Chapter 6

Summary
Observations on the wind pattern at the latitude of Cochin indicated that easterly winds prevailed during most parts of the premonsoon season with wind velocities showing a progressive increase, attaining high values during the peak of monsoon. The wind direction changed to mostly southwesterly during the postmonsoon season and wind velocities decreased considerably by October, attaining low values during the period.

Considerable interannual as well as seasonal variations in rainfall were evident and the annual average rainfall was 2832 mm which was mainly dependent on the southwest monsoon with contributions in May and October together comprising about 87% of the total.

Appreciable fall in seawater temperature was observed at subsurface depths near the coast in May and this could be closely related to the occurrence of upwelling. Thermal inversions were observed at 10 and 20 m depths during November – January registering an increase of 0.3°C at the subsurface levels.

The comparatively low density observed at the surface near the coast during the monsoon period was caused by the addition of fresh water from rain and river runoff. However, the bottom depths appeared to be influenced by the dense waters of low temperature during this period which upwelled from deeper depths and occupied the bottom of the nearshore coastal region.

The low values of vertical stability observed during monsoon season in the present study at bottom depths could be related to the upwelling process. Further, the negative values of stability observed at the 10 - 20 m bottom depth in November - January was indicative of unstable conditions and this could be due to the occurrence of thermal inversions at subsurface depths during this period.

The mean sea level was found to decrease considerably during May and was coupled with the appearance of upwelled waters at subsurface
levels of the inshore region. Further, the fall in sea level in July conformed with the time of peak upwelling. Following a reduction in intensity of the process, the mean sea level rose and the steep increase observed from October was indicative of the cessation of upwelling.

A striking feature of the results obtained was that the salinity values showed wide variations from season to season. Estimations of surface salinity at the nearshore stations revealed that it was very low during monsoon months, although the bottom values were much higher. Interestingly, it was found that low saline waters were restricted to the surface layers. The salinity gradient was also found to be very sharp during this season even at the shallow inshore stations resulting from stratification. The results indicated that concurrent with the fresh water discharge during monsoon months, there was an incursion of cold, high saline, nutrient-rich bottom waters from the Arabian sea to the subsurface layers of the shallow coastal waters resulting in upwelling.

Comparatively low DO values were recorded at the surface during monsoon months. The DO at the bottom during this period were also generally low and decreased towards deeper stations. The coastal waters were well aerated during most parts of the year except during the southwest monsoon season.

Higher values of phosphate were observed at stations near the coast during monsoon and it markedly increased at the bottom when compared to surface values. Further, the phosphate levels at the bottom increased towards deeper stations. The higher values of phosphate were observed in the nearshore stations at surface and bottom in October. In general, high values were observed during post monsoon season. The results obtained further indicated that high values of phosphate were often accompanied by a reduction in temperature. It can therefore be assumed that upwelling could be the driving force behind elevated phosphate levels in the surface waters.
In light of the above, it appears that when compared to seasonal runoff, upwelling is the major source of phosphorous enrichment.

Nitrate values were higher at nearshore stations during monsoon season. In October also, surface values were comparatively higher near the coast. However, in the postmonsoon period, the nitrate content decreased with depth and the surface values were below detectable limits. During latter part of the premonsoon season, higher values of nitrate were reported close to the coast at surface but were below detectable limits at stations away from the coast. The elevated levels of nitrate during the early part of postmonsoon season (October) and also in the latter part of premonsoon season (May), especially near the coast, could be related to the contributions from river runoff resulting from rainfall which occurred during these months.

Analysis of water samples from different stations indicated that the silicate levels were higher in July and August at the surface and bottom in the nearshore stations and gradually decreased towards deeper stations. High values were also recorded at the bottom close to the coast. Silicate values were also high in the surface layers near the coast in October. Generally, low values were observed at all depths in January. Silicate content were again higher at the surface and bottom near the coast in May. In general, silicate values decreased with depth during most of the months. It is therefore, reasonable to assume that the enrichment of silicate is mainly dependent on the influx of fresh water and the observed reduction in silicate concentration from surface to bottom is suggestive of an inverse relationship with salinity.

During the present study, chlorophyll a values were comparatively higher in monsoon season followed by postmonsoon and premonsoon seasons. Chlorophyll a values also indicated seasonal peaks in all the three seasons. Among the different nutrients, phosphate seems to be significant to chlorophyll a, as evidenced by a negative correlation observed between them during monsoon and premonsoon periods. The low correlation observed between chlorophyll a and nutrients especially during monsoon and post
monsoon periods in the present study suggests that *in situ* concentration of nutrients may not yield meaningful conclusions. In the present study, generally high values of ZB were recorded in the monsoon and early postmonsoon seasons.

Significant variations in sea water temperature, salinity; density and DO with depth observed during the monsoon and postmonsoon periods may probably be due to the effect of upwelling and river runoff prevailing during these seasons. Similar variations observed in the case of phosphate, chlorophyll a during monsoon season may also be related to the above cause and effect.

The influence of river flow on salinity, density, silicate and ZB during monsoon was clearly reflected in the significant variations observed between stations especially the nearshore region. Significant variations in phosphate and nitrate distribution were also evident during postmonsoon with the occurrence of below detectable levels (bdl) at certain stations and pockets of high values at adjacent stations. Tidal influences did not seem to have significant effect on the different parameters studied except phosphate which varied significantly with tide during all the three seasons.

Analysis of the data obtained indicated that the coastal region off Cochin clearly reflect the characteristics of upwelled waters during the monsoon season. The appearance of low temperature water during the present observation near the coast at bottom depths in May is an indication of the commencement of upwelling of deeper waters to surface layers. In fact the period of intense upwelling occurred during June – July and the process continued till October. A striking observation made is that DO estimation is also a handy parameter like temperature to assess upwelling Off Cochin. Further the variation observed in temperature and DO at 10 and 20 m depth during the monsoon season provide ample evidences of the actual intensity and duration of the process within the region off Cochin.
Chapter 6

Summary

The mean sea level cycle at Cochin pertaining to the study period confirms that sea level is also a good indicator of upwelling. It could be inferred from the sea level data that the process of upwelling commenced much earlier than the actual onset of the southwest monsoon. The minimum sea level was observed in July and the inshore waters off Cochin were characterized by low temperature and low dissolved oxygen. The observed variations in the intensity of the process could also be understood from the relative variations in sea level values.

The temperature and dissolved oxygen content at subsurface depths in the coastal waters increased when there was a lull in the intensity of upwelling in September 2001 within a spell during the monsoon months and as the process revived in October the values dropped down and the typical monsoon characteristics of water were restored.

With regard to the fishery of the different species under consideration, it was noted that the process of upwelling brings in characteristics changes in water properties within the shelf and nearshore region under study, greatly influencing the abundance and availability of these species.

The oil sardine stock was abundant during the premonsoon season along the coast resulting in good landings in April and May. The major landing period of the season coincided with the period of lower sea level. It was observed that during the early part of upwelling period, the stock appeared in large quantity along the coast. Curiously enough, the poor landings of oil sardine coincided with the late arrival of bulk stock in May as observed from the landings data in 2001. The drop in sea level also occurred much later in 2001 when compared to 2000 and 2002.

During the present study it was noted that the premonsoon availability of mackerel was low unlike oil sardines during all the three years of study. This could possibly be due to the fact that the stock was more wide spread and that the congregation of stock did not occur during
this period resulting in a substantial fishery. A striking feature of the observations made was that it did not support the inverse relationship between the annual landings of oil sardine and mackerel as suggested earlier.

It is also important to note that the landings during monsoon and post monsoon periods for both the species were constantly high while a reverse trend was observed in the premonsoon period.

Analysis of the data revealed that low catches of oil sardine, mackerel, threadfin breams, penaeid prawns and cephalopods in 2001 were influenced by the intense rainfall during the monsoon season, which was 20% higher than that in 2000 and 2002. Interestingly, the higher landings of oil sardine, mackerel and threadfin breams in 2002 coincided with the comparatively higher rainfall occurred during the premonsoon period of the year. However, the rainfall data did not seem to have any relationship with the landings of whitebaits. On the other hand, intense rainfall (in 2001) resulted in good landings of ribbonfishes. During periods when rainfall was low in the premonsoon and postmonsoon season as in 2000 when compared to 2001 and 2002, lizard fishes cephalopods and penaeid prawns landings were comparatively higher.

The striking difference observed in the landings of lizard fishes, cephalopods and threadfin breams was that, though all of them are demersal in nature, their peak landings did not occur in the same year. In the case of cephalopods and lizard fishes, abundant landings were obtained from August to early postmonsoon period following peak upwelling and the highest landings recorded was in 2000. The landings of threadfin breams was at its peak mainly in August, immediately after the peak period of upwelling in July and the highest landings occurred in 2002. It appears that the availability of cephalopods and lizard fishes are more related to feeding while, that of threadfin breams are linked with mainly upwelling intensity. It was observed during the present study that 60 to 80% of the total
annual landings of ribbonfishes were during September - October period and hence it is possible that these species also move in large quantity for feeding into the coastal waters following cessation of upwelling, resulting in bumper landings.

The peak period of occurrence of whitebaits was found to be November and the species becomes available consequent to the reversal of surface currents in October along the southwest coast of India. The cessation of upwelling and the availability of plankton blooms provide whitebaits a favourable environment for the commencement of northward migration along the southwest coast. The higher landings of whitebaits observed during March – May in the present study may be related to the return migration of the stock along with the southerly current prevailing during this period.