GENERAL INTRODUCTION

Modern human civilization has been petroleum driven for more than a century. This naturally occurring substance, which is a complex mixture of hydrocarbons and their derivatives derived from primordial organic deposits, is accumulated in geological reservoirs from whence it is extracted, transported, refined and converted to myriad products such as fuel, plastics and synthetics. Crude oil and natural gas are indigenous components of the natural ecosystem. Living organisms have evolved biological mechanisms to metabolise these complex mixtures within tolerable limits. However, massive influxes of petroleum hydrocarbons into the marine ecosystem occur due to anthropogenic activities with rapid alterations in structure and composition of the refined products introduced, as opposed to the low-level but long term inputs from natural seeps. This often results in the upsetting of the ecological equilibrium of affected habitats. Anthropogenic redistribution of petroleum and its byproducts into the atmosphere, geosphere and hydrosphere takes place through handling losses during every step of petroleum extraction and transportation, discharge of effluents during its processing and combustion or willful disposal of its byproducts such as fuel, plastics and synthetics. “Oil pollution” as a result is a ubiquitous phenomenon. The effects of this form of pollution are evident from its sources of extraction in the marine oil fields to erstwhile pristine habitats like the polar regions.

Visually and physically oil pollution is the most evident of all categories of pollution in the ocean. Aesthetically, this form of pollution in its extreme - as
oil spills - evokes the strongest of reactions, resulting in much media attention and mobilising of public opinion that reflects in mitigative efforts by means of legislation, policies and ocean management programmes.

The effects of tanker and oil rig accidents, spillage, oil well blowouts and sabotage of oil fields as acts of war are immediate, acute and very evident, though locally restricted and strongly dependent on local circulation, prevalent weather and geographical features for dispersal and removal. However, the above account for less than 5% of the petroleum hydrocarbons entering the marine ecosystem. The current estimates are that 65% of oil pollution arises from landbased sources such as dumping, atmospheric fallout, land run offs, coastal refineries and off shore platforms. Of the remaining 35%, 20% comes from shipping operations such as deballasting and bilge discharge and 10% from intentional discharges. The extent of damage inflicted on biological communities and ecosystems and the effects of low concentrations of petroleum hydrocarbons reaching and persisting in the sea goes virtually unnoticed. Owing to the social factors involved with oil spills, early investigators focused attention on the immediate effects of oil pollution and its effects on mostly non-commercial resources such as marine birds and seals or on mass mortality of adult fishes. This fact coupled with the readily biodegradable nature of oil and the remarkable stability of degraded oil derivatives in the marine ecosystem brought about a trend in scientific thinking that dismissed pollution by petroleum hydrocarbons as one of the lesser evils among marine pollutants. Not much attention was paid to long term impacts such as alterations in the effect of petroleum hydrocarbon toxicity on plankton community structure, subsequent recruitment of juveniles
of exploited fishery resources or epidemiology in afflicted communities. The effects of sublethal levels of oil on ecosystem modification and community structure still remain poorly understood.

The wreck of the oil tanker *Exxon Valdez*, in Prince William Sound, Alaska spilled 11 million tonnes of crude in March 1989. It created unprecedented world opinion against oil pollution, which renewed interest in this field of pollution research. Prior to this two other wrecks, one that of the tanker *Torrey Canyon* off the coast of Lands End, UK (1967) releasing 38.2 million gallons of oil and that of the tanker *Amoco Cadiz* off the coast of Brittany in France (1978) resulted in large-scale oiling of shorelines. The wreck of the *Braer* off the ecologically sensitive Shetland coast involving the discharge of 8 million gallons of oil (1991) was dwarfed by the catastrophe in the Persian Gulf which saw the release of 240 million gallons of oil into the sea during the Gulf War from the Sea Island installations off Kuwait and off Saudi Arabia. Until this event the blow out of *Ixtoc I* oil station was the single most devastating oil pollution incident involving 140 million gallons of crude. Subsequent effects of the Gulf war on the ecosystem are still in controversy as adequate documentation to the situation preceding the war was unavailable. The Persian Gulf, owing to its location rimming the most productive oil fields currently exploited in the world has been subjected to repeated large oil spills. The blow out at platform No.3 at *Nowruz* oil field, Iran involving 80 million gallons of oil (1983), the wreck of the tanker *Pericles GC*; in Persian Gulf, 30 km east-north of Doha spilling 14 million gallons of oil (1983), the tanker *Nova* in 1985 in the Persian Gulf, 140 km south of Kharg Island and innumerable other tanker and platform accidents during the
transport of massive quantities of oil year round lead to constant contamination of the seas in this region. In Indian waters, there have been several large scale spills, including that following the wreck of the Greek tanker Ampuria off the coast of Kutch (1970), the M. T. Cosmos Pioneer again in the north western coast of the Arabian sea (1973), the American oil tanker Transhuron which ran aground at Kiltan, Lakhshadeep (1974), the blow out of the oil well Sagar Vikas at Bombay High (1982), a large spill in the Andaman sea off Nicobar (1992), the bursting of oil pipelines close to Pirotan islands in the Gulf of Kutch (2000) and numerous minor spills especially in the harbours and coastal areas owing to handling losses and to willful discharge of bilge and ballast waters arising from economic considerations. Three major incidents of spillage were reported from Kochi port itself, (1992, 1993 and 1995) and one off the Vypeen –Cherai coast (1997).

The threat of oil pollution in our seas remains omnipresent though there has been a global reduction in the quantity of oil entering the marine ecosystem through improved oil tanker designs and increasing sophistication of oil extraction equipment and transferring facilities in harbours and dockyards, though the strongest contribution has been from strict law enforcement, especially in the Western hemisphere. Large inputs of oil have mainly arisen from accidents occurring due to inclement weather, mechanical failures and sabotage as an act of war rather than from human error. Shipping lanes and harbours world over show elevated values for petroleum hydrocarbon concentrations in water and sediment with the input source varying from ill maintenance of engines to deliberate discharge of bilge and ballast and bunkering accidents. However, in India there has been a lack of
critical assessment or quantification of oil input into the seas on a national scale. A maritime state like India with an extended coastline of over 8000 km, having its own oil extraction facilities as well as being located along some of the busiest shipping channels in the world, viz. the Arabian sea, has the possibility of facing highly polluted coastal waters in the years to come.

The complexity of effecting legislation over oil pollution results from the involvement of environmental and maritime laws of several countries and agencies simultaneously. The very nature of oil pollution defies national legislation alone for effective containment and requires international co-operation and legislation. The first international convention in oil pollution control was elaborated in 1924, though decisions taken remained ineffective as major oil producing nations were not party to it. The United Kingdom and France paid heavily in terms of ecological damage and revenue as a consequence of the Torrey Canyon disaster in 1967 and petitioned the Inter-Governmental Maritime Consultative Organization (IMCO) which responded by creating the IMCO Legal Committee to deal specifically with legislation pertaining to oil pollution at sea. The present framework of legislation is a refinement of legislation drafted from 1967 onwards. The major international legislation existing include laws drafted by the OILPOL- the 1954 International Convention for the Prevention of Pollution of the Sea by Oil, the 1969 Civil Liability Convention for Oil Pollution, the 1971 Convention and the International Oil Pollution Compensation Fund Convention, MARPOL- the 1973 International Convention for the Prevention of Pollution from Ships and its 1978 Protocol, UNCLOS- the 1982 United Nations Convention of the law Of the Sea, international voluntary agreements such as Tanker Owners
Voluntary Agreement concerning Liability for Oil Pollution (TOVALOP) Standing Agreement, the 1984 protocols amending the 1969 CLC and 1971 Conventions and the 1987 modification of the voluntary agreement. The United States has maintained a much stricter legislation policy against oil pollution and has recently effected the 1990 Oil Pollution Act.

Oil input sources other than those arising from extraction and transportation activities are myriad, ranging from automobile exhaust to urban and industrial drainage, even allegedly adulterated fuel oil with high benzene content. The ocean has been considered a vast sump with an infinite capacity for dilution, leading to the release of domestic and industrial effluents into it, generally without treatment or detoxification. Land runoff and precipitation from the atmosphere, particularly in relation to automobile exhaust, also contributes to chronic low level pollution. No reliable estimates are available for these categories of low-level inputs of petroleum hydrocarbons in India. Research on lethal and sublethal toxicity of petroleum hydrocarbons to marine organisms has been taken up by various research institutes and universities.

The history of oil pollution research records deeper insight, with increasing accuracy and reliability of phenomena associated with oil pollution which is reflective of an increase in sophistication of analytical instrumentation and software technology as well as enhanced infrastructure such as satellite imagery and aerial surveys. An understanding of the physical and chemical behaviour and the fate of oil in the water column are essential for evaluating the effects of its presence on the biological components of the marine ecosystems. Physical interactions of oil on the water surface and within the water column have been investigated by physicists and oceanographers in
attempts to understand the processes of evaporation, spreading and dispersion of slicks, chocolate mousse formation, oil droplet entrainment into the water column, sedimentation, sorption onto particulate matter and resuspension of petroleum hydrocarbons from oiled sediments.

Likewise a deeper understanding of the chemical alterations of hydrocarbons or their derivatives entering into the marine ecosystem, their chemical metabolism, the behaviour and effects of chemical remedies such as surfactants and sorbents has been gained. Prior to the mid-1970s, the chemical nature of petroleum hydrocarbon mixtures was poorly understood due to a lack of standardised instruments and techniques for analytical purposes. Improvised methods suited to individual situations were evolved which led to poor success in intercalibrations. These anomalies have been resolved to a very large extent over the years with refinement in analytical methodology with bodies such as the International Maritime Organisation providing a protocol of standardised methods for monitoring petroleum hydrocarbons in the environment and the American Petroleum Institute providing standard oil mixtures which could be used as reference oils.

The study of biological effects of petroleum hydrocarbons has shown corresponding changing trends. The focus of research moved from acute toxicity studies of common and commercial organisms in the early seventies to detailing of sublethal toxicology by the mid-eighties. By then the use of controllable environment systems within laboratories such as flow-through systems ushered in a period of sublethal toxicity investigations which included classical toxicological, histopathological and physiological experimentation. The effects of various types of oil and refined products on several molluscan,
polychaete, coelenterate and crustacean species were analysed which led to a better understanding of changes in behaviour, physiology and histology of these animals when exposed to petroleum hydrocarbons. A need for coordinating laboratory and field components of oil research was felt in the intervening years of the 1980s, which led to an increased number of transplantation studies examining the complexities of degraded petroleum products in the environment and their intake and metabolism by marine organisms. By the late eighties and early nineties much attention was being paid to the detoxification mechanisms which proved to exist in organisms exposed to hydrocarbons, especially in natural environments. Attention was also focused on the mutagenicity, behavioural alterations, and synergistic toxicity and on polar and tropical ecosystems and species. Biochemical investigations into the mixed function oxidation detoxification systems, coupled with ultrastructure studies provided much insight into subcellular mechanism of petroleum hydrocarbon metabolism in organisms. The nineties saw an increased demand for justification of research spendings along with the ushuring in of intellectual property regimes which swung research in various biological disciplines, as also oil pollution research in the direction of applications. The "polluters must pay" slogan raised during the Earth Summit (1989) was translated into more effective legislation against offenders and was consequently accompanied by advances in methodology to "fingerprint" sources of petroleum hydrocarbon pollution. The much criticised clean-up operations following the Exxon Valdez spill also saw a greater deal of attention being paid to bioremediation and other containment measures which were less damaging to already critically degraded ecosystems. Microbial
degradation is a major clearing mechanism for removal of oil from the environment. The insights gained into the evaluation of the environmental parameters conducive to enhanced rates of biodegradation to rate projection of such processes during the 70s and 80s was further refined and led to the eventual bioengineering of the first patented living organism, a bacterium of the *Ralstonia* species, used for bioremediation procedures for clearing oil spills. The recent trends in oil research in the West is inclined towards predictions of spill movement and of the impacts of acute, chronic, short-term and long term impacts on the ecosystems which is supported by recent advances in software technology enabling sophisticated simulation methods and advanced level ecosystem modelling. In India such research is rather limited owing to a paucity in infrastructure and the means for repeated trials. The living standards as well as the oil industry in India remains a few paces behind that of developed nations, which does not make such aspects of oil pollution research feasible for application here as yet. However with the liberalisation of markets and subsequent cultural changes, especially in terms of rapid industrialization and a trend in westernisation as far as consumer products and mode of transportation are concerned along with the massive expansion plans of the oil industry, such a change in direction of oil pollution research is also inevitable and imminent.

The effect of chronic low level or sublethal oil pollution manifests in long term shifts in the biological composition of the ecosystem of the affected area with a negative influence on stability and diversity indices and more resistant species dominating. In terms of the fishing industry, deterioration of near shore and inshore water quality plays a crucial role in the movement of
shoals and the health of stocks. The estuarine environment is characterised by short-term, severe abiotic fluctuations which results in a comparatively low diversity with resident species being tolerant of a wide range in fluctuations of physio-chemical parameters. Paradoxically, the impact of oil pollution is comparatively higher in more stable ecosystems such as the littoral communities or near shore pelagic communities due to the higher sensitivity of the component species. However, the estuarine biota cannot be expected to combat stress from various agencies over a threshold limit nor for prolonged periods without serious consequences to physical well being and energy optimisation at the organism level, reproductive success at the community level and stability of species composition at the ecosystem level. By nature estuarine ecosystems are unstable, with drastic changes occurring in population numbers. Anthropogenic activity around estuaries is also high which invariably signifies high inputs in terms of xenobiotics into estuaries. Deteriorating water quality, especially within shallow, partially confined bodies such as estuaries and fjords compounds the increasing fishing pressure on marine resources to the detriment of resource stocks. In almost all estuaries with human colonisation on the shores, chronic low level oil pollution combined with episodic inputs of large quantifies of crude and refined oils in those used as harbours, elevates the levels of petroleum hydrocarbons. It follows that in areas polluted beyond a level of adaptation for the existing system, opportunistic, short-lived, prolific species will dominate with marked fluctuations in abundance through space and time whereas climax species such as large fish will be displaced. The ability of ecosystems to recover from episodic events of oil pollution defines the limits to which such displacement
takes place though in terms of chronic low level pollution the effects are less
discernable and require careful and detailed long term monitoring before
conclusions can be drawn.

Oil pollution researchers have shown a preference for certain species
of marine organisms owing to their commercial importance or their subjectivity
to laboratory handling and procedures. These include molluscs such as *Mya
arenaris*, *Mytilus* spp., *Macoma* sp., and crustaceans such as *Cancer* spp.,
*Crangon* spp., and *Mysidopsis* spp. *Metapenaeus dobsoni*, the crevatte
shrimp, is a penaeid shrimp that is a major component of the penaeid shrimp
of both the east and west coast landings with the fishery along the southwest
coast being the most important. The fishery for this species is concentrated
within inshore limit up to the 80-metre depth zone. The ontogeny of the
species includes an estuarine phase with the postlarvae moving into the
estuary for feeding and growing into juveniles and migrating back to the sea
for maturation and breeding. The vast backwaters of Kerala support a large
fishery for *M. dobsoni* with juveniles forming 60-80% of the catch. They are a
principal species in traditional prawn filtration farms that impound incoming
postlarvae and grow them to marketable size in paddy-cum-prawn culture
operations, the largest and most productive farms existing in the Vypeen-
Cherai belt, near Kochi. The revenue for the economy of the country from the
export of shrimps is substantial in terms of foreign exchange and from the
domestic market. *M. dobsoni* was chosen as the test organism as it is
commercial important and is a representative of the benthic community, which
is most exposed to persistent petroleum hydrocarbons in the subsurface
waters and sediment of the estuary. Bombay High Crude, which is transported to Kochi by sea, was the toxicant utilised to investigate the stress responses of *M. dobsoni* to petroleum hydrocarbons in the present study.

When the stress experienced by an animal exceeds its zone of tolerance or resistance, the altered functional state of the animal affords measurable stress responses that can be investigated through physiological, biochemical, cytological and behavioural studies. These responses may be in alarm at the stimulus or may be an attempt to adapt to or resist the altered state or a failure to do either and finally succumb to the stress due to exhaustion or breakdown of life sustaining metabolic activities. The variations in basal metabolism brought about by these events can be estimated using physiological parameters such as scope for growth, growth efficiency or body condition index in long-term assessments and by measuring the rates of physiological functions such as oxygen consumption, nitrogen excretion or bioaccumulation. Actual damage to the organs and tissues, which is the cumulative effect of stress on metabolic pathways, is done using histopathological techniques. Sophisticated instrumentation techniques such as electron microscopy allow fine structure analysis of individual cells, providing a means for making further insights into and corroborating results obtained through other means of measuring stress responses.

An inference of detoxification mechanisms and identification of biomarkers is possible from the results of stress response investigations. Very often the correlation of laboratory experimentation with that of field results proves impossible due to an absence of ideal or controllable conditions and numerous or unknown variables. However, the laboratory experiments
provide a means for standardisation and the determination of ‘worst case scenarios’ which are important for predicting and assessing environmental implications of pollution. In the case of correlation between the incidence of diseases and pollution, long term field investigation could provide justifiable inferences whereas a laboratory investigation of incidental pathology using microbiological tests can outline dose response relationships between all parameters concerned without ambiguity.

An attempt was made to understand the effects of petroleum hydrocarbons on the penaeid shrimp *Metapenaeus dobsoni* (Miers) through laboratory based investigation. Its local estuarine habitat, the Cochin backwaters, was monitored for a short period to determine the environmental load of oil contaminants. The methodology employed and the results obtained have been discussed in the ensuing chapters.