CHAPTER II
REVIEW OF LITERATURE AND METHODOLOGY

REVIEW OF LITERATURE

2.1 INTRODUCTION

India has about 7500 km long coastal margin in addition to the estuarine, intertidal, lagoonal and marshy zones, which provides a lot of scope to work on Ostracods. It is clearly understood from the literature survey that Recent marine and marginal marine water (brackish water habitat such as estuaries, lagoons, salt marshes, mangroves) Ostracods are not fully known from the Indian subcontinent. There are many studies on taxonomy, distribution and ecology of Ostracoda from marine environments of Atlantic area, including the Mediterranean, North and Baltic Oceans and from the Pacific and Indian Oceans. Comparatively, similar studies are few in number for the Indian sub-continental region and Arabian Gulf region. Various aspects, like, physicochemical aspects of marine water; sediment geochemistry and shell chemistry that are related to benthic Ostracoda from Indian and International regions are discussed in this chapter. A survey pertaining to these studies is reviewed briefly in the following pages.

2.2 INDIAN SUBCONTINENT

Honnappa (1983) gave an account of the Quaternary and Recent Ostracods from the east and west coasts of India. Later, Bhatia (1984) reviewed the reports on the Ostracod fauna of Lower Paleozoic to Quaternary sediments of the Indian subcontinent. This includes an account on the Recent Ostracoda from different beaches and a discussion on their paleozoogeographic and Paleo-ecologic implications. Hussain and Rajeswara Rao (1996) presented an account of Recent Indian marine Ostraocods and discussed their zoogeographic distribution and faunal affinity. Venkataraman and Mohideen Wafar (2005) studied all along the Indian (South and West) coast and recorded 38 species from the east coast and 28 species from the west coast.

The existing information on Recent Ostracoda, its taxonomy and ecology from southeastern coastal part of India is scanty. So far, only sporadic reports of research work have been carried out to bring out an understanding of the faunal diversity and their relationship of the Ostracod fauna to the substrate as well as other ecological parameters that are congenial for the population abundance in the shallow inner shelf regions.

The contribution pertaining to the study of Recent Ostracoda from the Indian subcontinent is given under two heads:

1. East coast of India, and
2. West coast of India.

2.2.1 Recent Ostracoda from the East coast of India

A noteworthy earliest contribution of the Ostracod study from the Indian subcontinent is that of Brady (1986), who studied the dredged samples from Calpentyn, Gulf of Mannar and reported 35 species of Ostracoda. Ratnam and Rao (1965) recorded three genera – *Perissocytheridea*, *Candona* and *Limnocythere* – from the Chilka Lake. Guha (1968) recorded 32 taxa from the Archipelago series, exposed in Interview and Guitar islands of the Andamans.

Maddocks (1969a, and 1969b) presented a report on the Ostracods from the Bengal coast and Andaman Island, obtained during the Indian Ocean Expedition. She (op. cit.) recorded a new species, *Propontocypris* (*Schedopontocypris*) *bengalensis*. This species occurs commonly all along the coasts of the Bay of Bengal and Arabian Sea. Gramman (1975) made a casual reference to some Indian Ostracod taxa. Jain (1976) illustrated and described six species from the Chilka Lake, Orissa. This included four new species, namely, *Kalingella mckenzieii*, *Loxoconcha tewarii*, *Phlyctenophora bhatiai* and *Keijella oertlii*.

Misra and Shrivastava (1979) recorded 25 species of Ostracoda from the bottom sediments collected from off the coast of Tuticorin. Rama Sarma (1979a, 1979b, 1981) and Annapurna (1981) reported new species recorded by them (op. cit.) include *Tanella indica* and *Bradleya ganapatii* which appears to be conspecific with *Tanella gracilis* and *Chrysocythere keiji*, respectively, from the Bimili-Balacheruvu tidal stream.

Annapurna and Rama Sarma (1982) presented a review of the distribution of Ostracoda in relation to sedimentological characteris such as sand-silt-clay percentages, organic matter content as well as bottom water parameters, like, temperature, dissolved oxygen and salinity in the Balacheruvu tidal stream and Bimili backwaters. From these areas, they later (1986) recorded 3 new species, namely *Leptocythere andhraensis*, *Tanella estuarii,* and *T. kingmai*. Subsequently, Varma *et al*., (1993) revised and opined that these species are conspecific to *Hemicytheridea andhraensis* and *T. gracilis,* respectively.

Annapurna and Rama Sarma (1987) further identified 40 species of Ostracoda belonging to 27 genera from these marginal marine environments. Bhatia (1991) pointed out many inconsistencies and incorrect interpretation made in the taxonomic description of some Ostracoda reported by Sreenivas *et al*., (1991) from Pulicat lake.

Hussain (1992) for the first time gave a detailed systematic account of 52 Ostracoda species along with their ecological studies, from the sediments of the Gulf of Mannar, off Tuticorin. He (op. cit.), after making a seasonal study of different environmental parameters and Ostracod population size analysed the distribution of the fauna in relation to ecological factors. Hussain *et al*., (1996a) presented the distribution of widespread Ostracods and subsequently, they (1996b) also discussed the faunal diversity of the Gulf of Mannar.

Hussain *et al*., (1998) reported two new species, namely, *Triebelina tutitcorensis* and *Hemicytheridea khoslai* from off Tuticorin. Varma *et al.*, (1993) recorded 25 ostracod taxa from the Tekkali creek, east coast of India, which included three new species *Hemicytheridea bhatiai*, *Loxoconcha tekkaliensis* and *Neomonoceratina jaini*. They (op. cit.) recorded *Neosinocythere dekrooni* and *Paijenborchella* (*Eopaijenborchella*) *malaiensis* for the first time from Indian waters.

Shyam Sundar *et al*., (1995) reported 33 species of Recent Ostracoda from Goguleru creek and the adjacent beaches of the east coast of India. These included 5 new species: *Copytus coromandalensis*, *Loxoconcha guhai*, *Neocytheromorpha goguleruensis*, *Paijenborchella keiji* and *Paradoxostoma bhatiai*. They (*op. cit.*) also recorded *Keijia* *demissa* for the first time from Indian waters. Sridhar *et al*., (1996) enumerated a detailed systematic account of 48 ostracod taxa and studied their ecology from the sediments of Palk Bay, off Rameswaram. Naidu *et al.*, (1997) presented the diversity and distribution of Recent Ostracoda from the shelf sediments off Pentakota and Kalingapatnam, near Visakhapatnam.

Kumar and Hussain (1997) reported for the first time 10 Ostracod species from Pitchavaram mangroves, Tamil Nadu. Sridhar *et al.*, (1998) studied the response of recent benthic Ostracoda with the inner shelf sediments from the Palk Bay, off Rameswaram, east coast of India. Hussain and Mohan (2000) have reported 26 species from the Adyar river estuary. Further, they inferred the fast rate of sedimentation in the estuary using the carapace valve ratio Hussain and Mohan (2001), Mohan *et al*., (2001) have identified 51 species and discussed the ecology of Ostracoda in the Bay of Bengal, off Karikkatukuppam. They reported four new species namely, *Hemitrachyleberis siddiquii*, *Puricythereis whatleyi*, *Neocythromorpha reticulata* and *Pterigocythereis chennaiensis*. They have also observed that the salinity, water depth and $CaCO_3$ content control the overall abundance and distribution of Ostracod population in this regions. Mohan *et al.*, (2002) has observed living and total population sizes found to be more during April than July which is attributed to the higher temperature, salinity and dissolved oxygen of the bottom waters.

Sridhar *et al.*, (2002) have illustrated 48 Ostracoda species from Palk Bay, off Rameswaram and studied their ecology and observed siltysand and sand are the favorable substrate for the forms to thrive in the sediments of Palk Bay, off Rameswaram. Further, they also recorded their species, namely, *Kotoracythere inconspicua*, *Neocytheretta snelli* and *Paradoxstoma subtile* for the first time in this region. Twenty-nine species have been diagnosed and illustrated from the sediments of Pichavaram mangroves along with its ecological conditions by Arul *et al*., (2003). Hussain *et al*., (2005) recorded 22 recent benthic Ostracod from Tamiraparani estuary, Southeast coast of India.

Hussain *et al.*, (2006) reported 74 genera of Foraminifera and 29 species belonging to 22 genera of Ostracoda from tsunamigenic sediments of Andaman island. Anil Bhandari and Singh (2006) recorded 24 Ostracoda species belonging to 14 genera from the Krishna river estuary and Gautami-Godavari estuary and discussed upon the frequency and diversity in the upper, lower estuaries.

Mohammed (2006) have identified 10 species belonging to 10 genera from the faunal assemblage in the Marakanam and Odinur estuaries and he (*op. cit.*) reported that the population of Ostracoda seems to be controlled by salinity. Sridhar *et al.,* (2007) discussed the ecology and zoogeography of *Kotoracythere inconspicua* from the Palk Bay, off Rameswaram, southeast coast of India. Hussain *et al*., (2007) investigated recent benthic Ostracoda and their environmental implication with its ecological factors (temperature, salinity and dissolved oxygen) that controls the total population and also reported that the Summer season (April) seems to have more population of Ostracoda in Andaman islands. Ganesan *et al.,* (2008) have presented the influence of environmental parameters on the distribution of Recent benthic Ostracod from Tamiraparani estuary and off Punnaikayal, Tamil Nadu, southeast coast of India. Hussain *et al*., (2009) discussed the biodiversity of Recent Ostracoda from the Bay of Bengal, off Karikattukupam near Chennai, southeast coast of India.

Elumalai *et al.,* (2010) reported systematic study of recent benthic Ostracoda for the first time in Ennore creek, north of Chennai. They (*op. cit.*) have reported 30 species belonging to 24 genera, 15 families, 2 super families and 2 suborders of Podocopida. Elakkiya (2012) have reported 17 species of recent Ostracoda belonging to 12 genera, 10 families, 3 super families and 2 suborders from Cauvery river estuary of Poombuhar region. Among the 17 species, only six species *Cytherelloidea leroyi, Paijenborchella sp, Stigmatocythere indica, Keijella reticulata, Loxoconcha sp.,* and *Phlyctenophora orientalis* are found to be wide spread and abundant.

Elakkiya *et al.,* (2013) investigated distribution of Foraminifera and Ostracoda from tsunami inundated area of Kameswaram in Nagapattinam, Tamil Nadu, Southeast coast of India. They (op. cit.) identified 7 species, and among them 4 are Foraminifera and 3 are Ostracoda, namely, *Ammonia beccarii, Globigerina bulloides, Quinqueloculina sp., Spiroloculina orbis* are Foraminifera and *Propontocypris bengalensis, Propontocypris* *crocata* and *Phlyctenophora orientalis* are Ostracoda. These species might have been brought to the shore by the high energy tsunami waves, which might be a 2004 tsunami deposit. Hussain *et al.,* (2013) studied in Velanganni region southeast coast of India and identified 7 species, of which 4 are Foraminifera, namely, *Quinqueloculina lamarckiana, Quinqueloculina seminulum, Ammonia beccarii, Elphidium norvangi* and 3 are Ostracoda, namely, *Tanella gracilis*, *Neomonoceratina iniqua* and *Caudites javana*.

2.2.2 Recent Ostracoda from the West coast of India

During the Indian Ocean Expedition, Maddocks (1996a, 1996b) dealt with Ostracod taxa from the recent sediments of Cochin and Mangalore coasts. Four species of pelagic Ostracoda were recorded by James (1973a, 1973b) from off Kerala coast. Honnappa (1975) presented the morphology, taxonomy and a statistical account of *Actinocythereis tumefacentis* (Lubimova and Guha) from the Mangalore harbour area. Detailed studies were carried out by Jain (1978), who described and illustrated 56 taxa from the beach sands of Mandvi Beach of Kutch in Gujarat State. This includes a new genus, *Vijaiella*, a new subgenus, *Carinocythereis* (*Tandonella*), as well as sixteen new species. Later, he (1981) had documented 34 species from the beach sands of Kerala.

Honnappa and Venkatachalapathy (1978) dealt with pyritisation and color variation observed in the Ostracod carapaces recovered from Mangalore beach. In the subsequent year (1979), they made a mention of predation noticed on the shells of *Leguminocythereis*. Bhatia and Kumar (1979) recorded 13 Ostracoda species, including a new genus, *Jainella* and one subgenus, *Neohenryhowella*, from the vicinity of Karwar area, in Anjadiv island. Eighteen species of Recent Ostracoda, belonging to four families, were listed by Guha (1980) from the sea bed samples of Bombay and Ratnagiri.

From the beach sediments of Nalgaon and Adgram (Maharashtra), Tapaswi (1980) recorded 12 species. Though Khosla *et al*., (1982) reported 58 taxa from the sediment of Miani Lagoon; many species were kept under open nomenclature. Four species belonging to *Bairdiidae* and 21 species (including six new forms) have been reported from the coastal sediments of Bhatkal and Karwar areas by Honnappa and Abrar (1983), but a through taxonomy and morphology revision is essential.

Honnappa *et al*., (1984) described one new genus *Neomangaloria*, from the Mangalore-Karwar coastal sediments and this is undoubtedly a junior synonym of *Phlyctenophora*. *Actinocytheris tumefacentis* recorded by Honnappa (1975) from the same area and has been considered conspecific with *Henryhowella* (*Neohenryhowella*) *hartmanni*, by Bhatia and Kumar (1979). Vaidya (1993) described and figured 80 Ostracoda species from around Karwar, out of which 19 are new.

Vaidya *et al*., (1995) studied the relationship between the bottom sediments and recent benthic Ostracoda from Karwar. Rajesh Raghunath *et al*., (1999) have reported 21 Ostracod species belonging to 17 genera from the inner shelf off Kasargod, west coast of India. Gopalakrishna *et al*., (2007) have reported 61 species belonging to 48 genera from the inner shelf of Malabar Coast, Kerala, south west coast of India, and among these, *Leptocythere pulchra* is recorded the first time in the Indian waters. *Hemitrachyleberis siddiquii* and *Neocytheromorpha reticulata* are recorded for the first time from the west coast of India.

Gopalakrishna *et al*., (2008) have identified 61species from 76 sediment samples, (28 near shore and 48 offshore locations) off Malabar coast, Kerala. From Q-mode cluster analysis, they (op. cit.) have described the Ostracod faunal assemblages together with the details of physical and ecological parameters and suggested that the controlling factors are substrate, organic matter and salinity; and temperature does not have a significant role in the distribution and diversity.

2.3 SEDIMENTOLOGICAL AND HYDROGRAPHIC STUDIES

Many micro-palaeontologists have attempted to evaluate the nature of sea bottom sediments of different localities on the east coast of India, on the basis of particle size, calcium carbonate and organic matter content. Some analysis have also been made for the waters of the Bay of Bengal to determine the same reveals that many of these studies are within the depth of 50 m. However, no much work has been done on sediments and waters of shallower depths.

The foremost work is that of Sewell (1952), who studied the nature of seabed as well as deep-sea deposit of the Andaman Sea and Bay of Bengal. Jayaraman (1951, 1954) analysed the chemistry of seawaters off Chennai and off Mandapam, respectively. The seasonal cycle of sea surface temperature and salinity along the east coast of India was reported by Lafond (1954).

Subba Rao (1956) gave an account of sedimentary environments off Kalingapatnam-Gopalpur coast, on the basis of coarse fraction studies. Raghu Prasad (1957) gave an account of the seasonal variations observed in the surface temperature of seawater near Mandapam, from January 1950 to December 1954. Subba Rao and Mahadevan (1957) presented an account of the distribution of $CaCO_3$ in the sediment of Visakhapatnam, in relation to distance from the coast, configuration of shelf and silt-clayey material of the sediments.

Subba Rao (1958, 1960) made a detailed study on the calcium carbonate and organic matter contents of the shelf sediments of the Bay of Bengal, north of Chennai. He (*op. cit.*) inferred that the sediments from less than 20 fathoms (36 m) depth are generally have poor calcium carbonate content and that the fine-grained sediments show higher values of organic matter content than the coarse-grained ones. Subba Rao (1958) and Rao (1969) have reported calcium carbonate content in certain parts of the eastern continental shelf of India.

Viswanathan (1959) observed seasonal variations from 1950 to 1954 for salinity, dissolved oxygen and nutrient at two inshore stations in Gulf of Mannar and Palk Bay. Several workers have worked on the continental shelf sediments of Visakhapatnam (Subba Rao, 1964; Venkataratnam, 1968; Rao *et al*., 1980; Murthy *et al*., 1987 and Murthy, 1989). Further, several workers have focused on the chemical (Ramaraju *et al*., 1987; Sarma *et al*., 1982; Ganapathi and Raman, 1979) and geochemical (Satyanarayana *et al*., 1985) studies of the Visakhapatnam harbor and coastal environment. Subba Rao (1962) infered that the sediments of Visakhapatnam and from Puri to Port Nova (Mohapatra *et al*., 1992) are sandy near the shore and fine seaward becoming clayey-silt or silty-clay.

The textural characteristics and clay mineralogy of shelf sediments of Visakhapatnam were reported by Murthy (1994), opined that molluscan shells, shell fragments and Foraminifera control the distribution of calcium carbonate in these sediments. An investigation of different physicochemical factors of the seawater of Chennai was made by Muthu (1965). Freda Chandrasekaran *et al*., (1968) made a study on the surface waters over the pearl and "chunk" beds off Tuticorin, for a period of 5 years.

An account of the calcium carbonate content and the texture of shelf sediments of Chennai as well as Karaikal coast were presented by Madhusudhana Rao and Murthy (1968). Out of 21 samples drawn from the continental shelf, they made a study of only 4 samples from depths of less than 29 m, two each from off Chennai and Karikkal. On the basis of their study, they (*op. cit.*) found that the calcium carbonate content showed a steady increase with increasing depth. Ramanathan (1969), while dealing with Foraminiferal assemblages from the Vellar estuary sediments, gave an account of the nature of the substrate and the micro-faunal variations. Rasheed and Ragothaman (1978) presented a detailed account of sediment, water parameters and ecology of Foraminifera from off Porto Novo. Reddy and Reddy (1981) dealt with seasonal variation observed in the size distribution of assemblages of sediments in Pulicat estuary. Setty and Nigam (1982) reported the Foraminiferal assemblages found in sediments and their relation to organic carbon in selected near-shore areas from the Gulf of Kutch, Bombay-Damon sector and Karwar area of the west coast of India.

Ramanathan *et al*., (1988) analyzed major and minor element geochemistry of water and suspended and bed sediments collected from the upper reaches of Cauvery estuary to understand the geochemical processes in the tropical eastern system. The investigation of characteristics of the sediments from a core collected from the Gulf of Mannar revealed high concentrations of $CaCO_3$ (61.4%) and low organic carbon values, distinctly different from the anoxic sediments of Bombay (Ray *et al*., 1990).

Hussain (1992) dealt with sediment and bottom water parameters from off Tuticorin in relation with the Ostracod population and distribution, which is considered to be the first of its kind in India. Subsequently, Vaidya (1993) made an attempt to discuss the relationship of the Ostracod fauna with the sediments from around Karwar, west coast of India. Rao and Sara (1993) collected 75 sediments samples of the coast between Bhimunipatnam-Amalapuram, central east coast of India and an overall analysis revealed that the geochemistry of sediments of the Bay of Bengal controls their texture.

Raman (1995) made a detailed study spread over more than a couple of decades of the physico-chemical characteristics of the Visakhapatnam harbor and revealed that during the past two decades the environmental conditions have been affected and the harbor is also subjected to a high degree of pollution caused by industrial and urban wastes. Purnachandra Rao *et al*., (1988) studied the clay minerals and the influence of source rock and fluvial input on the shelf sediment of the east coast of India. Rosenberg (2001) reported benthic shelf bottom animal activity in the sediment due to in-faunal presence.

2.4 RECENT MARINE OSTRACODA FROM INTERNATIONAL WATERS

Many published records are available on the recent Ostracod morphology, taxonomy and ecology from different localities of the world. A brief review of the same is presented under the following headings:

1. Recent Ostracoda from the Atlantic region
2. Recent Ostracoda from the Pacific and Indo-Pacific regions and
3. Recent Ostracoda from Arabian Sea

2.4.1 Recent Ostracoda from the Atlantic region

Amongst the work carried out on Ostracoda during the 20th century, the studies made by Elofson (1941) and Remane (1993) are considered to be significant. They gave a good report of the systematics and ecology of Ostracoda inhabiting shallow marine waters of the North and Baltic seas. Elfson (*op. cit.*) is one of the most significant ecological workers of Ostracoda. This is because Elofson made the initiative and opened the era of investigating the ecology of Ostracoda by studying environmental indicators in recent and sub-recent estuarine deposits of the Netherlands (Wagner, 1957). Puri (1960) studied recent Ostracoda from the west coast of Florida and recorded 70 species, which included many new taxa. Besides, his work, the ecology of recent marine Ostracod is considered to be one of the noteworthy monographic contributions and is widely used by Ostracodologists even today.

Kornicker (1961, 1969) presented the taxonomy and ecology of *Bairdia* and *Cytherelloidea* species around Bahama region and reported some new species under both genera. Puri *et al*., (1964) while dealing with the ecology of Ostracoda from the Gulf of Naples, pointed out that among the various environmental parameters depths, substrate and salinity appear to control the distribution. However, according to them, no single factor seems to be responsible for the distribution of forms. A seasonal study of recent Ostracoda of the Redfish Bay, Texas, was made by Korniker (1965). Engel and Swain (1967) discussed the environmental relationship of Ostracod from Mesquite, Arkansas and Capano Bays.

From the estuary to the Gulf, in the coastal Mississippi area, Krutak (1975) found that the living population of Ostracoda decreases from the former to the latter. White (1993) presented a detailed account of the taxonomy and biogeography of 59 Ostracod taxa from West African beach sediments. Thirteen Ostracod species from the Cape Verde Islands, Atlantic Ocean have been identified by Wouters (2003) and he observed *Keijia demissa*, *Kotoracythere inconspicua* are widely distributed in the tropical zone based on their zoogeographic study.

Alvarez Zarikian *et al*., (2009) investigated the variability of benthic Ostracoda assemblages in relation to ice-rafting episodes and changes in ocean circulation and deep ocean environmental condition over the past 170 ky at IODP site U1314 in the sub-polar North Atlantic. A diverse, more than 75 species and ecologically wide range of Ostracod taxa including all major deep sea North Atlantic (*Krithe*, *Cytheropetron*, *Henryhowella*, *Pennyella, Legitimocythereis, Pseudobosquetina, Pelecocythere, Ambocythere and Dutoitella),* and subarctic and Arctic genera (*Polycope, Cluthia, Elofsonella, Finmarchinella* and *Heterocyprideis*) were recognized. Coimba and Carreno (2012) recorded 21 Ostracoda species from Trindade island and 23 species from Rocas Atoll. The correlative fauna show low richness and low abundance compared with other oceanic islands. They (op. cit.) described the tropical species such as *Kotoracythere inconspicua* (Brady) and *Triebelina sertata* Triebel.

2.4.2 Recent Ostracoda from the Pacific and Indo-Pacific region

Kingma (1948) presented an important contribution to the knowledge of Cenozoic Ostracoda from the Malay region. He recorded 97 taxa, which included 47 new species and 6 new genera, namely, *Atjehella*, *Hemicytheridea*, *Javanella*, *Neomonoceratina*, *Paijenborchella* and *Tanella*. Benson's (1959) work on Ostracoda from the Todos Santos Bay region, Baja California, is one of the significant contributions on Ostracod ecology. Hartman (1964) is credited for his excellent taxonomic and ecological work on the recent Ostracoda from the Red Sea. Further, his (1978) work on Ostracoda from tropical and sub-tropical waters of Australia are much essential for any Indo-Pacific Ostracod studies.

Keiji (1964) reported thirteen species of *Cytherelloidae* from northwestern Borneo, of which eight were new. Benson (1966), in his article on Recent *Podocopid* Ostracoda, discussed the last 100 years of study on this group, their historical development and their importance in paleontological studies. Maddocks (1966) presented the distribution patterns of *Podocopid* Ostracoda recovered from Nosy Be area of Madagascar. McKenzie and Swain (1967) gave an account of recent Ostracoda of the Acammon Lagoon, Baja California.

Maddocks (1966b) revised many species referred to *Bairdiidae* earlier and proposed two new genera, *Neonesidea* and *Paranesidea* along with *Bairdopillata* and *Triebelina*, to accommodate many taxa which represented *Bairdian* family. Swain and Gilby (1974) reported the occurrence of 80 species of Ostracoda from the Pacific coast of North and Central America, which included 4 new genera and 16 new species. The contributions of Hartmann (1982) are worth mentioning for the studies on the zoogeography and biology of littoral Ostracoda from South Africa, Angola and Mozambique. With regard to the Indo-West Pacific region, mention should be made of the comprehensive work by Whatley and

Quanhong (1988, 1989) who recorded 129 taxa from the Malacca straits, among which 22 species and 2 genera (*Bythocytheropetron* and *Alataconcha*) were new.

Zhao and Whatley (1989a) reported 101 taxa of *Podocopid* Ostracoda in the Sedili river and Jason Bay of the south-eastern Malay Peninsula. Besides, they (1989b) also revised some of the earlier work of Brady (1869) and Kingma (1948). Zaho and Whatley (1988) studied 14 species of *Neomonoceratina* from the west Pacific region. In a monographic work, "*Bairdian* dynasty", Malz (1988) discussed in detail the historical development of the *Bairdian* group since the Carboniferous.

Howe and Mckenzie (1989) recorded 130 species in Darwin and Northwestern Australia. A detailed account of the Ostracoda species from the seas of China and Japan has been dealt by various Chinese and Japanese Ostracodologists (Wang and Zhao, 1985; Zhao *et al*., 1985; Zhao, 1987; Ishizaki, 1968, 1971; Ishizaki and Gunther, 1974). Zhao and Whatley (1989b) made a revision of the different new species established by Kingmai (1948). Bonaduce *et al*., (1975) described and illustrated 246 species of Ostracoda including two new genera *Typhlocythere* and *Loxoconchidea* that were erected from the Gulf of Aqaba, Red sea. Bonaduce *et al*., (1976) studied 52 species from the Gulf of Aqaba, Red Sea. They established four new genera.

Titterton and Whatley (1988a, 1988b) described 21 taxa belonging to *Bairdiinae* from the Solomon island, of which 13 were recorded as new. They also discussed the origin, migration history and distribution of Indo-Pacific shallow water Ostracoda fauna ever since the closure of Tethys, which is an interesting piece of work. Mostafawi (1992) identified 116 species from the Sunda shelf between the Maly Peninsula and Borneo of which, 23 species, one sub-species and four genera, namely, *Spinoceratina*, *Borneocythere*, *Venericythere* and *Heinzmalzina* are described as new. Wouters (1997) have identified a new genus namely *Peripontocypris* and two new species from the Maldive islands, Papua New Guinea and from Easter island. He (1999) further reported two new species of the genus *Phlyctenophora*, namely, *P. mesembria* and *P. polygona* from Cape Range, Australia and Sulawesi, Indonesia, respectively.

Eager (1998) studied the recent benthic Ostracoda from Tarawa atoll, Kiribati, Pacific Ocean and discussed upon the decrease in the number of species reflecting sea level changes and the effects of the construction of causeways linking the islets of the atoll. Subsequently, he (1999) has identified 24 species of Ostracoda from Tarawa Atoll and 15 species from Kuria island. He (op. cit.) observed that the Kuria island forms showed coarser texture shell ornamentation than the Tarawa and this may be due to a small number of specimens colonized the new locality and having a limited gene pool. Eager and Geoffrey Read (2004) have reported a new species *Pontocypria omaha* that occurred as a parasite or live in association with a polychaete *Chaetopterus* sp. from Hauraki Gulf, New Zealand.

Titterton *et al*., (2001) reviewed fifteen key species of Recent Ostracoda (all but one from Indo-Pacific waters), selected for the collection of G.S. Brady and deposited in the Hancock Museum, Newcastle upon Tyne and The Natural History Museum, London. Holotypes and lectotypes have been formally designated and illustrated by SEM in the case of seven of these species: *Neonesidea crosskeiana* (Brady, 1866), *Neocyprideis decora* (Brady, 1866), *Pontocypris attenuata* (Brady, 1868), *Neocyprideis spinolusa* (Brady, 1868), *Keijia demissa* (Brady, 1868), *Cytherella semitalis* (Brady, 1868).

Gengo Tanaka *et al.,* (2009) reported two new species, namely, *Loxoconcha vietnamensis* and *Caudities huyeni*. Totally, 75 species have been reported with systematic studies and biographical significance of the euryhaline species of recent Ostracoda from 15 recent surface sediments and it is from the northeastern coast of Vietnam, a part of Indo-chinese peninsula and faces of south China sea. Ferda Percin Pacal (2011) recorded 56 Ostracoda from 28 stations from Iskenderun Bay in eastern Mediterranean Sea. Nine species occur abundantly in the study area namely, *Costa edwardsii*, *Cytheridea neapolitana*, *Cyprideis torosa*, *Loculicytheretta pavonia*, *Loxoconcha agilis*, *Loxoconcha rubritincta*, *Pontocythere elongata*, *Pontocythere turbida,* and *Xestoleberis communis*.

2.4.3 Recent Ostracoda from the Arabian sea region

An Ostracoda assemblage from the Abu Dhabi lagoon, Persian Gulf, was recognized by Bate in 1971. Paik (1977) reported 52 species from the Gulf of Persia, Oman. Al Abdul

Razaaq *et al.,* (1982) presented the distribution and ecology of Ostracod fauna recovered from Sulaibikhat Bay, a shallow warm tide-dominated embayment. A seasonal ecological response of microzooplankton in the southern Arabian Sea is presented. *Copepods* formed the most dominant, followed by *Chaetognaths, Ostracoda* and *Siphonophores* in which *Copepods* formed the most dominant group in the total abundance in the inshore waters compared to the offshore. During the Peak summer monsoon (PSM), the abundance of *Copepods, Chaetognaths, Ostracod, Siphonophores* and *Euphausids* were higher than Onset summer monsoon. The increase of the abundance of these groups during PSM was more pronounced in the inshore waters compared offshore. The highest abundance of *Copepods, Chaetognaths* and *Siphonopores* were recorded in the inshore location of 10˚ N followed by 11.5˚ and 8˚ N during PSM.

Mostafawi (2003) identified 50 species in the Persian Gulf, in which 7 are new taxa, namely, 1) *Aglaiocypris pellucida*, 2) *Cinderella bigemina*, 3) *Cinderella retroflexa*, 4) *Cytherellasericea*, 5) *Heinzmalzina ocellata*, 6) *Paijenborchella calcarina* and 7) *Stigmatocythere nupta*. Compared to a previous sampling in 1965, eight additional Ostracod species occurred in the modern Persian Gulf. Ecological factors were water depth and substrate that control the distribution of some Ostracod species. Contrary to previous statements, none of the recorded species in this study are shared with the Mediterranean fauna, except for the cosmopolitan species, namely, *Cyprideis torosa*.

Ramlan and Noraswana (2009) reported 1231 specimens belonging to 12 families, 25 genera and 31 species. *Trachyleberididae* was most dominant family with 329 specimens, the most dominant species were *Pistocythereis braddyi* with 198 specimens. Ecological parameters, physicochemical, hydrographical and sediment characters were the controlling factors in Pahang island in Malaysia. Abundance and diversity is most related to the character of the sediment. Mostafawi *et al.,* (2010) reported 83 species belonging to 54 genera and their bio-geographic distribution have been discussed with taxonomy. Nine species were newly identified and eleven species left in open nomenclature, reported from the Gulf of Oman, Northern Arabian Sea. Meshelp (2012) recorded twenty six species of marine and non-marine Ostracoda from the Al-Faw town, south of Iraq region, including twelve taxa that were recorded first time. There are three eco-facies proposed depending on the salinity which is controlling the distribution of Ostracoda. The species are influenced by freshwater; there is a decrease in salinity of freshwater fed by rivers as well as species indicate a saline water covered region belonging to Al-Hammar formation because of transgression in mid-Holocene and fluctuation of the sea level during this period.

Mohammed *et al.,* (2012) reported 64 species belonging 45 genera from Aden City, Yemen. They have identified one new genus, *Microhoweina*, and erected five new species, namely, *Corallicythere adenensis, Cytherella brettingi, Microhoweina elongata, Neocytheromorpha tawahinsis and Paracytheroma abyanensis*. The fauna show a close similarity to other Ostracod assemblages of the Indo-Pacific, East West African coasts and Red sea regions. *Tanella gracilis* (Kingma 1948) and *Kotoracythere inconspicua* (Brady 1880) are found to be abundant. Tsourou (2012) have reported 51 species belonging to 34 genera comparing the Ostracod assemblages from different biotopes. It is clear that although many species can be found in different substrate, they show a certain preference to one type of substrate where they occur in higher numbers. Accordingly, many species present wide bathymetrical distribution, but they occur in higher numbers in a restricted depth range, from central Aegean sea, southeast Andros island, Greece.

2.5 PHYSICO-CHEMICAL STUDY WITH OSTRACODA

Ostracoda are environmentally sensitive organisms which readily preserve as fossils because of their calcitic shells. Ostracod occurrence appears to be controlled by hydrochemical parameters such as water composition and salinity and also by the seasonal variability of water temperature (De Deckker and Forester, 1988). The chemistry of sea water in Mandapam areas have been described by Jayaraman (1954) on the basis of observation during 1950-1953, the data related to seasonal variation in salinity, dissolved oxygen and nutrient salts at two inshore stations in Gulf of Mannar and Palk Bay. The origin, distribution and rate of utilization of these inorganic components have become an important area of scientific research in coastal areas in the last few decades. The studies related to physico-chemical parameters with Ostracoda are briefed in the succeeding paragraphs.

2.5.1 National

Viswanathan (1959) reported some of the chemical and biological characteristics of seawater off Mandapam to analyze their trends and he (op.cit) found that the salininty and dissolved oxygen were lower in Palk Bay than in the Gulf of Mannar. Studies on the effect of various industrial effluents on Damodar river Ecosystem, West Bengal was undertaken by Ghatak and Konar (1992). The Physico-chemical and biological characteristics of Damodar River water, West Bengal in India was found gradually changed due to the toxic effects of various industrial effluents. The concentrations of DO, Alkalinity, Phosphate and hardness of river water were significantly decreased, at various sampling stations. This also resulted in a reduction of planktonic population (both Zooplankton and Phytoplankton) and also bottom organisms significantly.

Karuppanapandian *et al.*, (2007) reported coral bleaching when the temperature goes beyond the optimum level in Palk Bay, Mandapam region. They (op. cit) also reported that sewage and other effluents cause destruction of marine organisms particularly coral reefs, and fishes. Prabu *et al*., (2008) studied seasonal variation of physicochemical parameters in Pichavaram mangroves, of Tamil Nadu. Hulyal and Kaliwal (2008) reported monthly and seasonal variation in the population during 2 years and are presented four different groups namely, *Cladocera, Copepoda, Ostracoda* and *Rotifera* representing zooplankton community, and they (op. cit) found that the Ostracoda were abundant during winter and their population decreases during monsoon seasons in Almatti Reservoir Bijapur, Karnataka in India.

Satpathy *et al*., (2010) reported seasonal variation in physicochemical parameters and the impact of tsunami and its adverse effect on the primary productivity of coastal environ at Kalpakkam. Govindaraju *et al.*, (2011) reported that the sewage effluents affect the quality of sea water as well as flora and faunal off Kudankulam and they (op. cit) also found that the increasing rate of sedimentation affects the coral reef ecosystem. Sankar *et al*., (2010) studied the seasonal variation of physicochemical parameters in water samples, and found that the parameters are useful tool for further ecological assessment and monitoring of these coastal ecosystems in Uppanar estuary, Nagapattinam, India.

Satpathy *et al*., (2011), observed seasonal water quality, hydrographic parameters and physicochemical properties of coastal waters with micro-organism (Chlorophyll-*a*) from off Kalpakkam for different seasons, namely, summer, pre-monsoon and post-monsoon. Koli and Muley (2012) studied the Zooplankton diversity and seasonal variation with physico-chemical parameters in Kolhapur district in Maharashtra, west coast of India and reported 39 species of zooplanktons, of which 15 were *Rotifer*, 12 were *Copepod*, 10 were *Cladocera* and 2 were *Ostracoda*. In this study, the population of zooplanktons were correlated with the physico-chemical parameters like atmospheric temperature, water temperature, turbidity, pH, dissolved oxygen, salinity, total dissolved solids, chlorides, hardness, biological oxygen demand and the plant nutrients like, phosphates and nitrates.

Shah and Pandit (2013) reported that the diversity and distribution of Crustaceans in the Wular lake are controlled by a combination of parameters like, temperature, depth, pH and alkalinity. Gomathy *et al*., 2013 reported the physicochemical characters, like, dissolved oxygen, level of carbondioxide, chloride, salinity, bicarbonate alkalinity, carbonate alkalinity, total hardness and calcium hardness of groundwater adjoining the coastal tracts of Rameswaram where the holy waters (theertham) are available in the Ramanathar temple in different location on shore. Agni theertham shows a very low level of dissloved oxygen, Free CO_2 and Carbonate alkalinity but are not found to be present in Nala and Agni theerthams. High values of CO_2 and Bicarbonate alkalinity are found in Savithri, Gayathri and Saraswathi theerthams.

2.5.2 International

Supporting the life processes in marine coastal ecosystems require many inorganic substances. Nitrogen, phosphorous and silicon are considered to be more important than others, as they play a key role in phytoplankton abundance, growth and metabolism (Raymont, 1980; Grant and Gross, 1996). Though maximum rates of bio-erosion may have been lower during the Paleozoic, we can assume that, as in modern reefs, bio erosion rates were functions of availability of food resources (James and Macintyre, 1985). Bhasker *et al*., 2003 reported the physicochemical and bacteriological parameters on certain locations of the river Torsa in Bhutan and reported that the water was highly alkaline with high concentration of free ammonia.

Kulkoyluoglu *et al*., (2010) reported 9 living and 5 sub fossil of Ostracoda taxa and among the species, *Ilyocypris getica* was reported in Turkey for the first time, while *Stenocypria fischeri* was found for the second time in the country in 55 years. The most abundant species, *Limnocythere inopinata*, was collected in dry and wet months, *I. bradyi* recorded during the wet months only. Hallock and Schlager (2013) reported worldwide coral reefs ecosystem that are adapted to the nutrient deficient waters of tropical and subtropical shallow shelves and oceanic islands. Increased nutrient input reduces water transparency and disrupts the hermatypic reef community, resulting in diminished rates of carbonate production and increased rates of bioerosion. However, the solution to the mystery of carbonate platform drowning in the geologic record related to the sensitivity of the hermatypic organisms to nutrient enrichment of their environments.

2.6 SEDIMENT GEOCHEMISTRY AND OSTRACODA

The studies on the distribution and seasonal variations of metals in the sediment are important to decipher the source, to evaluate their enrichment pattern and to assess any probable localized influence. These leads to better understanding of their behavior in an aquatic environment, and sediment characters also help to detect the source of the pollution as reported by Pekey (2006); Buccolieri *et al*., (2006); Satpathy *et al*., (2011). Ruiz *et al*., (2013) from fresh and marine water.

2.6.1 National

Vanmathi (1995), found that the heavy metals, especially Cadmium, are significantly higher than other coastal regions, affecting the biota in the sediments off Tuticorin coast. Jonathan *et al*., (2004) suggested long-term perturbations and proper wastewater treatment to be undertaken by the concerned industries not only to prevent further degradation but also to restore the quality of the marine ecosystem of the Gulf of Mannar, in India, as the contamination is not under severe stress. By comparing the hydrological parameters, Bindu *et al*., (2007) found that the concentration of trace metals are due to anthropogenic activities in Palk Bay and Gulf of Mannar.

Krishna kumar *et al*., (2010) analyzed the metals, like Fe, As, Cd, Co, Cr, Cu, Mn, Ni, Pb and Zn accumulation in coral and concluded that the coral reefs are damaged by anthropogenic activities in Gulf of Mannar. Sundararajan and Srinivasalu (2010) found that Calcium carbonate and organic matter controlled the calcium oxide concentrion due to detritial constituents in Gulf of Mannnar. Paimpillil *et al*., 2010 reported from all over the east coast of India, observed enrichment of trace metals in water and in zooplankton at the open ocean stations are linked to bioaccumulation and biological concentration factor and metal contents in zooplankton is appreciably varied for all elements except for iron and zinc. From its findings clearly indicates the importance of bioavailability of metals in seawater and to the relative enrichment of heavy metal accumulation by planktonic species.

Yogesh kumar and Geetha (2012) investigated the trace metal accumulation of coral and reef environment in sediment and water of the Gulf of Mannar Biosphere Reserve, off Tuticorin. The concentration of trace metal in the water is in the order of Fe > Pb > Zn > As > Mn > Cd > Cu and in sediments it is in the order of Fe > Mn > Pb > Zn > Cu > Cd and in coral rubbles it is in the order of Fe > Mn > Pb > Zn > Cu > Cd. From this study, they (op. cit.) concluded that the Tuticorin group of islands were little higher than the Vembar group of islands, and it might be due to discharges pumped from the industrial belt of Tuticorin, domestic sewages from Tuticorin town, harbor activities and thermal power plant operation along the southern side of the Gulf of Mannar. Veerasingam *et al.*, (2013) found that the trace metals in the surface sediment are of low level and their adverse effects are rare in Adyar estuary, the Bay of Bengal.

2.6.2 International

Bodergat (1978, 1998) reported from Bouch-du-Rhone, Marseille in France and concluded that the Cerium in *Aurila apeyeri*, is from the nearby fire proof industries sewers. He (op. cit. 1983, 1991) had reported Cl and Fe in *Cyprideis torosa* are due to chlorine rich industrial sewage from brackish water region of Camargue in South Eastern France and

Alicante in South Eastern Spain. Reyment (1996) reported that the chemical composition of the Ostracod shell depends possibly on urban pollution, based on the single species valve *Leptocythere psammophyla* in southeast France in southeast Spain marine environment. Rio *et al*., (1997) reported the anisotropic fixing of elements in the carapace before or during molting of *Leptocythere psammophila* and the distribution of elements, namely, Si-Al-Fe-Ca-Mg-Na-Mn-Ba-Sr-P-S-Cl are controlled by metabolism and passive trapping in a marine environment of Baltic Sea, North Sea and English Sea.

Debenay *et al*., (2001) investigated the changes of assemblages of Ostracoda and benthic Foraminifera are due to different sources of pollution in the Joinville Harbour, France (Atlantic coast). Ruiz *et al*., (2005) reviewed Ostracod responses to pollution-induced environmental changes by anthropogenic impacts world wide. They (op. cit.) concluded that in addition to popultion and community changes, morphological and geochemical changes can also be detected in the Ostracod carapace, that serves as a tracer of the water quality during the moulting processes.

Riyadi *et al*., (2012) reported spatial temporal variation of trace element contamination in the Jakartha Bay by analyzing 19 surface sediment samples and concluded that the Zn, Cu and Pb enrichment agrees the Geo-accumulation index, which reflects the degree of anthropogenic contamination of the metals in the sediments. Ruiz *et al*., (2013) reported the correlation of water properties with both external ornamentation and geochemical composition of Ostracoda and they (op. cit) metnioned that the worldwide freshwater Ostracod are excellent bio-indicators with a remarkable response to variable, like, salinities, water depth, temperature ranges and pH.

2.7 SHELL CHEMISTRY OF OSTRACODA

The Ostracod shell is a source of four geochemical parameters (Mg, Ca, Sr and Ca) with the potential to provide environmental information (De Deckker and Forester, 1988). Shell geochemistry offers a mean of testing Ostracod environmental interpretation and in many cases a means of refining those interpretations (Nevio Pugliese *et al*., 2006). The Ostracod are mainly calcareous (calcite) and composed of Ca, C, O, with minor Mg apart from other elements depending upon the environment. In some cases, the presence of amorphous calcium carbonate is reported (Xia *et al.*, 1997). The following Indian and International researchers have done research related to shell chemistry in various localities of Indian and International water bodies.

2.7.1 National

Holmes *et al.,* (1992) reported trace element chemistry of non-marine Ostracod as a mean of palaeontological reconstruction. He (op. cit.) had reconstructed the palaeoenvironment of the quaternary of Kashmir, northern India by determining salinity using Sr/Ca in *Ilyocypris* and concluded a little change of salinity; small varition in the temperature of the lake water.

2.7.2 International

Bodergat *et al*., (1993) stated specifically that they could find no statistically significant differences between the chemical composition of the carapaces from the three stations (Kieler Forde, Baltic sea; Sahlenburg, Northsea; Roscoff, Britan in English Channel). The plot of the log-ratio canonical variate scores yields an almost perfect subdivision into three mutually exclusive groups, one for each of the sampling localities. Hence, there are significant chemical differences between each of these sites.

Roca and Wansard, (1997) reported the fossil occurence of *Herpetocypris brevicaudata* and its use in paleoenvironmental reconstructions as a potential indicator of water temperature and concluded that the time required to calcify the Ostracoda is also longer when it is below the threshhold. Palacios-Fest *et al*., (2002) reported the utilization of the seasonal variation in the shell chemistry of *Limnocythere* by inferring the temperature records and concluded that the *Limnocythere* may be produce more than one generation within a year. Ito *et al*., (2003) reported the stable isotope values and cation ratios (Mg/Ca and Sr/Ca) as well as the species assemblage of Ostracod. Carapaces provide powerful tool for the reconstruction of paleo-climate and paleohydrology, in particular, the changes in Mg/Ca and Sr/Ca of well calcified Ostracod shells record the qualitative changes in solute composition and when the dissolved Mg/Ca remains relatively constant, the Mg/Ca in the Ostracod shell is proportional to water temperature.

Vaan *et al*., (2004) reported the population, ecology and shell chemistry of *Loxoconcha matagordensis* Swain, 1955 from three different locations, namely, Demeron marsh, York river and Chesapeake Bay in United States. They (op. cit) studied the shell chemistry of *Loxoconcha* during different seasons, particularly, the parameter like, temperature that affects several physiological process of Ostracod, influence of breeding in the phytal Ostracod collected from Zostera marina seagrass beds in the Chesapeake Bay. The lack of an obvious correlation between Mg/Ca and Sr/Ca ratios in the fossil *Loxoconcha sp*. indicate "vital" effects between the two species in terms of Sr substitution during calcification, different seasonal ecology, or unknown hydrological factors.

Cronin *et al*., (2005) studied the seasonal ecology and shell chemistry of the Ostracod, *Loxoconcha matagordensis,* an island related species of *Loxoconcha*, from regions of eastern North America. It reveals that the shell size and trace elements (Mg/Ca ratio) are useful in palaeothermometry using fossil populations. Seasonal sampling of populations from Chesapeake Bay, augmented by samples from Florida Bay, indicate that the shell size is inversely proportional to water temperature and the Mg/Ca ratios are positively correlated with the water temperature in which the adult carapace was secreted. Microprobe analyses of sectioned valves reveal intra-shell variability in Mg/Ca ratios but, this does not strongly influence the utility of whole shell Mg/Ca analyses for paleoclimate application.

Strasser *et al*., (2008) studied the chemical composition of bivalve shells that can reflect the environment, making them useful indicators of climate, pollution, and ecosystem changes. This study examined the effects of bivalve shell growth rate and age on the incorporation of elements into juvenile soft shell clams of *Mya arenaria*, and its growth rate siginificantly correlated negatively with elemental ratios for 7 of the 15 analyses. They (op. cit.) did the analysis on the effect of the age on elemental incorporation into the *M. arenaria* shell and found that the higher variability closer to the umbo than further away, which caused significant differences with age of clams.

Mg/Sr and Sr/Ca ratios of living Ostracoda belonging to 15 species recovered from samples that were collected monthly over one year cycle at five sites (2, 5, 13, 33 and 70 m water depth) in western Lake Geneva (Switzerland) compared the oxygen-carbon isotope composition measured and, suggested that the distinctive Mg and Sr partition coefficients for the analysed taxa result from different valve calcification strategies that may be phylogenetic (Laurent Decrouy *et al*., 2012).

METHODOLOGY

2.8 FIELD PROCEDURES

In order to study various environmental aspects of recent Benthic Ostracoda, bottom surface sediments (BSS) and bottom water samples (BWS) were collected from the offshore region (shallow inner shelf) in the Gulf of Mannar off Rameswaram island in the southern transect with the help of a motor launch and collecting samples using a van Veen grab sampler for bottom sediments, and Aquatrap sampler for bottom water samples. The samples were collected during four different seasons in one year duration representing all the seasons that exist in the study area, namely, 1. Northeast monsoon (October-December 2010), 2. Winter season (January-March 2011), 3. Summer (April-June 2011), and 4. Southwest monsoon (July-September 2011). Totally, 60 BWS and 44 BSS have been collected from fifteen stations representing four different seasons of the year. The date of collection were generally adjusted to the day of new moon or full moon. Each transect of the collection starts from the coast to inner shallow shelf region upto 15 km, and the stations are equi-spaced 1 km. Souther transect starts from the Ramakrishna Memorial, a known landmark, up to 15 km off the coast in the inner shallow shelf region.

2.8.1 Bottom sediment samples

From the sediment samples in each station that was collected using Grab sampler, the top 4 cm sediment was scrapped carefully manually and was preserved in a plastic container by adding 10% formaldehyde such that the preserved sample is being immersed. Out of the fifteen locations, only eleven samples were collected as the sediments were not recovered from four stations. The preservation of sediment samples were done in the field itself on board, and a pinch of sodium carbonate was added in order to maintain the alkaline medium of formaldehyde, otherwise the formaldehyde may become acidic with time (Walton, 1964). Another part of sediment sample was collected in a polythene bag for other sedimentological investigations. The preserved BSS is further subjected to laboratory analysis following Arnold *et al*., (1985) for determining living species of Ostracoda using Walton's (1952) technique. Calcium carbonate and organic matter were determined from collected BSS adopting the methodology, after Loring and Rantala (1992), and Gaudette *et al*., (1974), respectively. Sand, silt and clay percentages were computed by Pipette method, in accordance with Krumbein and Pettijohn (1938). Trilinear plots were prepared and Trefethen's (1950) textural nomenclature has been utilized for finding out the nature of the substrate. A part of sediment sample was subjected to geochemical analysis.

2.8.2 Bottom water samples

Depth of water column, pH, and temperature of the BWS were observed in the field itself. pH measurement was carried out by a pH meter in the field itself by portable hand held pH meter (PCS Testr 35). Dissolved oxygen and salinity were determined from BWS by adopting methods briefed by Strickland and Parson (1968) and Knudsen (1901), respectively. Water samples were collected in each station in three different plastic containers of 100, 500 and 1000 ml respectively. The samples that were collected in 100 ml of polythethylene container have been fixed by adding 1 ml of Winkler A and Winkler B solutions and further covered with black covers to mask the sunlight, to find out Dissolved Oxygen latter in the laboratory (within 24 hours). Two or three drops of chloroform were added to the samples that were collected in 500 ml polythene bottle, and the samples that were collected in 1000 ml container have been neatly packed and transported carefully to the laboratory where the physicochemical parameters are determined. The flow chart showing research methodology is in **Fig. 2.1**.

2.9 LABORATORY ANALYSIS

From the BSS and BWS that were collected in the field, the following analyses were done in the laboratory making use of standard procedures that are described below:

2.9.1 Calcium carbonate

Calcium carbonate content of each sample is being determined in the laboratory. Calcium is often an important component of marine sediments and has been found to be an important indicator of provenance and dispersal of terrigenous material (Loring and Nota, 1973). In the present study, calcium carbonate was determined following the procedure explained by Piper (1947) by the titration method. The carbonate determined by this method includes other carbonates such as magnesium, which is negligible and hence, for all practical purposes the total carbonate is referred to as calcium carbonate in the present investigation.

Procedure

The procedure for determining the calcium carbonate content in sediments is as follows: 5.0 g of sediment soil is weighed and transferred to a tall 150 ml beaker. Then 100 ml of 1 N hydrochloric acid (87.6 ml of HCl in 1000 ml of distilled water) is added to it making use of a pipette with an enlarged jet. The beaker is covered with a watch glass and stirred vigorously several times for a period of one hour using a mechanical stirrer. After allowing the mixture to settle, 20 ml of supernatant liquid is pipetted out and transferred to a small Erlenmeyer flask. To it are added 6 to 8 drops of bromothymal blue indicator that forms a blue color, and it is titrated with 1 N sodium hydroxide until the blue color completely fades out. A blank titration is carried out using HCl against 1 N NaOH after adding bromothymal indicator, to get the titration value for blank solution. Then, the percentage of $CaCO_3$ is being calculated as follows:

$$\text{Percentage of Calcium carbonate} = \text{Blank titration} - \text{Actual titration} \times 5$$

2.9.2 Organic matter

The readily oxidisable organic carbon content is determined by the Walkey-Black method (1934), adopted and modified by Jackson (1958) and detailed by Gaudette *et al*., (1974) who found that this method provided excellent agreement with the LECO combustion method of organic carbon analysis; this procedure has been followed in the present study. The Walkey-Black method utilizes exothermic heating and oxidation with potassium dichromate and concentrated sulphuric acid of the samples followed by the titration of excess dichromate with 0.5 N ferrous ammonium sulpahte solution to a sharp, one drop end point. Oxidation of chloride can be made use of silver sulphate in the digestion mixture.

Procedure

The sediment sample is dried in a hot air oven to remove the moisture content. Some quantity of the sample is crushed into fine particles and from it 0.5 g of sediment (sieved 63 µm fraction) is transferred to a 500 ml conical flask. Then, exactly 10 ml of 1 N potassium dichromate solution (49.1 g of $K_2Cr_2O_7$ in 1000 ml of distilled water) is added and the contents were mixed by gently rotating the flask for about a minute. This has to be done carefully to insure complete mixing of the reagents with the sediment, while avoiding splashing of the sediment on to the sides of the flask out of contact with the reagents. The mixture is allowed to stand for 30 minutes at the end of which 200 ml of distilled water, 10 ml of 85% orthophosphoric acid and 0.2 g of sodium fluoride are added. Then, 15 drops (0.5 ml) of the diphenylamine indicator are added to the sample flask. The solution is titrated with 0.5 N ferrous ammonium sulphate solution to a one drop end point (brilliant green). As the titration proceeds, the color of the solution progresses from an opaque greenish brown to green upon the addition of approximately 10 ml of the ferrous solution. The colour continues to shift upon titration to a bluish-black-grey. At this point, addition of 10-20 drops of the ferrous solution shifts the colour to a brilliant green giving one drop end point. A standardization blank without sediment is run with each new batch of sediment samples.

Calculation:

% of organic matter (readily oxidisable) = 10 (1-T/S) × F

where, T = Sample titration (ml of ferrous solution)

S = (Standardization) Blank titration (ml of ferrous solution)

F = Factor derived as follows:

F = (0.1 N) × 12/4000 × 1.72 × 100/sample weight

= 1.03 when sample weight is exactly 0.5 g

where, 12/4000 = meq. wt. carbon

1.72 = factors for organic matter from organic carbon.

2.9.3 Type of substrate (Sand-Silt-Clay ratio)

In order to find out the percentages of sand, silt and clay, each sample is completely dried in a hot air oven to eliminate the moisture content. The sample is subjected to preliminary treatment like, removal of carbonates (10% HCl), iron oxide coating (15 ml Oxalic acid) and organic matter (30% H_2O_2) as described by Ingram (1970). Each sample is then dispersed overnight with sodium hexametaphosphate solution of 0.025 N for disintegration. The material thus, disintegrated is washed through a 230 ASTM sieve mesh (opening = 0.063 mm) made of phosphor-bronze wire mesh until clear water passes through, taking care that the washings do not exceed 1000 ml. The material retained on the sieve is dried and weighed for obtaining the weight of the material coarser than 1/16mm, that is, “sand”. The fine material (silt and clay) that pass through the sieve in the washings is analyzed by the Pipette method in accordance with the procedure adopted by Krunbein and Pettijohn (1938). The suspension collected in a jar after complete washing is less than 1000 ml and with it distilled water is added to make it up to 1000 ml. The suspension in the measuring jar is then well agitated using a stirring device, in order to have a uniform distribution of the particles in suspension. As soon as the agitation stops, the time is noted. Exactly after 2 hours and 3 minutes, a 20 ml pipette is slowly lowered in to the jar up to 10 cm in the solution and the sample is withdrawn from the place with uniform suction. The pipette out sample is transferred to a 50 ml beaker and dried in an oven. Care should be taken to prevent boiling and splattering. After complete drying, the weight of the residue is found out to get the weight of “silt”. Then, the respective weights of sand, silt and clay are converted into weight percentages and plotted on a tri-linear diagram. Trefethen’s (1950) textural nomenclature has been used to describe the sediments in the present study.

Calculation

1) Sand:

Sand weight = Weight of the sample retained in the 230 mesh.

$$Sand\ \% = \frac{sand\ \ weight}{\text{total weight of sample}} \times 100$$

2) Clay:

Clay weight = Clay with beaker weight – Empty beaker weight

$$Clay\ \% = \frac{clay\ weight}{\text{total weight of sample}} \times 100$$

3) Silt:

Silt weight = total weight of sample - (sand weight + clay weight)

$$Silt\ \% = \frac{silt\ \ weight}{\text{total weight of sample}} \times 100$$

2.9.4 Determination of Dissolved Oxygen

Dissolved Oxygen (DO) has been determined for each bottom water sample by Winkler's titration method (Strickland and Parson, 1968). Divalent manganese solution, followed by a strong alkali, is added to the seawater sample. Any dissolved oxygen rapidly oxidizes an equivalent amount of divalent manganese to basic hydroxides of higher valency state which is a precipitate of manganese hydroxide in the sample. When the solution is acidified, the oxidized manganese reverts to divalent state and equivalent to the original dissolved oxygen content of the sample.

Winkler A and B solutions:

48 g of Manganese chloride was dissolved in 100 ml triple distilled water in the laboratory to make Winkler "A" solution. 50 g of Sodium hydroxide pellets and 13.5 g of Sodium iodide were dissolved in 100 ml triple distilled water in the laboratory to make Winkler "B" solution. The preparation of Winkler "A" and Winkler "B" solutions were done, previous day of the field work, following Strickland and Parson (1968) method. These Winkler "A" and "B" solutions were used in the field and added 1 ml each with bottom water samples on board.

Procedure

For estimating the dissolved oxygen present in seawater, there are physicochemical, electrochemical and pure chemical methods. In the present study, Winkler's method (Strickland and Parsons, 1968) was employed. In this method, the dissolved oxygen present (fixed at the time of collection on board) rapidly oxidises an equivalent amount of divalent manganese to basic hydroxide of higher valency state. When the solution is acidified in the presence of iodide, the oxidised manganese reverts to the divalent state. Also, iodine, equivalent to the original dissolved oxygen content of water sample is liberated, which is titrated against sodium thiosulphate soultion.

$$Mn^{2+} + 2\,(OH) \longrightarrow Mn\,(OH)_2$$

$$2Mn\,(OH)_2 + O \longrightarrow 2Mn\,O\,(OH)_2$$

$$MnO\,(OH)_2 + 4H^{+} + 3I \longrightarrow Mn^{2+} + I_3 + 3H_2O$$

$$I_3^{-} + 2S_2O_3^{2-} \longrightarrow 3I^{-} + S_4O_6^{2-}$$

100 ml of sample (already fixed at the time of collection on board) was taken in a conical flask. After adding some drops of H_2SO_4 to the sample, instantly three drops of starch indicator were added. A blue colour developed. This was titrated against the N/40 sodium thiosulphate until the colour was discharged. By calculation,

1 ml. of N/40 $Na_2\,S_2\,O_3$ = 0.2 ml. of dissolved oxygen.

[ml/l dissolved oxygen present = $\frac{0.2\times1000}{\text{Vol .of fixed solution}} = \frac{0.2\times1000}{100} = 2$]

So, burrette reading × 2 = ml/l of dissolved oxygen when 100 ml. of fixed solution was taken.

2.9.5 Determination of Salinity

The average waters of the world's oceans contain 3.5% dissolved salts and 96.5% water. The content of dissolved salts in grams of salt per kilogram of seawater is called salinity. The average ocean salinity is about 35 g/kg. Salinity is a measure of the total salt content of the water; salinity can be determined by estimating the chlorinity as these two are related by the Knudsen equation as:

$$\text{Salinity} = 0.03 + 1.805\ Cl$$

where, Cl = the chloride content in 1 ml of water.

The standard titration method proposed by Knudsen (1901) has been followed in the present study. The precipitated halide halogens in a specified volume of sea water are determined by titration with silver nitrate solution using a chromate end point.

Procedure

5 ml of the sea water sample is diluted by adding 100 ml of distilled water. 25 ml of the diluted water sample is taken in a clean, dry 125 ml Erlenmeyer flask and a few drops of 5% Potassium chromate indicator solution (5 g of potassium chromate in 100 ml of distilled water) is added; the solution turns yellowish in colour. The sample is then titrated with a standard solution of silver nitrate (4.791 g in 1000 ml of distilled water) to get a pale red end point. A blank is run with distilled water and the correction is carried out for each sample. The chloride content in 1 ml of the sea water sample is calculated as, [(S-B) × Dilution Factor]/5

where,

S = the volume of silver nitrate solution consumed for the sample and

B = the volume of silver nitrate solution consumed for the blank.

The salinity is then determined using the Knudsen's equation.

2.9.6 Physicochemical parameters

Ostracods are environmentally sensitive organisms which readily preserve as fossils because of their calcitic shells. Ostracod occurrence appears to be controlled by hydro-chemical parameters such as water composition and salinity and also by the seasonal variability of water temperature (De Deckker and Forester, 1988). The bottom water samples were collected in pre-cleaned polyethythene bottles. Water samples were drawn by using an Aquatrap sampler. Turbidity of the water samples was measured by turbidity meter (Cyber Scan IR TB 100) having 0.01 NTU resolution. All estimations of dissolved nutrients in sea water were carried out in the filtered water samples. The analysis was made almost immediately after bringing the sample to the laboratory to avoid any possible bio-chemical changes in the stored water. The dissolved micronutrients include such as, nitrite, nitrate, ammonia, silicate, phosphate, along with Total Nitrate and Total Phosphate, that were estimated by calorimetry following standard methods (Grasshoff *et al*., 1983; Parsons *et al*., 1984), after filtering the water samples through 0.45 μm filter paper. For all the spectro-photometric analyses, a double beam UV Visible Spectrophotometer (Chemito Spectra scan UV 2600) was used. All parameters were analyzed in the Tamil Nadu Water Supply and Drainage Board (TWAD) Hydrological Laboratory.

2.10 MICROFAUNAL STUDY

2.10.1 Staining techniques

Ostracods live mainly in the upper 4 cm of the sediment, and most of them are live in the upper 5 mm, the flocculent layer and the top of the oxidized layer (Ikeya and Shiozaki, 1993). The study of living and dead population is essential in understanding the ecology of modern Ostracod (Phelger, 1960). Hence, the first step in the study of ecology of Ostracod is the differentiation of 'living' from the 'dead'. Any specimen in a sample preserved in neutralized formalin is considered to be alive at the time of collection, if it contains protoplasm. Recognition of the presence of the preserved cell in a specimen without the use of a colour aid, such as a biological stain, is laborious and not well-suited for rapid examination of large suites of speciments (Phleger, 1960). Different staining methods have been used for distinguishing the 'living' from the 'dead', namely, Rhumbler's 'Methgreosin' method (1935), Phelger's Biuret method (1951). The most positive method for identifying living Ostracoda is Walton's (1952) staining techniques with rose Bengal (Phelger, 1960).

The rose Bengal technique was used by zoologist for staining bacteria and cytoplasm. After conducting a series of experiments to ascertain the effect of this dye with different concentrations, Walton found that Worms, Arthropods and Ostracods that contain protoplasm were stained a deep-rose, leaving the empty shells, inorganic and organic debris unstained. This technique is equally applicable to calcareous and arenaceous and agglutinated forms since it does not involve treatment with any acid. Walton's technique has since been widely adopted for its obvious advantages over the earlier methods. Schafer and Sengupta (1969) employed Walton's technique with a slight modification of storing the sample itself in isopropyl alcohol, which had been mixed with rose Bengal dye.

In the present study, the sediment samples preserved in neutralized formaldehyde were subjected to laboratory treatment according to Walton's (1952) rose Bengal staining technique. The preserved sample was washed over an ASTM 230 mesh, sieve (opening = 0.063 mm) to remove the finer particles. The sieve with the residue was kept for about an hour in a tray containing an aqueous solution of rose Bengal (1 gram of rose Bengal dye in 1 litre of distilled water), ensuring that the residue on the sieve mesh was fully immersed in the solution. After sufficient soaking, the sample on the sieve was washed over water in order to remove the excess stain, and then dried. The Ostracod specimen were then seperated from this residue under a stereo-zoom-microscope, using .00 Windsor and Newton sable hair brush.

2.10.2 Counting and mounting of Ostracoda

The faunal specimens, thus, obtained were spread over a picking tray. The different genera and species were identified. The living and dead populations were counted. Where the population size was considerably larger, it was split to obtain a workable population. Selected specimens from each species were mounted on micro-paleontological slides, according to the family, genus and species, over a thin layer of tragacanth gum. Before the gum dried, each specimen was oriented to the desired position for further study. The hypo-types were mounted on a double side adhesive tape stuck on brass stubs for Scanning Electron Microscope (SEM) photography, in order to know the morphological variabilities as well as its shell chemistry by EDAX.

2.11 SEDIMENT GEOCHEMISTRY

Sediment samples have been digested for the present study following the procedure elaborated by Tessier *et al*., (1979). For total or residual trace metal analysis, the sample was digested with 5:1 mixture of Hydrofluoric and Perchloric acids. 1 g (dry weight) sample of sediment was first digested in a platinum crucible with a solution of Conc. $HClO_4$ (2 ml) and HF (10 ml) to near dryness; subsequently, a second addition of $HClO_4$ (1 ml) and HF (10 ml) was made and again the mixture was evaporated to near dryness. Finally, $HClO_4$ (1 ml) alone was added and the sample was evaporated until the appearance of white fumes. The residue was dissolved in 12 N HCl and diluted to 25 ml. The resulting solution was then analyzed by flame Atomic Absorption Spectrophotometer (AAS) for trace metals using the standard addition technique. The solution was finally analyzed for total Al, Fe, Mn, Zn, Cu, Pb, Cd, Ni, Co, and Cr on a AAS equipped with a deuterium background corrector. Flame Atomic Absorption was employed, except in the instance of Cd, graphite furnace was used because of its much lower concentration. Trace element concentration were determined using Atomic Absorption Spectrophotometery (AAS - Perkin Elmer AA700 AAS equipped with a deuterium background corrector) involving direct aspiration of the aqueous solution into an air-acetylene flame. The following technique were used for the first four fractions:

For the trace metals Cd, Co, Cu, Ni, Pb, and Zn, a standard addition technique was employed because of matrix effects, presumably due to material leached from the sediments; these effects would have contributed in many cases to an error of as much as15%. For the metals present in high concentrations (Fe and Mn) the supernatant solution was diluted 20 to 50 times with deionized water and the concentration were obtained directly from appropriate calibration curves prepared with the components of the extracted solution which is diluted by the same factor. Aluminium concentrations was determined using a nitrous oxide-acetylene flame. Al was obtained by fusion with lithium metaborate followed by dissolution of the fused material in 1.2 N HCl.

2.12 SHELL CHEMISTRY

Selected specimens from each species were mounted on micro-paleontological slides, according to the family, genus and species, over a thin layer of tragacanth gum. The hypo-types of each species were further subjected to cleaning process to remove material from the valve that could potentially modify the chemical composition of the shell. The cleaning process were done before they were mounted on a double side adhesive tape stuck on brass stubs for Scanning Electron Microscope (SEM) EDAX to determine the elements that compose the shell.

The species selected were dead species. As the species for the present study are from recent Ostracoda there is no coating over the shells. They contain rarely the external organic layer, which may alter the results of EDAX, therfore, most of the potential contamination comes from adhering particles. Foreign particles can be composed of organic material and/or clay particles. However, in practice, for fossil populations without a chitin sheath, most authors (Barker *et al*., 2003; Jin *et al*., 2006; Keatings *et al*., 2006) found that the use of a chemical reagent to remove the organic fraction (sodium hypochlorite, hydrogen peroxide) alter either the isotopic or the elemental composition of carbonates and is therefore, not recommended. Consequently, foreign organic matter should be removed only physically from the valve.

This outlines the potential danger of considering a carbonate samples "clean" when observed and suggested that cleaning procedure resticted to manual cleaning is not appropriate for the precise determination of Ostracod valve Mg/Ca ratio. Barker *et al*., (2003) and Jin *et al*., (2006) suggested the use of successive ultrasonic method and de-ionised water cleaning to efficiently remove clay minerals without altering the chemical composition of the sample. The element of Al is abuntant in clay minerals and only at trace level in carbonates. Therefore, the Al/Ca ratio of Ostracoda can be used to check the cleaning method efficiency in removing adhering clay particles from Ostracoda valves. The following cleaning protocol was used for the Ostracod valves: visible particles were removed from the valves with the help of a .00 brush and Milli-Q water. Valves were then individually transferred into 1.5 ml vials filled with purified methanol and left 2 minutes in the ultrasonic bath. The methanol was then rapidly removed from the vials with a miropipette and vials refilled with Milli-Q water. The vials were transferred into the ultrasonic bath for another 2 minutes. After removal of the Milli-Q water, the vials were left under an HEPA-filtered laminar-flow hood until the valves became dry. Occasionally, valves with remaining visibly adhering particles were cleaned a second time following the same protocol. Around 6% of the valves were borken or lost during the cleaning process.

In order to monitor eventual remaining contamination after the cleaning step, the hypo-types that were picked and identified species-wise were made use of their shell chemistry in EDAX. The instrument model number is S3000n whose brand name is Hitachi, attached with an Scanning Electron Microscope (SEM) instrument. In the present study, the following elements were determined: C, Ca, Mg, O, Al, Si, Na, Cl, K and Fe. Shell-chemistry offers a mean of testing Ostracod environmental interpretation and in many cases a means of refining those interpretations (Nevio Pugliese *et al*., 2006). The Ostracods are mainly calcareous (calcite) and composed of Ca, C, O, with minor Mg apart from other elements depending upon the environment. In some cases the presence of amorphous calcium carbonate is reported (Xia *et al*., 1997). Consequently, the use of the total assemblage (live and dead specimens) was preferred as an indicator of average environmental conditions for documenting of the Ostracoda response to anthropogenic inputs as in the case of Foraminifera (Armynot and Debenay, 2004).

2.13 PHOTOGRAPHY

The handpicked faunal specimens from each samples (25 ml of preserved wet sediment) were transfered to 24 chamber micropaleontological slides and mounted over a thin layer of tragacanth gum according to the family, genus and species. The different genera and species were identified; type specimens of each species were selected and transferred to round punch micro-faunal slides with cover slips. The hypo-types were mounted on brass stubs (2.5 cm in diameter) using a double sided adhesive carbon tape and coated with platinum for about 3 to 4 minutes before scanning using Scanning Electron Microscope (SEM). Mounting of the specimen with carbon tape will further decrease charging, and enhance resolution and viewing for longer periods at high voltage under SEM. To obtain lucid illustrations, microphotographs of different views of the species of Ostracoda were taken using SEM. The instrument model number is S3000n whose brand name is Hitachi. All the hypo-types were duly indexed with numbers and placed in the repository of the Department of Applied Geology, University of Madras.

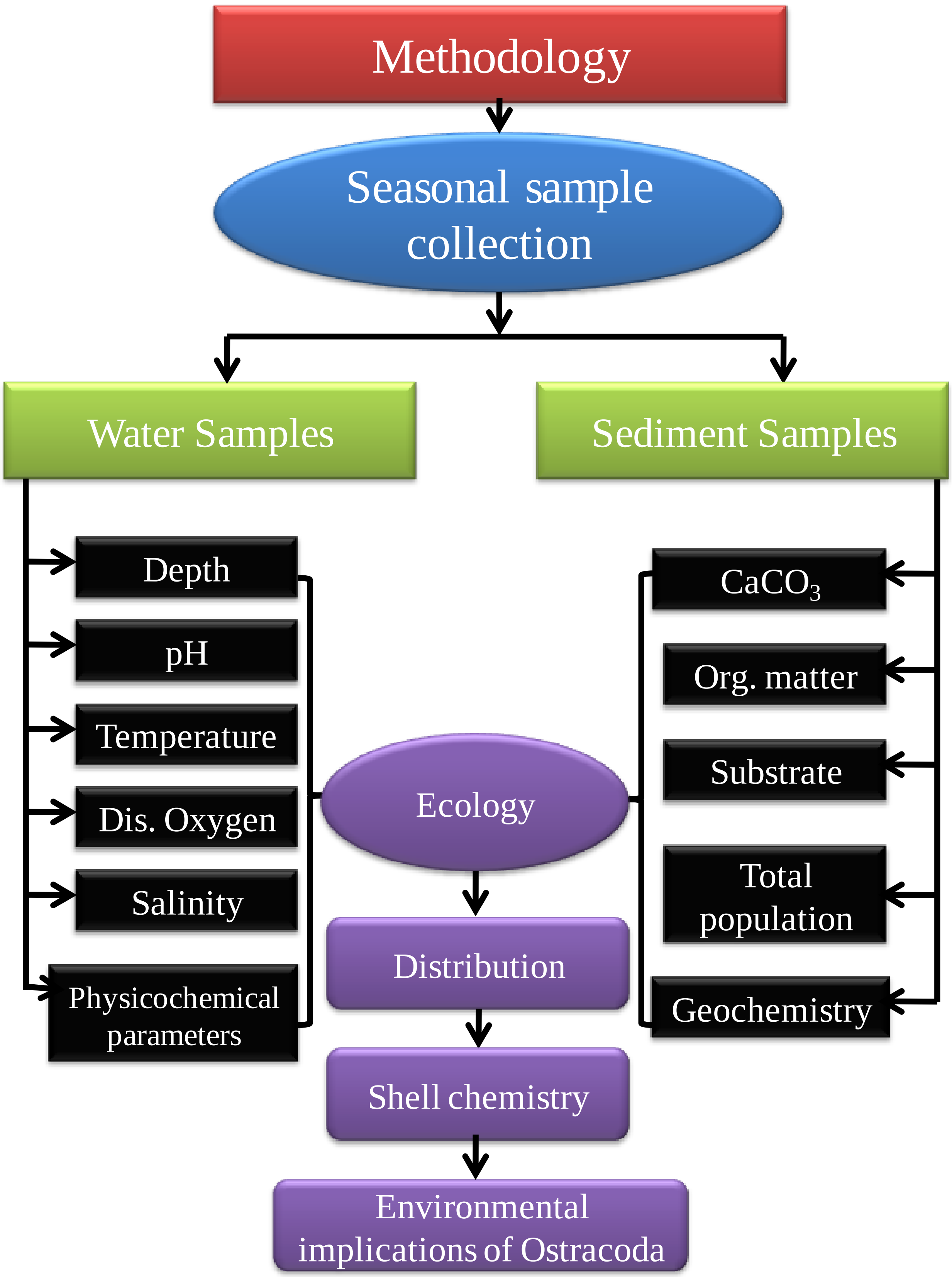

Fig. 2.1 Flow chart showing methodology