CHAPTER 4
RESULTS AND DISCUSSION

In this chapter satellite observations of oceanographic events/features, their significance to fisheries, results of synergistic analysis of chlorophyll and SST images, satellite observations of the coupled bio-physical processes, interpretation of satellite derived images for exploration of fishery resources and results of the observations of in-situ data collection through direct fishing have been discussed. This chapter emphasis the remote sensing perspective patterns of variability in fishery resources and their habitat. Preliminary observations of secondary production using remote sensing derived variables have been briefly discussed.

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CHAPTER 4 – RESULTS AND DISCUSSION

4.1. Satellite Observations of some oceanographic events/features

Several Remote Sensing techniques can provide information regarding surface circulation features of importance in defining marine fish habitats. These include the location and evolution of frontal boundaries, upwelling areas, currents and circulation patterns in general. Optical and thermal characteristics of surface waters can be used as natural tracers of dynamic patterns. Hence, the previous discussion of sea surface colour and temperature retrieval should be considered again in light of this application. Microwave techniques, particularly the use of active sensors (radar, altimeter), also have applications regarding large-scale circulation features. Understanding the physical and biological processes, as well as their interactions, is a central goal for fisheries management over continental shelf areas. A complex suite of seasonal physical processes influence phytoplankton productivity and standing crops.

4.1.1. Upwelling

Upwelling is the process, which causes the upward movement of water from depths into the surface layer. Since the temperature in the sea usually decreases with depth, the upwelled water will be cooler than the surface water, which it displaces. Coastal upwelling are regions of high nutrient concentration and therefore high productivity and can sustain large fish populations. Most of the important fisheries of the oceans are found in regions of coastal upwelling. Coastal upwelling is most prevalent in trade wind zones, due to the consistency of prevailing winds, but can occur wherever winds result in the offshore transport of water.

Coastal upwelling is primarily a wind driven process. Wind blows on the surface of the ocean making surface waters flow horizontally in a direction, which depends upon the direction of the wind. The rotation of the Earth and Ekman transport causes the surface water to flow at a 90º angle to the direction of the wind. This horizontal flow is compensated by the rising of cold, nutrient-rich water from depth (Boje, 1978). If the wind is blowing in the Northern Hemisphere with a coastline, then the Ekman transport, being to right of the wind, will carry surface water away form the coast. The flow is maintained by water rising near the coast to replace the surface water which is moving offshore (Bowden, 1983). If the action of the wind continues to occur for an extended period of time, the sea level adjacent to the coast is lowered, creating a slope of the sea surface upwards in the offshore direction. This process creates a geostrophic flow parallel to the coast, with the surface rising to the right or left of the current, depending upon the hemisphere, so that the geostrophic component of flow is in the direction of the wind (Smith, 1983). Coastal upwelling is time dependent because it is highly unusual for wind to maintain a steady state of upwelling for any extended period of time. The occurrence of winds in the appropriate direction will initiate an upwelling event, reach a steady state, and then taper off as winds subside.

The common features of most coastal upwelling areas (Cushing, (1978), Smith, (1968), Boje, (1978) are:

- The offshore Ekman transport in the surface layer is to the right of the wind in the northern hemisphere and to the left in the southern hemisphere.
- Coastal upwelling occurs both near the coast and above the edge of the continental shelf.
- The isothermal and isopycnal surfaces rise towards the coast
- The upwelled water spreads offshore from the coastal zone and then tends to sink at a convergence site over the outer shelf.
- Where sinking converging water occurs, a frontal zone develops between the coastal and oceanic surface water. The front displays a sinuous course, which denotes the presence of eddies between the upwelled coastal water and oceanic surface water.
- Many along shore variations occur in the upwelling processes. Upwelling is not necessarily uniform along any coast.

Satellite observation of coastal upwelling formation processes

Satellites are very useful to locate and to monitor coastal upwelling, which required the frequent observation over large area. Time series AVHRR SST imageries of September and October 1995 were analyzed to study various phases of the upwelling process in the Arabian Sea.

Upwelling along the coast of study area was initiated during September 1995 is clearly seen in the images of SST derived from NOAA AVHRR data (Plate. 4.1).

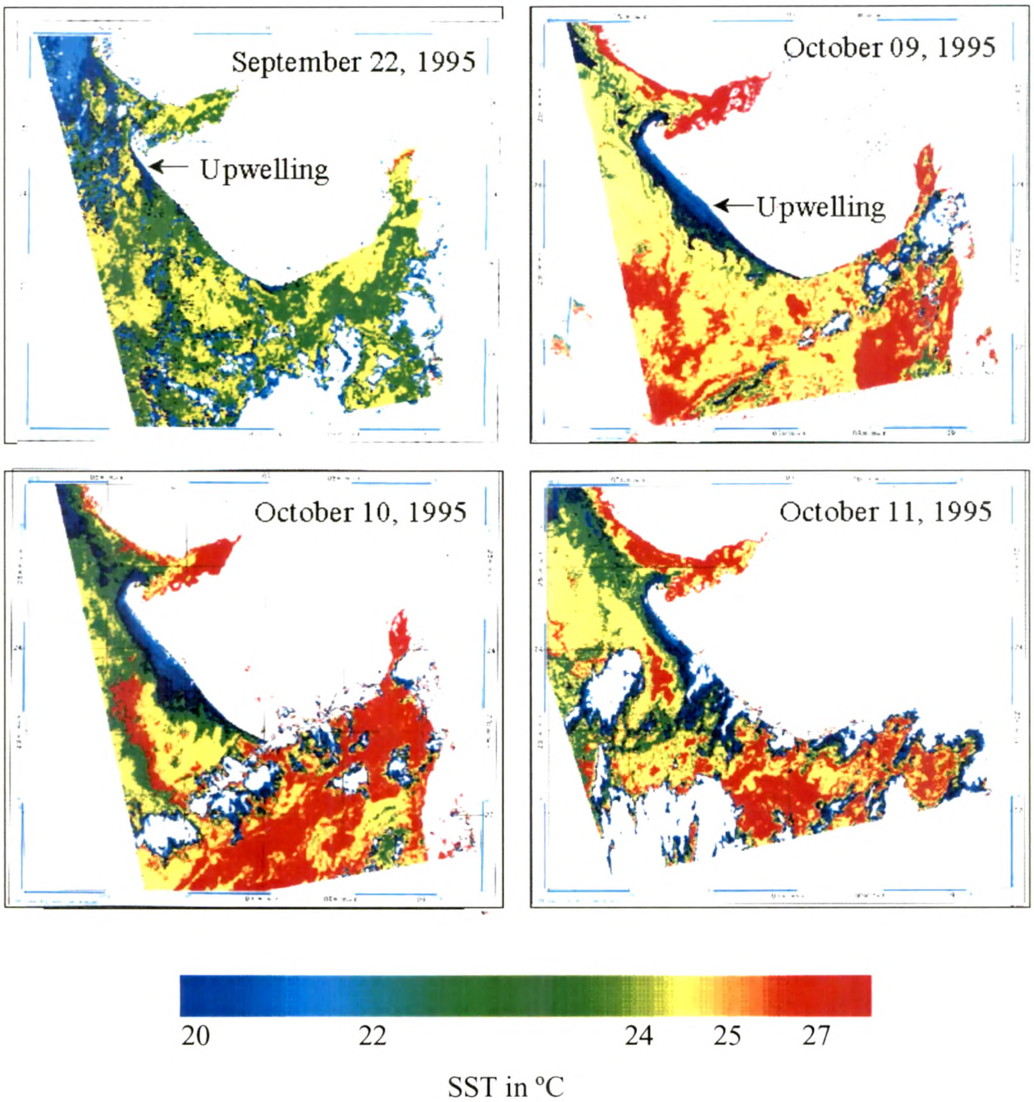


Plate 4.1. Upwelling event observation in SST image derived from NOAA-AVHRR along the Gujarat coast during October 1995. Different shed of blue colour along the coast is coastal upwelling process.

During initiation phase of upwelling very large oxygen minimum zone occurs in euphotic zone. Oxygen utilized by the microbes that feed on the sinking particulate organic matter through the water column in the upwelling area. But, in the euphotic zone photosynthesis masks the respiratory processes do not have enough time to deplete their oxygen supply. Consequently, the oxygen minimum zone is likely to be developed below the upwelling source water where the particulate organic matter has a longer residence time. During the decay of excessive particulate organic matter microbes consume oxygen and are force to couple their respiration to alternative electron acceptors. Their first choice after oxygen is nitrate and as nitrogenous acceptor becomes scare they tern to nitrite (NO_2), nitrate oxide (N_2O). Finally, microbes start reducing sulphate (SO_4). At this point the end product, sulfide ($S^=$), starts accumulating in the water column. This is disastrous for organic ecosystem because $S^=$ is toxic to the fish and invertebrates. There are chances of low oxygen content in the upwelled water. Hence, initiation of upwelling should be avoided as during this phase water contain low oxygen and fishes avoid the low oxygen content waters mass. In the figure 4.1 the cool water band in blue colour along Gujarat coast clearly visible in the image of October 09, 1995. This image indicates the maturation phase of upwelling and extended from Okha to Diu. During this phase the phytoplankton growth starts as in due course nutrient supply is expected in the euphotic zone, which enhances the production in the upwelling area. This phase is good as feeding ground of fishes. Simultaneously zooplanktons and herbivorous fishes accumulate in the upwelling zone. Hence, in upwelling area fishes accumulate which may be considered as good fishing ground.

4.1.2. Eddies and rings

Basin circulation consist of major ocean gyres that circulate clockwise (anticyclones gyres) in the northern hemisphere oceans and anticlockwise (cyclonic gyres) in the southern hemisphere oceans. These processes are known as subtropical gyres. These gyres are driven by global wind patterns that are created by uneven heating of the Earth's surface and by Coriolis force (Earth's rotation). Besides large ocean gyres, smaller basin like the Arabian Sea is characterized by seasonal gyre/eddy formation. Some of these gyres may be viewed as another type of upwelling. Often, these processes are open sea upwelling events of dynamic pumping of bottom water to surface. These events are stimulated by complex wind and sea current patterns with bottom topography playing an important role. Usually, gyres are characterized by certain seasonality and vary in duration, strength and size. Depending on the direction of the process, gayer may create a region with warmer (anti-cyclonic gyre) or colder (cyclonic) SST. These processes can be identified through AVHRR SST images depending on their difference in temperature as compared to the surrounding area. Monitoring of gyre activity in the oceans becomes important because it reveals surface geotropic currents, seasonal chlorophyll concentration and seasonal offshore feeding grounds for fishes.

Satellite observations of cyclonic Eddies and Rings formation processes

The cold core eddies and rings can initially characterized by low temperature and salinity, high nutrient concentration and great biological activity. Satellite observations are limited to SST and biological production (chlorophyll concentration).

Rings transport both nutrients and biota. The transport nutrients are important in sustaining the limited productivity. Eddies and rings formation was studied using time series OCM data. The area selected for this study was 20°-23° N and 65°-68° E. This area is known for eddy formation and high production during winter months (Banse, 1994). Eddies were monitored for the month of March 2004 to study their formation, maturation and formation of ring as their derivatives. The general morphological change in the structures of eddies and rings with time are shown in the plate 4.2. This figure indicates eddies and rings formation and decay stages. Four different eddies have been marked with serial numbers.

Eddy marked as "1" in plate 4.2 is initiated formation and decayed after one month. This feature started forming on March 01, 2004, it was found rotating in anti-clockwise fashion and moving toward southwest direction. It formed complete circle and formed a ring during March 21-25, 2004. Slowly this ring started decaying and on March 27, 2004 the feature found decayed. The feature marked as "2" is a ring formed during March 3-5, 2004 in 21°-22° N and 67°-68° E grid. It resides in the same grid and found persisted for a month in the same grid with little shifting. This ring started decaying in the image of March 27, 2004. This ring may be highly energetic as it persists for longer period. Such persisted feature support the high production as nutrient supply continuously available due to rotation of ring. Feature marked as "3" is indicating different stages of eddy formation. This is a weak eddy. It started forming on March 07, 2004 and founded decaying during March 25-27, 2004. With time, however mixing and heating modify the surface water properties related to water quality and biological production. There are five physical mechanisms leading to the decay of eddies and rings. They are dispersion, instability, interaction with

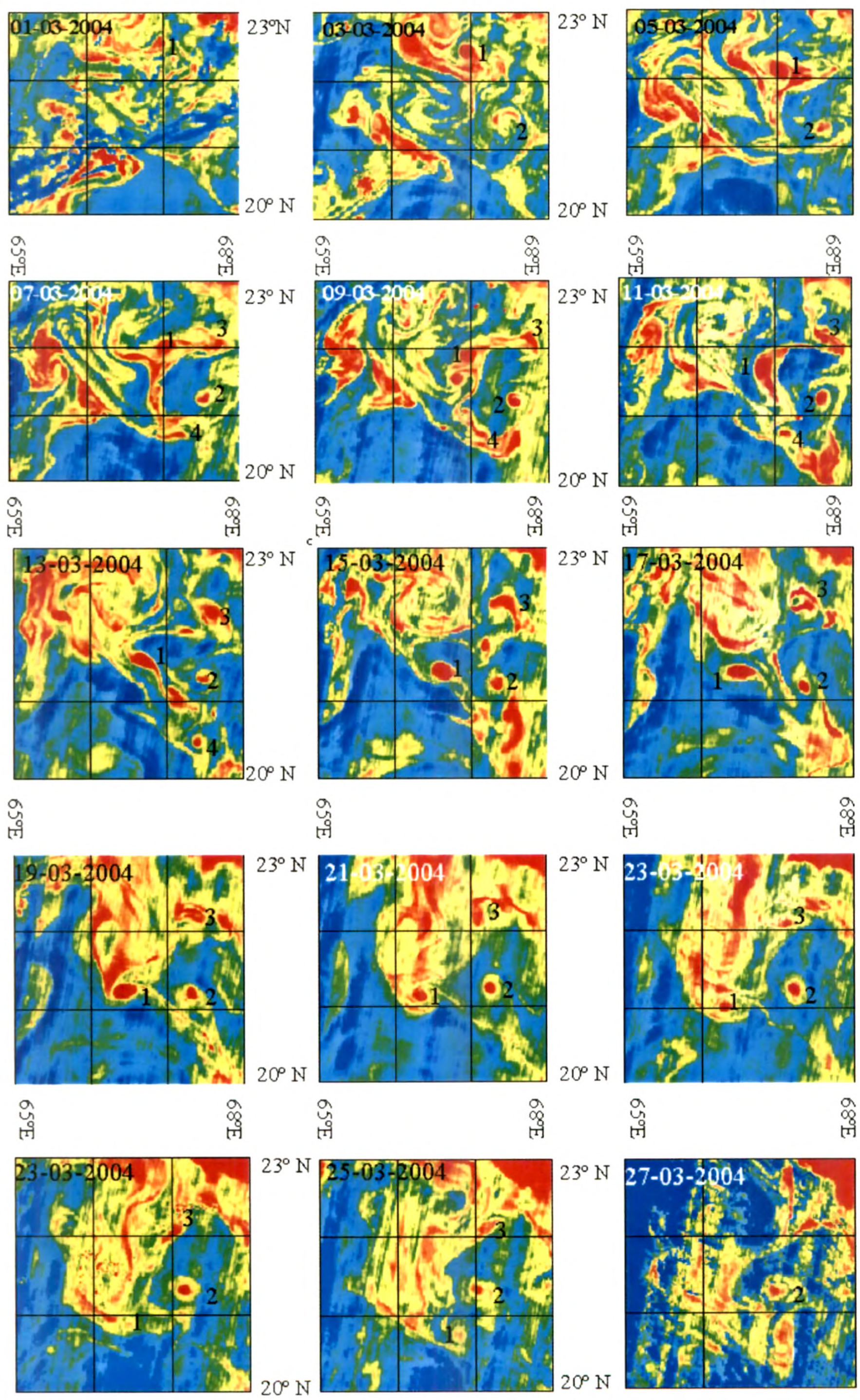


Plate 4.2. Observations of cyclonic eddies and rings using OCM data

mean flow, small-scale friction and surface wind mixing and heat exchanges. The sharp biological contrasts that exist at ring formation also decline with time. However, this time related biological transformations appear accelerated compared to physical ones. Chlorophyll concentrations are a measure of the phytoplankton biomass and were founded highest in the rings. The highest biomass occurs near the center of a ring and progressively declines toward the ring edge (plate 4.2). Because it is difficult to maintain continuous observation of ring there is little information about their longevity. Estimates of ring age have been derived by satellite identifying and collecting successive observations of rings.

Significance of cyclonic eddies and rings in Northern Arabian Sea

Cyclonic eddies transport water rich in nutrients to layers near the surface. Thus an important requirement is fulfilled for an abundant development of plankton in this regions. This serves as food for higher organisms, which, in tern form the basis of nourishment for edible fish. A satellite observation of eddies and rings have provided an initial understanding of their behaviour. With these data we can begin to assess the influence of rings on the distribution of physical, chemical and biological properties of the Sea. In the ring formation process, a large volume of water is transported across this interface. As the ring decays there is partial exchange of this water with surrounding, thus the rings generate a flux of properties from shelf to open ocean. Further more, because the rings bodily carry water with them, the transfer of properties took place well within the oceanic region not just at the slope boundary.

Estimates can be made of the importance of transport of heat, salt and nutrients by rings, but further research will be needed before firm statements can be made. Flux comparisons for biological variables come out rather differently. However, since most biological properties are not conservative, we must also consider that the effect of a ring is not just to produce a flux of organic material but also to provide a site of enhance production for most of its lifetime. Although rings do represent the most energetic form of mesoscale eddy, combined in-situ and satellite based studies study have begin to resolve the complex physical, chemical and biological changes occurring during the life of a ring. Our estimates of the importance of rings in determining circulation, water characteristic and ecology of the Arabian Sea suggest that the study of rings will lead to understanding not only of mesoscale oceanographic processes but also the circulation and structure of the ocean as a whole.

Satellite observation of anti-cyclonic eddies – the biological deserts in ocean

Clockwise rotation of eddies accumulate warm water in the center of the eddy. Anti-cyclonic eddies are considered as biological deserts as the center of eddy is full of warm water which is poor in nutrients and do not support the biological production. Plate 4.3 shows satellite-derived time series images of anti-cyclonic eddy. The center of eddy was observed with low chlorophyll concentration and in the periphery of the eddy relatively high production was observed. The area covered by the warm core eddy was found very large. It spread over around 100km x 100km area. The patterns of variability in anti-cycloic eddies was observed for more than two weeks. The formation process was initiated in third week of February, which is clearly visible in image February 25, 2003. The shape of the eddy was change on February 27, 2003 to

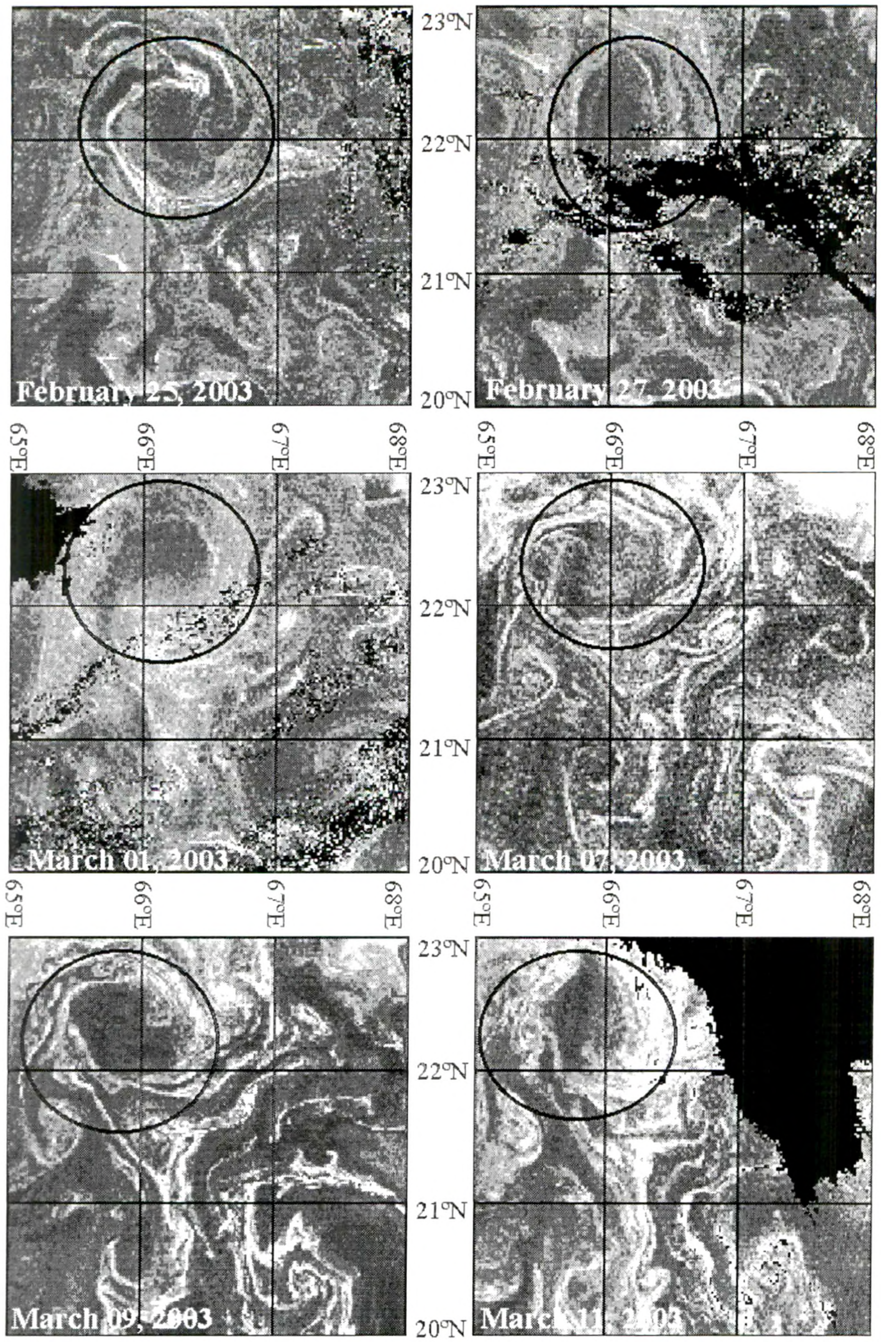


Plate 4.3. Satellite observations of anti-cyclonic eddy using OCM data during February – March 2003. Darker to lighter tone indicate the lower to higher chlorophyll concentration. Anti-cyclonic eddy with poor chlorophyll concentration is shown in the circle.

March 9, 2003. Gradually the area was found decreasing in the image of March 11, 2003. After that it was not possible to monitor due to cloudy data. It persisted for longer period in the same grid of area with little shifting in the position. Such eddies are non-productive. Monitoring of such ocean event using satellite is very useful for guiding fishermen to avoid the fishing in such areas.

The structure of the water bodies within eddy area is determined by the direction of rotation, which is of important for the life (biological) conditions in ocean. To understand these relations, one must remember that light and nutrients the essential requirements for the development of phytoplankton - is the basis of food for zooplankton, which in tern feeds the higher organisms. An abundant plankton population consumes the nutrient and descending dead organisms transport them into deeper layers. Because of chemical decay processes, the decomposition constituents are again dissolved in the water and contribute to accumulation of nutrients. Therefore, the water layers near surface lose their nutrients if they are not replenished from the depths. Areas of accumulation of surface water in the central parts of the anti-cyclonic eddies are, therefore, areas poor in nutrients and do not permit a significant development of micro-organisms. They are the *deserts of the ocean* particularly, the central parts of the great anti-cyclonic eddy.

4.1.3. Oceanographic fronts

Frontal zones, representing the boundary between horizontally juxtaposed water masses of different properties, are the fundamental properties of geophysical turbulence and play important role in the ocean dynamics. They are the regions of convergence and relatively strong vertical motions. Fronts are found in the surface layers, at mid depth and near the ocean bottom. All the frontal systems share common properties of persistence ranging from hours to months in spite of the diffusion of properties across strong horizontal gradients and surface convergence with associated strong vertical convection.

Fronts are important in the ocean dynamics since they are regions where vertical advection and exchange of momentum and other properties are locally intense. The design of fishing strategies for maximum yields involves the detail knowledge of the location oceanic front, the regions of high biological productivity. The algal blooms, which often form in re-stabilizing water masses near frontal zone, can develop, under favorable conditions. Further, survival strategies of fish on the continental shelve presumably include the response to temporal and spatial scales of coastal front.

Oceanic fronts are areas of particular interest contributing to the continual nutrient mixing of the ocean. In oceanic front areas, there is rapid change in temperature, chlorophyll and salinity distribution while the horizontal gradients of these properties are homogeneous in the surrounding water masses. Fronts have significant effect on biology. These systems tend to form zones of convergence of different water masses resulting in accumulation of planktonic organisms. This aggregation also affects the distribution of secondary producers and pelagic herbivorous.

Waters of the continental shelf tend to be slightly less saline (due to runoff and river water input) than the rest of ocean being also more prone to heating and cooling. In the boundary between continental shelf and open ocean waters exits front marking the transition from shelf water to the open ocean (shelf break front). In winter cooling and wind mixing mean that the shelf water is cooler and less saline than warm saline off shore. The in turn results are increase the primary production and fish aggregation. Ocean frontal boundaries are located through out the world's oceans. They represent the areas of high interest to scientists of many disciplines and commercial fisheries industry because they represent regions of strong anomalies in the ocean, high biological activity, dynamic chemical processes and change in acoustic propagation. It is commonly known that fish orient themselves toward fronts.

Satellite observation of fronts

In remote sensing images, these represent boundary between two water masses of different properties. The fronts can be easily delineated in sea surface temperature images and in the ocean colour images due to variation in SST and chlorophyll concentrations. Plate 4.4 shows the chlorophyll concentration fronts in ocean colour images. The sharp boundary is clearly visible in an image. The different types of shape of fronts have significance to fishery resources. For example, the meandering types of fronts occupy more areas spatially as compared to linear fronts.

In oceanic front areas, there is rapid change in temperature, chlorophyll and salinity distribution while the horizontal gradients of these properties are homogeneous in the surrounding water masses (Plate 4.4). Fronts with large SST or chlorophyll concentration act as boundary for resources distributions. Fishery resources follow the frontal boundaries for their movement and for search of their food. These systems tend to form zones of convergence of different water masses resulting in accumulation of planktonic organisms. This aggregation also affects the distribution of secondary producers and pelagic predators.

4.2. Synergistic analysis of oceanic features

The synergetic analysis of biological (chlorophyll concentration) and physical (temperature) processes allow us to understand oceanic environment supporting the food chain in the dynamic medium. Present study only deals with features, i.e. the shapes of different water mass, at different concentration of chlorophyll to that of its environment represented by SST. The pattern and persistence of colour and thermal features were analyzed. The comparable features were marked in the serial number in both sensor images (Plate 4.5 & 4.6). Chlorophyll concentration and SST features showed inverse pattern. The high chlorophyll concentration was observed in the comparatively cold-water masses. This indicates that the cold-water masses consist of nutrients in euphotic zone, which enhance the primary productivity. The details of features types, its morphology, occurrence, persistence and appearance in SST and chlorophyll images are given in Table 4.1. The chlorophyll concentration images showed many well-developed features exhibiting water circulation patterns and distribution of biomass. The prominent features were observed in both sensor images, although all the features seen in the chlorophyll concentration images were not seen in the SST images. Local wind, tidal currents and bottom topography may play major role in the formation as well as distribution of features. Oceanic features were well-

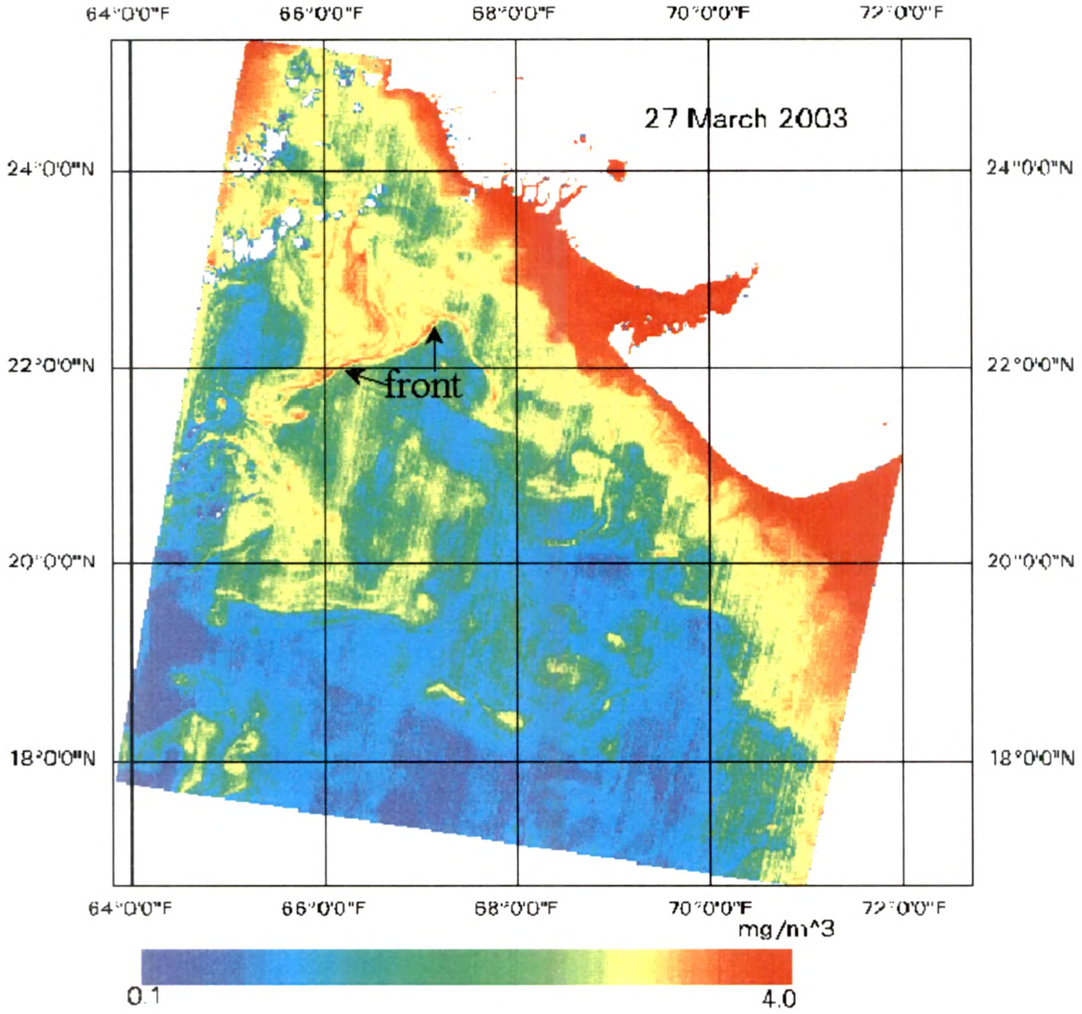
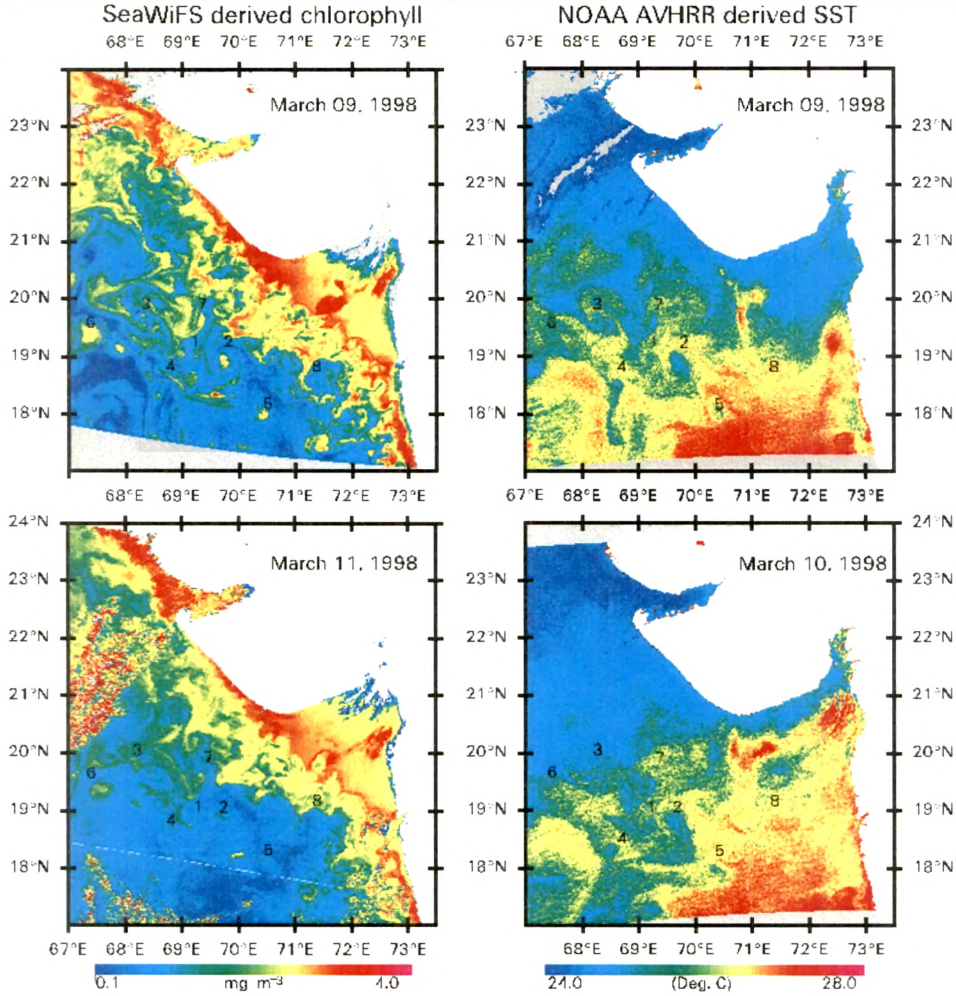


Plate 4.4. A typical image showing ocean colour front showing sharp gradient of chlorophyll concentration and its extent of distribution.

defined in chlorophyll concentration image as compared to SST image. The reasons could be the characteristics of satellite sensors. The infrared sensor can detect radiation emitted from the sea surface only; hence it provides only surface information. The ocean colour sensor has the ability to detect the back scattered radiation originated from down to one attenuation depth. Hence, the colour sensor can distinguish the water masses on the bases of different column production. The chlorophyll frontal zone positions were coincided with temperature boundaries at some locations. This indicates that the physical and biological processes were closely coupled at these locations. The co-existence of colour and temperature features with some horizontal displacement and with some difference in the fine morphology of the features.

Synergistic analysis of chlorophyll & SST features



•Some chlorophyll features were found coincided with temperature boundaries (1-5). This coincidence indicates closely coupled bio-physical process at some locations.

•Inverse relationship was observed. High catch was observed at location of matching features.

Plate 4.5.: The plate shows results of synergistic analysis of oceanographic features. Serial numbers indicate the matching features in chlorophyll concentration and SST images

Table 4.1: Feature types and their characteristics observed in the images

Sr. No.	Feature type	Figure	Feature No.	Characteristics in Chlorophyll image	Characteristics in SST image	Remarks
1.	Rings	1	1,2,4,5 & 6	High chlorophyll concentration was observed inside the rings. Chlorophyll concentration decreased on subsequent day.	Cold core rings were observed. Ring persist on subsequent day. Off shore rings were not clearly seen.	Cold core ring was observed with high chlorophyll concentration.
		2	5	Anticlockwise circulating ring with high chlorophyll concentration was observed.	Relatively cooler water seen around the areas of ring. Ring was not clearly seen.	Ring was clearly seen in chlorophyll image as compared to SST image.
2.	Tongue shaped	1	3	Low chlorophyll concentration along the periphery and high concentration inside the feature was observed.	Relatively warmer water along the periphery and cooler water inside the feature was observed.	Temperature variation within feature was comparatively less.
3.	Mushroom shaped	1	8	Low chlorophyll concentration water was surrounded by high chlorophyll concentration.	The feature was not clearly seen on March 09, 1997.	Feature was observed only in chlorophyll image.
4.	Anchor shaped	1	7	Shelf water with high chlorophyll concentration was found pushed toward off shore.	Relatively cool water was seen in anchor shaped shelf water mass.	The movement of shelf water masses towards off shore was observed.
5.	Coastal jets	2	1 to 4	Coastal jets were found along the coastal line. High chlorophyll concentration was observed.	Coastal jets were seen with relatively cool water in the image.	Coastal jets were formed due to tidal current.

6.	Meanders	2	6 & 9	Shelf water with relatively moderate chlorophyll concentration entered in the off shore water masses.	Meanders were not clearly seen.	Feature was clearly observed in chlorophyll image only.
7.	Fringe front	2	7 & 8	The high chlorophyll concentration containing shelf water was pushed towards eastward.	Fringe fronts were not prominent in SST images.	Feature was found more prominent in chlorophyll image.

There are several reasons for horizontal displacements such as cross frontal diffusion, time required for phytoplankton. Plate 4.5. depicted near synchronous SeaWiFS derived chlorophyll concentration and NOAA AVHRR derived SST images of March 1998 show comparable features. Features delineated are marked on the image for the biological process like delay in the growth of phytoplanktons, supply of nutrients and different scanning timing. Therefore, colour features have been dynamically related to biological processes under influence of several factors from photosynthesis, wind direction to the space and time apart from the temperature alone.

The fish catch points were plotted on chlorophyll concentration and SST images (Plate 4.6). The high catch points were observed in the vicinity of persistent thermal as well as colour features. The cool water is an indicator of high nutrient availability. In such areas probability of enhanced production is more as compared to stratified warm waters. Thus, coincidence of ocean colour and thermal features can be utilized for exploring fishery resources. In general, the features showing inverse correlation are considered to be productive areas and hence are known to be potential fishery resources zones.

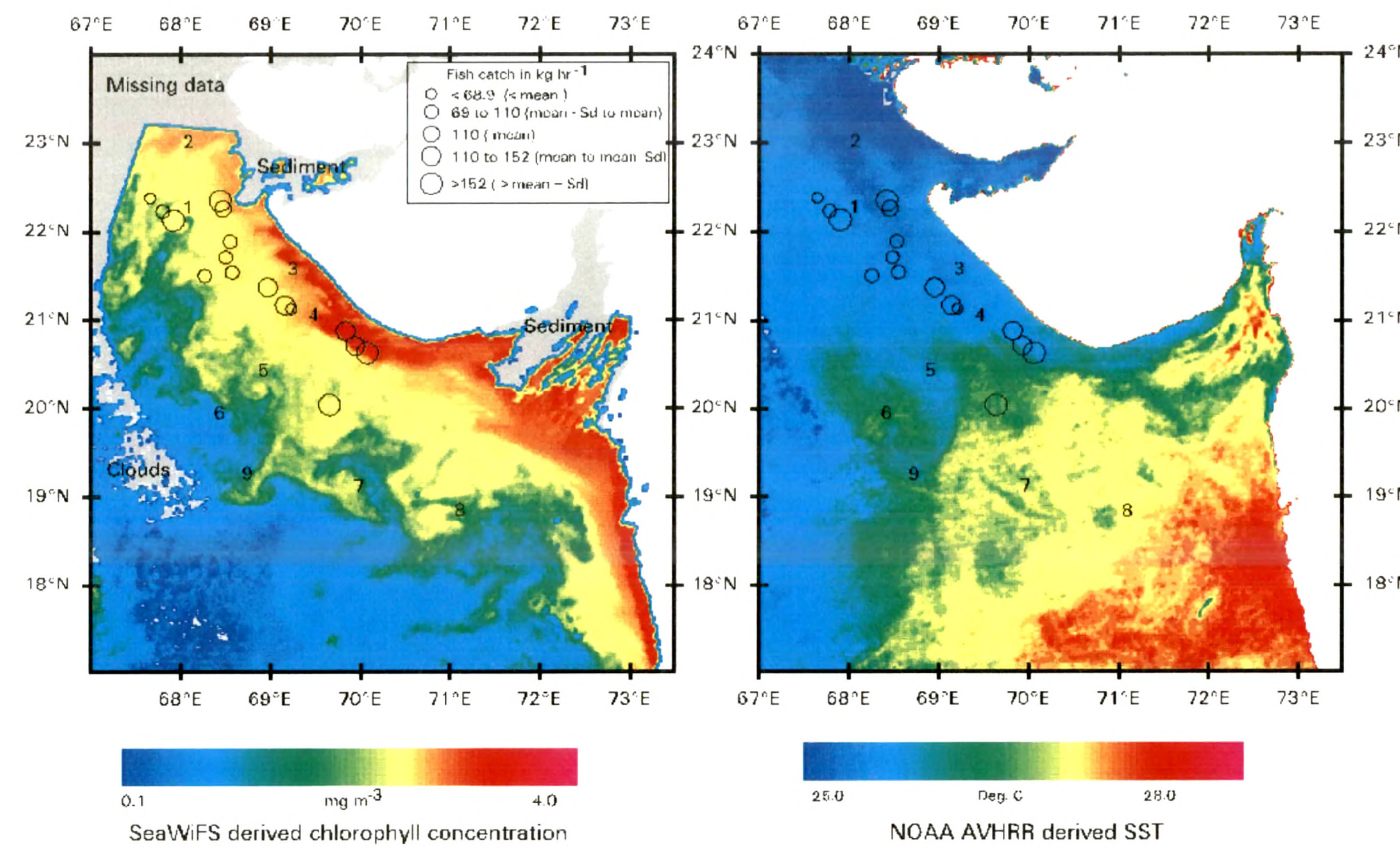


Figure 4.6. Near synchronous chlorophyll concentration and SST images of November 19, 1997 show comparable features and fish catch points. The catch points were classified in different categories based on the mean (μ.) and standard deviation (SD).

4.3. Observations of Biological and physical coupled processes in the sea

The biological–physical interactions in the sea are characterized dynamics processes. These dynamic processes occur on multiple interactive scales. The dynamic processes, whether physical, biogeochemical, or ecological, occur on multiple interactive scales. They are time and scale dependent. The matching, mismatching, and/or competing scales among physical and biological processes determine the sensitivity of a particular response to the rate of a forcing process. The physical processes on an hourly time scale affect primarily the physiology of plankton, diurnal scales affect on growth rate and at longer scales affect on population as well as community dynamics. Thus, the rate of emergence of a particular physical event and its duration can strongly influence the biomass and size distribution of organisms. The large-scale interactions (such as changes in the global wind field) can influence small-scale interactions among predator and prey species. This affects the species composition and age structure of a food web. Similarly, smaller-scale processes influence upon larger scale processes. Nutrients are injected directly by the lifting of isoclines of constant nutrient. These events have been shown to have basin-scale implications on primary production. The understanding of the linkages among physical processes with biological processes and the transfer of produced organic matter through the marine food web involve several kinds of interactions. These interactions may be associated with exposure of phytoplankton cells to nutrients re-mineralized in the deep sea, exposure of phytoplankton cells to nutrients via heterotrophs in near-surface waters, the exposure of phytoplankton cells to light and predator–prey dynamics. A review of

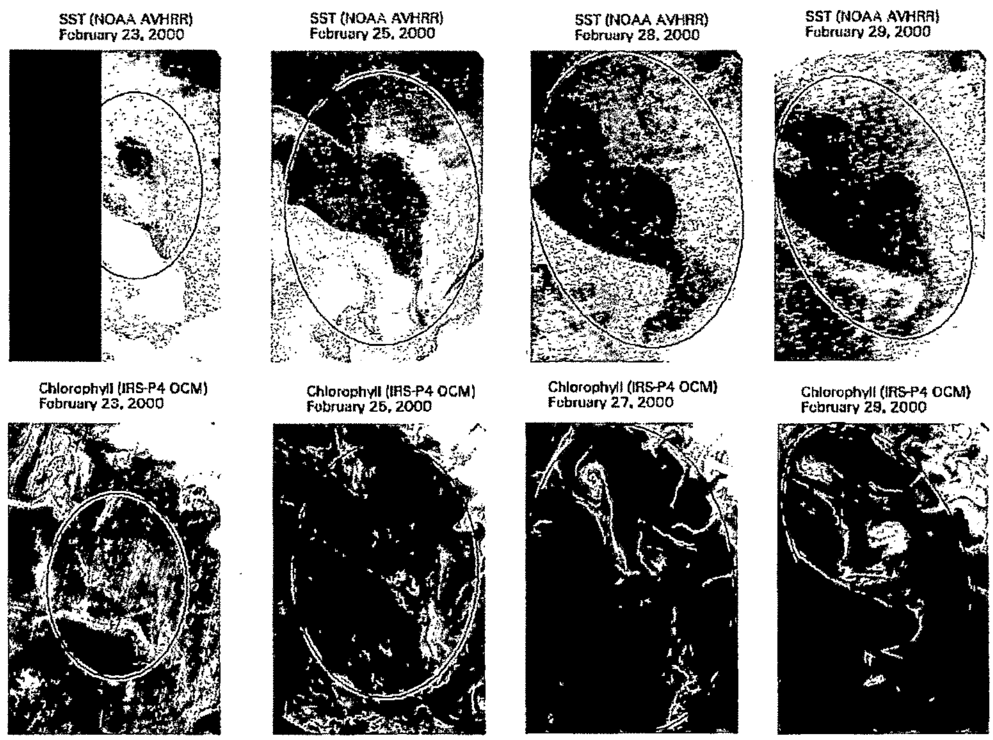


Plate 4.7: A comparison of OCM derived chlorophyll concentration and AVHRR derived SST. Most of the oceanic features are co-located in CC image and SST image indicating coupled biological and physical process. Dark to light sheds indicates lower to higher values of CC and SST.

biological and physical interactions in the sea had been documented by McCarthy *et al.*, (2002).

4.3.1. Signatures of bio-physical processes

Time series AVHRR SST and OCM chlorophyll concentration (CC) processed images are shown in plate 4.7. This indicates that the features observed in CC images are also visible in AVHRR SST images. The inverse relationship between CC and SST is clearly visualized in an image. Similar observations were made by Chaturvedi *et al.* (1998). The features shown in the circle are similar in the shapes in both CC images and SST images. This is the case of anti-clock eddies visible in SST and chlorophyll images. On February 23, 2000 cold water mass was observed in SST image forming cold core eddy. Temperature is decreasing day by day from February 23 to February 29 forming two cold-core eddies in same area, as indicated in the circle. Chlorophyll concentration was found increasing gradually day by day. The high chlorophyll concentrations were observed on the February 25 and 26, 2000 in the areas of eddy. The gradual progress toward the development of eddy formation is clearly visible in this area. They persisted for longer duration in the same areas. This indicated the inverse relationship between the two variables. This confirms that the biological and physical processes are closely coupled in a given area represented by CC and SST, respectively.

Plate 4.8 exhibits composite image of ocean colour features in the IRS-P4 OCM derived CC image and SST contours derived from NOAA AVHRR, which

Identification of PFZs

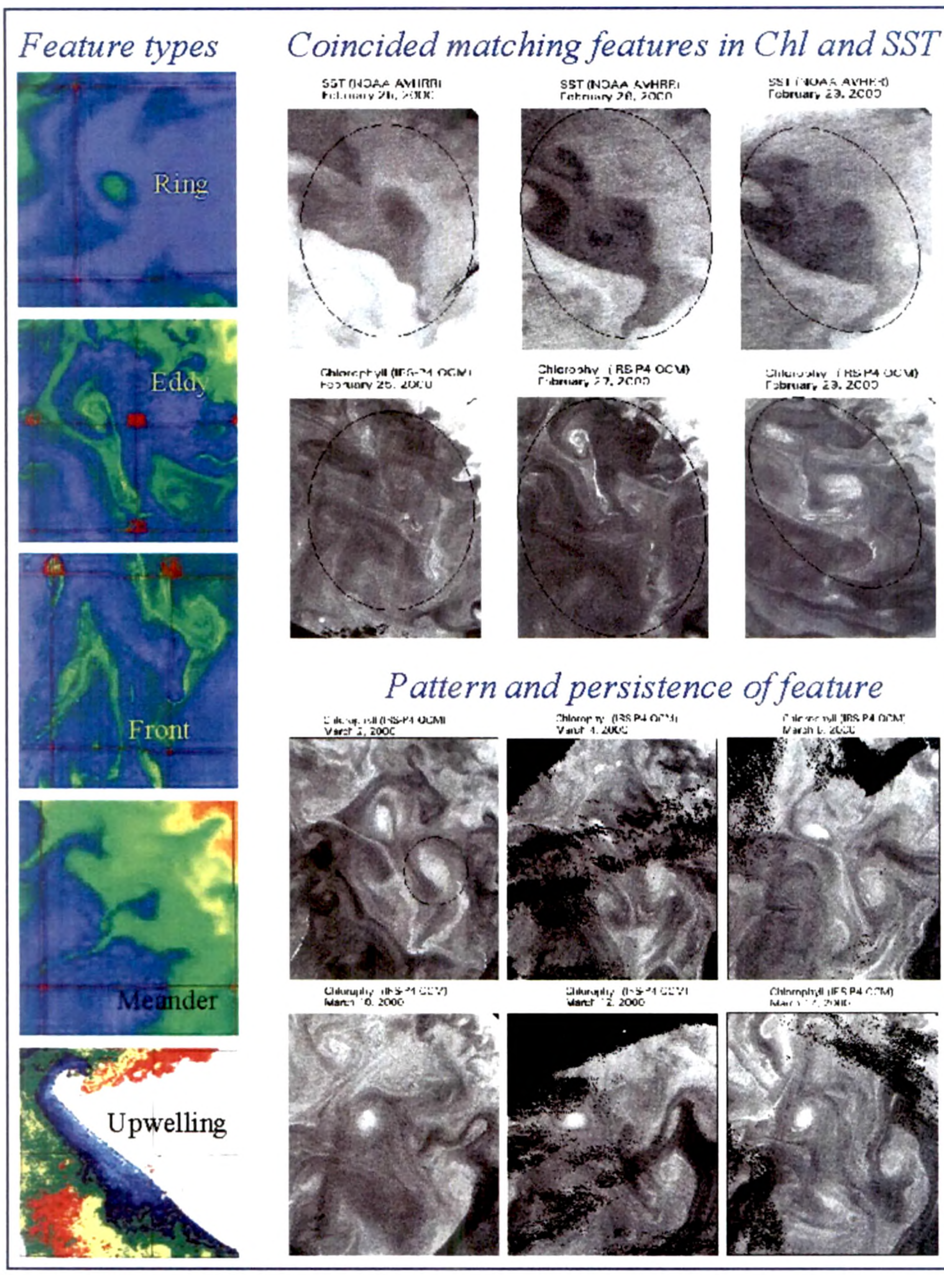


Plate 4.10. Feature types and event for identification of PFZs and their selection criteria. (Refer table 4.3 for relevance of each feature type with fishery resources)

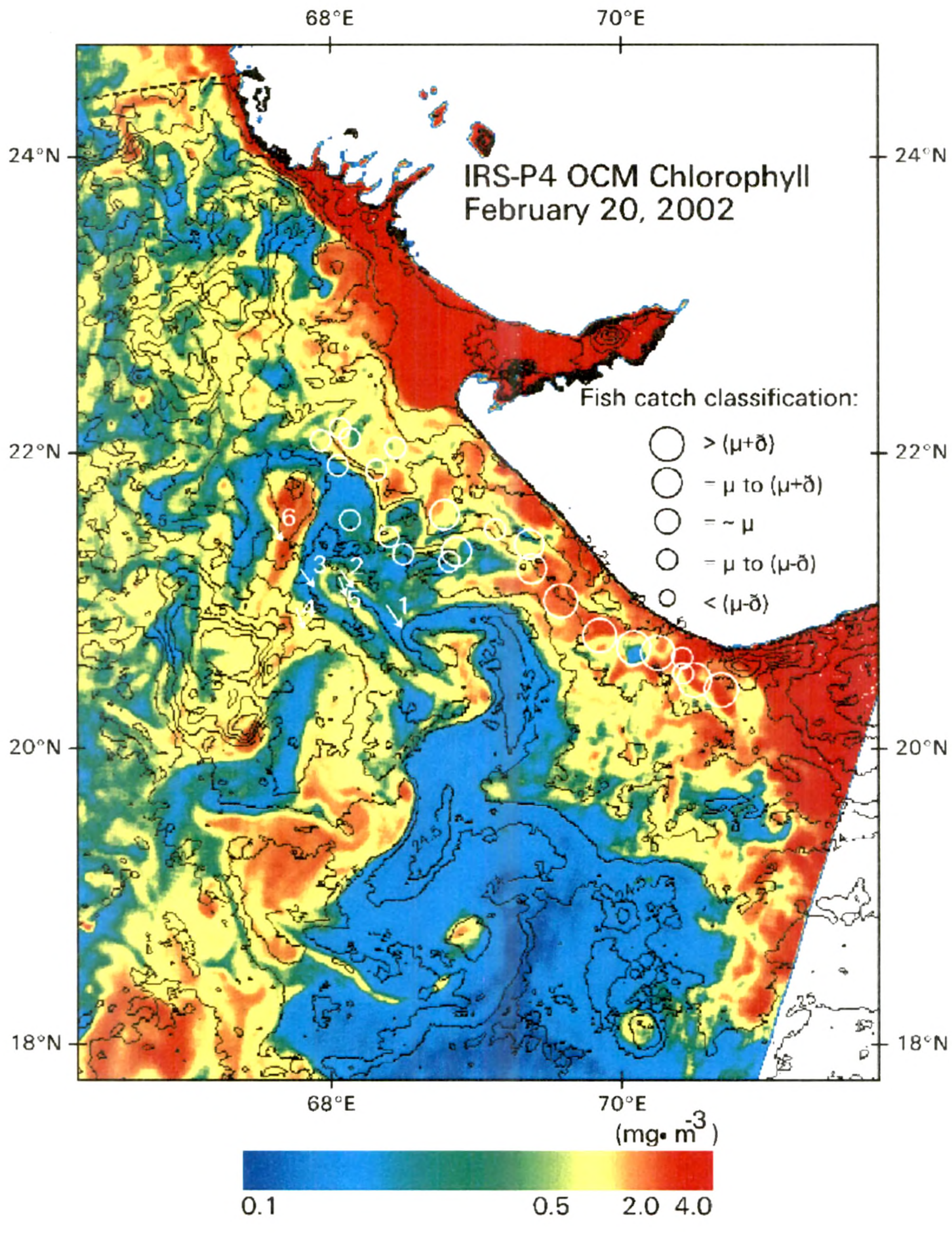


Plate 4.8: A composite image of chlorophyll concentration and SST contours indicating ocean colour features co-incided within thermal boundaries at some locations. Circles indicate the categorized fish catch and arrows indicate the tuna long liner fishing tracks.

represent the thermal features. The ocean colour feature and SST features found closely co-located/matching at some locations in the composite images produced through integration of CC and SST. The coincidence of ocean colour and thermal features represented the biological and physical closely coupled processes. Hence, ecosystem structure is closely coupled with variations in physical forcing. The concentration of chlorophyll pigments is an index of primary production and SST is assumed as an index of physical environment, which control the physiology of the living organisms and also represent supply of nutrients to an ecosystem. Up-welled cool water is considered as nutrient rich water as compared to warm stratified water. High CC was observed in areas of comparatively cold water. The dynamic closely coupled bio-physical processes had indicated the sites of increased biological production.

4.3.2. Application of bio-physical processes for fishery resources

The areas of matching features were selected for fishing. High catch was reported near the areas of closely coupled bio-physical process. Comparatively higher CPUE values were found in the vicinity of matching features (plate 4.8). About 85 per cent observations were found with increased fish catch in identified PFZs areas as compared to other areas. An average magnitude of increase in catch was found to be ~ 104 per cent in identified PFZs areas. The catch composition was consists of ribbon fishes, cat fishes, decopterids, sardines, mackerels, croackers, perches etc. Tuna long line fishing operations were carried out in the off shore areas. Table 4.2 indicates details of fishing and the per cent hooking rate of each fishing trial with reference to white arrows marked on an image (plate

4.8.). High per cent hooking rate were found close to the algal blooms and thermal boundaries in comparatively warmer clear waters. The closely coupled bio-physical processes are indicator of healthy ecosystem which supports the living organisms.

Table 4.2: Catch details of tuna long liner used for tuna fishing in identified PFZs

Sr No	Date	Positions of fishing areas		Depth (m)	Hooking rate (%)	Species caught
		Shooting	Hauling			
1.	18/02/02	20° 57' N 68° 24' E	20° 50' N 69° 29' E	2590	3.8	Thunnus *albacares* *Katusawonus pelamis*
2.	19/02/02	21° 11' N 68° 05' E	21° 06' N 69° 09' E	1700	1.9	*Thunnus albacares* *A. pelagieus*
3.	20/02/02	21° 12' N 67° 48' E	21° 06' N 67° 53' E	1876	1.0	*Thunnus albacares*
4.	21/02/02	20° 56' N 67° 46' E	20° 49' N 67° 49' E	2725	1.2	*Thunnus albacares*
5.	22/02/02	21° 08' N 68° 04' E	21° 03' N 68° 06' E	1790	2.1	*Thunnus albacares*
6	23/02/02	21° 30' N 67° 36' E	21° 25' N 67° 40' E	1860	1.9	*Thunnus albacares* Isurus oxyrhincus

Physical processes in the upper ocean influence biological processes and ultimately determine distributions of living resources. The rate of progression of a physical process affects the physiological rates, growth rates, and population dynamics of marine organisms. Physical processes of front genesis include horizontal advections that increase concentration gradients associated with shearing flows, convergence, wind-driven / topographic upwelling and tidal mixing, which eliminates stratification on one side of a front (McCarthy et al., 2002). The biological processes involved in frontal dynamics vary by location and trophic level. Biological scales and rates associated with these processes vary by orders of magnitude from the lowest to the highest trophic levels.

4.4. Identification of PFZs

The basic premise is the observations of ocean colour from space, which provides a measure of the areas of enhanced biological production and plant biomass occurred at the frontal structures, shelf sea fronts, topographic structures (banks and ridges), upwelling zones and at physical features (current system, eddies spurts, jets etc.), where zooplankton and fish populations are known to accumulate for feeding, spawning and early life development. Remotely sensed measurements of SST provide an additional measure of these physical structures where biological processes are enhanced. Thus imageries of ocean colour and SST provide information of both a measure of primary production (biomass), at the base of the food chain and the location of the areas where the higher trophic levels will thrive. Demersal (bottom living) fishes are likely to thrive at zones of high pelagic production, since their benthic food resources are directly enhanced by the high primary production in the euphotic zone.

The identification of PFZs is based on satellite-derived oceanographic biophysical parameters and their relevance to fishery resources. This is mainly concern with identification, quantification, and synthesis of information derived from satellite sensor as well as understanding the linkage with habitat of fishery resources. The habitat factor influencing the distribution, abundance, growth, food and feeding habits, species interaction (prey-predator), spawning habitat and survival of resources in an ecosystem. Fishery biology related knowledge of anatomical structures, physiological limitations and early life history is required to relate the information derived on images with resources availability. Hence, the identification of PFZs require immense knowledge of satellite parameter retrieval limitations, oceanic environment, the fish behavior, food and feeding habit, anatomical structure, physiological limitations, reproductive physiology and early life history of fishes. The feature types selected for identification of PFZs, their scientific significance, selection criteria and their relevance with fishery resources distribution have been discussed here.

4.4.1. Image interpretation key for identification of PFZs

The composite product of integration of chlorophyll concentration and SST generated using methodology mentioned in chapter 3. Composite product generated using integrated approach shows chlorophyll concentration/features and SST values/features. Interpretation of this composite is critical to identify the PFZs. There are different criteria for identification of fishing ground and their locations on the image data. These are based on identification of feature types (their characteristics, shape, size, persistence, and morphology) and oceanographic events (initiation, maturation and dissipation) in satellite derived products.

Plate 4.9 shows feature types for PFZs identification and their selection criteria. The description of interpretation of features and their relevance to fishery resourecs have been presented in table 4.3. Plate 4.10 indicates the selected PFZs based on the criteria and relevance discussed.

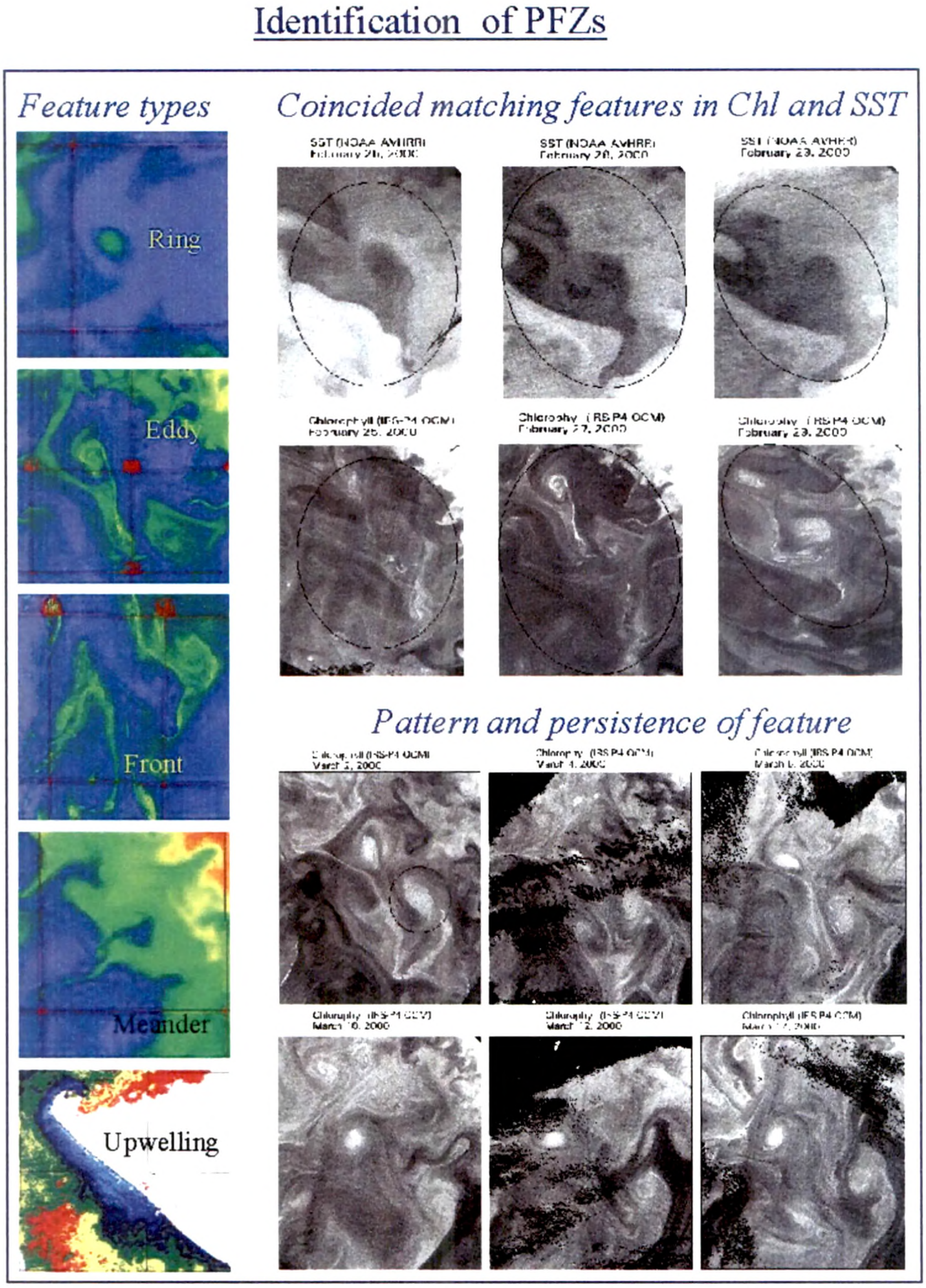


Plate 4.90. Feature types and event for identification of PFZs and their selection criteria. (Refer table 4.3 for relevance of each feature type with fishery resources)

Table 4.3: Oceanographic features and their relevance to fishery resources

Sr. No.	Feature type	Definition/morphology description	Relevance to fishery resources
1	Oceanic fronts (Colour and thermal)	Fronts are the boundary between the two water masses with different property. They can be easily detected as breaks in ocean colour (chlorophyll concentration) or SST of water mass on an image.	High chlorophyll is an indicator of biomass production. Hence, resource sustained for longer period. The chances of development of local ecosystem are more, which enables benthos exploration. Higher SST gradient is an indicator of upwelled water from deeper layer. Hence, the water with more nutrient concentration would be available in euphotic zone, which enable enhanced production. Restrict the movement in the case of species, which prefer particular temperature range e.g. Tuna.
2.	Meandering pattern of features	A turn or winding of the current that may be detached from the main stream. Easily detected through curvatures in the images.	They cover large area extends. So that even if feature shift potential area may not shift totally. This also helps in delayed fishing. In the smaller area large amount of phytoplankton concentration is available as compared to linear feature. It forms enclosed pocket, hence confine the resources. Some time it turns into rings, which are productive and important for resources exploration.
3.	Eddies	The current of water often on the side of the main current, especially one moving in a circle. Easy to monitor in space and time.	Rotating water masses cause deep mixing and hence nutrient enrichment occurs leading to high production. Persistence for relatively longer duration. The visual predators like tunas prefer periphery of eddies and steamer.
4.	Rings	Rings are derivatives of meanders and eddy. Easy to identify on an image.	Rings are productive and already localized developed ecosystem. These features ensure secondary and tertiary production.
5.	Mushroom shaped features	The feature appears as mushroom shaped on an image.	Form an enclosed pocket. Periphery is important. Sometimes ring from inside which may be productive. Form due to wind driven current.

6.	Coastal Upwelling	Easily detected in thermal imagery. Appear as different bands of thermal gradients in the images.	Indicates the nutrient rich water transported from bottom to surface. Form in different phases like initiation phase, stabilization phase, and maturation phase. Initiation phase should be avoided for fishing due to low oxygen water. In the maturation phase well developed ecosystem forms, should be exploited.
7.	Shelf break front	Formed due to bathymetry at shelf and slope depth gradient.	If it is high depth gradient it will appear many times at same location. Persist for longer period. Supporting ecosystem. Not suitable for bottom trawling.
8.	Plume front	Plumes form mostly in the coastal area near river mouths as well as discharge points of effluent.	Coastward side should be avoided because of the turbidity; generally fish avoid turbid water due to poor visibility and blocking of gills. Seaward side may explore for resources. Sediment images may be checked before suggesting the PFZs.
9.	Diverging fronts	Water flow in the different direction from the center due to diverging current.	The process enrich the nutrient supply, which support the enhance production.
10.	Converging fronts	Two or more fronts converge at one point.	Causes mechanical aggregation of resources and planktons, center may be more productive, can be used for resources exploration.

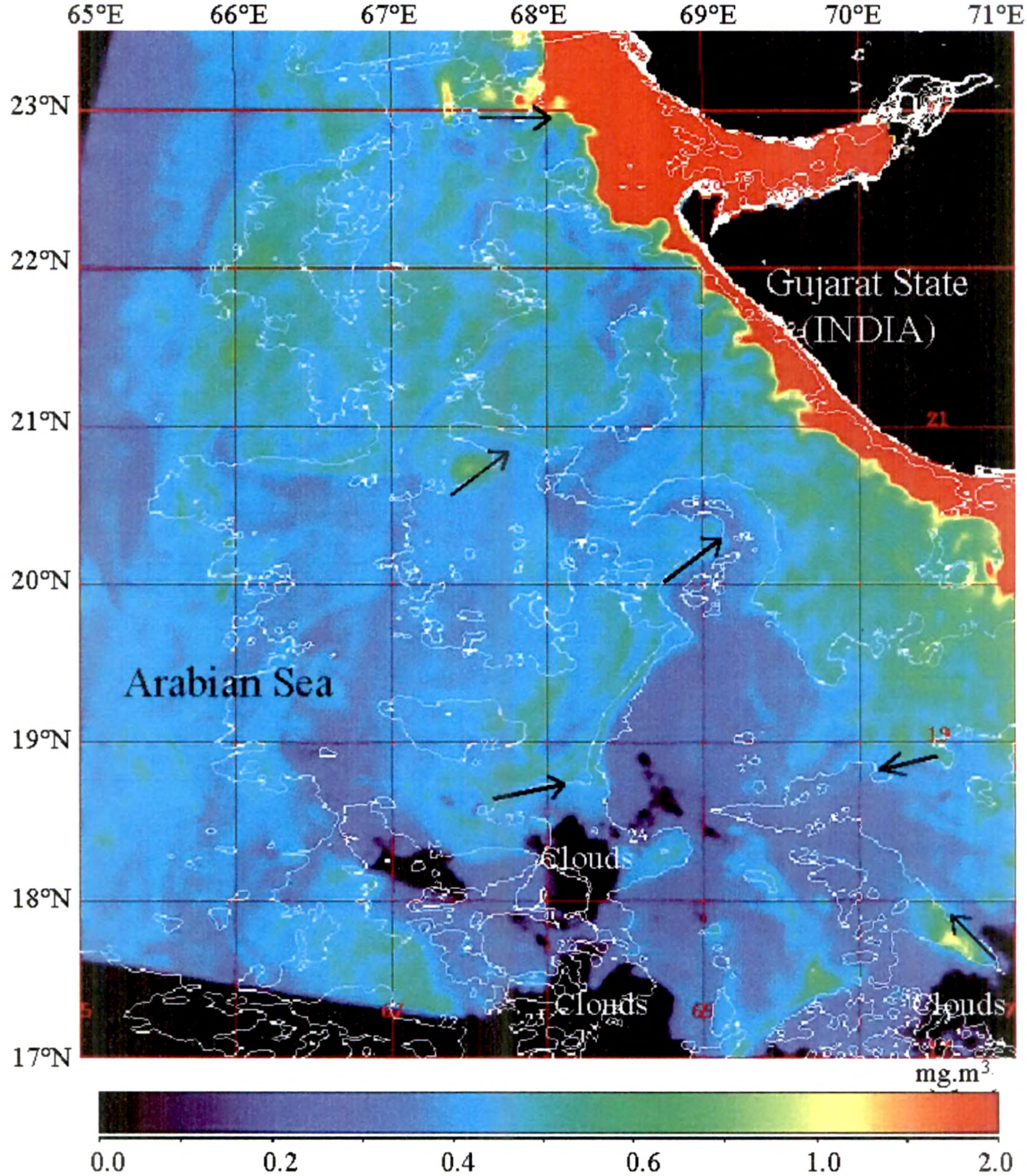


Plate 4.10: A typical composite image generated from satellite derived chlorophyll concentration image (background image) and sea surface temperature (SST in °C) contours. Synchronous near real time satellite data of March 08, 2000 was used. The image shows matching features of chlorophyll and SST. Black lines in images indicate the suggested PFZs.

4.4.2. Selection criteria

The criteria for selection of feature types for identification of PFZs are as discussed here. PFZs selection criteria are very critical and so careful selection is required. There are many features alike. Out of many features few potential features in feasible areas for fishing should be selected. Selection is mainly based on analytical and interpretation experience, historical studies of images, knowledge of the optical and thermal signatures of oceanographic features, food and feeding habit of fish, migration behaviour etc.

Aerial extent - Fronts should be with large aerial extent covering more front zone area in small image area. Preferably, fronts should be meso-scale. Small-scale fronts are transient and dissipate faster. Liner front should be avoided, as many time linear extent of feature is not feasible to explore. The extent and shape of feature amenable to remote sensing, which have a strong bearing on prolong fishing activity.

Shape of front - A curve, non-linear front is preferred, as the resources remain confined to the enclosed pocket. *Meander* feature types are promising areas for PFZs exploration.

Magnitude of gradient – Fronts with large gradient of SST and Chlorophyll concentration are suggestive of high primary production available to fishery resources for longer period. A front with large gradient desirable as it acts as barrier for resources distribution and production sustain for longer period.

Persistence – Persistent features can be sighted in an image through time series historical images of previous dates. If feature persist for longer period probability of predator prey interaction is more, this enables sustenance of resources for longer period. A stable front in time is a promising as it provides food resources for longer period which enable prey-predator relationship. More time lags would be available, which is ensuring for formation of local food chain and also result in prolonged fishing activity.

Matching features – Matching features in the chlorophyll concentration and SST images should be selected because matching features are indicators of closely coupled bio-physical processes. Where ever the closely coupled features are seen those areas are most productive, hence, resources sustain in these areas. Combination of chlorophyll concentration and SST matching features indicate

i) Where enhanced production is? (indicated by ocean colour signatures)

ii) Whether the nutrient rich water is available to enhanced production at the sites or not? (indicated by SST signatures)

Co-incidence of ocean colour and SST features indicates that the physical and biological processes are closely coupled.

Spatial shift – Spatial shift of features may be monitored in time series images (historical image data) and conclude the shift direction. QScat Sea winds derived sea wind data may utilize to understand the spatial shift in features.

Maturation of features – Features should be monitored for observations of chlorophyll concentration and SST to understand the maturation of the water within feature area. Increased chlorophyll concentration is an indicator of matured features (i.e. high phytoplankton production) which is conducive of fish aggregation. If chlorophyll concentration is decreasing the features should be avoided to select as biomass is decreasing because of dying of plankton, decreased reproduction due to environmental factors or consumed by predators.

Event related - The events like upwelling features should be monitored critically. Upwelling signature appears first in SST image because of low temperature of upwelled benthic water. This is the initiation phase of upwelling. During this phase signature of upwelling are not seen in the ocean colour images. This phase should be avoided because during this phase low oxygen water will be in euphotic zone and fishes generally avoid low oxygen content water. In the maturation phase the high chlorophyll concentration are visible in ocean colour images at the same time band of low SST are visible in SST iamges. This is the phase of selection for PFZs. Trend analysis method may be adopted to understand the maturation of features in the given areas.

Time lag – Time lag should be long enough for production of phytoplankton. For this, cool water mass should be monitored using SST images and wait till the ocean colour signature appeared in ocean colour images. This ensures the primary production, which would be food source for zooplanktons and ensure the accumulation of fishery resources. When signatures of cold water in SST images disappeared and chlorophyll concentration start decreasing, the ground will not support for longer for fishing activity, during this phase the feature should not be selected.

Fish behavior and habitat consideration - Fish behaviour and preferred environment may considered for selection of PFZs. For this, food and feeding habits should be considered, eg. Tuna is visual predator, it require clear water to capture prey (Laurs *et al* 1985). Certain fishes like Tuna have limits of temperature for their distribution (Maul *et al* 1985). They prefer certain ranges for the distribution (Laevastu and Hayes, 1981). Areas of high sediment should be avoided as sediment choke up the gill of fishes, hence they do not prefer the high sediment areas. Fish habitats were considered for selection.

4.5. Habitat of fishery resources and link with satellite-derived in PFZs

A vast historical database of such published studies exists (Froes and Pauly, 2000; Bal and Rao, 1990) which has enabled a number of useful generalizations to be made for ecosystem based management of fisheries. The food and feeding habits of commercially important species that significantly contributed in fish to the catches in PFZs has been compiled in Table 4.4.

Table 4.4: Description of food and feeding habits of significantly contributed fishery resources in PFZs.

Sr. No.	Common/ English name	Species name	Habitat	Food and feeding habitat
1.	Ribbon fish	*Trichiurus lepturus*, *Lepturacanthus savala*, *Epleurogrammus intermedius*, and *E. muticus*.	Pelagic	The food of ribbon fish consist of fish followed by crustaceans, shrimps including, Acetes, Squilla. The diet of adult consist of fishes like *Stelephorus, Thrissous, Sphyaena, Hemirhamphus, Sardinella, Tetrodon, Leiognathus, Dussumieria, Atherina, Stolephorus, Sardenella, Kowala coval, Polynemids*. Rest of the diet is made up of Acetes, other shrimps, squilla, crab larvae, megalopa larvae, young ones of Sepia, zoea larvae. *Lucifer*, alima larvae of stomatopods etc. The food items preferred show that the fish is surface feeder. Ribbon fish are predacious, carnivorous and some times cannibalistic feeders. Majorities are pelagic feeders.
2	Cat fish	*Tachysurus sona*, *T. maculates*, *T thalasinus*, *T. dussumieri* and *T.jeilla*.	Demersal	*T. sona* feeds mostly on fish and crustaceans. The fish diet consists of eel larvae, young ones of *Harpodon, Trichiurus, Coilia, Anchoviella, Chirocentrus* etc. crabs shrimps , squilla, mollusks, *Acetes* and Salps form next important item. *T. maculates* feed on detritus, polychaetes. particles. Other items like foraminifera, ocstracods, amphipods, shrimps, squilla, crabs, bivalves consumed through out year and the food items always found in association with mud and sand suggesting that they are benthic feeders. *T. thalassinus* and *T. tenuispinis* are voracious carnivores feeds at bottom mainly on crustaceans like crabs, prawns, squilla, teleosts and mollusks. *T. dussumieri*, a predacious carnivorous consumes bivalves, gastropods, crabs, ***Acetes***, ploychaetes whereas *T. jella* favours cephalopods and crabs. Cat fishes are generally predatory, carnivorous and scavengers, and voracious bottom feeders. They generally prefer muddy ground for distribution.

3.	Sciaenids (Dhoma, Ghol, croakers, jew fish, Koth)	*Pseudosciaena diacanthus* (Ghol) and *Otolithoides brunneus* (Koth), *Otolithes ruber, O.argenteus, Johnius dussumeri (Dhoma)*	Midwater Midwater Demersal	Their feeding preferences are generally crustaceans, followed by fishes and certain extent on mollusks, echinoderms, annelids. *P. diacanthus* favoured forms are *Ilisha filigera, Thrissaocles, Nemipterus japonicus, Caranx, Leiognathus.* Their crustacean food consists *M. affinis, P. tenmipes* along with crabs, Bivalves, gastropods and cephalopods are also consumed. *Otolithoides brunneus* also switches its preference from crustaceans in its juvenile stage to piscivorous consist of *Coilia dussumieiri, Trichiurus* and *H. nehereus.* *Otolithus ruber* prefers cruacean food, through out the year, fish form the secondary food item, while cephalopods are taken occasionally. The fish food consists *Bregmaceros* sp., *P. heptadactylus, Sciaena* sp., *Stromateus* sp., *H. nehereus*, etc. *O. argenteus* feeds occasionally on *echiuroids, polychaetes* and *mysids*, in addition to its main items of food, viz. crustaceans and fish. Among the *crustaceans, Acetes* and *Squilla* are the main species favored and fish like *Stolephorus, Bregmacerous.* In general, Ghol and Koth are carnivorous and active predators. They are surface and midwater feeders. Domas are bottom feeder but O. rubber seems to restrict itself to surface and midwater feeding. *O. argenteus* like *O. rubber* is a surface feeder.
4.	Barracudas	*S. jello* and *S. commersonii*	Pelagic	The food composed of fish like *Bregmaceros mcclellandi, Appogon spp.*, and crustaceans through out the year. They are pelagic, diurnal and solitary but can be found in small schools. They are predaceous and carnivorous.
5.	The lesser Sardines	*Sardinella jussieu, S. albella, S. fimbriata, Kowala covla, Dussumieri*	Pelagic	They are essentially plankton feeders with preference for zooplanktonic organisms, diatoms, filamentous algae. *Sardinella jussieu*, and *S. albella* feed on zoea larvae, copepods, *Lucifer*, pteropods and blue green algae *Trichodesmium erythraeum. S. fimbriata* feeds on phytoplankton and zooplanktonic organisms. *Kowala covla* is plankton feeder, with zooplanktoinc organisms dominating among its food. *Dussumieri acuta* feeds on crustaceans

		acuta, D. seltii		while *D. hasseltii* known to subsist on planktonic organisms. Majority of them are plankton feeders.
6.	Squids	*Sepioteuthis arctipinnis* and *Lologo duvauceli*	Pelagic	Cruastaceans, viz. shrimps and crabs and small fish constitute the principal food. They are also cannibalistic in its diets. They are pelagic and move in the shoals,
7.	Mackerel	R. *kanagurta, R. brachysoma, R. fauhni.*	Pelagic	Their food consists of phytoplanktons and zooplanktons. The phytoplanktons comprises the diatoms represented chiefly by *Coscinodiscus, Pleaurosigma, Chaetoceras, fragillaria, Thalassionema, Skeletonema, Thalassiothrix, Biddulphia, Dipnophysis,* etc. The zooplanktons belongs to varied groups of organisms , the crustaceans form the major portion with copepods in high percentage. The Indian mackerel is a surface feeder.
8.	Nemipteds	Nemipterus japonicus and *N. bleekeri*	Demersal	They are bottom living. They feeds on wide range of bottom living animals, invertebrate worms, chytocerous, mussels, cephelopods and fishes. The diet changes litle with size. They are benthic feeder.
9.	Carangids	*Decapterus russelli, Caranx elampygus, C. carangus*	Columne r/demersa l	Food of *Decapterus russellii* is mostly clupeoid fish, some diatoms, copepods and other crustaceans. The juveniles feed on *Acetes* and copepods. Food of *Caranx melampygus* is mostly copepods and crustaceans and larval fishes while food of *Caranx carangus* is stomatopod larvae, crustaceans and polychaete worms. *Alectis indicus* (Thradfin Trevelly) feed zoea larvae, amphipods, cirripede larvae and copepods. They are bottom cum column feeders.

The information on food and feeding habits of fishes is essential for a better understanding of their life history including growth, breeding and migration. This information is also important for management of fishery resources using remote sensing. The knowledge of favorable feeding grounds of commercial fish stocks is of great practical significance to fishermen to expand their fishing effort profitably. Partially, this information can be derived through the interpretation of remotely sensed parameters. At the same time knowledge of prey-predator relationship is very useful to interpret availability and management of fishery resources using remotely sensed techniques.

Fishing operation results indicated the mix catch of species belong to different habitats, i.e. pelagic, demersal and column. The sampling efforts in term of actual fishing were carried out in 30-100m depth of the continental shelf. In this area majority of the water column comes well within light penetration depth. This enables distribution of pelagic and column species up to the bottom. Hence, the fishery resources remain largely indiscernible in the light penetrating zone of the water column. The food and feeding habitats play a key role in the distribution of resources. Congregation of food in different habitats at surface, column and sea bed controls the distribution of fish population. The production and congregation of food resources at surface and subsurface can be easily detected by ocean colour sensor as it has capability to look into the sea. The ocean color sensor can detect the radiation back-scattered from one attenuation depth in the water column. This helps to locate sites of enhanced production available as food to the resources in the habitat zones. Habitat of fishery resources also depends on physiologically suitable environment. Satellite derived sea surface temperature (SST) partially explain the environmental suitability to fish with reference to their physiology. Fishery resources of benthic zone depend on the food resources available on sea floor, detritus material, vertically migrated plankton and other marine living resources. Hence, where ever surface and column production is more, the probability of availability of food resources at different trophic levels including benthos is comparatively more in an ecosystem. Majorities of the species contributed in PFZs are primary, secondary or tertiary consumers feeding on different stages of life cycle of prey except herbivorous like sardines and mackerels. This indicates the high ecosystem diversity, i.e. variations in communities of species within an ecosystem and high physiological diversity, i.e. variations in feeding, reproduction and predator avoidance strategies within the community. The high ecosystem diversity reflects availability of a wide variety of ecological niches. High physiological diversity reflects a greater ability of community within an ecosystem to adjust to environment. High species and physiological diversity in an ecosystem are indicators of a healthy ecosystem. Hence, the ecosystem of PFZs is stable, yielding high CPUE.

4.6. Patterns of variability in fishery resources in PFZs and other areas

Figure 4.1 depicts the comparison of species-wise seasonal mean catch with the mean catch in PFZs for season October 2000-March 2001. Significant increase in the catch of ribbon fish, catfish and horse mackerel was observed in the PFZs as compared to monthly mean catch in other areas. The ribbon fish and

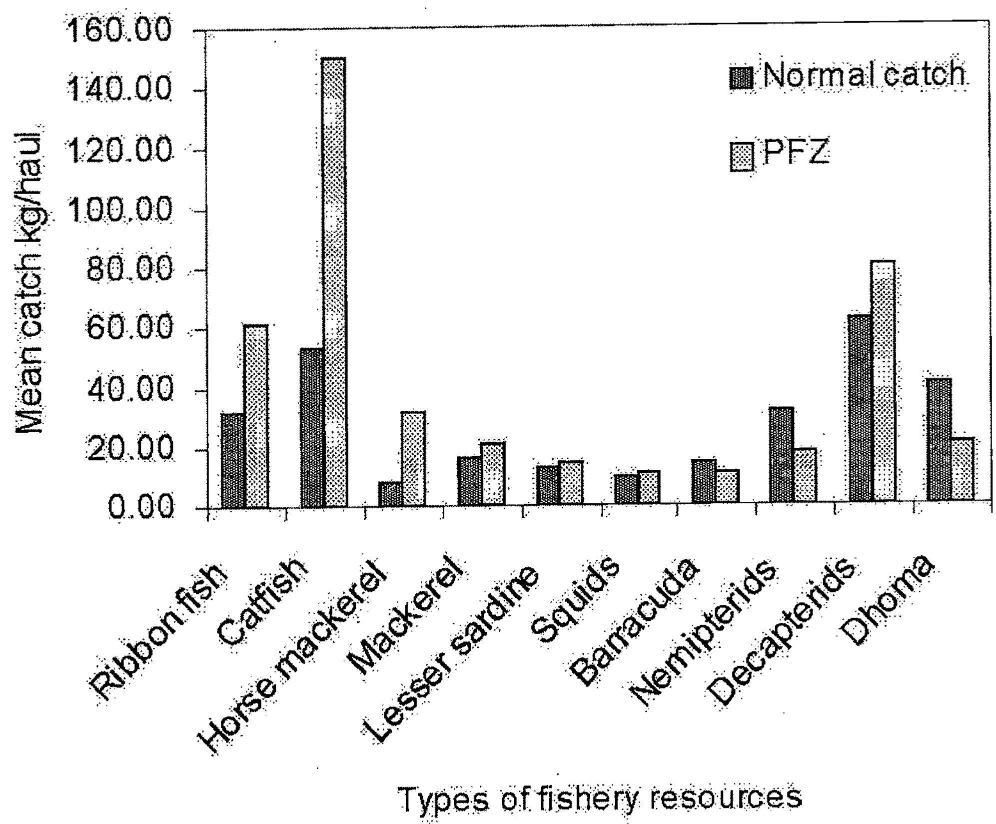


Figure 4.1: Comparisons of fishery resoures composition between normal mean CPUE in other areas and seasonal mean CPUE in remotely sensed PFZs. The fishery resources are from different habitats.

mackerels are pelagic. Comparatively low catches of sciaenids, decapterids and nemipterids were observed in the PFZs as compared to monthly mean catch from the entire fishing area. These are demersal group of species. Other species showed marginal increase in the PFZs. Cat fishes being demersal in habitat contributed fairly high in PFZs as compared to their monthly mean other fishing areas. The catfishes are living at the muddy bottom. The nutrient supply from muddy bottom is known to continue for longer period, favoring the phytoplankton growth in the euphotic zones of muddy bottom areas, which can be captured / sensed by ocean colour sensor. An abrupt increase in mackerel and horse mackerel catch was observed in PFZs. They are herbivorous fishes. This indicated the capabilities of optical satellite sensor to detect the areas of high biological productivity.

Species wise Monthly variability in fishery resources -

Figure 4.2. indicates monthly species-wise mean catch in the PFZs and its comparison with normal catch. This indicates the patterns of the resources availability in the PFZs. The peak season for ribbon fish appears to be in November, catfish catches increase as the season proceeds with peak in the month of February. Lesser sardine and mackerel showed high catch during the beginning of the season and season almost comes to an end in December. Barracuda occurs through out the season and squids show peak in November with decline as season proceeds. Over all catch of all the species declines in January. This may be due to the reversal of current and wind patterns during the North-East monsoon. Monthly trend analysis helps in identifying the trend in the fishery resources, which improve the decision making capabilities at the grass root level for

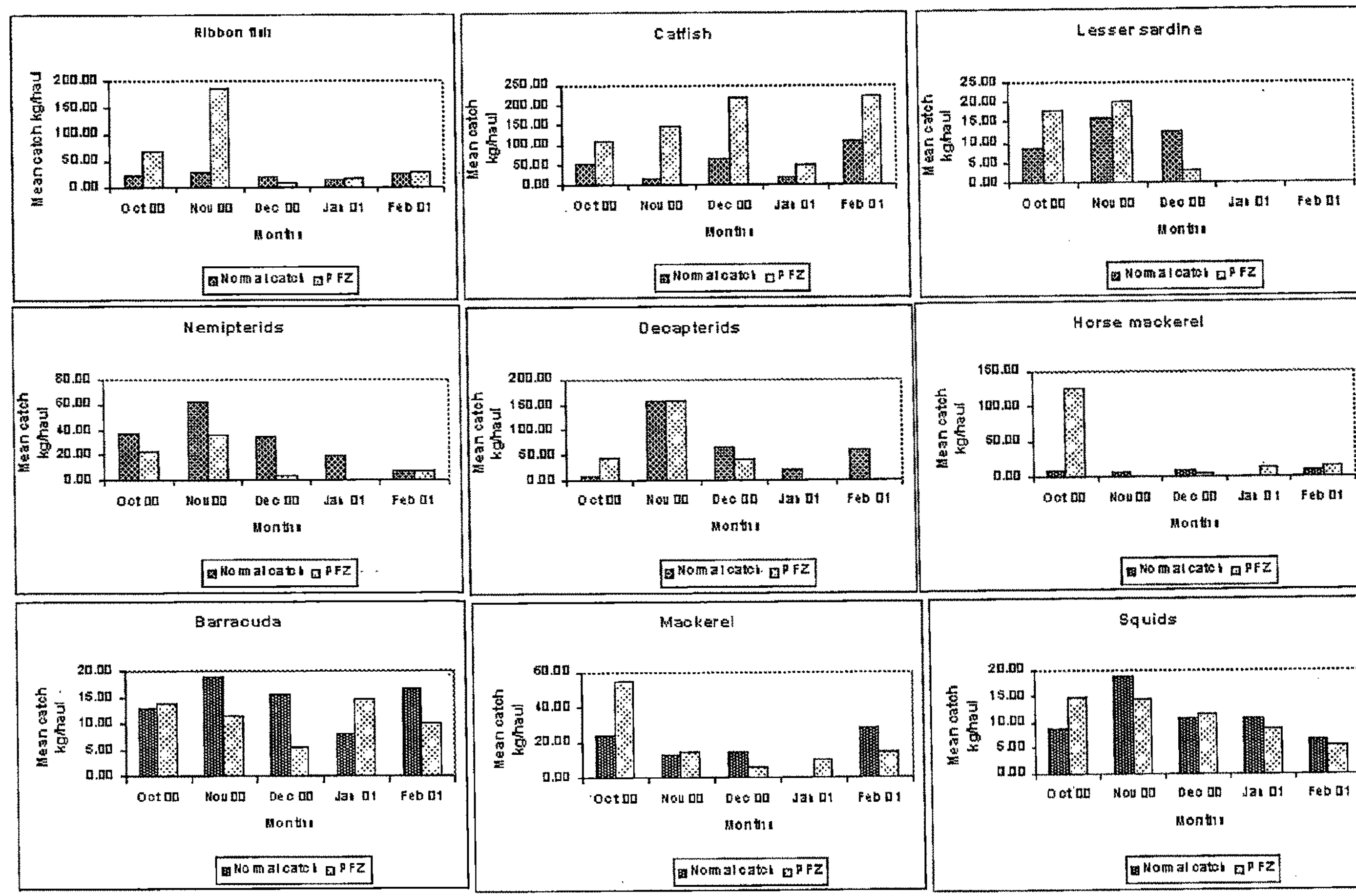


Figure 4.2 Patterns of the monthly variability in different types of fishery resources in remotely sensed PFZs and other areas. A comparison of species wise monthly means CPUE in PFZs with normal catch in other areas

directing fishing efforts. It was observed that within 50m depth zone ribbon fisheries, sciaenids, cat fishes, perches are main the principal component whereas in 50-100m depth zone ribbon fishes, threadfins, sciaenids and horse mackerel are main contributors.

Per cent contribution of species-

Table 4.5 shows the comparison of seasonal species-wise percent contribution in the entire area fished within the PFZs during fishing operation using trawl net. This table also indicates the mean and standard deviation of each species. About 50% of the catch was contributed by ribbon fish and cat fish in the PFZs while the seasonal contribution by these species together was 30%. The contribution of the demersal species like scieanids was 5% in PFZs as compared to 15% seasonal contribution of these species. The per cent contribution of Nemipterids was only 4% in PFZs while their seasonal percent contribution was 11%. However, rest of the species observed to be marginally increased or decreased in the catches from the PFZs. This clearly indicates that basically the technique is more suitable for pelagic resources as compared to the demersal resources. However the catches of cat fishes are highly significant and being demersal in habitat its per cent contribution in trawl catch from the PFZs is 35 % as compared to seasonal mean contribution 19%. This may be because of their bottom habitat where the muddy bottom nature supports high nutrient supply enriching the ecosystem. These results call for R & D to improve in the technique through incorporation of other relevant parameters like bottom nature, wind speed, sediment concentration, bathymetry, current etc. and interpretation of results in GIS environment.

Table 4.5 -Per Cent contribution of species significantly contributed in PFZs

Species	Habitat	Mean & SD Seasonal CPUE Kg.hr^2	Mean & SD CPUE in PFZs Kg.hr^2	% seasonal contribution	% contribution in PFZS	% increase in PFZs
Ribbon fish	pelagic	31.07 ± 19.2	61.17 ± 10.2	11	15	96.87
Catfish	demersal	52.69 ± 14.1	150.37 ± 17.5	19	35	189.18
Horse mackerel	pelagic	7.16 ± 2.0	31.60 ± 8.4	3	8	332.90
Mackerel	pelagic	15.80 ± 5.4	20.25 ± 3.2	6	5	26.50
Lesser sardine	pelagic	12.30 ± 4.0	13.66 ± 3.8	4	3	11.60
Squids	Column/ pelagic	8.80 ± 3.0	10.80 ± 2.1	3	3	22.00
Barracuda	pelagic	14.34 ± 6.0	11.01 ± 2.2	5	3	-23.29
Nemipterids	demersal	31.66 ± 10.4	17.18 ± 6.8	11	4	-45.70
Decapterids	columner	62.22 ± 10.6	80.00 ± 9.8	23	19	28.57
Dhoma	demersal	40.70 ± 9.4	20.90 ± 4.4	15	5	-48.60

Source: Fishery Survey of India, Mumbai.

The per cent contribution of pelagic and column resources are more in the PFZs as compared to seasonal mean of entire area during the fishing season. This proves the capability of satellite sensors to visualize the production over a large area. Comparatively the contribution of the demersal resources in the catches is lower in PFZs. The limitation of satellite sensor to visualize the marine resources at bottom is reflected as the catfish catches were found to be higher due to the muddy bottom. The exploration of demersal resources through remote sensing is based on the inter-link between the surface/column production of biomass with distribution of detritus material and living resources at the sea floor. This can further be linked with vertical migration of biomass and movement of the demersal resources towards the upper layers of the column in search of food, causing variation in the local ecosystem at different trophic levels, which supports benthic biomass. The contribution of pelagic and mid-water fishery resources in the bottom fishing may due to the sampling depth (30-100m) which happens to be the light penetration depth. Hence, entire water column is suitable for plankton production. This enables the pelagic/column resources traverse and dwell up to the bottom.

4.7. Fishing operations data analysis - a remote sensing perspective

Remotely sensed SST is being used for fishery forecast in India and other countries. There are some limitations of the SST based approach for resources exploration. Heating of the sea surface during summer gives rise to stratification of water mass. This inhibits the appearance of SST gradient in the SST images. Another limitation is the perturbation of thermal frontal structure due the wind and current. In view of this, chlorophyll concentration (which indicates primary production) has been introduced in the present study. Chlorophyll concentration prediction from space provides a measure of the areas of enhanced biological production. The zooplankton and fish population are known to accumulate for feeding and spawning at oceanic features like, fronts, eddies, rings, meanders and upwelling. Remotely sensed SST characterises the oceanic environment suitable for enhanced biological production. The use of both variables would explain the oceanic environment and food resource availability in an ecosystem for exploring fishery resources.

Plate 4.11. shows A typical image showing integration of OCM chlorophyll concentration and AVHRR SST of January 14, 2000. The contours of SST (°C) indicate the matching features in chlorophyll concentration and SST images. Arrows indicate suggested PFZs. Circles indicate the categorized fish catch based mean (μ) CPUE (kg/hr) and standard deviation (SD). SST contours overlaid on the chlorophyll concentration

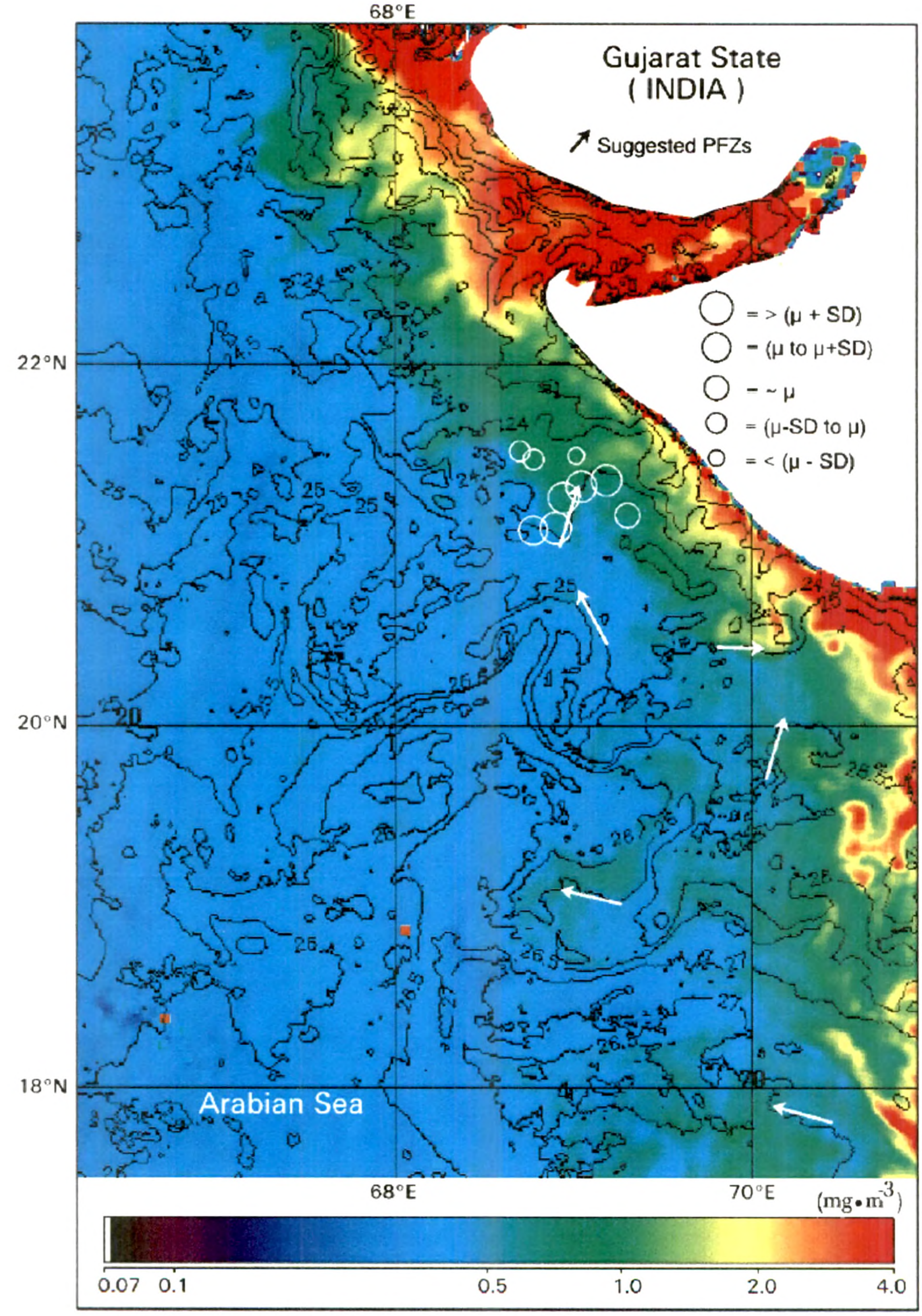


Plate 4.11.: A typical image showing integration of OCM chlorophyll concentration and AVHRR SST. The contours of SST (°C) indicate the matching features in chlorophyll

image indicate some matching features in images derived from both optical and thermal infrared sensors. Cool water is an indicator of high nutrient waters. In such areas, the probability of enhanced production is greater than for stratified warm waters. This indicates that there is an inverse relationship between chlorophyll concentration and SST (Solanki *et. al.*, 1998a). Areas of matching features were selected for locating PFZs and suggested for experimental fishing (plate 4.11). The coincidence of chlorophyll and SST features at some locations indicates that physical and bio-chemical processes are closely coupled at these locations. High catch points were observed in the vicinity of thermal as well as colour persistent features (Laurs *et al.* 1984, Solanki *et al.* 2001b). Thus coincidence of ocean colour and thermal features can be utilised for exploring fishery resources. The features known for fish aggregation, the details of their morphology, occurrence, appearance of these oceanographic features in the images and their relevance to fishery resources accumulation are shown in Table 4.3. The persistent features for longer periods are most important for resources exploration.

Fishing operation data analysis

The categorised CPUE have been plotted on the chlorophyll-SST composite (Plate 4.11). CPUE with high fish catch were found in fishing hauls

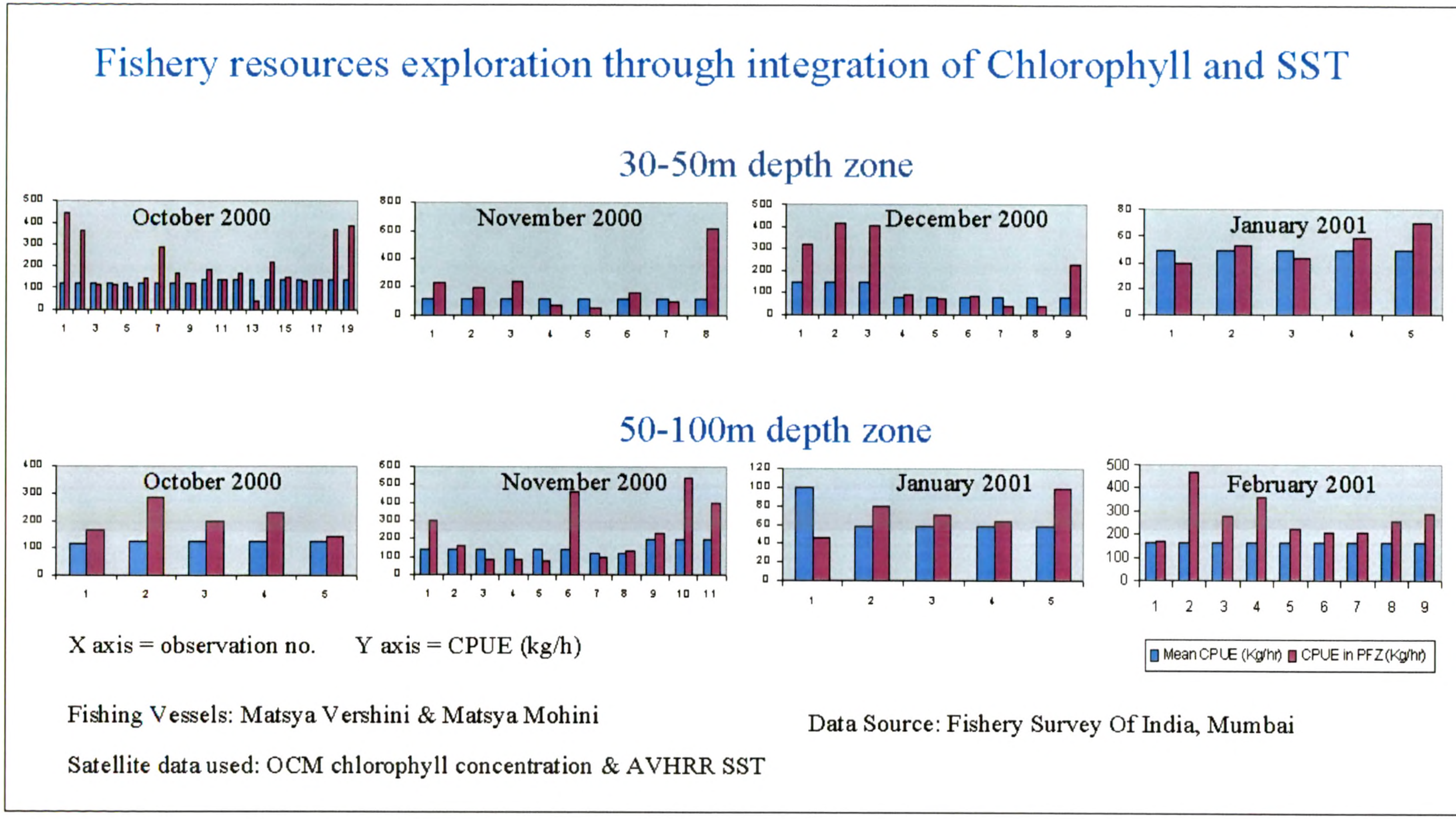


Figure 4.3 Results of PFZs validation experiment carried out during October 2000 – February 2001. The depth wise and month wise comparison of mean (μ) CPUE (kg/hr) in PFZs and mean (μ) CPUE in other areas has been shown. 4.5. Patterns of fish catch with respect to oceanic features

taken in the vicinity of features. Comparatively low catch was observed in fishing haul taken away from the features. The catch composition consists of species of sharks, skates, rays, sardines, mackerels, ribbon fish, catfish, perches. The month wise and depth zone wise comparison of mean CPUE of all observations of month has been shown in the form of bar charts (figure 4.3). This figure indicates an overall increase in catch in PFZs as compared to monthly mean catch in other areas. About 68% of observations were positive in the 30-50 m depth zone whereas 80% of observations were positive in the 50-100 m depth zone. Some observations indicated an abrupt increase in catch two to three fold in PFZs. The high CPUE may indicate the most favourable oceanographic environment/condition for resources accumulation and fishing operations. This may be considered representative of the potential of satellites to locate the most favourable fishing zones. The CPUE also depends on the skill of the skipper, gear specifications, wind direction, sea state and bottom topography. The technique may be extended for exploring deep-sea fishery resources.

4.8. Impacts of surface wind on oceanographic features

Wind induced ocean flow affect the oceanographic processes through surface-layer transport and vertical transport of water mass. The knowledge of the surface layer transport processes is important in fisheries because the dispersal mechanism control the distribution of early life stages and thereby influences the recruitment and future harvest of marine organisms. Wind velocity also effect the formation, persistence and decay of different types of oceanographic features like eddies, upwelling, fronts, meanders, gyres etc., which are responsible for fishery resources distribution/accumulation. Hence, there is a need to study the impacts of wind on oceanographic process.

4.8.1 Shift in the features

The shift in the features was monitored using time series data of OCM derived chlorophyll concentration. Wind vectors of respective date were overlaid to understand the impact of wind of the feature shifting. Plate 4.12 is the typical image showing the shift of features during February 23 – March 25, 2003. The features marked as 1, 2 and 3 in the circle were monitored in for the shift due to surface wind. We have used different data for development of equation. Correlation between speed of wind and speed drift of feature yielded $r^2 = 0.82$ (figure 4.4). The displacement of the features can be calculated from the following equation.

$$\text{Displacement of feature (Km/day)} = 1.3668x + 1.7422$$

Here, the displacement in feature due to wind speed and direction only considered. However, displacement of feature or mass water transport also depends on the feature type, strength of feature (energetic consideration of features like energetic eddies), their persistence and the biological production status. There was variation in chlorophyll concentration in the selected feature. Some features were indicated increasing trend and some shows decreasing trend. This may be due to developmental stage of different types and time lags between the formation of features and maturation.

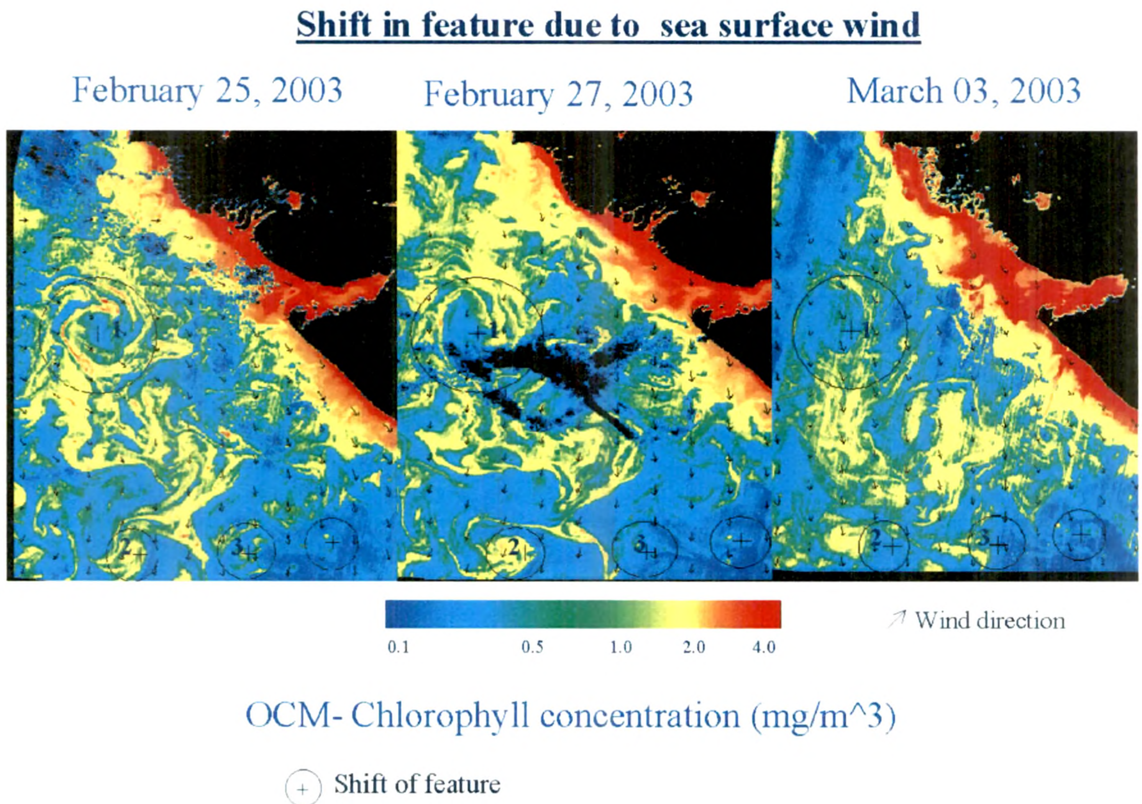


Plate 4.12: Feature displacement due to wind speed. Features marked as 1,2, and 3 are monitored in for feature shift analysis to develop an algorithm to compute probable shift in the feature

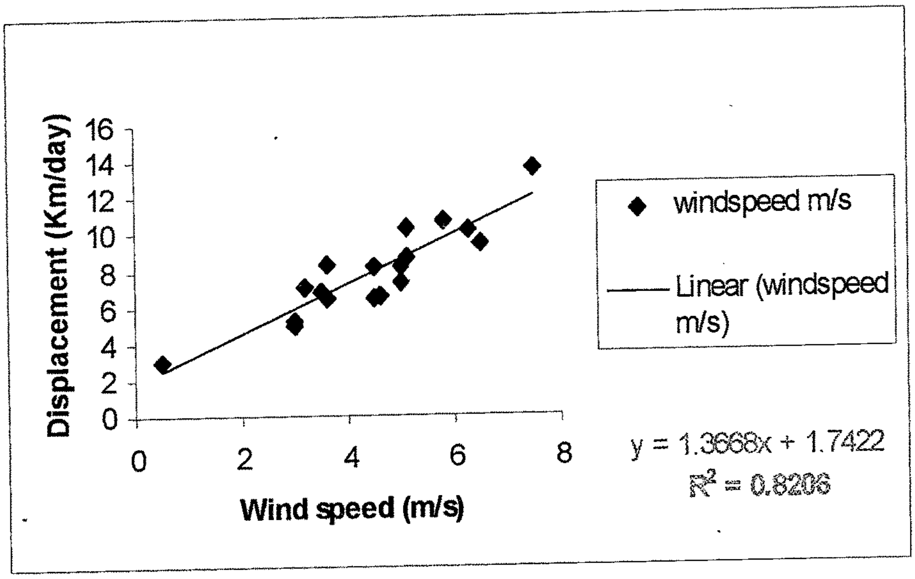
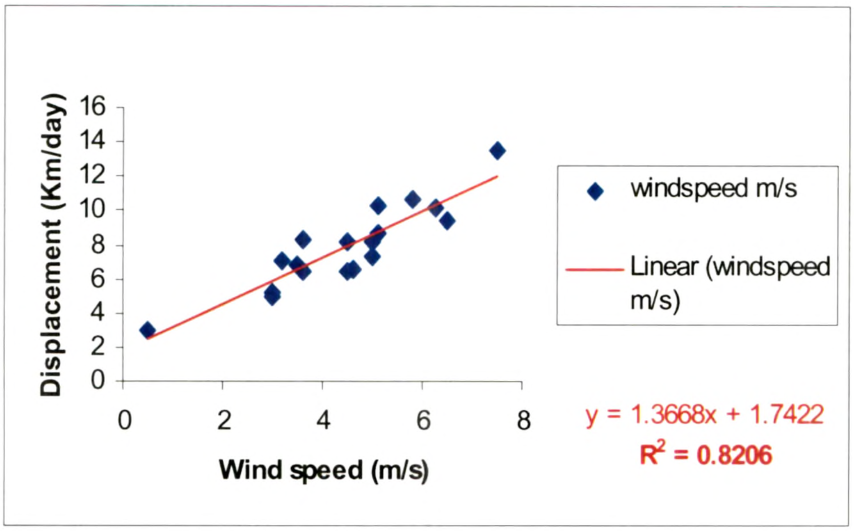


Figure 4.4: Scatter plot of wind speed and respective actual displacement in oceanic features indicates the results of regression analysis to derive the algorithm for feature shift estimation.

4.8.2. Water-mass Transport

The water mass transport was computed using QSCAT-SeaWinds derived wind speed and direction. The output of horizontal water-mass transport at surface has been showed in Plate 4.13 This image indicates the direction and speed of the wind as well as surface current. This gives the directional information as well as horizontal transport of features. This information is an input in improved PFZs forecast methodology along with the feature shift computation for prediction of PFZs.



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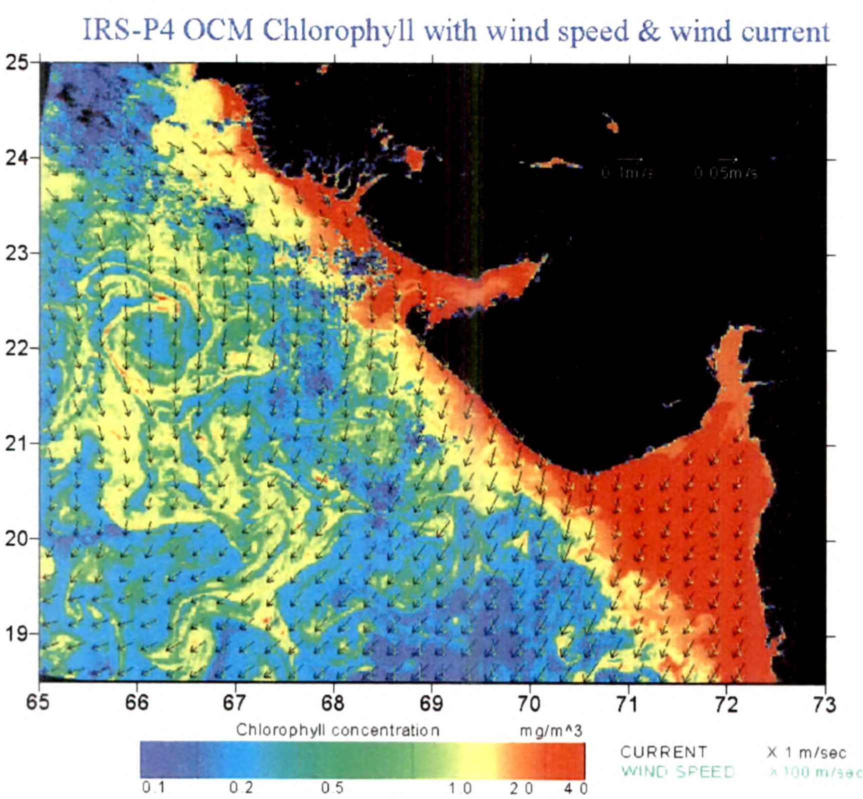


Plate 4.13: Surface current and wind vectors overlaid on OCM derived chlorophyll concentration showing the water mass transport

4.9. Remote sensing of secondary production

One of the underlying aims of fisheries research is recruitment prediction. Although interesting academic advances have been made in the understanding of processes involved, any practice / an application has not been implemented on wide range of scale. This is largely due to the complexity of biological linkages between the scale of the physical forcing environment and the local perception of an individual fish or fish larva. The modeling studies are simplifications of the real world, they do at least provide a means to manipulate and study processes operating over such a wide range of scales. A key factor for the recruitment is the availability of food for fish larvae, in particular nauplii. The development of the spatial distribution of prey fields is in marine systems controlled by physical and biological processes on various scales. A theoretical description of these complex processes can be achieved by coupled physical biological models. Chlorophyll concentration and temperature explain the coupled physical and biological processes.

4.9.1 Copepods egg production modeling using RS data

The maps of SST and chlorophyll for February 2000 were chosen for model testing and March 2003 were used for model validation. The SST shows a gradual warming trend as the seasons progress, which is to be expected. Areas of persistent cloud and land are masked out in black. The corresponding chlorophyll images show a generalized maximum in the chlorophyll concentration over the model domain in February which coincides with the bloom.Northern Arabian Sea shows higher values of chlorophyll during the winter months that during Jnauary to March. Higher values of chlorophyll (2 – 3 $mg.m^{-3}$) occur off the shelf break (17°-22° N latitude, 66°-70° E longitude) during this period. Most of the phytoplanktons are confined to the shelf region in other season. However a note of caution must be sounded here as some of the apparently high concentrations of chlorophyll could be caused by sediment loading especially in regions close to coast. This causes an error in the chlorophyll algorithm which in turn will lead to an overestimate of the secondary production. In deep oceanic waters however there can be a high degree of confidence placed in the chlorophyll concentration satellite retrieval and hence the estimate of secondary production will be made using realistic figures.

Plate 4.14 shows the output of model i.e. copepod egg production rate estimation using inputs from satellite derived chlorophyll concentration and SST. The in-situ observation stations are marked as "+" with station no. The copepod egg production rate was observed to be highest at station no. 4 and 5 on 03-03-2003. This id the eddy area with high biological production as seen in chlorophyll image and confirm with in-situ observations.

Dependence on food availability and suitable temperature can be double in their number in of few days. Most of copepods eat about one half of their body weight on phytoplankton each day. So wherever phytoplankton production is more there are chances of more production of copepods. The egg production and hatching is temperature dependent. Hence, the egg production in the model is related to the surface temperature and chlorophyll. Copepods take the most of their food at the surface. The relation between egg production and chlorophyll concentration during ship observations supports the use of chlorophyll concentration in the model.

In-situ observations of zooplanton production

Volumetric analysis of planktons – The volumetric measurements were carried out after filtering the residual in each net for respective depth of range. Table 4.6 shows wet biomass at different depth ranges. It indicates that biomass was higher on March 03, 2003 stationed at latitude 20° 38'N and longitude 66° 58'E. Sub surface (15-30m) biomass observed to be higher as compared to surface. Surface biomass was higher on 01-3-03 and 04-03-2003 as compared to other stations.

Table 4.6 indicates the identified zooplankton in their population per meter. Copepods were found to be dominating and their per contribution was 67%, which is fairly matching with the observation made by Rao et al (1973). This was followed by ostrapods and chaetognaths with per cent contribution 20% and 8.7%, respectively. Ostrapods and cheatognaths were mostly found in deep waters. Other zooplanktons like decapods, amphipods lusifers, mysids, salps were not found with significant per cent contribution.

Station wise Copepod populations have presented in Figure 4.5. The highest copepod production was observed on 03-03-2004 (latitude 20° 38'N and longitude

Table 4.6 Zooplankton identification and their population in the study area during Sagar Sampada Cruise

Station No.	Date	Time	Latitude	Longitude	Sampling depth ranges (m)	Important zooplankton identfied (no. per m^{-3})							Wet biomass (ml)
						Copepods	Ostrapods	Chaetognaths	Deca-pods	Amphipods	Lucifer	Mysids	
1.	28/02/03	1430	17° 19' N	70° 08' E	100-80	96	147	-	-	-	-	-	-
					80-60	188	92	72	-	-	-	-	-
					60-40	180	36	36	8	-	4	-	-
					40-20	354	-	66	-	-	30	-	-
					20-0	140	-	21	-	-	34	-	-
2.	01/03/03	1146	18° 47' N	68° 39' E	100-80	51	34	-	-	-	-	-	-
					80-60	140	105	14	-	-	-	-	0.22
					60-40	207	36	45	9	-	-	-	0.4
					40-20	344	-	96	-	8	8	-	0.66
					20-0	176	-	32	-	-	8	-	0.602
3	02/03/03	1321	19° 48' N	66° 52' E	80-60	49	63	-	-	-	-	-	0.36
					60-40	170	315	-	-	-	-	-	0.4
					40-30	280	210	-	-	-	-	-	0.6
					30-20	192	108	-	-	-	-	-	1.2
					20-0	75	72	20	-	-	50	-	2.0
4	03/03/03	1130	20° 38' N	66° 58' E	70-50	140	147	112	7	-	-	-	0.8
					50-40	420	196	70	14	-	-	-	1.61
					40-30	476	126	84	56	-	-	-	2.6
					30-15	773	40	26.7	26.7	13.3	-	-	4.8
					15-0	1194	-	74	30	15	30	30	4.0

5	03/03/03	1323	20° 33' N	67° 19' E	70-40	84	280	36	4	-	-	-	0.53
					40-30	276	96	96	-	12	-	-	0.8
					30-15	1120	9	65	-	-	19	-	2.13
6	04/03/03	1110	20° 28' N	67° 29' E	70-40	132	36	30	-	-	-	-	-
					40-30	350	42	42	14	-	14	-	-
					30-20	228	216	48	-	-	12	-	-
					20-0	560	98	4	-	-	14	-	-

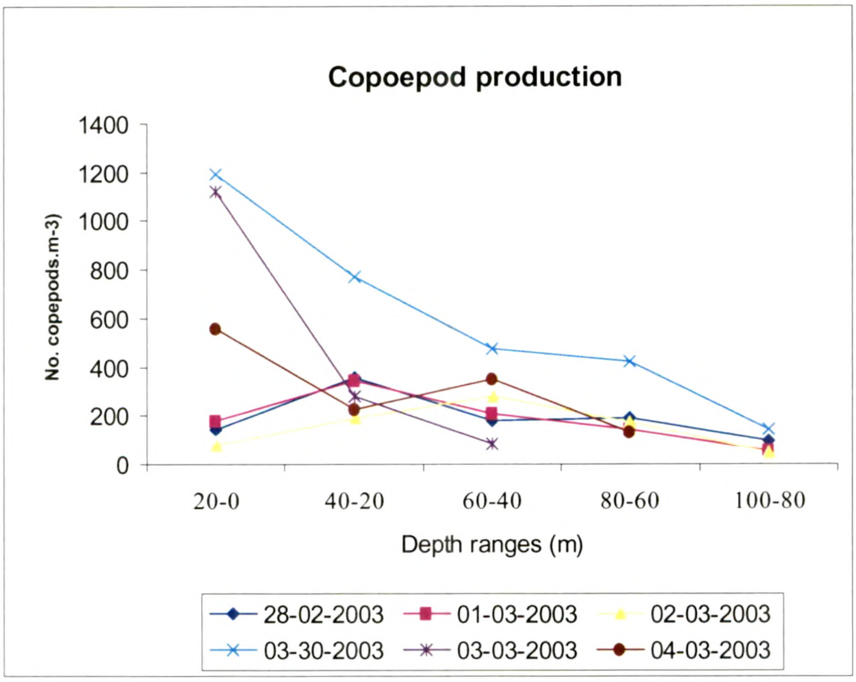
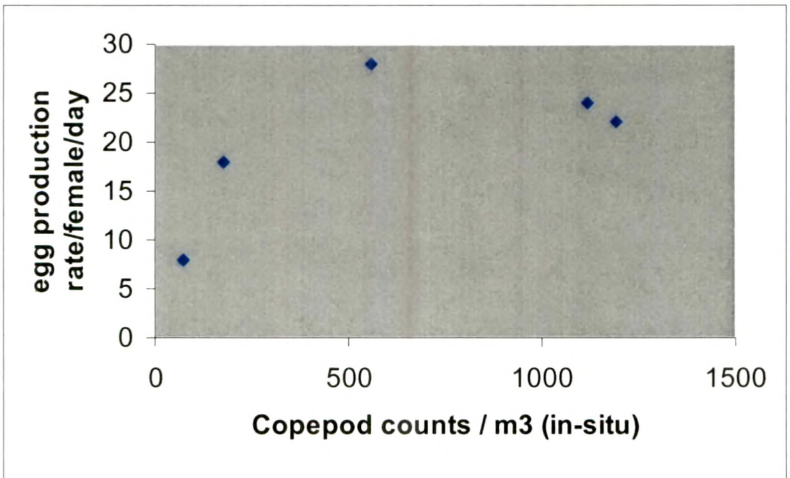


Figure 4.5: Copepods production at different depth ranges at different stations during ship observations.



FORV 212 (Sagar Sampada) cruise

Figure 4.6. Scatter plot of the copepod population counts and the satellite estimated egg production rate

66° 58'E). High copepod egg production was observed on same day image. The modeled copepod egg production rate based on satellite images showed well match with population of copepod in the respective areas (plate 4.14). This indicates that model works for the Arabian Sea. Figure 4.6 indicate the modeled egg production rate and in-situ observed copepods counts. It is clear that high counts od copepods belongs to modeled high egg production rate using satellite derived products.

4.9.2. Computation of Secondary production

The model parameters were initially set to those of Calanus and Acartia; although the model can be run for other species of copepod[4]. It is thought that these two species make up the majority of the secondary production relevant for the study of Rastirelliger kanagurta, Scomber scombrus, the species of mackerel. The output of the model, shown in plate 4.14 for the example of Calanus, is in units, of numbers of eggs per female per day. As such represents a potential for the female copepod to produce eggs based upon the physical and biological environment and takes no account of how many copepod are present in any one location. However, these values are meaningless for the retrieval of secondary production and purely reflect the background environmental conditions of the top few meters of the water column. o tern the model out put into meaning values for food availability, the numbers should be weighted by the number of female copepods present in particular grid location using enough in-situ data from Multiple Plankton Net (MPN) or Continuous Plankton Recorder (CPR) surveys. The parameterization was necessarily approximate, because of the scatter data and because the observed production/chlorophyll relationship change with time.

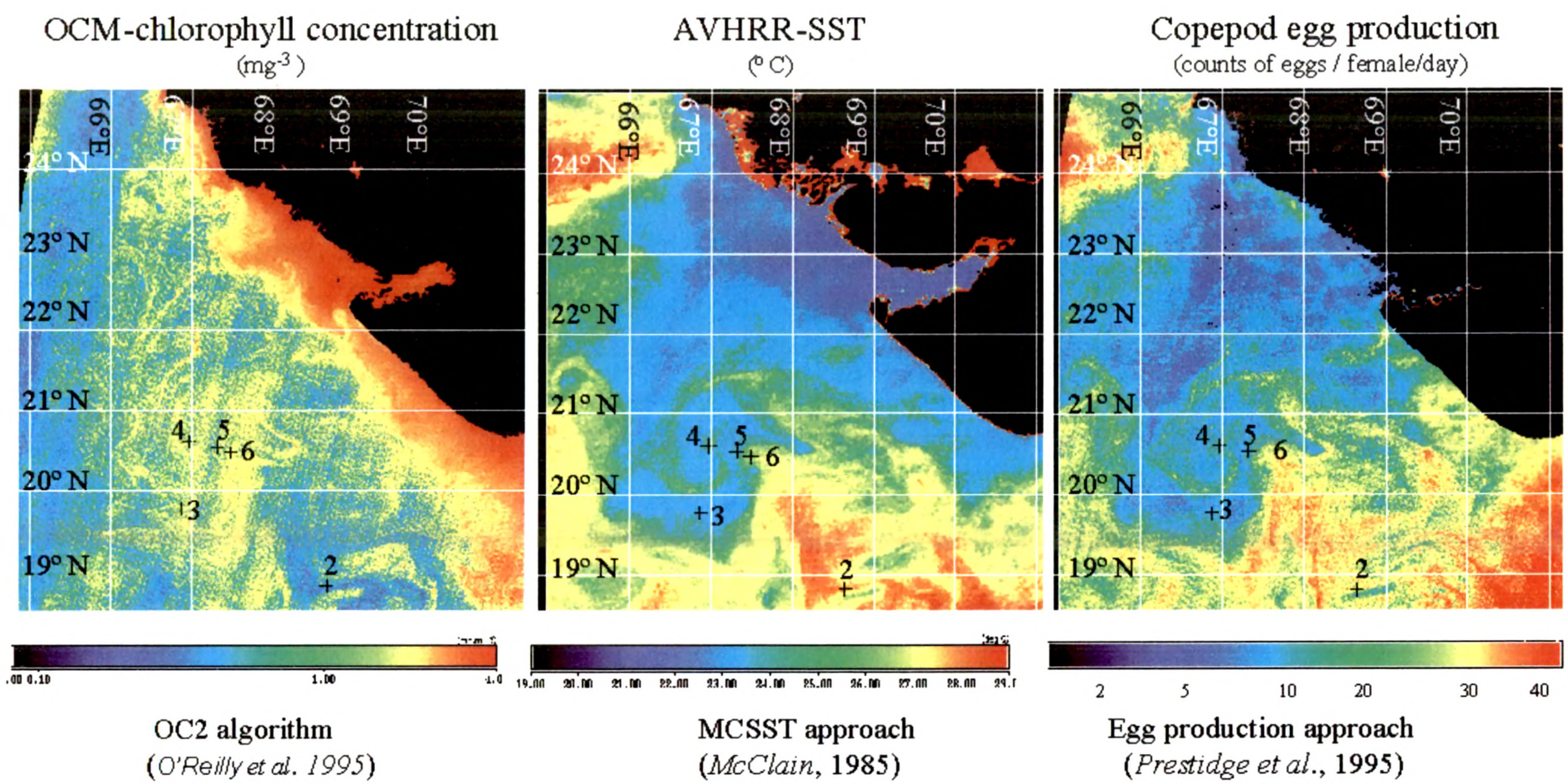


Plate 4.14 Estimation of copepod egg production rate using chlorophyll and SST derived from OCM and AVHRR

These are some initial results, the study provides an approach to used the satellite derived chlorophyll and SST for secondary production. Further investigations for values of parameters, fine tuning of the model as per regional hydrography, and sufficient in-situ observation for secondary production computation suggested.

4.9.3 Model validation approach

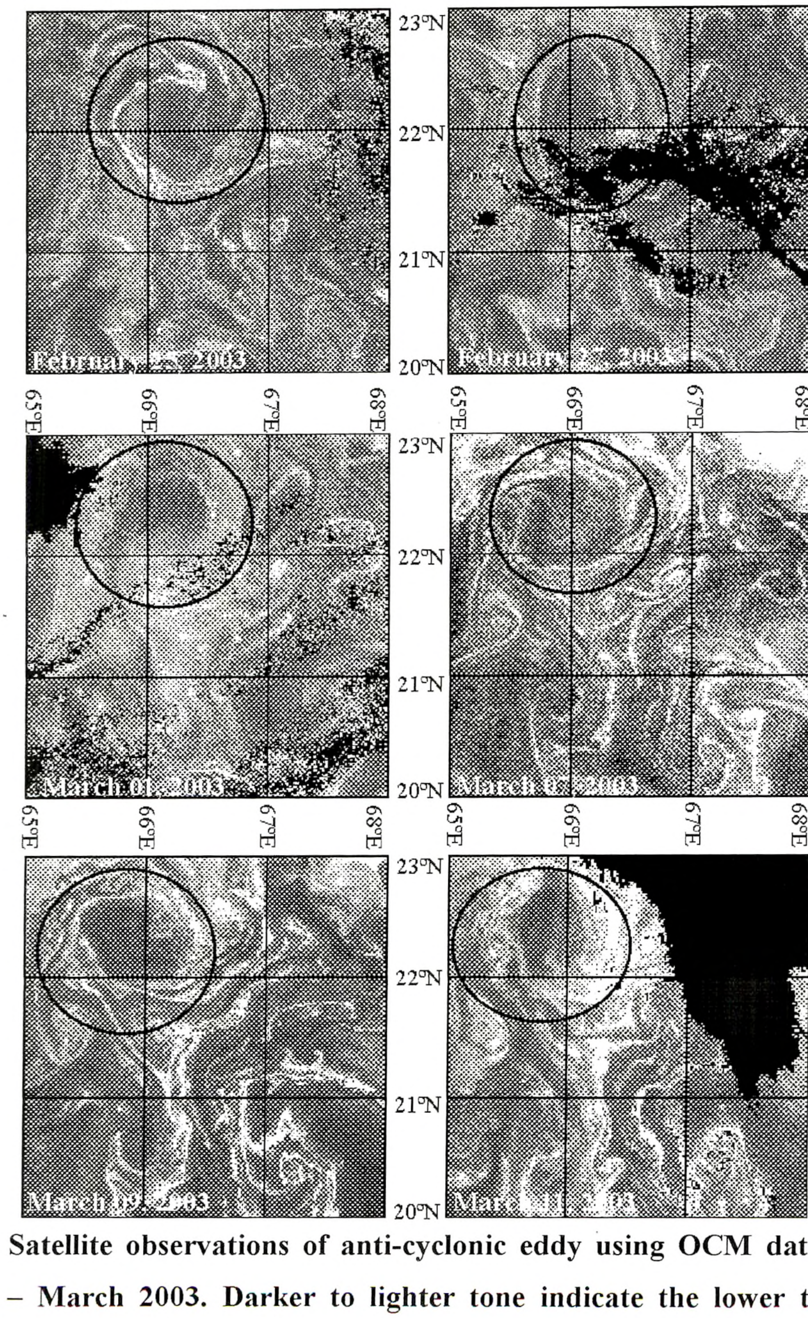
There are two approaches to validate the model output. The first approach uses estimates of primary production and assumes 10% incorporation into secondary production. The second uses estimates of the CPR biomass and the associated grazing requirements, again assuming 10% incorporation. Similar approach may adopted for Arabian Sea area. Here an example of studies carried out by Joints *et al.* (2001) has been quoted.

i) Primary production approach

For examples, Joint et al. (2000) calculated for this shelf edge region that primary production was approximately 16mgCm $^{-3}$ d $^{-1}$. Assuming a 10% efficiency transfer to mesozooplankton this gives 1.6mgCm $^{-3}$ d $^{-1}$. If Calanus makes up between 10 – 35% and Acartia 1 – 3% of the biomass this gives species specific secondary production to be between 0.16 – 0.56mgCm $^{-3}$ d $^{-1}$ for *calanus* and 0.016 – 0.048mgCm $^{-3}$ d $^{-1}$ for *acartia*.

ii) Biomass approach

Similarly, The CPR summer biomass was found (Joint et al 2001) to be 3mgCm $^{-3}$, corresponding to a grazing requirement of 5mgCm $^{-3}$ d $^{-1}$. Assuming a 10% incorporation rate and the same percentage biomass contributions as above results in species specific secondary production to be between 0.05 – 0.18mgCm $^{-3}$ d $^{-1}$ for *Calanus* and 0.005 – 0.015mgCm $^{-3}$ d $^{-1}$ for *Acartia*. There is a factor of three differences in the two different approaches, which provides a range for comparison with the model output.



late 4.4. Satellite observations of anti-cyclonic eddy using OCM data during ebruary – March 2003. Darker to lighter tone indicate the lower to higher hlorophyll concentration. Anti-cyclonic eddy with poor chlorophyll oncentration is shown in the circle.