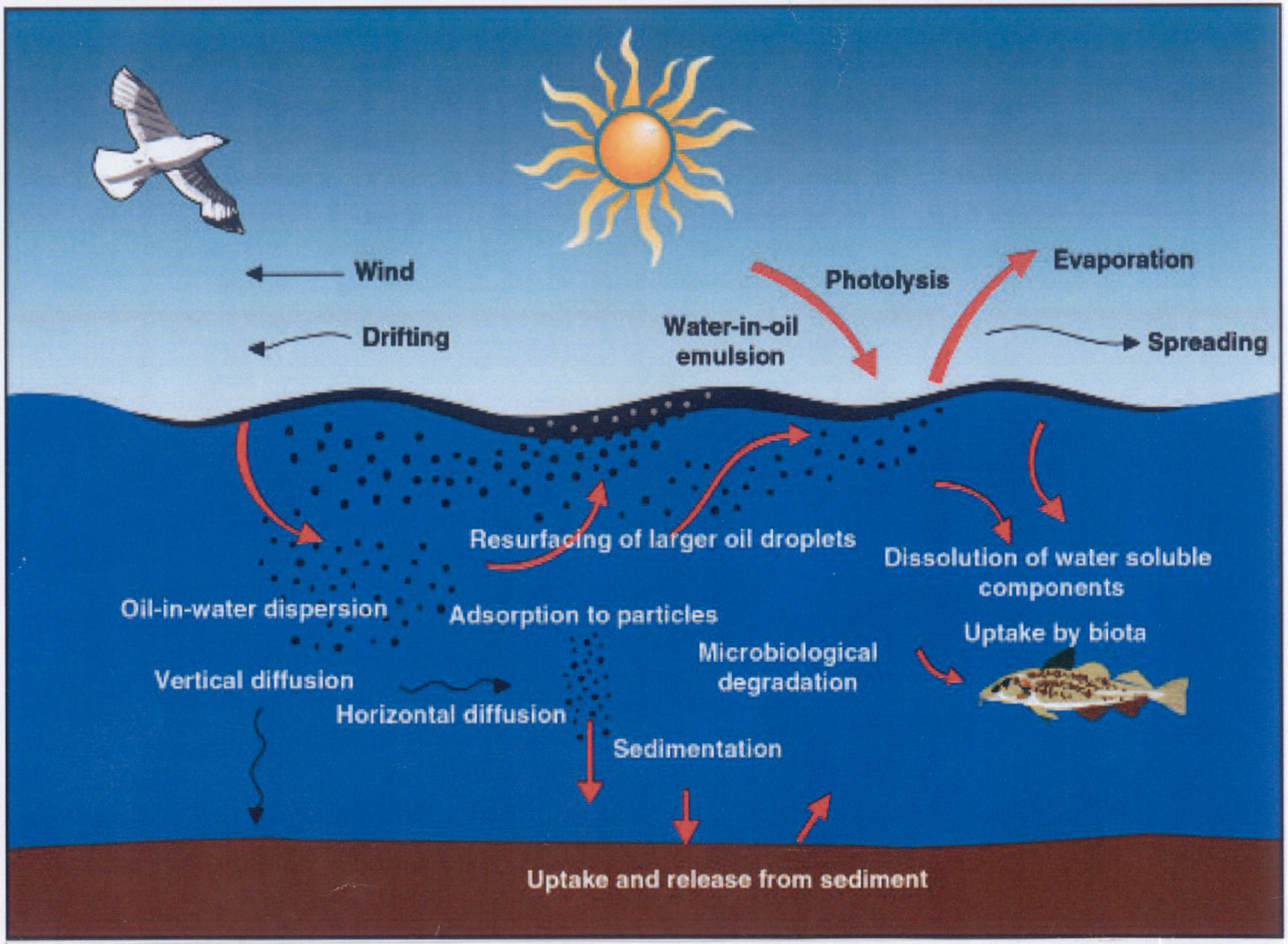


Figure 6.1.1: Weathering processes of an oil spill in marine environment

Figure 8.1.1a: Wave action along the shore of Alibaug on 10 August 2010

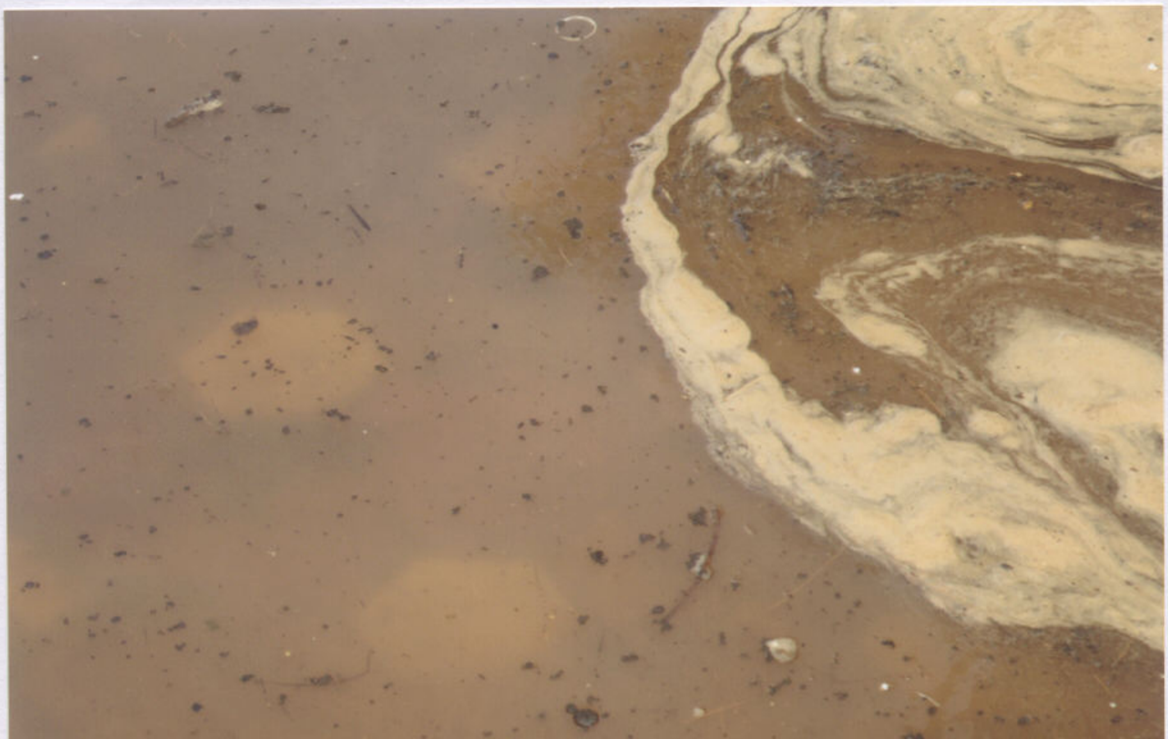


Figure 8.1.1b: Tar balls on the Alibaug beach on 10 August 2010

Figure 8.1.2a: Oil patch noticed at Kihim beach

Figure 8.1.2b: Sampling in the tidal water at Kihim beach

Figure 8.1.3a:The container washed ashore at Dighodi

Figure 8.1.3b: The mangroves noticed (10 August 2010) free from oil coating at Dighodi

Figure 8.1.5a:The site around Dharamtar jetty

Figure 8.1.5b: No oil patch noticed at Amba estuary on 10 August 2010

Figure 8.1.6a: Shore sampling carried out at Uran 1 on 10 August 2010

Figure 8.1.6b: Broken containers noticed at Uran 1

Figure 8.1.7a: Oil patches noticed (10 August 2010) close to shore at Uran 2

Figure 8.1.7b: The rocky areas found coated with oil at Uran 2

Figure 8.1.9a: The oil coated intertidal segment noticed at Vashi
(10 August 2010)

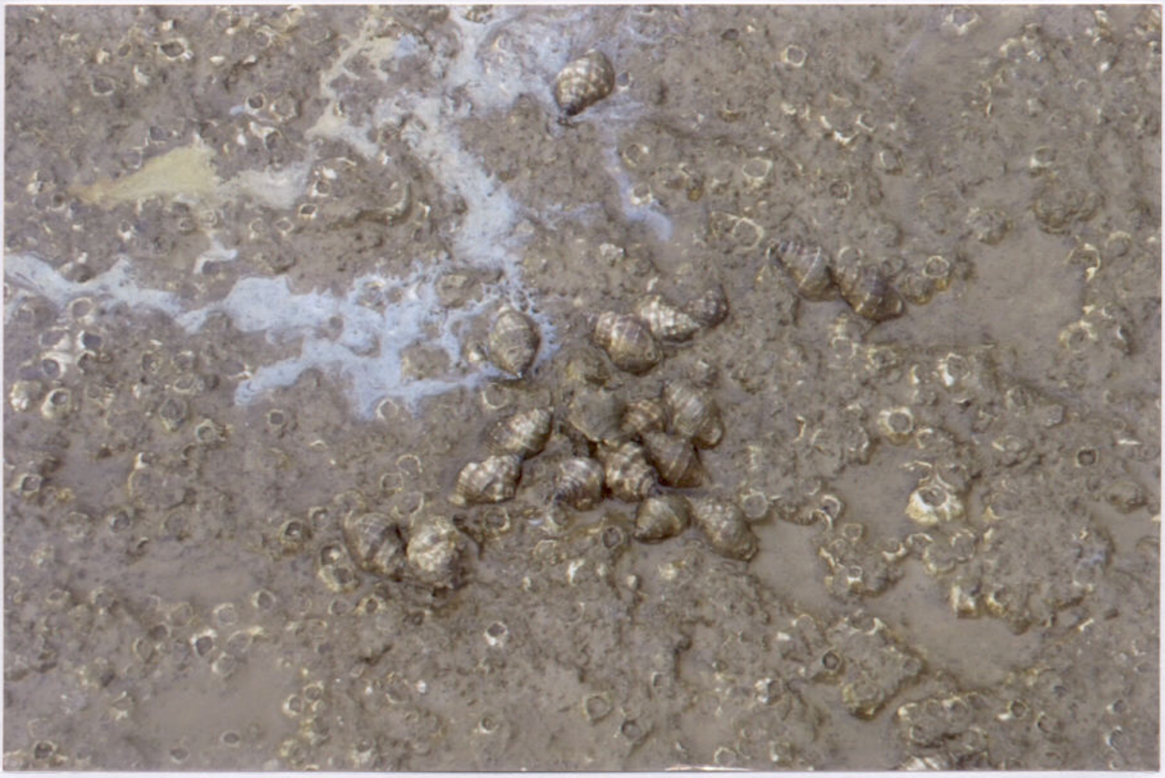


Figure 8.1.9b: The gastropods moving on oiled sediment at Vashi

Figure 8.1.10a: Mangroves coated with oil at Trombay

Figure 8.1.10b: Oil coated mangrove seedlings and pneumatophores at Trombay

Figure 8.1.10c: Mangroves selectively tagged for monitoring at Trombay

Figure 8.1.10d: Mud skippers and crabs noticed in mangrove area at Trombay

Figure 8.1.10e: Mangrove seedlings coated with oil at Trombay

Figure 8.1.10f: High mortality of oil coated seedlings at Trombay

Figure 8.1.10g: Fading of mangrove leaves noticed after a month at Trombay

Figure 8.1.11a:Oil coated rocks at Colaba

Figure 8.1.11b: Oil contaminated tidal pools at Colaba

Figure 8.1.11c: Live corals in the intertidal zone at Colaba

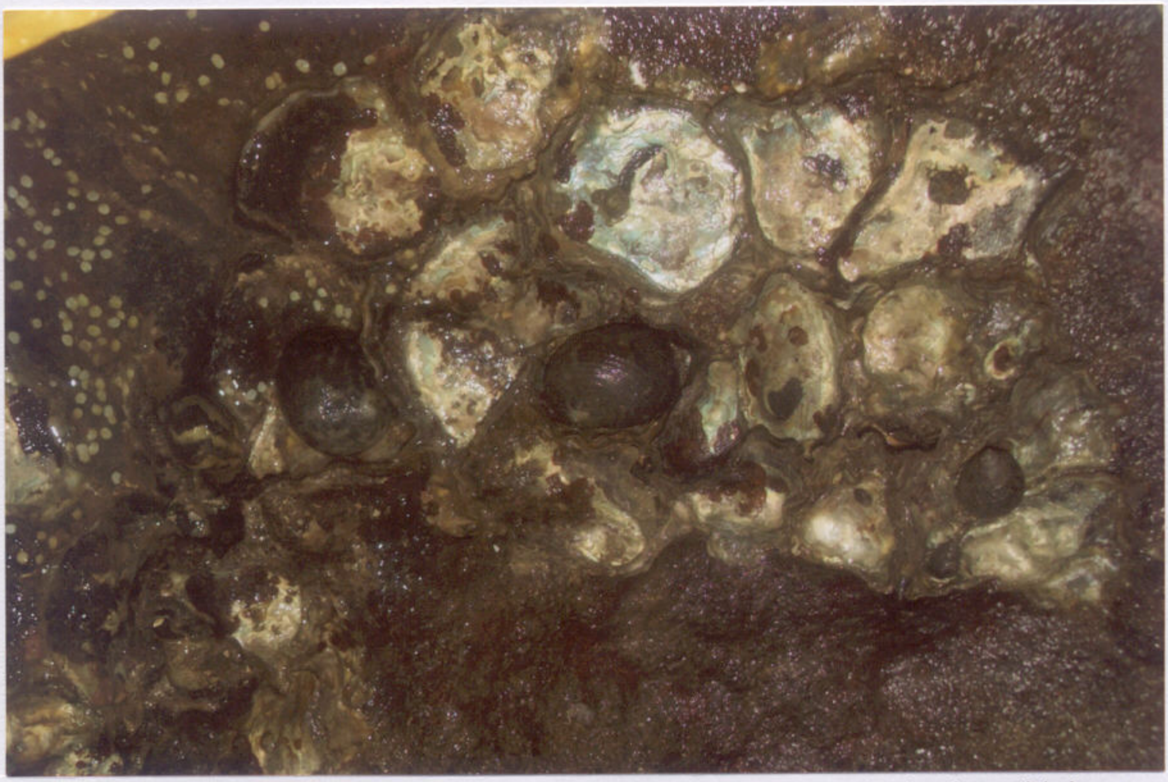


Figure 8.1.11d: Barnacles, oysters (spat) and gastropods in the intertidal zone at Colaba

Figure 8.1.11e: Spawning of intertidal gastropod at Colaba

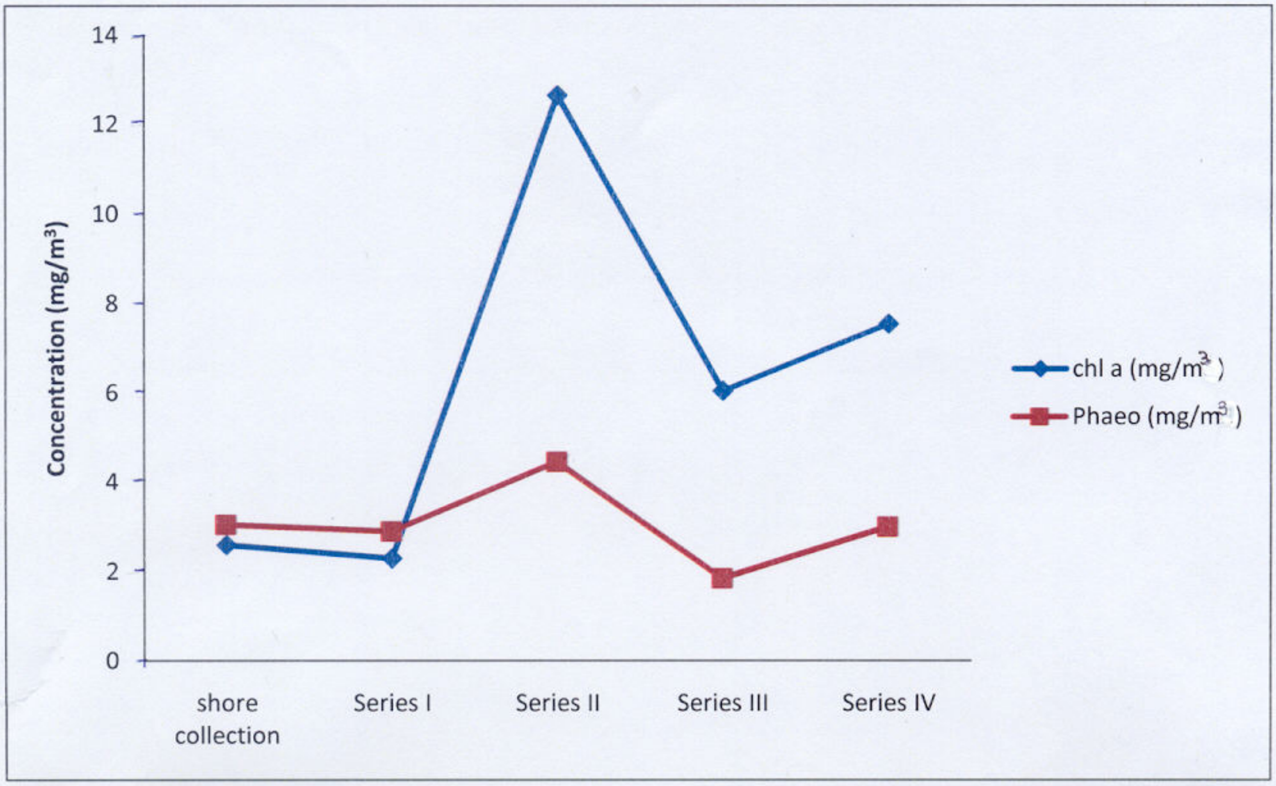


Figure 8.1.16a: Average concentration of phytopigments in the study area during August-September 2010

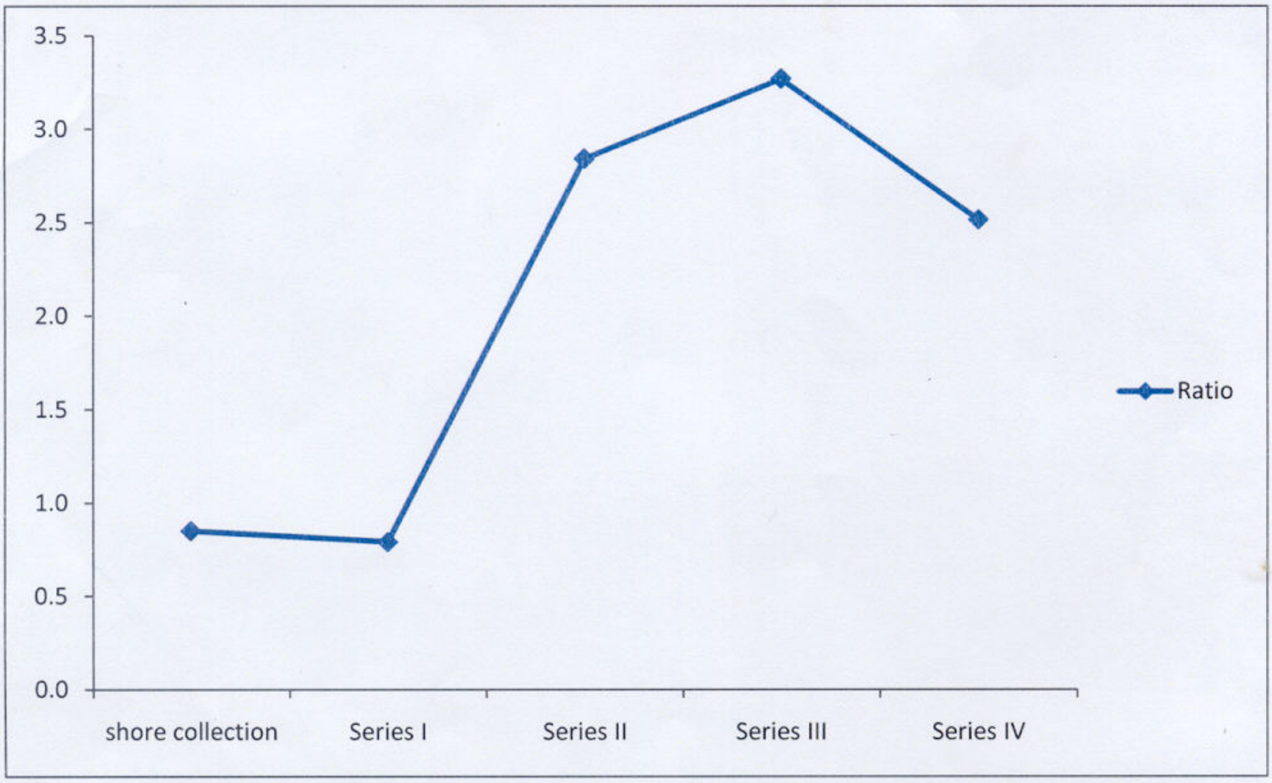


Figure 8.1.16b: Average ratio of chlorophyll a/ phaeophytin in the study area during August- September 2010

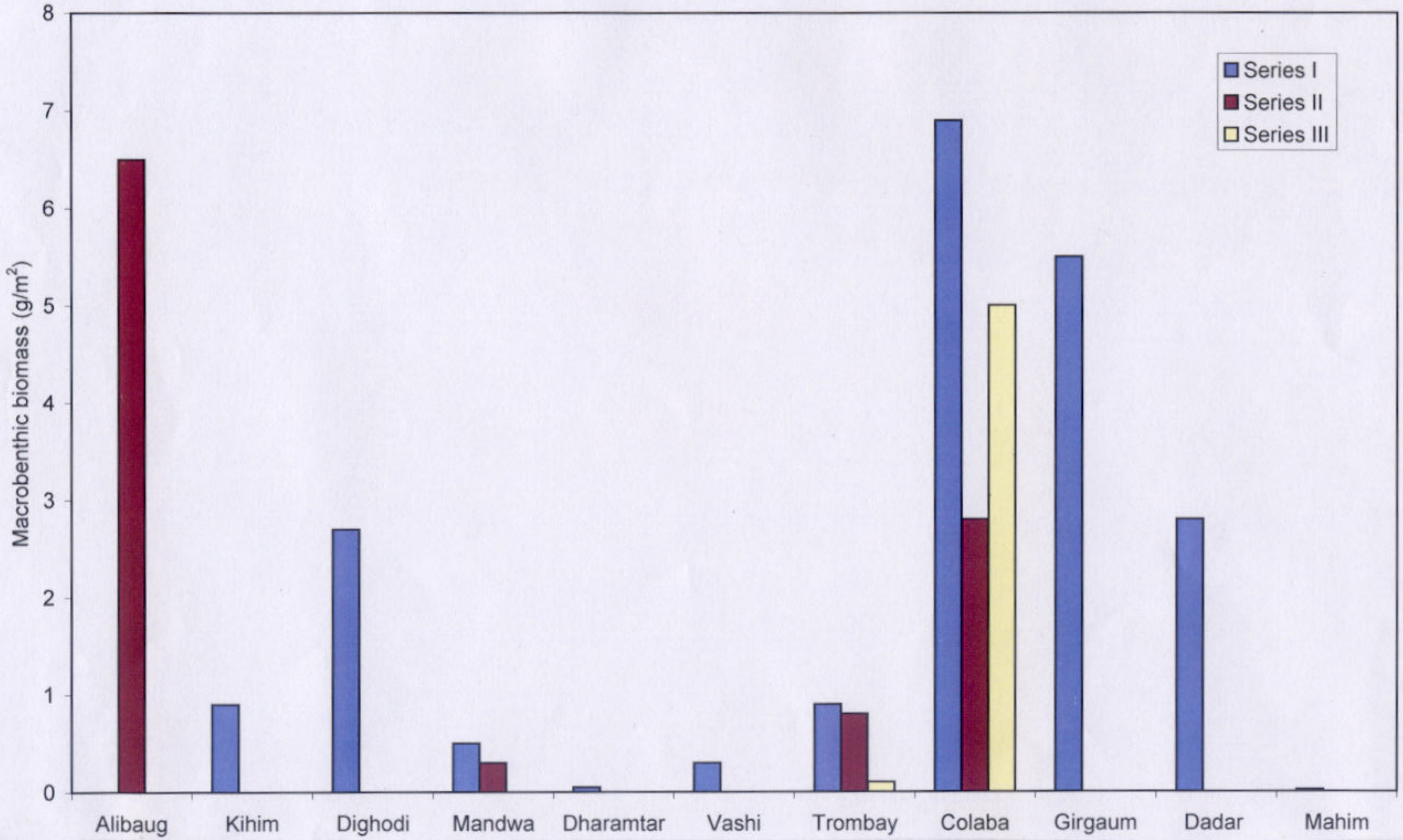


Figure 8.1.16c: Average macrobenthic biomass at the shore transects during August-September 2010

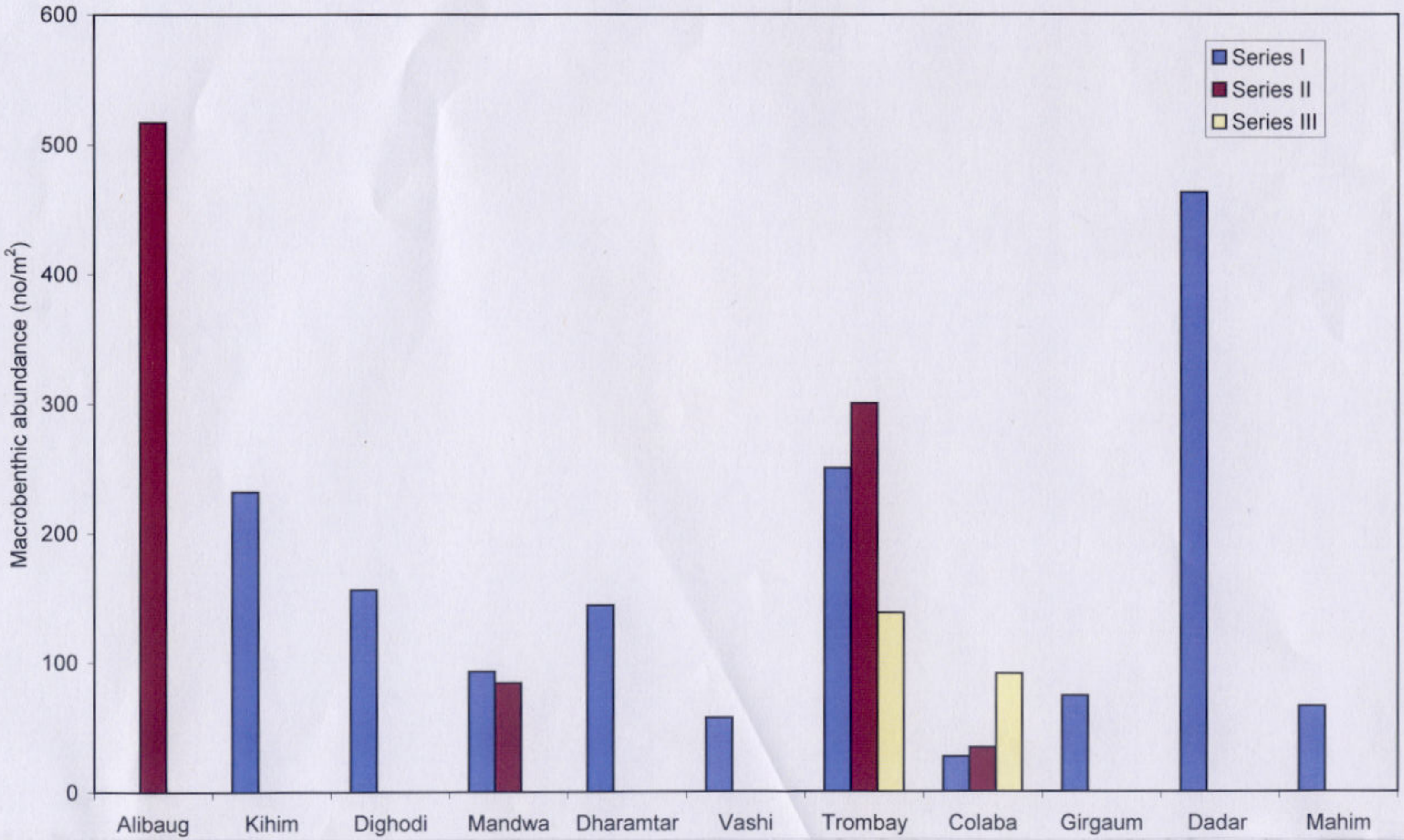


Figure 8.1.16d: Average macrobenthic abundance at the shore transects during August-September 2010

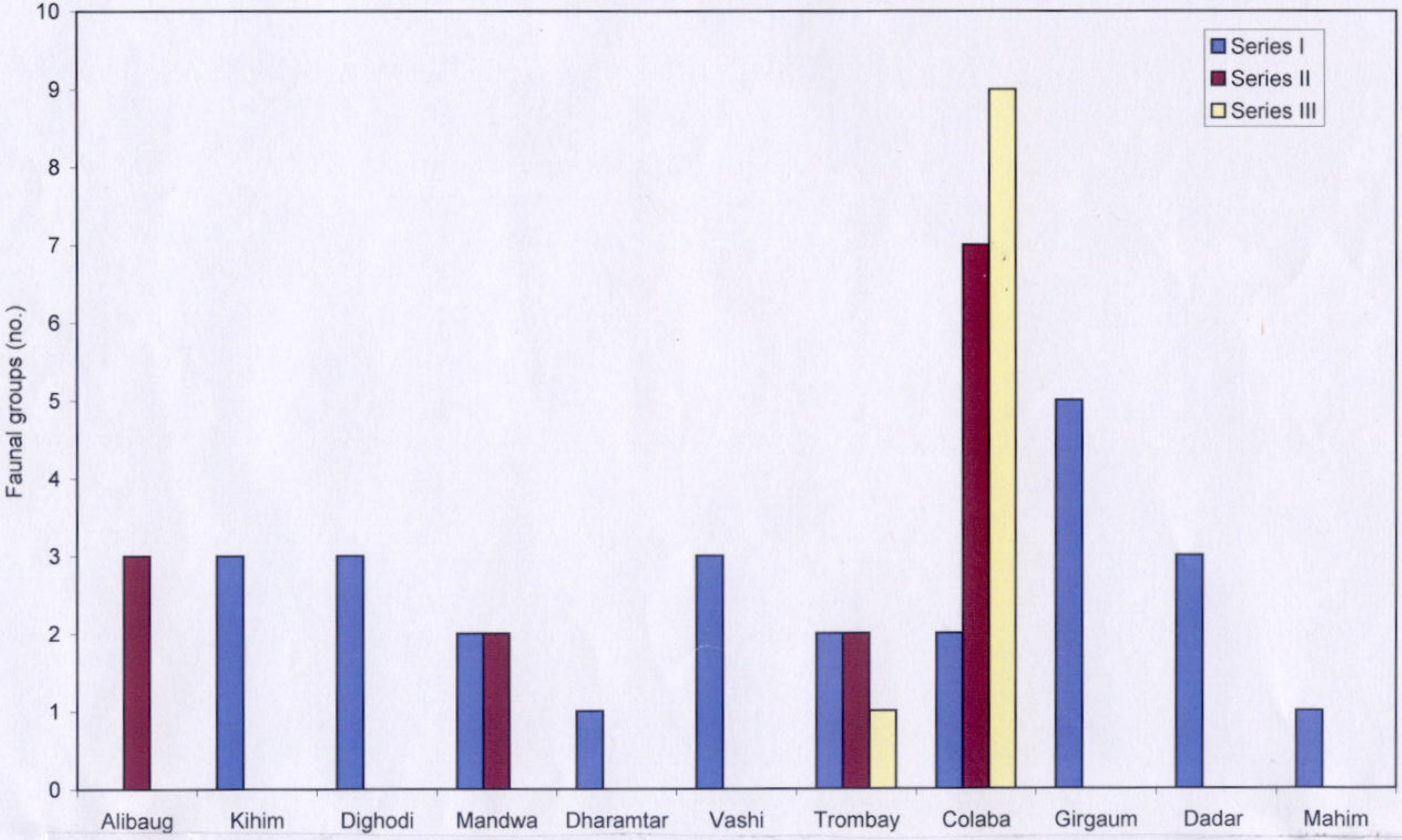


Figure 8.1.16e: Average macrobenthic group diversity at shore transects during August-September 2010

Figure 8.2.1: Ribbon formations of oil slick in Central Bay on 11 August 2010

Figure 8.2.2: Oil slick at Elephanta on 11 August 2010

Figure 8.2.3: The dispersed oil slick at Trombay on 12 August 2010

Figure 8.2.4: The oil slick in surface water downstream of Trombay on 12 August 2010

Figure 8.2.5: A portion of oil slick noticed at Vashi on 12 August 2010

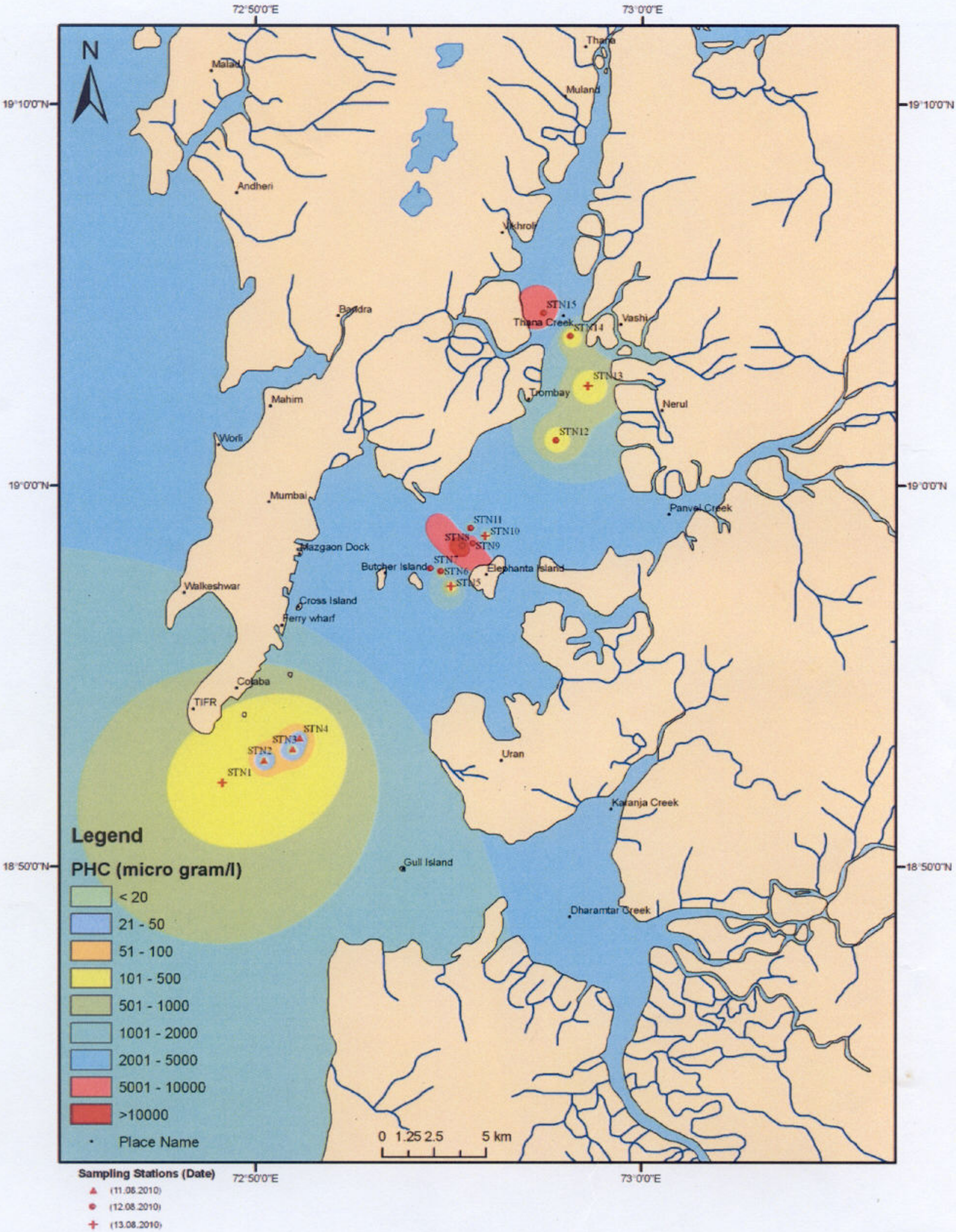


Figure 8.2.6: PHc concentration in subtidal water in Mumbai Bay during Series I

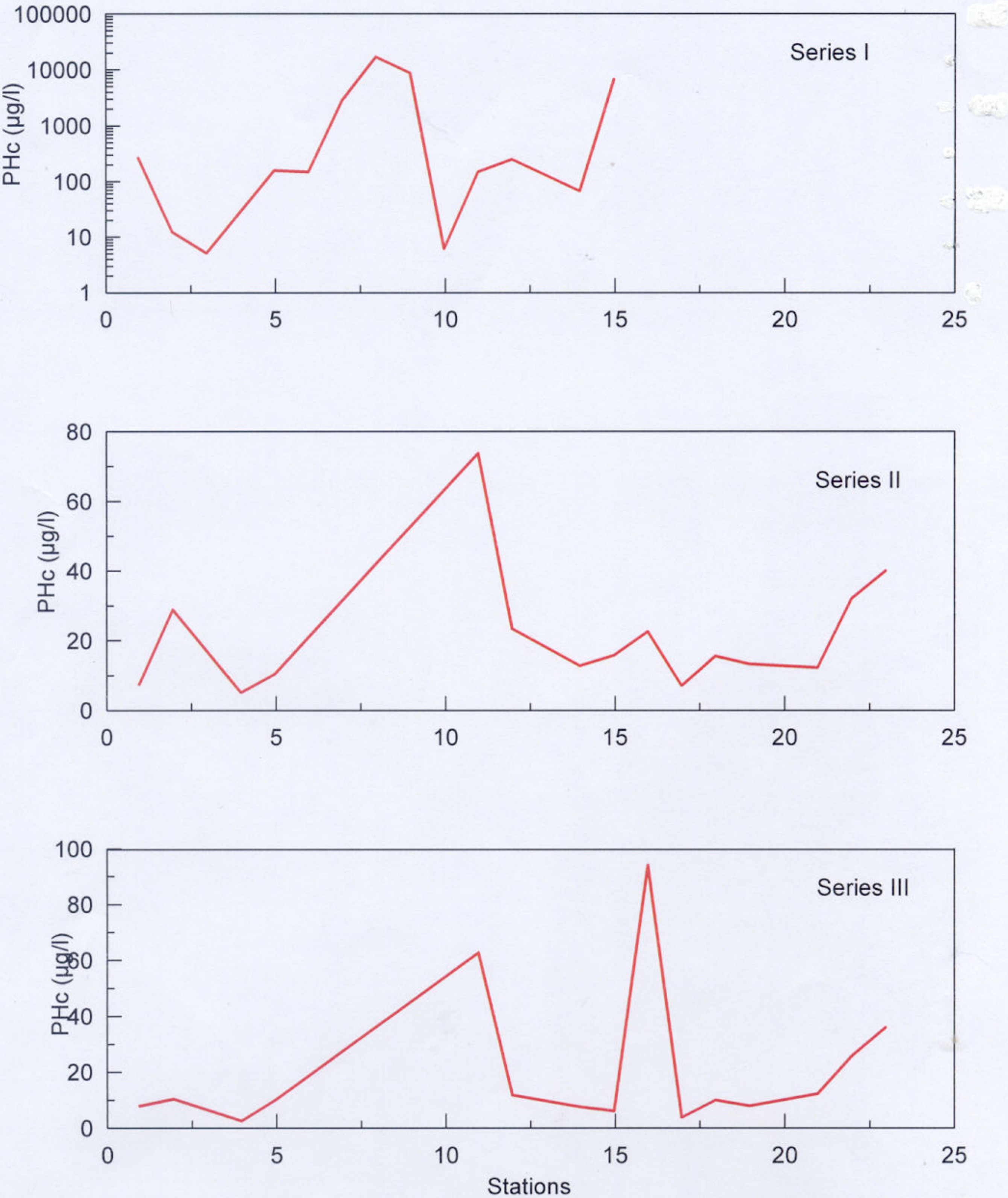


Figure 8.2.7: Variation of petroleum hydrocarbons (PHc, µg/l) at different stations at Mumbai Bay during post-spill period

Figure 8.2.8: PHc concentration in subtidal water in Mumbai Bay during Series II

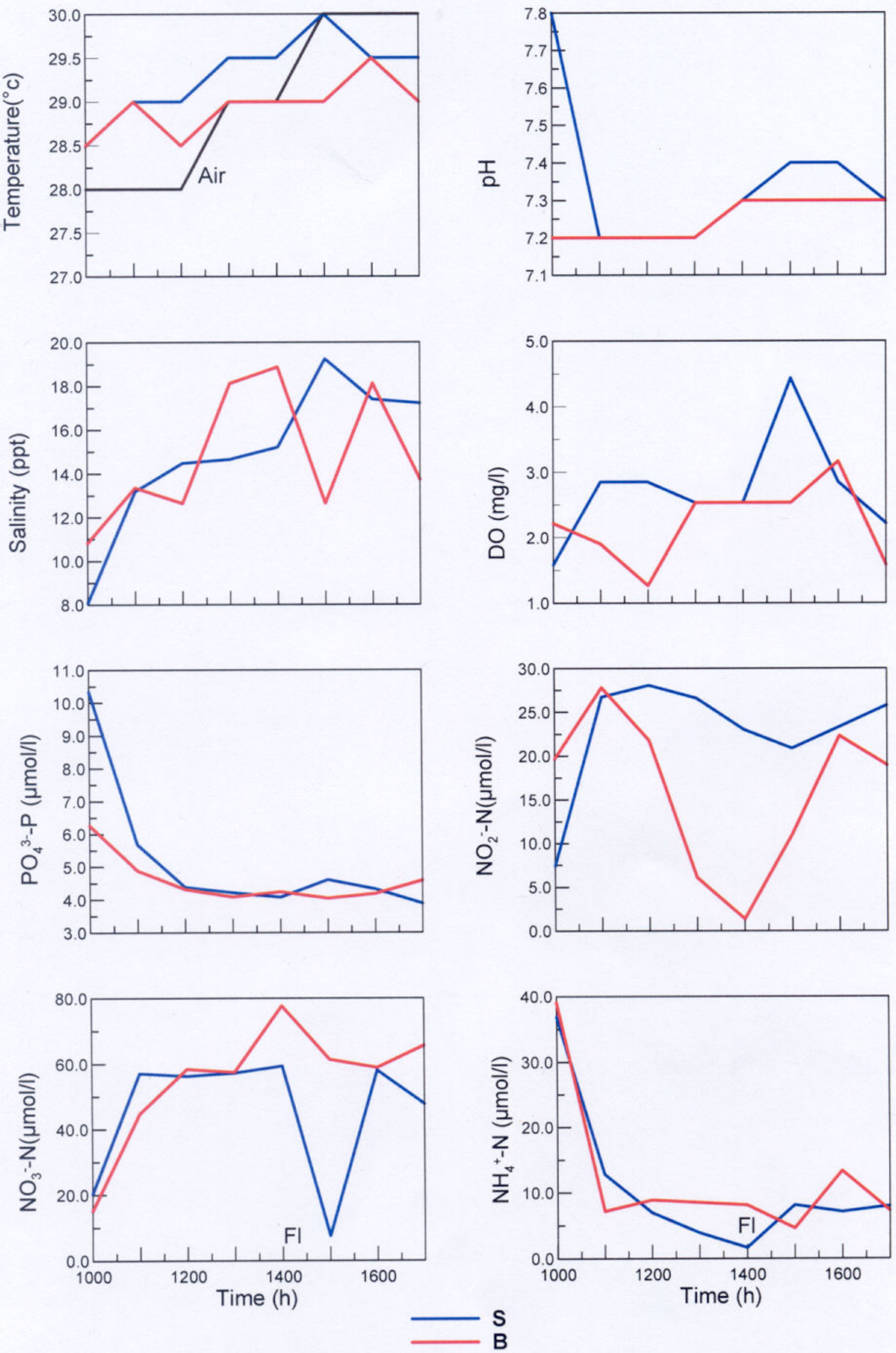


Figure 8.2.9: Water quality at station 13 (Mumbai Bay) on 13 Aug 2010

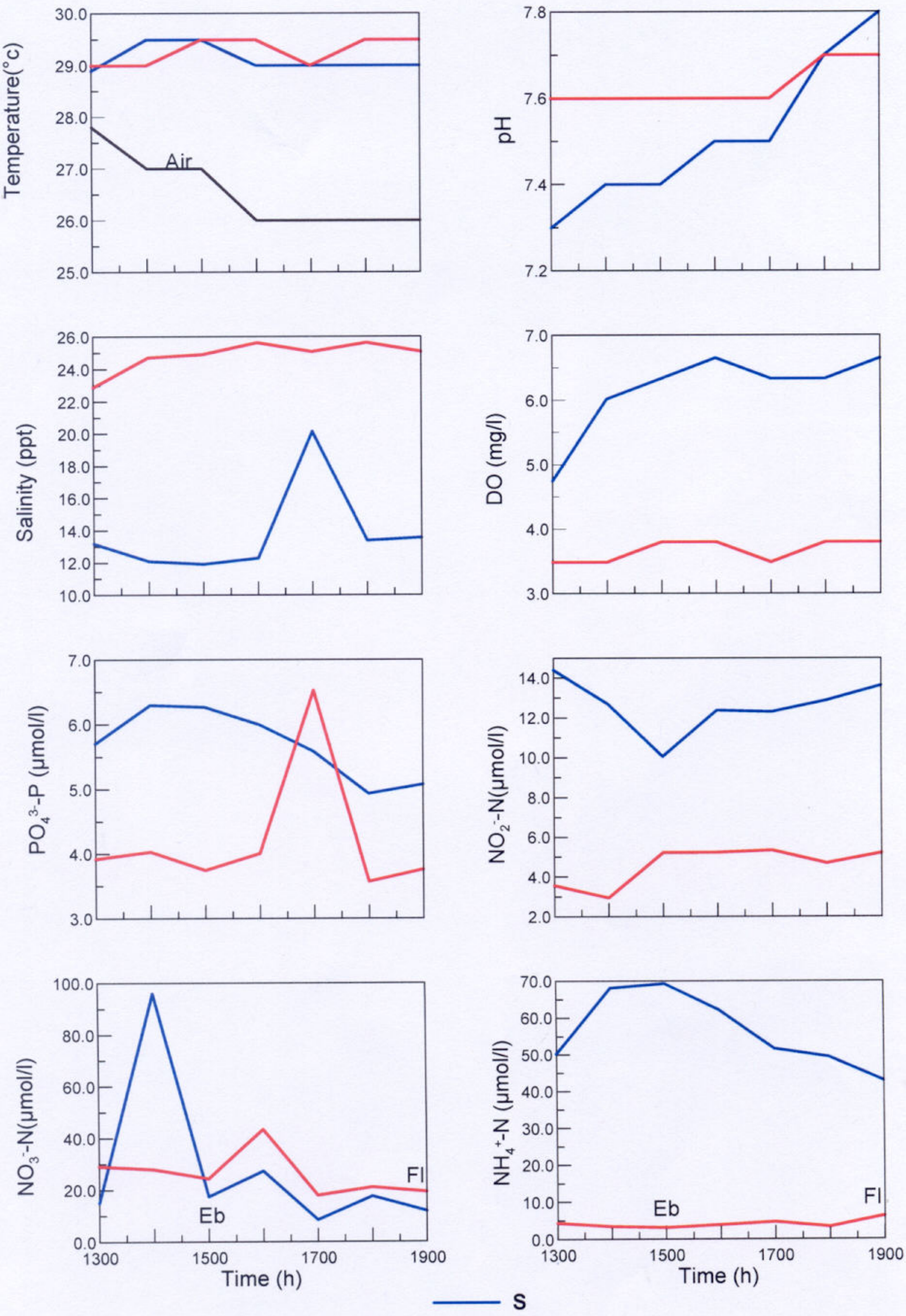


Figure 8.2.10: Water quality at station 13 (Mumbai Bay) on 18 Aug 2010

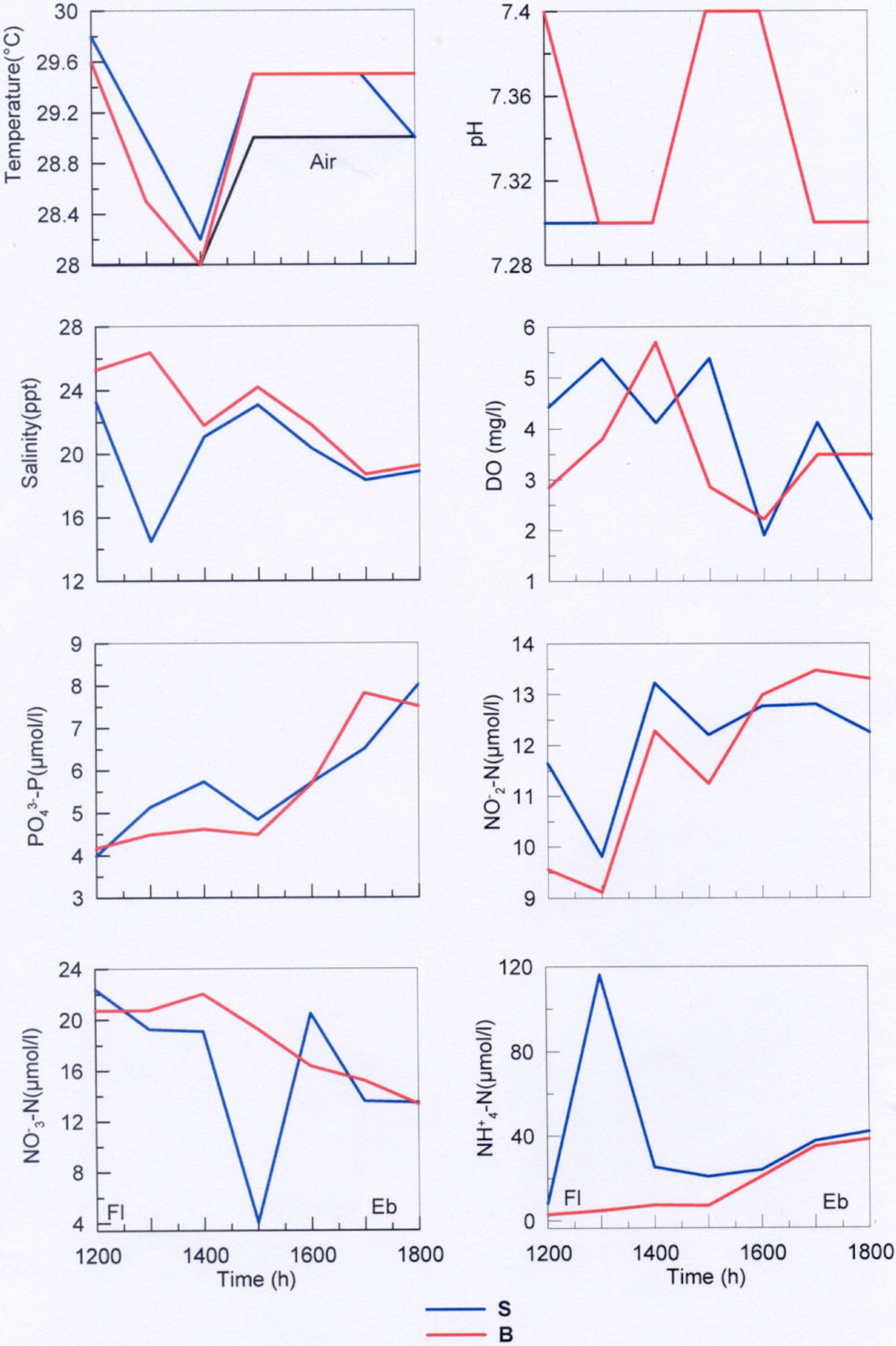


Figure 8.2.11: Water quality at station 13 (Mumbai Bay) on 25 August 2010

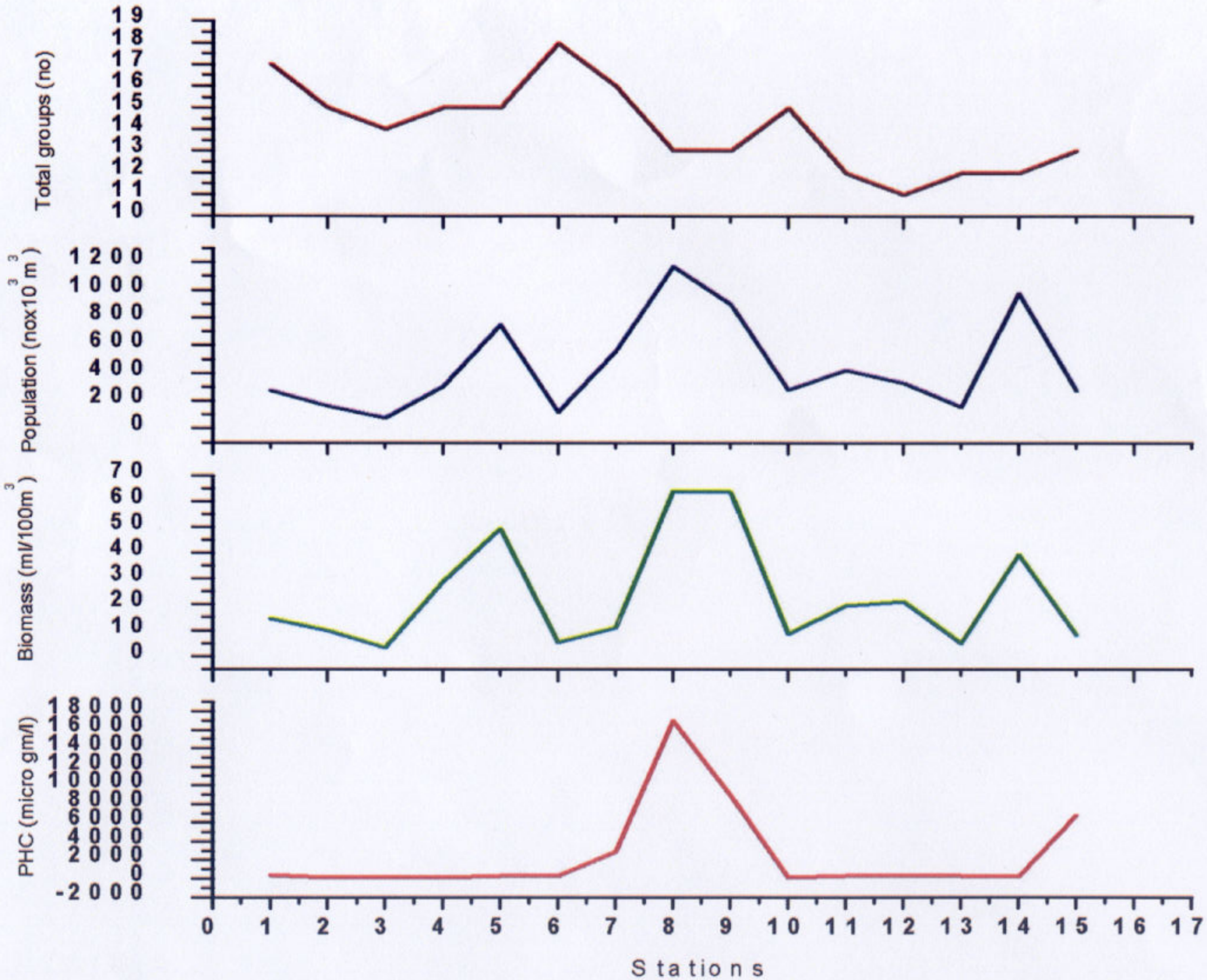
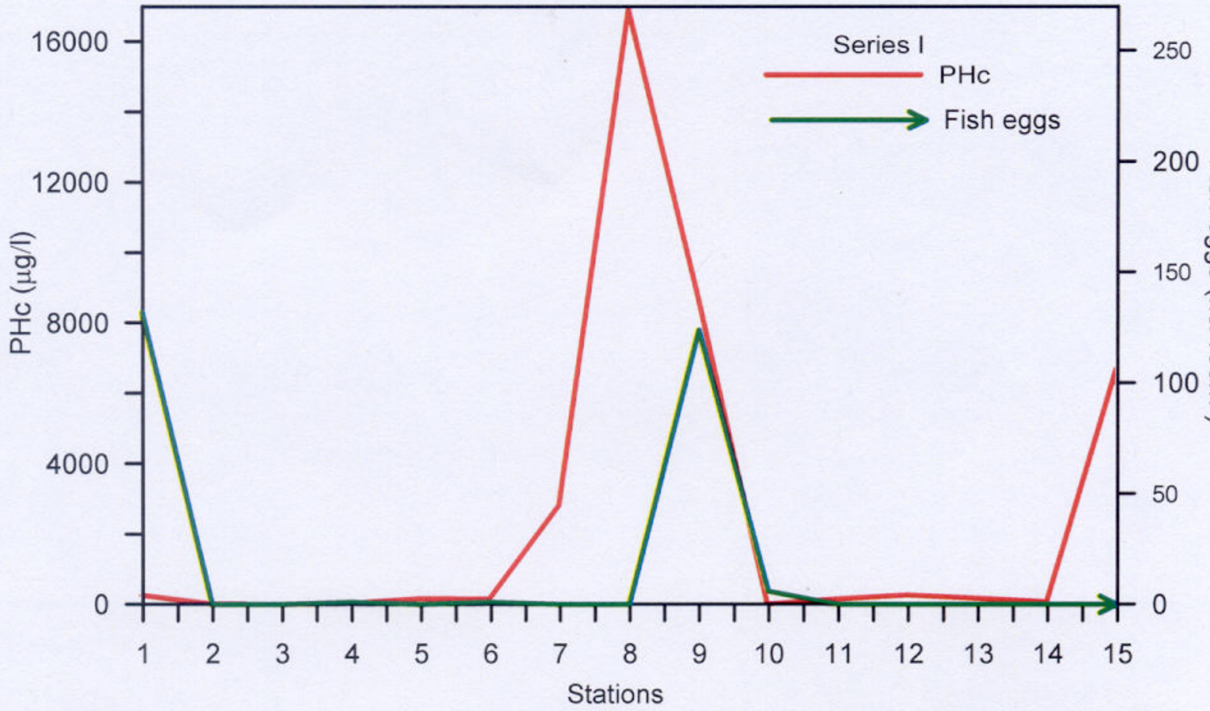
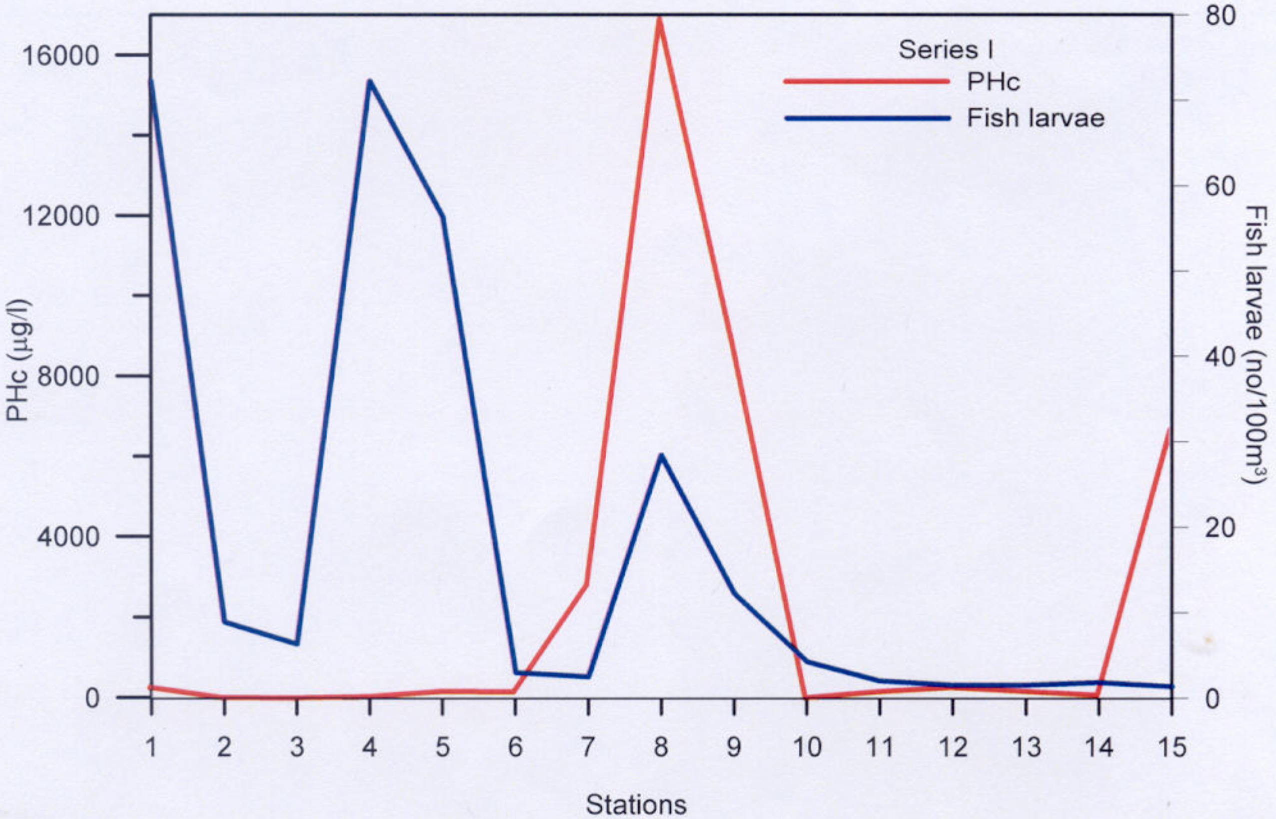


Figure 8.2.12: Distribution of zooplankton standing stock and faunal group and PHc in water along Mumbai Bay during 2nd week of August 2010 (Series I)





gure 8.2.13: Abundance of fish eggs and larvae and PHc in water along Mumbai Bay during 2nd week of August 2010 (Series I)

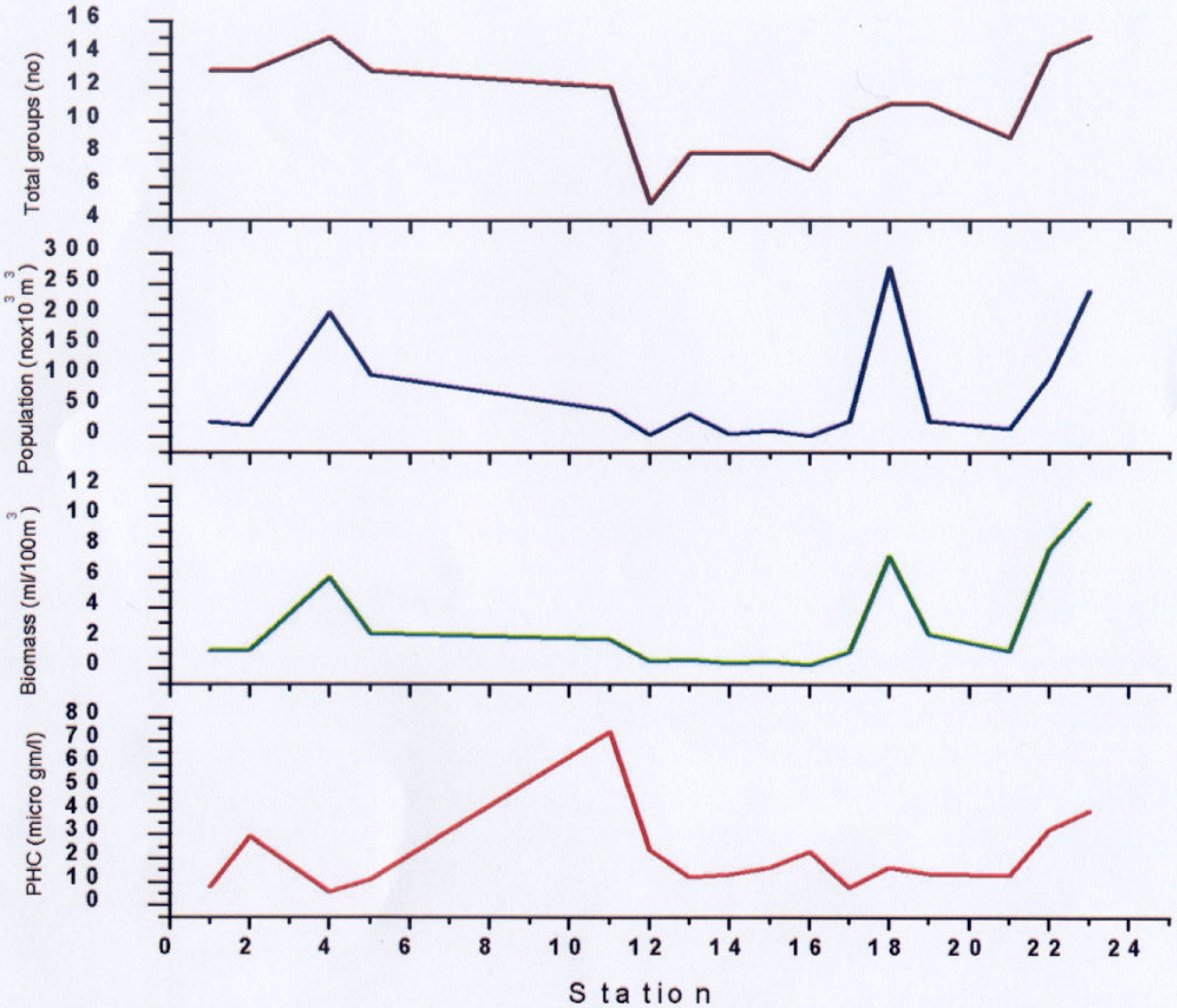


Figure 8.2.14: Distribution of zooplankton standing stock and faunal group and PHc in water along Mumbai Bay during 3rd week of August 2010 (Series II)

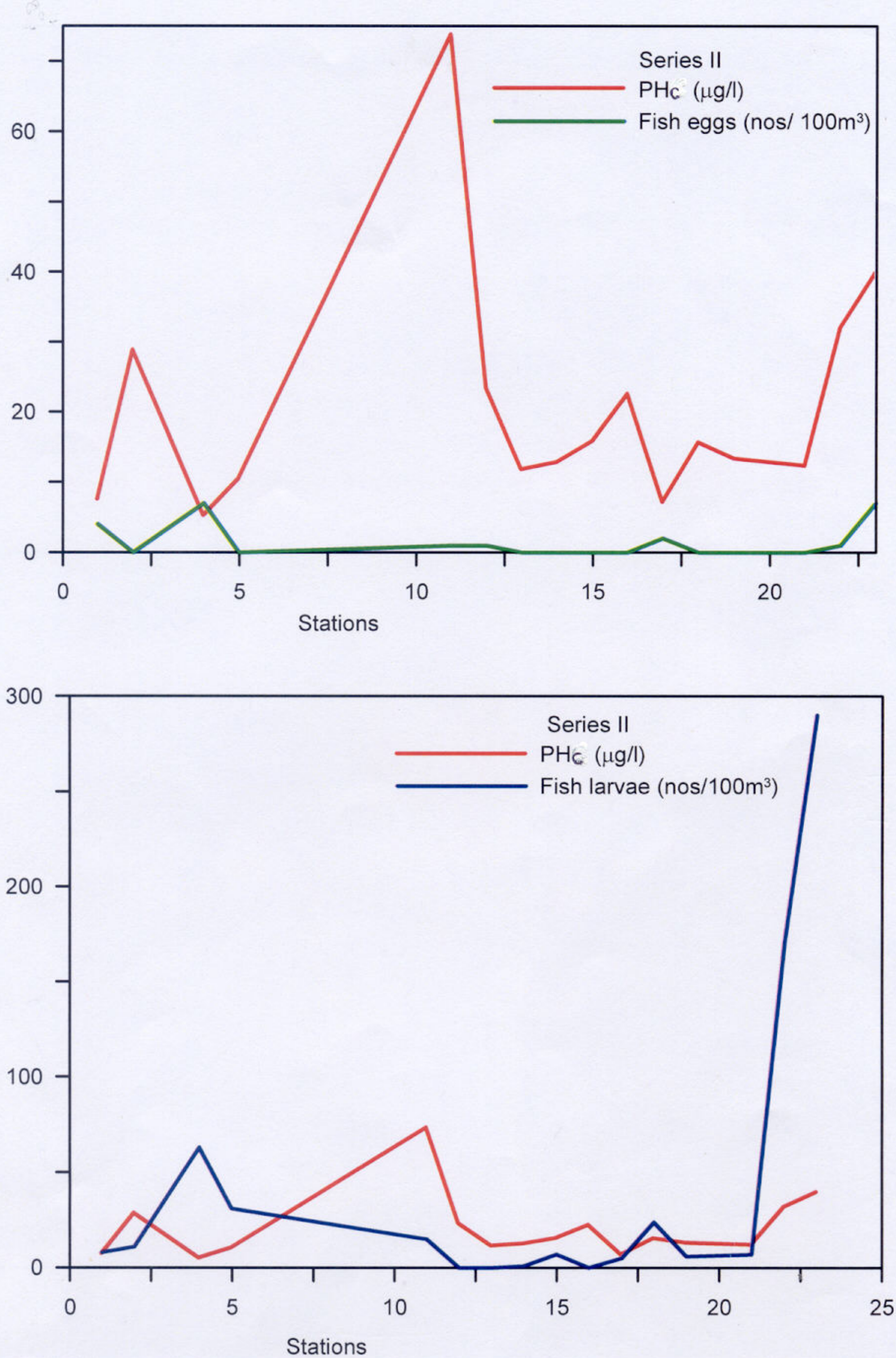


Figure 8.2.15: Abundance of fish eggs and larvae and PHc in water along Mumbai Bay during 3rd week of August 2010 (Series II)

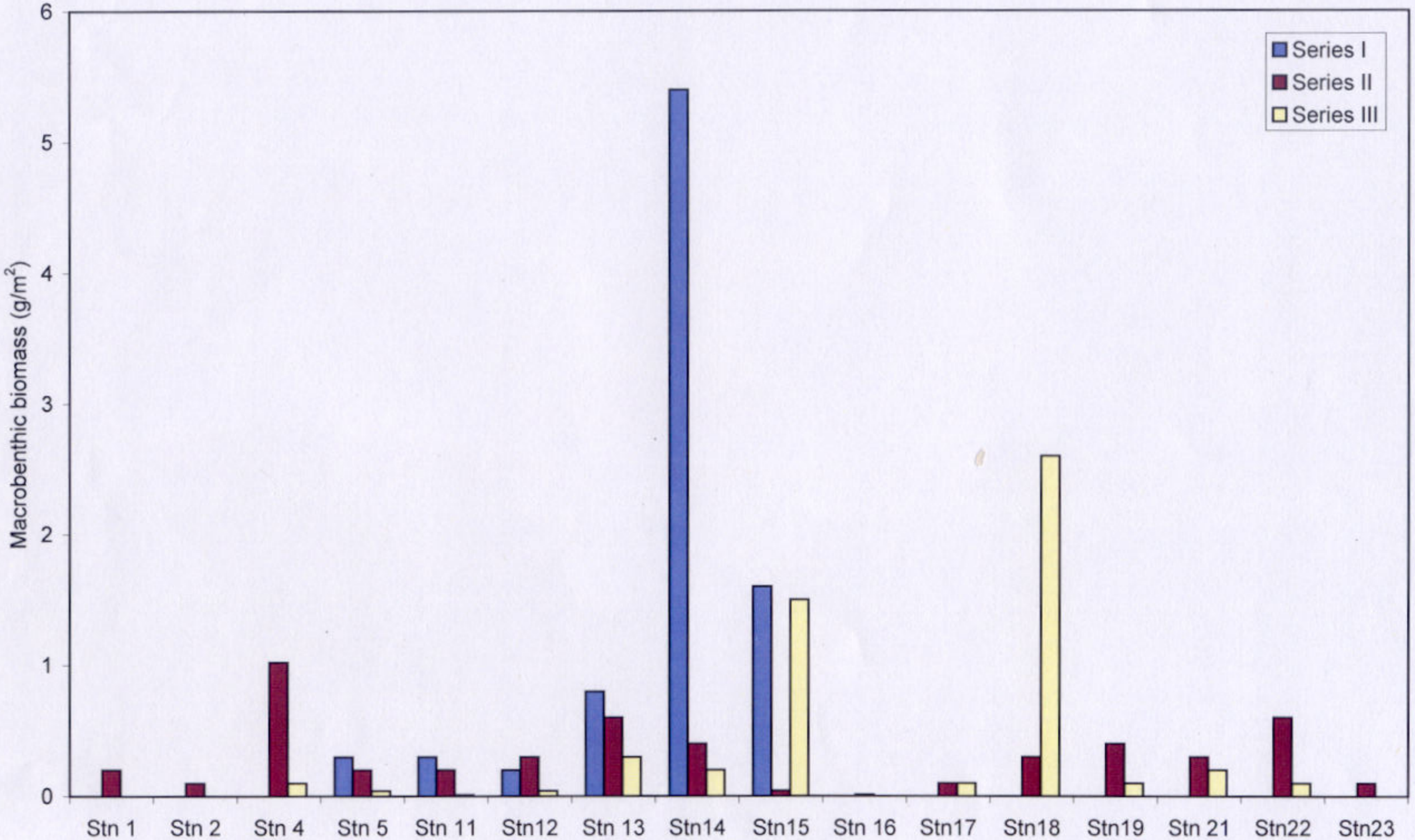


Figure 8.2.16: Average macrobenthic biomass at the subtidal stations during August-September 2010

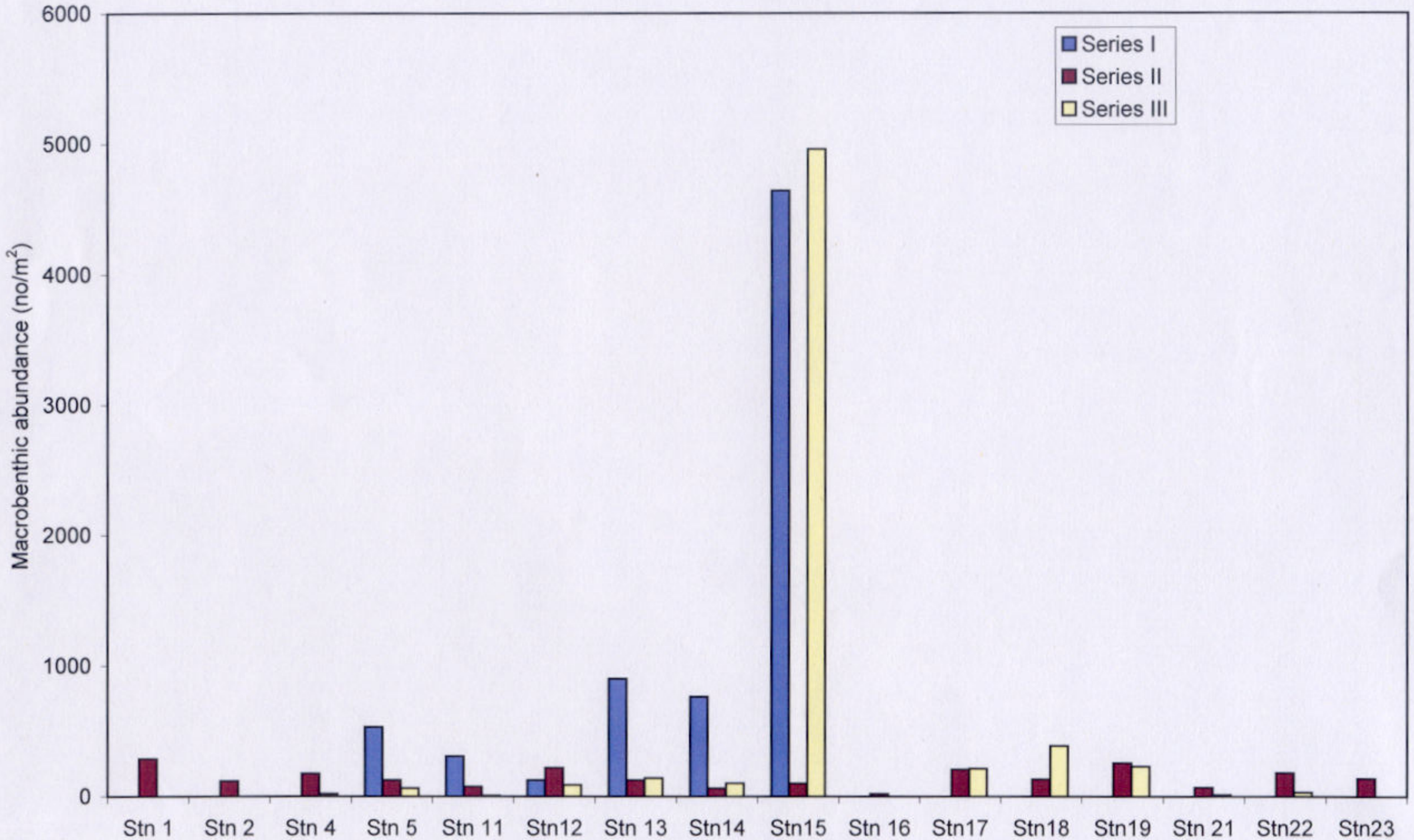


Figure 8.2.17: Average macrobenthic abundance at the subtidal stations during August-September 2010

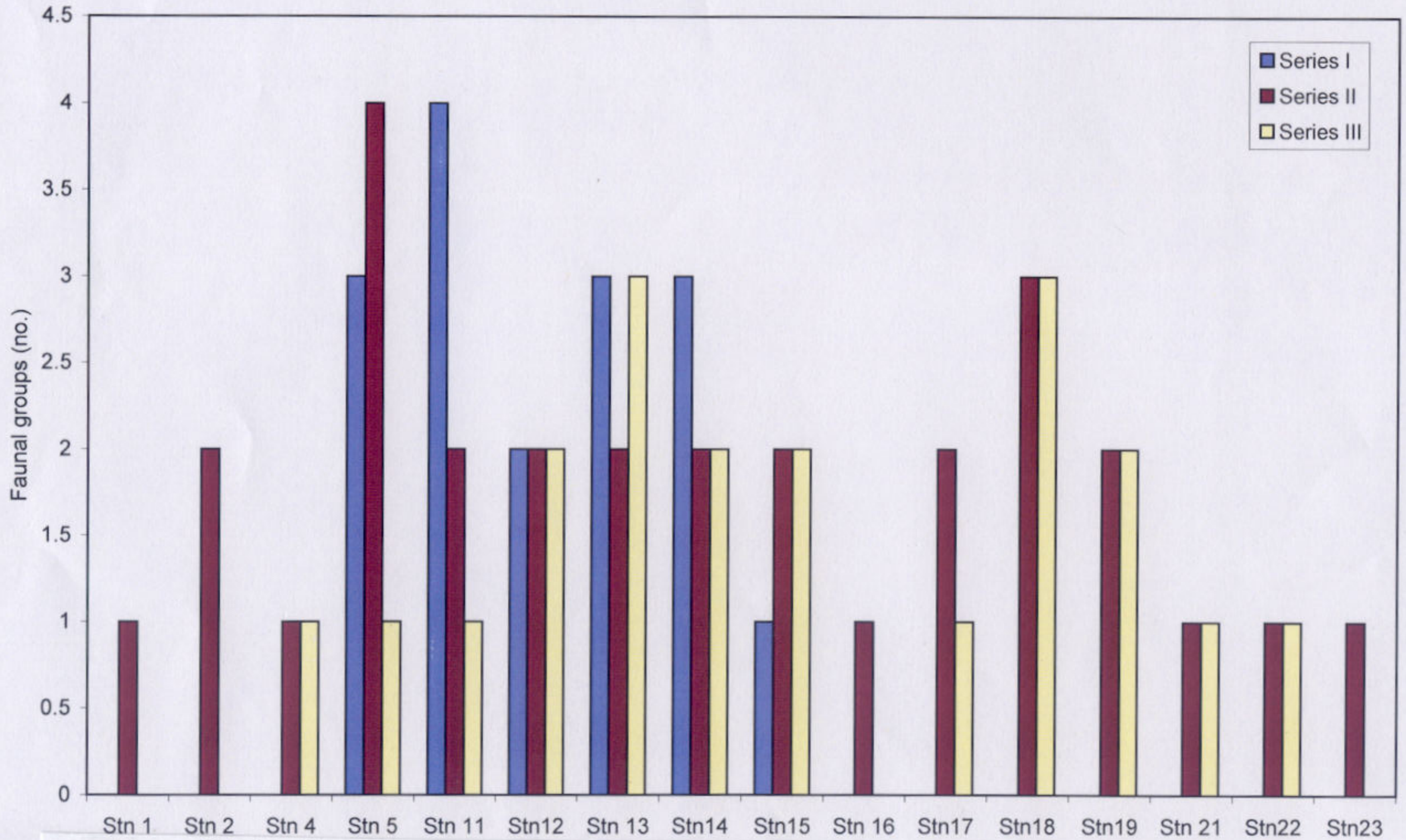


Figure 8.2.18: Macrobenthic group diversity at subtidal stations during August-September 2010

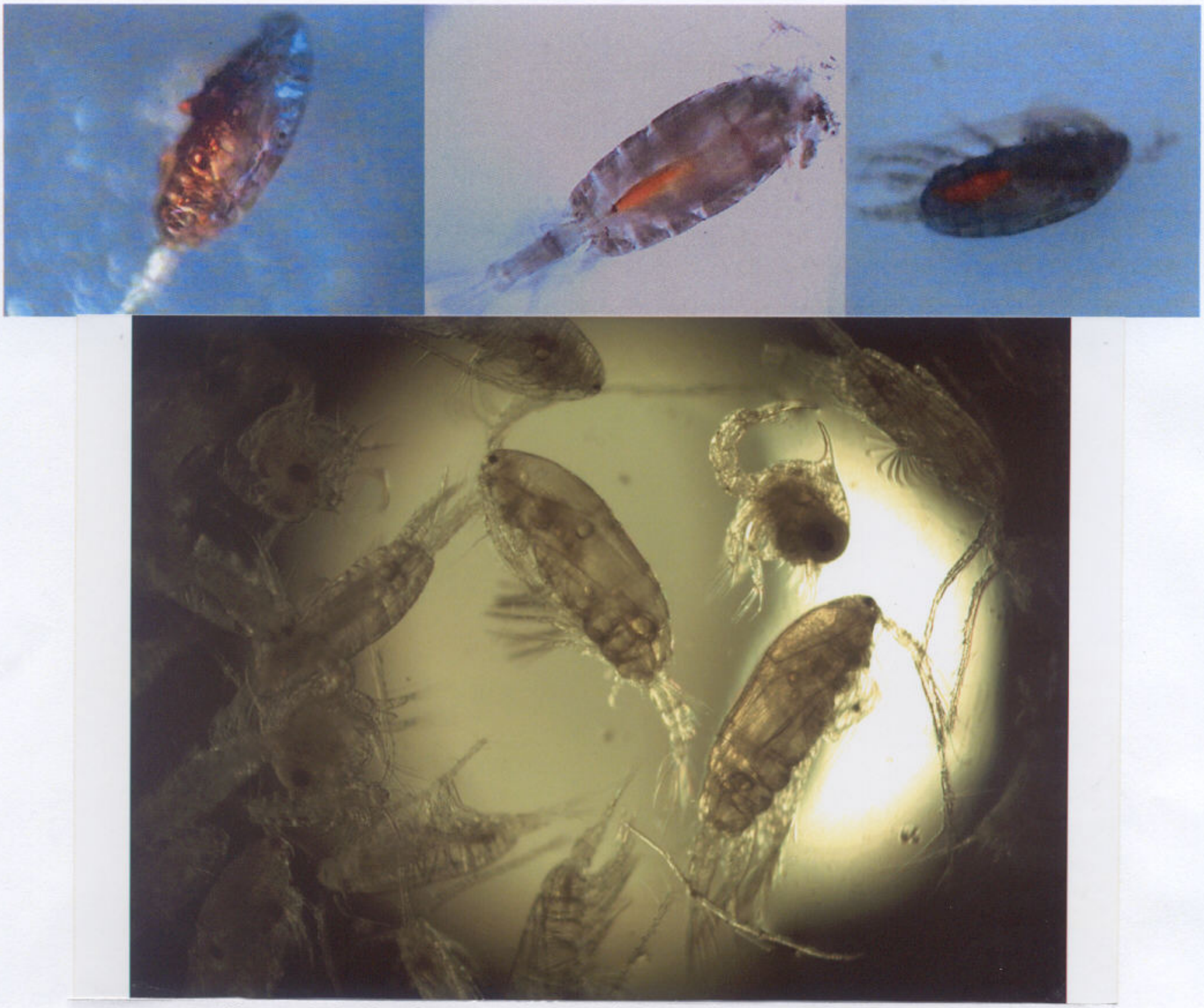


Figure 8.2.19: Copepods and decapods contaminated with oil

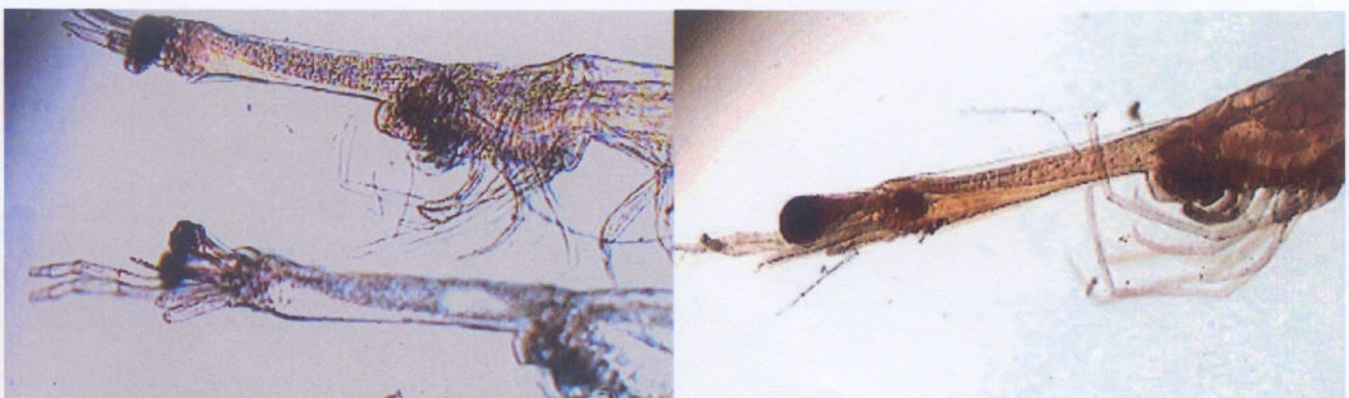


Figure 8.2.20: *Lucifer* found (a) with & without oil coating and (b) female *Lucifer* coated with oil

Figure 8.2.21a: Copepod with oil in the digestive tract

Figure 8.2.21b: The digestive tract of a copepod free from oil contamination