1. GENERAL INTRODUCTION

Worldwide harvest of aquatic products by fisheries is currently close to its maximum sustainable level of productivity. Aquaculture is a rapidly expanding industry, and its effluent can be a major source of pollution in marine ecosystems (Hargreaves, 1998). Aquaculture is therefore the only means of promoting production to meet the increasing demand for aquatic products (FAO, 2005). Aquaculture is also an important instrument for promotion of economic growth in developing countries and rural areas because it creates jobs, business and income. Nevertheless, in order to compensate for the negative environmental impact of aquaculture, due attention must be paid to methods of production and the environmental consequences of the production process implemented. The environmental impact of aquaculture varies and includes conflicts between the needs of different users of its products, alteration of the hydrological regime, introduction of exotic species to the wild, and pollution of water resources (Read et al., 2001). According to Boyd (2003), pollution of water resources by pond effluents is probably the most common complaint, and this concern has attracted the greatest amount of official attention in most nations.

Environmental studies into the effects of aquaculture are limited and have mostly focussed on in-pond water quality, with little research conducted into the ecological impacts of wastewater on receiving waters (Pillay, 1992). In flow-through aquaculture systems like raceways and tanks, effluents are discharged to the environment with enhanced concentrations of nutrients and solids. Such effluents may have a serious negative impact on the quality of the receiving water when discharged untreated (Forenshell, 2001; Miller and
This study was therefore initiated to assess the potential impact of aquaculture and agriculture effluents on the water quality of receiving waters and to estimate the larval abundance and biomonitoring capacity of *Modiolus modiolus* from the Palk Strait region. The study was carried out in Karangadu where a string of aqua farms and crop fields were situated and constituted a real case for assessment of the potential additive impact of farm effluents on receiving waters. The case may be compared with the neighbouring water body i.e. Thondi in all the aspects of the study.

The monitoring of traditional water quality parameters has identified that downstream impacts of shrimp effluent, and other forms of aquaculture, are only measurable in close proximity to the discharge point. Hensey (1991) observed that environmental monitoring of aquaculture effluent using water quality sampling techniques showed no impacts. Samocha & Lawrence (1997) observed large diurnal fluctuations in water quality parameters measured downstream of shrimp farm discharge points, and that no increase in total suspended solids or nutrient concentrations could be measured further than 400 m from the farm’s discharge. It is possible, however, that sediment impacts such as increased organic matter and anoxia, may extend further (up to 1 km) than water column impacts (Wu et al., 1994).

In coastal marine systems a variety of point source inputs from aquaculture ponds, sewage treatment plants, fertiliser plants, agriculture and urban runoff can make it difficult to determine responsibility for ecological impacts (Grant et al., 1995). With increasing conflict column nutrients, these biological indicators reflect the availability of biologically available nutrients.
which provides more ecologically meaningful information. The aims of this study were to assess the influences on the receiving environment of wastewater discharges to a shallow estuarine system. Changes in receiving water and sediment quality analyses were compared with biological impacts measured as a consequence of shrimp farm and sewage effluent discharges. The region of influence of these two pollutant sources is defined, and mechanisms are suggested which may aid in discerning relative impacts of these two discharges on a common receiving environment.

Environmental pollution with toxic metals is becoming a global phenomenon. As a result of the increasing concern with the potential effects of the metallic contaminants on human health and the environment, the research on fundamental, applied and health aspects of trace metals in the environment is increasing (Vernet, 1991). Activities in the coastal zone have a different permitting process than those on land. Mariculture, the farming of aquatic organisms in the marine environment, is both one of the newest and oldest uses of the coastal zone (Marine Aquaculture Task Force, 2007). Advances in knowledge of the concentrations and distributions of trace metals in the marine environment have occurred since the mid 1970s (Burton and Statham 2000). This is mainly due to developments in procedures for contamination-free sampling, the adoption of clean methodologies for handling and analysis of samples, and increased application of improved analytical methods such as inductively coupled plasma-mass spectrometry (HG-ICP-MS) (Burton and Statham 2000). Aquaculture modifies its receiving environment. There is real and significant potential for aquaculture induced impacts across a variety of environmental components such as benthic
nutrient and oxygen loads, local biodiversity and species assemblages, pelagic communities and hydrodynamic conditions (Devanport et al., 2000).

Heavy metals occur naturally as they are components of the lithosphere and are released into the environment through volcanism and weathering of rocks (Fergusson, 1990). However, large-scale release of heavy metals to the aquatic environment is often a result of human intervention (Denton et al. 1997). Coastal regions are some of the most sensitive environments and yet they are subject to growing human pressures (David, 2003) because of increasing urbanization, industrial development, and recreational activities. Therefore, pollution levels are often elevated in the coast because of nearby land based pollution sources (Fergusson 1990).

Biological pollution is another environmental problem related to aquaculture because ecosystems are being altered and biodiversity is being reduced. In aquatic health research, much attention is focused on aquatic pollution and its harmful effects on ecosystems. Aquatic health is an essential research field in which various monitoring tools and assessment protocols have been developed to monitor and manage the impacts of pollution on aquatic ecosystems. This includes the use of biomarkers, where the response of aquatic organisms resulting from exposure to pollutants, are measured in terms of sensitivity. Hence, the severity of the impact of the pollutant on the species and the larger system in which they occur can be determined.

Onshore marine habitats can be distinguished from offshore environments in terms of their physical stability. In particular, onshore benthic systems, including intertidal habitats, are exceptionally unstable,
disturbed, and more subject to unpredictable physical changes than offshore environments (McKinney, 1986; Jablonski and Botjer, 1990). From an evolutionary point of view, since onshore environments are highly variable at different spatial and temporal scales, one would expect selection to produce a larger diversity of marine invertebrates in onshore than in offshore systems (Jablonski and Botjer, 1990).

Much debate about the evolution of marine invertebrate species has focused around the onshore-offshore pattern of species distribution. The suggestion is that many higher taxa originated in onshore environments, followed by offshore expansion with many onshore-originated groups moving into offshore areas. Finally, some higher taxa that moved offshore would have permanently settled in the offshore environments (Jablonski and Botjer, 1990). Support for this theory comes from McKinney (1986). He suggests that more onshore species exhibit a progenetic reproductive strategy, in which organisms become sexually mature while still morphologically juvenile. The organisms exhibiting this strategy also exhibit shorter generation times and smaller body size. These characteristics make onshore organisms more prone to rapid evolution and more resistant to extinction than offshore ones (McKinney, 1986).

Bivalve mussels (Mytilus spp.) are sessile organisms living at the sediment/water interface and filter large volumes of water, including suspended materials and colloids. They live in environments characterized by a wide array of salinity and temperatures, and are extremely tolerant towards sudden changes of abiotic and biotic parameters, representing therefore suitable models to study the physiological alterations imposed by transitional
environments. Owing the consistent responses developed after exposure to chemical pollutants, Mitylidae are also widely employed as sentinel organisms in environmental biomonitoring programs at the international level, including UNEP, RA.MO.GE, BEEP, etc. (Viarengo et al., 2007). Mussels are useful indicator organisms in this regard as they are sensitive to their environment, are easily attainable, and have a relatively long lifespan allowing the identification of both acute and chronic effects after exposure to pollutants. Mussels occupy a relatively narrow band in the intertidal. Physical stresses such as salinity, temperature, wave action, wave-generated storms and exposure to air limit the distribution of mussels intertidally and affect the mortality of adults considerably. For example, temperature and the risk of desiccation limit the distribution of mussels at the upper tidal levels (Suchanek, 1985). Subtidally, their distribution is often limited by predators, such as starfish, dogwhelks and subtidal fish (Seed, 1976; Suchanek, 1985). Also, the availability of suitable substrata can be a limiting factor for the distribution of mussels. Even within the narrow band that is inhabitable for mussels, they are subjected to the stresses induced by intra- and inter-specific competition for space (Seed, 1976; Suchanek, 1985).

Despite the factors that delimit the distribution of the mytilid family, mussels are still among the dominant organisms on rocky shores and provide ideal habitats and refuges for many other invertebrate species (Harris et al., 1998). Indeed, mussel beds form a packed matrix that decreases the effect of wave action, temperature and sunlight (Suchanek, 1985). As a result, mussels can be considered to be “physical ecosystem engineers” able both to modify and to maintain the environment and to create the perfect habitat for many other species (Seed et al., 2000). The success of mussels can partly be found
in their evolutionary history. Indeed, the neotenous retention of the post-larval byssus, used for attachment during metamorphosis, facilitated their expansion from soft sediments to hard substrata, by allowing a firm fastening of mussels to rocks (Suchanek, 1985; Seed et al., 2000). The heteromyarian shell shape, which is characteristic of mussels, also provides an ideal form for space occupancy and offers an excellent design for gregarious behaviour, for living in high densities and, again, for strong attachment to the substratum (Seed et al., 2000).

Mussels have solved the problem of survival under the unstable and variable conditions typical of the intertidal zone by securing themselves to the rocks and by being gregarious. The great success of mussels on the shore would appear to come in spite of the limitations of their reproductive strategies and larval histories. Mussels are highly sedentary and, in contrast to barnacles, exhibit external fertilization. This involves an enormous amount of energy loss or wastage. With the release of sperm and eggs into the water, most gametes are lost and, even after external fertilization has occurred, almost 99% of zygotes die (Suchanek, 1985; Underwood and Fairweather, 1989; Underwood and Keough, 2001). In addition, dispersal of larvae in the water column results in a further loss of potential recruits to the final adult populations (Underwood and Keough, 2001).

The energetic investment required by mussels for their reproductive strategy appears to be very high. Although the total energy available to each individual is limited, mussels seem to spend lots of energy in three processes that involve great loss: external fertilization, long-lived larval dispersal and final settlement (Todd, 1985). However, life histories are generally
phylogenetically constrained and can evolve only in certain directions. Also organisms can only select amongst a limited set of habitats (Todd, 1985).

The colonization of the highly disturbed rocky shore environment and reproduction through external fertilization, with its attendant risks, along with the associated risks of dispersal and settlement, may be the best evolutionary option that mussels have had. The habitat in which these mussels occur is highly unpredictable, due to strong wave action, currents and the harsh conditions typical of the intertidal zone, especially in subtropical regions (Suchanek, 1985). Although the mortality of larvae is very high, it is more predictable than the mortality of adults, which are more subject to the unstable conditions of the shore (Thorson, 1950; Widdows, 1991). The production of large quantities of gametes is certainly a great advantage for mussels, considering the precarious conditions the pelagic larvae have to withstand during dispersal (Underwood and Keough, 2001). The small size of larvae could also be considered an advantage for the survival of the larva itself. In fact, it is believed that mussel larvae are transported like passive particles in the water column (McQuaid and Phillips, 2000). Their characteristic small size allows them to float and to be carried in the water instead of sinking to the sea bottom, away from rich food areas or settlement sites (Underwood and Keough, 2001).

During dispersal, pelagic larvae can potentially be carried over large distances (Widdows, 1991; McQuaid and Phillips, 2000; Poulin et al., 2002). Larval transport in the water, associated with settlement on the shore of competent larvae, allows the colonisation of empty patches of rocks or even new areas and regions (Underwood and Fairweather, 1989). Dispersal and
settlement strongly shape population structure and, therefore, affect the entire community associated with the adult beds (Morgan, 2001).

Since larvae remain in the water column for quite some time, their transport and survival chances are exceptionally variable (Bayne, 1965). In fact, the nature of dispersal and settlement can make larval and settler abundances particularly variable, as they are strongly influenced by unpredictable environmental conditions (Underwood and Fairweather, 1989; Eckman, 1996). Thus, the availability and settlement of mussel larvae are highly variable because of mussel reproductive strategies and also because of the general characteristics of the environment in which the larvae are found. Variability of larval availability and of settlement intensifies even further when different spatial and temporal scales of the environmental and biological components are considered (Jenkins et al., 2000; Morgan, 2001; Drouin et al., 2002).

Following gametogenesis in these adult mussels, gametes are free-spawned into the water column where fertilization takes place and embryos develop into planktotrophic (feeding) veliger larvae. This study provides the first description of larval culturing techniques and larval development through the early veliger stage for any hydrothermal-vent or cold-seep bivalve and includes a description of the larval shell that can assist in identifying larvae collected from the plankton.

To assess the health status of these specimens in toxicity studies and field assessments, a standard protocol is followed that includes a necropsy (macroscopic examination of external features and internal organs as well as
blood sampling), calculation of somatic indices and condition factor as well as a qualitative and quantitative histological assessment of selected target organs. Together with the qualitative aspect, a quantitative histological assessment allows an objective comparison between exposed and control specimens, as well as statistical analyses of the results.

Histology, the microscopic study of tissue, provides essential knowledge of living cells as the basic building blocks of all living organisms. It examines the structural organisation of these cells in different tissue types allowing better understanding of morphological aspects and physiological processes of different organs. According to Short and Meyers (2001), histology is an important field regarding fish health that can often detect subtle conditions or early signs of disease not easily recognised on gross examination. Results from a histological assessment, can provide better insight into the environmental and/or physiological demands presented to fish in their natural environment (Short and Meyers, 2001).

1.1 SCOPE OF THE PRESENT STUDY

Aquaculture development within the Palk strait environment is currently hindered by a lack of information and knowledge relating to the impacts of large scale culture on open-coast locations, and also by general paucity of data relating to the Palk Strait region. This thesis endeavour to address these issues by overcoming the present uncertainties. Previous research indicates that the benthic environment is vulnerable to aquaculture development (Cranford et al., 2003). The overall goal of this study is to
determine the impact of aquaculture based contaminants on the mussel *M. modiolus* in the Palk Strait region. Hence it includes the following objectives

- Hydrographic conditions prevailing in Thondi and Karangadu coast with special reference to metal distribution in water and sediment

- Variation in the larval availability and settlement of the mussel *Modiolus modiolus* in the Palk Strait region: A Spatio temporal approach

- Impact of Aquaculture pond effluents on the proximate biochemical composition in the horse Mussel *Modiolus modiolus* L.- A seasonal approach

- Assessment of the impact of aquaculture pond effluents on metal accumulation in various soft tissues of *Modiolus modiolus* collected from Thondi and Karangadu.

- General morphology and the effect of aquaculture pond effluents on the histological alterations in *Modiolus modiolus*.

### 1.2 DESCRIPTION OF THE STUDY AREA

During the quaternary period the Palk Strait must have been originated introducing a close connection to the Southern Gulf of Mannar and to the Northern Bay of Bengal. This seen in the map with in the latitude of 90° and 10° N and longitude of 79° and 80° E. Northern boundary of the strait is of Kodiyyakkarai. Southern one is restricted to the Adams Bridge and the
Eastern limit is to the Sri Lanka, Thalaimannar region. The Palk Strait being influenced mainly by the northeast monsoon. The Strait has strong potential of living and non living resources.

Thondi is a small village situated in the Palk Strait region of Tamil Nadu. The study area lies in the latitude of 9°44’N and longitude of 79°19’ E. The rainfalls in Thondi region are mainly due to North East and South West monsoon. Thondi coast has a very minimal wave action. Turbidity of the seawater is moderately low and also they are rich in nutrients hence, it serves as a treasure house for valuable marine resources like seagrass, seaweeds and

**Figure 1 Map showing the Palk Strait Area**
invertebrates like coelenterates, echinoderms and shell fishes. The major occupation of the people is fishing.

Karankadu estuary is formed by the confluence of Kotaikerai River with the sea on the Palk bay side at the southeast coast of India. The estuary (SITE I) lies between 9°38′42.1″ N to 9°38′49.3″ N and 78°57′54.2″E to 78°56′24.8″ E, SITE II N 09° 38′ 44.4″, E 078° 57′ 56.6″. The width and depth of estuary ranges from 120m to 246m and from 1 to 2m respectively. This mangrove is bordered by two villages Karankadu and Pudukadu, important habitat is the mangrove rainforest situated over an area of about 400 hectares in the village Karankadu, along the bank of estuary in Kotaikerai. The mangrove habitat receives seawater up to a distance of 5km towards the riverside during high tide. From the fishing hamlet more than 600 mechanized and non-mechanized fishing vessels are operated. The bottom of the estuary consists of clay, silt with admixture of sand and large amount of organic detritus. Karankadu is familiar for economically important renewable resources like mangrove, seaweeds, shrimps, Holothurians and finfishes.